

THE TAYLOR PRINCIPLE AND THE
FISHER RELATION IN GENERAL
EQUILIBRIUM

by

CERI REES DAVIES

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*Economics Section,
Cardiff Business School,
Cardiff University*

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ABSTRACT

This thesis presents a structural framework which accounts for two key empirical phenomena in monetary economics: the ‘Taylor principle’ and the ‘Fisher relation’. The former suggests that there exists a greater-than-proportional relationship between the nominal interest rate and inflation in the short-run and the latter implies that a one-for-one relationship holds at lower frequencies.

Although these relationships do feature in the ubiquitous, ‘cashless’ New Keynesian framework, it has been suggested that monetary variables are required in order to render this model ‘complete’ (e.g. Nelson, 2008a). Chapter-I demonstrates that an ‘implicit’ interest rate rule can be derived as a general equilibrium condition of models in which the central bank adheres to a money growth rule. Chapter-II compares the equilibrium condition of a standard cash-in-advance model to the interest rate rule of Taylor (1993) for a post-war sample of U.S. data. However, we demonstrate that in order to replicate the Taylor principle, the underlying model must be generalised to allow the velocity of money to vary. We use the model of Benk et al. (2008, 2010) to do so and show analytically that the resulting ‘implicit rule’ features the requisite greater-than-proportional relationship. Chapter-III applies standard econometric techniques to simulated data obtained from the Benk et al. model and the estimates obtained offer support for this theoretical prediction.

Chapter-IV establishes that the Fisher relation emerges when low frequency trends in the simulated data are retained and under a related ‘long-run’ implicit rule. Chapter-IV also considers the post-war sample of U.S. data analysed in Chapter-II. While disparate empirical literatures have obtained evidence for both the Taylor principle and the Fisher relation, we show that these results can be obtained from a unified theoretical framework. Several restricted empirical specifications further suggest that standard interest rate rules which omit monetary variables might provide biased coefficient estimates.

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CONTENTS PAGE

GENERAL INTRODUCTION	1
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CHAPTER-I: MONEY-BASED INTEREST RATE RULES

1.1 Interest Rate Rules for Monetary Policy.....	6
1.1.1 Interest Rate Rules and ‘The Consensus Model’.....	8
1.1.2 Interest Rate Rules, the NK Model and Monetary policy without ‘ <i>M</i> ’.....	10
1.2 ‘Implicit’ Interest Rate Rules.....	18
1.2.1 A Conventional Interest Rate Rule.....	22
1.2.2 A Quantity-Theory-Based Implicit Rule.....	24
1.2.3 Implicit Rules for the NK Model.....	30
1.2.4 Euler-Equation-Based Implicit Rules.....	37
1.3 The ‘Taylor Condition’.....	46
1.3.1 The ‘Long-Run Taylor Condition’.....	54
1.4 The Remainder of the Thesis.....	55

CHAPTER-II: CALIBRATION EXERCISES

2.1 Contemporaneous Rules.....	56
2.1.1 Data.....	58
2.1.2 Issues of Interpretation for the Taylor Rule.....	60
2.2 Implied Nominal Interest Rate and Discrepancy Series.....	61
2.2.1 Summary Statistics.....	62
2.2.2 Divergence.....	64
2.2.3 Taylor Rule Discrepancies: An ‘Historical Approach’.....	68
2.2.4 Implicit Rule Discrepancies.....	76
2.3 Inflation Misperceptions.....	79
2.3.1 Unexpected Inflation and the Taylor Rule.....	84
2.4 Summary and Implications for Remaining Chapters.....	85

CHAPTER-III: AN ANALYSIS OF THE TAYLOR CONDITION

3.1 Introduction.....	87
3.2 Stochastic Endogenous Growth with Banking.....	91
3.2.1 The Consumer's Problem.....	92
3.2.2 The Banking Intermediary's Problem.....	94
3.2.3 The Goods Producer's Problem.....	95
3.2.4 Monetary Policy.....	96
3.2.5 Definition of the Competitive Equilibrium.....	97
3.3 The General Equilibrium Taylor Condition.....	97
3.3.1 Misspecified Taylor Condition with Output Growth.....	103
3.3.2 Misspecified as a 'Taylor Rule'.....	104
3.4 Calibration, Target Values and Implied Theoretical Predictions.....	105
3.5 Analysis of Model-Simulated Data.....	106
3.5.1 Methodology.....	106
3.5.2 General Taylor Condition.....	109
3.5.3 Taylor Condition with Output Growth.....	113
3.5.4 A 'Taylor Rule'.....	116
3.6 Alternative Forms for the Taylor Condition.....	117
3.6.1 A Contemporaneous Taylor Condition.....	117
3.6.2 A Credit Interpretation.....	118
3.7 Discussion.....	119
3.8 Conclusion.....	121

CHAPTER-IV: A UNIFIED ACCOUNT OF THE TAYLOR PRINCIPLE AND THE FISHER RELATION

4.1 Introduction.....	124
4.1.1 Empirical Evidence and Theoretical Rationalisations.....	127
4.2 The Taylor Condition.....	130
4.2.1 Misspecification: Output Growth Replaces Consumption Growth.....	132
4.2.2 Misspecification: A Conventional Taylor Rule.....	132

4.2.3 The ‘Long-Run Taylor Condition’	133
4.3 Calibration, Target Values and Implied Theoretical Predictions.....	134
4.4 Empirical Analysis: The Taylor Principle.....	135
4.4.1 Estimating Equations.....	137
4.4.2 The Taylor Condition for Model-Simulated Data.....	138
4.4.3 The Taylor Condition for U.S. Time Series Data.....	143
4.4.4 A ‘Taylor Rule’ for Model-Simulated Data.....	147
4.5 Empirical Analysis: The Fisher Relation.....	148
4.5.1 Extending the Medium-Term Cycle for Model-Simulated Data.....	148
4.5.2 Restricted Estimating Equations.....	149
4.5.3 Error Correction Model.....	153
4.5.4 Fitting the ECM to U.S. Time Series Data.....	155
4.5.5 Fitting the ECM to Model-Simulated Data.....	161
4.6 Conclusion.....	164

CHAPTER-V: GENERAL CONCLUSION

5.1 Contribution.....	166
5.1.1 The Taylor Condition and the Taylor Principle.....	166
5.1.2 The Taylor Condition and the Fisher Relation.....	167
5.1.3 Chapter-by-Chapter Summary.....	168
5.2 Final Remarks and Future Research Agenda.....	179

REFERENCES.....	181
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FIGURES AND TABLES.....	201
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LIST OF FIGURES

- Figure 2.1: Inflation, the Output Gap and the Output Growth Rate
- Figure 2.2: Taylor and Implicit Rules over the Full Sample Period
- Figure 2.3: Taylor and Implicit Rule Discrepancy Series
- Figure 2.4: Taylor Rule vs. Implicit Rule Counterpart
- Figure 2.5: 'Original' Divergence Series and Components of Inequality (2.4)
- Figure 2.6: Differences between the Real Terms of the Taylor/Implicit Rule
- Figure 2.7: Discrepancy Series by 'Policy Era'
- Figure 2.8: The Pre-Volcker Era
- Figure 2.9: The Volcker Disinflation Era
- Figure 2.10: The Greenspan-Bernanke Era
- Figure 2.11: Crisis Period
- Figure 2.12: ZLB frontiers
- Figure 2.13: The ('augmented') Fisher Relation (1960q1-2011q1)
- Figure 2.14: Canzoneri et al. (2007) Analysis for the Implicit Rule (2.2)
- Figure 2.15: Figure 2.14 Expressed in terms of the Nominal Interest Rate
- Figure 2.16: Inflation Misperceptions and Discrepancy Series for the 'Long-Run Taylor Condition'

LIST OF TABLES

Table 2.1: Numerical Calibration of Equations (2.1) and (2.2)

Table 2.2: Empirical Specifications

Table 2.3: Summary Statistics

Table 3.1: Parameters

Table 3.2: Target Values

Table 3.3: Full Taylor Condition (HP)

Table 3.4: Full Taylor Condition (3-8)

Table 3.5: Full Taylor Condition (2-15)

Table 3.6: Output Growth instead of Consumption Growth (2-15)

Table 3.7: A Taylor Rule (2-15)

Table 3.8: Full Taylor Condition (Unfiltered Data)

Table 4.1: Parameters

Table 4.2: Target Values

Table 4.3: Unit Root and Stationarity Tests for Simulated Data

Table 4.4: Full Taylor Condition for Model-Simulated Data

Table 4.5: Full Taylor Condition for U.S. Data, 1960q1-2011q1

Table 4.6: A Standard Taylor Rule for Model-Simulated Data

Table 4.7: Full Taylor Condition for Alternative Filter Specifications

Table 4.8: Restricted Taylor Conditions for Model-Simulated Data

Table 4.9: A Restricted Taylor Condition for U.S. Data, 1960q1-2011q1

Table 4.10: A 'Long-Run Taylor Condition' for U.S. Data, 1960q1-2011q1

Table 4.11: Unit Root and Stationarity Tests for U.S. Data, 1960q1-2011q1

Table 4.12: Cointegrating Regressions for U.S. Data, 1960q1-2011q1

Table 4.13: An ECM for U.S. Data, 1960q1-2011q1

Table 4.14: Estimated Marginal Tax Rates for U.S. Data, 1960-2011 (Annual Frequency)

Table 4.15: An ECM for Tax-Adjusted U.S. Data, 1960q1-2011q1

Table 4.16: Cointegrating Regressions for U.S. Data, 1960q1-2011q1

Table 4.17: An ECM for Model-Simulated Data

Table 5.1: Summary of Inflation Coefficient, Model-Simulated Data, GMM estimates only

Table 5.2: Summary of Inflation Coefficient, U.S. Time Series Data, 1960q1-2011q1

GENERAL INTRODUCTION

This thesis provides a unified account of two well-established empirical phenomena. Firstly, the nominal interest rate has been found to vary more-than-proportionally with the rate of inflation, at least during times of macroeconomic stability. For instance, Taylor (1999) and Clarida et al. (2000) provide empirical evidence that this relationship holds for post *circa* 1980 U.S. data which corresponds to a period of macroeconomic quiescence known as the Great Moderation. On the other hand, a less-than-proportional relationship has often been found between prior to c.1980 (Clarida et al., 2000), a period characterised by macroeconomic instability, particularly during the 1970s with respect to inflation. The ‘conventional’ interpretation of these empirical findings is that the estimating equation used to obtain the short-run relationship between the nominal interest rate and inflation represents the interest rate rule, or ‘reaction function’, adhered to by policymakers. The dependent variable is taken to represent the instrument of monetary policy and an inflation coefficient of less than one indicates that monetary policy responded too timidly to inflationary pressures.

Secondly, over longer-time horizons, the nominal interest rate varies in direct proportion (one-for-one) with the rate of inflation according to the Fisher relation (e.g. Crowder and Hoffman, 1996). The nominal interest rate is now taken to represent the return on risk-free government bonds and the one-for-one relation simply suggests that investors require compensation for erosion in the purchasing power of money over the life of the bond. The long-run Fisher relation is not interpreted as a reaction function. For one thing, Nelson (2008a) notes that nominal rigidities are crucial to the monetary policy transmission mechanism under a conventional interest rate rule. Once these rigidities dissipate, which they presumably must do in the long-run, it is not clear how the central bank supplies the requisite ‘nominal anchor’ for price level determination. Nelson argues that given the well-established empirical link between money growth and inflation at low frequencies, money supply control offers the obvious solution to the ‘incomplete’ account of the long-run offered by the conventional interest rate rule.

But this poses a potential problem for economic models which typically incorporate a conventional interest rate rule because monetary relationships are subservient to the rule and do not need to be specified at all in order to solve the model.

The starting point for our analysis is to question the conventional 'reaction function' interpretation of the short-run relationship between the nominal interest rate and inflation. We are by no means the first to do so. Hetzel (2000), for example, reminds us that reduced-form relationships are not capable of revealing policymakers' underlying preferences with regards to inflation (or other objectives); Cochrane (2011a) demonstrates that it is difficult to find a suitable identification strategy to recover the coefficients of the 'reaction function'; and Lucas (2003) argues that conventional interest rate rules offer little new insight because the Fisher relation already accounts for the empirical link between the nominal interest rate and inflation. As a prelude, Chapter-I describes the rationale for monetary policy rules and how interest rate rules in particular have come to form the favoured representation of monetary policy. We then explain the importance of the interest rate rule to the 'consensus' New Keynesian (NK) model often used to conduct monetary policy analysis and why monetary relationships are effectively superfluous in this framework. However, in addition to the theoretical consideration of Nelson (2008a), there is also a wealth of empirical evidence that monetary relationships can still be 'useful' for policy analysis and, indeed, policymakers have themselves expressed concerns about a theoretical framework in which monetary policy is implemented solely through the nominal interest rate.

To provide a conceptual framework for our scepticism about the conventional 'reaction function interpretation' of the empirical relationship between the nominal interest rate and inflation, Chapter-I proceeds to introduce the notion of an 'implicit interest rate rule'. These are equilibrium relationships that share certain similarities with conventional interest rate rules but which are derived from underlying models in which the central bank adopts some alternative policy prescription. They effectively describe the relationship between the nominal

interest rate and inflation (and other variables) engendered by the directly modelled policy regime. In principle, a whole host of policy prescriptions might generate interest-rate-rule-like behaviour but for the reasons documented above we primarily focus on ‘money-based interest rate rules’. We demonstrate that ‘implicit’ rules of this type have been derived from ‘textbook’ reduced form models and extended NK models which include money but we generalise these derivations to apply to structural models which allow for fully flexible prices. Obtaining an expression which compares to a conventional interest rate rule from a flexible price framework only adds to doubts as to whether empirical studies are capable of recovering the central bank’s ‘reaction function’ from aggregate data as they claim. We first explain how an implicit interest rate rule can be derived from a flexible price cash-in-advance model. This ‘rule’ features a term in inflation along with a real term, the consumption growth rate, and corresponds to Arnwine and Yigit’s (2008) ‘augmented Fisher relation’. As such, the coefficient on inflation is constant at one and the Taylor principle cannot be replicated.

We show that the Taylor principle can be recovered from the interest rate rule implicit in a cash-in-advance model if the velocity of money is permitted to vary. We achieve this by granting the representative consumer a choice between the use of zero-interest-yielding money balances and intratemporal credit for exchange purposes as in Benk et al. (2008, 2010). We label this particular implicit rule ‘the Taylor Condition’ in order to simultaneously recognise the similarities it shares with a conventional interest rate rule but also its status as an equilibrium condition as opposed to a conventional rule. The Taylor Condition is expressed in terms of the nominal interest rate and in full it features forward-looking terms in inflation, consumption growth, non-leisure time growth, velocity growth and the nominal interest rate (a lead dependent variable term). We suggest that the full Taylor Condition applies in the ‘short-run’ and demonstrate that an expression corresponding to the ‘augmented Fisher relation’, which contains terms in inflation and consumption growth only, can be obtained as its long-run counterpart. As such, we construct a unified account of the short-run Taylor principle, but in terms of an *implicit* rule rather than a conventional rule, and the long-run Fisher relation, but controlling for consumption growth as Arnwine and

Yigit (2008) suggest one must do in order to accurately reflect Fisher's original theory.

Chapter-II uses simple calibration techniques in order to compare the contemporaneous equilibrium condition ('implicit rule') derived from a standard, constant velocity cash-in-advance model to the contemporaneous interest rate rule proposed by Taylor (1993) rule over a post-war sample of U.S. data. However, in order to evaluate the 'full' Taylor Condition we resort to appropriate econometric procedures. Chapter-III first presents a full derivation of the Taylor Condition and then proceeds to obtain estimates for the coefficients of the Taylor condition from 1000, 100 period samples of artificial data simulated from the Benk et al. model. The simulated data is passed through several statistical filters prior to estimation in order to extract high frequency fluctuations; it is at these frequencies that we wish to test for the short-run Taylor principle. To do so we apply several of the single-equation estimation techniques considered in the empirical literature. The estimates obtained provide support for the notion that the Taylor principle holds – i.e. we find a more-than-proportional relationship between the nominal interest rate and inflation – and, on average, the estimated coefficient closely resembles the theoretical prediction implied by the calibration used to generate the data. We also show how the Taylor principle result breaks-down if the 'true' estimating equation is restricted in various ways and explain that it would be spurious to infer that monetary policymakers have changed their preferences towards inflation based upon these estimates; they simply result from model misspecification.

Chapter-IV establishes the circumstances under which the Taylor principle result reverts to the one-for-one relation implied by the Fisher relation. In order to investigate this issue, our strategy is to adopt the econometric techniques typically employed within the respective Taylor rule and Fisher relation literatures. This should not necessarily be taken to represent an endorsement of these techniques, however. The aim is to approach the data as a researcher searching for either relationship would. Accordingly, we follow Clarida et al. (2000) when considering the Taylor principle and adopt an error correction

model of the type often employed in the Fisher relation literature (e.g. Arnwine and Yigit, 2008) when considering the long-run relationship. The error correction model takes the Fisher relation to be a long-run equilibrium relationship and uses a reduced form process to account for departures from this long-run state. Further motivation for the error correction approach is provided by the fact that the coefficient on inflation obtained from the unrestricted Taylor Condition tends towards one as lower frequency fluctuations are retained in the model-simulated data. The predicted one-for-one relation is confirmed for this artificial data; the Fisher relation holds.

Chapter-IV also considers the same sample of U.S. data analysed in Chapter-II. Clarida et al.'s (2000) procedure is applied to an unrestricted estimating equation which corresponds to the full Taylor Condition, with terms in inflation, consumption growth, the growth rate of productive time, the velocity growth rate and a forward interest rate. For 'stable' post-Volcker subsamples, the magnitude of the coefficient on inflation is found to be similar to the estimates obtained in the literature for comparable historical periods. However, for the 'unstable' pre-Volcker subsample, the coefficient on inflation, though smaller as the existing literature suggests, exceeds unity so that the Taylor principle is satisfied for both pre- and post-Volcker subsample. This differs from empirical studies which have found that the Taylor principle was violated pre-c.1980 and suggests that omitting some of the non-standard variables which feature in the Taylor Condition, the velocity growth rate for example, might generate downward bias in the reported estimates.

Chapter-V offers a summary, a general conclusion and a potential research agenda based on the findings of this thesis. In future research we might seek to derive implicit rules from alternative policy regimes which allow other commonly-considered variables, such as the exchange rate, to enter the implicit rules presented in Chapter-I.

CHAPTER-I: MONEY-BASED INTEREST RATE RULES

1.1 Interest Rate Rules for Monetary Policy

It has become routine in the literature to conduct monetary policy analysis using 'interest rate rules', or central bank 'reaction functions'. Such rules – essentially a statement of the way in which policymakers ought to (normative), or have in practice (positive), set a short-term interest rate in response to the state of the economy – have received considerable attention in the academic literature since the seminal contributions of Taylor (1993), Henderson and McKibbin (1993) and the articles gathered in the volume edited by Bryant et al. (1993). Taylor (1993), perhaps the best-known of these early contributions, posits that monetary policymakers initiate adjustments to a short-term nominal interest rate in response to prevailing economic conditions, as summarised by the rate of inflation and the output gap.

The prominence of interest rate rules of this type can be interpreted as a response to a series of theoretical contributions which suggested that granting monetary policymakers the freedom to set monetary policy in a wholly discretionary manner has the potential to lead to unsatisfactory economic outcomes (e.g. Sargent and Wallace, 1976; Kydland and Prescott, 1977; Barro and Gordon, 1983).¹ The quest for an appropriate rule for monetary policy can also be viewed in the context of the 'rational expectations revolution' in macroeconomics which emphasises the need to account for the forward-looking nature of economic agents and the way in which they use their knowledge of the structure of the economy when forming expectations. Taylor (1993, pp.196-197) specifically cites 'time inconsistency' and 'the Lucas critique' (Lucas, 1976) amongst several motivating factors for further research into the type of policy rule he proposed. Rules-based monetary policy is potentially useful because a well-formulated, transparent rule might be capable of credibly constraining the behaviour of policymakers by serving as a 'commitment mechanism' which binds them to act in

¹ For example, Sargent and Wallace begin thus: "There is no longer any serious debate about whether monetary policy should be conducted according to rules or discretion. Quite appropriately, it is widely agreed that monetary policy should obey a rule..." (Sargent and Wallace, 1976, p.169).

accordance with their stated intentions in future periods.² The research agenda launched in the early 1990s aims to find a 'desirable' form for this monetary policy rule, both in terms of the variables that enter the rule and the magnitude of its coefficients.

However, there is nothing in the rationale for monetary policy rules which compels them to be expressed in terms of the nominal interest rate and no obvious reason why they should involve feedback on the state of the economy. For example, Friedman's (1960) suggestion that monetary policymakers should simply ensure that the money supply grows at a constant rate (the so-called 'k-percent rule') would qualify as a 'monetary policy rule' even though it embodies neither of these features. Firstly, it is deemed to be preferable to cast the nominal interest rate as the policy instrument because this is consistent with the way in which monetary policy is communicated by central banks in many of the world's major economies (Romer, 2000, p.155; Mehrling, 2006). As such, the dependent variable of the rule can be directly associated with the announced nominal interest rate – e.g. the Federal Funds Rate in the U.S. or 'Bank Rate' in the U.K. – thus providing an intuitive link between theory and practice. Secondly, Taylor (1993) explains that the functional form of the seminal interest rate rules of the early 1990s were informed by simulation exercises which implied that fixed settings for monetary instruments were sub-optimal and that monetary policy should respond to changes in the price level or real GDP (Taylor, 1993, p.196).

Subsequent contributions to the literature have employed the interest rate rule framework as a means of investigating the extent to which undesirable macroeconomic outcomes can be attributed to inept monetary policy. To do so, calibrated interest rate rules have been used to generate implied interest rate series which are then compared to the observed nominal interest rate (e.g. Taylor, 1993). Alternatively, interest rate rules have been used to construct estimating

² Other suggested remedies to this 'time inconsistency problem' have considered: the inherent preferences of central bankers, e.g. Rogoff's (1985) 'conservative central banker'; the nature of the institutional arrangement between the central bank and its political masters, e.g. Cukierman (1992); and contract theory, to ensure that central bankers are suitably incentivised to conduct monetary policy in a 'desirable' manner (Walsh, 1995).

equations which can be used to recover ‘reaction coefficients’ from time series data for different historical periods. The key result from these empirical studies (e.g. Taylor, 1999; Clarida et al., 1998, 2000) is that the macroeconomic stability experienced during the post-c.1980 ‘Great Moderation’ period can be associated with the transition from a ‘bad’ to a ‘good’ interest rate rule and that the distinction between the two primarily depends upon how decisively policymakers respond to nascent inflationary pressures. To engender stable outcomes, an interest rate rule should embody a more-than-proportional interest rate response to inflation deviations from target, i.e. the ‘reaction coefficient’ for inflation must exceed unity.

Interest rate rules would acquire greater influence if they could be integrated into a fully-articulated, micro-founded model of the economy. Although the seminal papers cited at the outset of this chapter did conduct simulation exercises using state-of-the-art models of the time, we turn next to the modelling framework in which interest rate rules are frequently applied in the contemporary literature. As we shall see, interest rate rules fit naturally into this framework and the properties of the rule turn out to have an important bearing on the overall coherence of the model.

1.1.1 Interest Rate Rules and ‘The Consensus Model’

An interest rate rule of the type discussed above forms one of three equations in the simplest version of the New Keynesian (NK), or New Neoclassical Synthesis (NNS), model.³ Specifically, the interest rate rule stands alongside an ‘intertemporal IS’ equation (NKIS) and the ‘New Keynesian Phillips Curve’ (NKPC) in the three equation system. Numerous modifications and extensions have been made to this basic form (e.g. Smets and Wouters, 2003), but many studies take the

³ A comprehensive exposition of this framework can be found in Woodford (2003). See also Walsh (2003a, Ch.11) and Galí (2008), amongst many others. The term ‘consensus’ is derived from Goodfriend’s (2007) reference to the emergence of a “consensus theory”; similar sentiments can be found in Goodfriend and King (1997); Blanchard (2009); and Woodford (2009). Even critical reviews of the NK framework – such as Hoover (2006) and Chari et al. (2009) – often acknowledge the convergence of opinion between different schools of thought, at least from a methodological perspective (Chari et al., 2009, speak of, “an agreed-upon language”, despite their criticisms of the NK modelling paradigm). Similarly, Woodford (2009, p.269), clearly a proponent of this framework, states that, “the methodological stance of the New Classical school and the real business cycle theorists has become the mainstream.”

three equation system to offer a complete representation of the model (e.g. Woodford, 2008). Given the prominence of this modelling framework in the contemporary literature, the integration of the interest rate rule into the NK model greatly extends the influence of the research undertaken during the early 1990s. Indeed, one of Woodford's (2003) stated objectives is: "to provide theoretical foundations for a rule-based approach to monetary policy." (Woodford, 2003, p.2). Several features of the NK modelling paradigm make it a natural framework in which to embed an interest rate rule. For instance, the logic underpinning the use of the nominal interest rate as the policy instrument generally requires the central bank to possess leverage over the real rate of interest – the rate which matters for economic decision making – even though it only has power to directly influence a nominal interest rate. Therefore, the model needs to provide some mechanism to generate 'pass-through' from the nominal to the real rate. The NK model provides policymakers with the traction they require by assuming that nominal rigidities exist in goods and/or labour markets.⁴

The precise nature of the feedback from the state of the economy to the nominal interest rate described by the interest rate rule turns out to be of crucial importance to the NK model. It has long been known that a nominal interest rate peg can potentially generate 'endogenous fluctuations', whereby a multiplicity of valid, rational expectations equilibria may coexist.⁵ If one is committed to modelling the nominal interest rate as the instrument of monetary policy then a certain degree of feedback from the other endogenous variables is necessary in order to render the model theoretically coherent (McCallum, 1981; Woodford, 2003, pp.86-87). This subsequently allows the researcher to be more precise about what is meant by a 'desirable' interest rate rule in terms of the magnitude of the rule's coefficients. Woodford (2003, pp.252-261) derives, for various different interest rate rules, a series of analytical conditions which must be satisfied in order for the three equation system to deliver determinate outcomes. A useful

⁴ As Clarida et al. (1998) explain in their open economy context: "To make sense of the class of policy reaction functions we study, our analysis appeals to existence of temporary nominal wage and price rigidities. With nominal rigidities, of course, monetary policy affects real activity in the short run; by varying the nominal rate, a central bank can effectively vary the real interest rate and the real exchange rate." (Clarida et al., 1998, p.1036).

⁵ The origins of this proposition can be traced back to Wicksell's (1898) 'cumulative process'.

'rule-of-thumb' turns out to be that the rule's inflation coefficient ('reaction coefficient') must exceed unity. This gives rise to the common interpretation of the so-called 'Taylor principle': A 'desirable' interest rate rule is characterised by a more than one-for-one response to inflation deviations from target.⁶

As noted above, this theoretical result is supplemented by empirical studies which have found that historical periods characterised by 'unfavourable' economic outcomes – for instance, the high and variable inflation observed in the U.S. during the 1970s – are associated with an interest rate rule which violates the Taylor principle (e.g. Taylor, 1999; Clarida et al., 2000). In contrast, the Great Moderation period (post c.1980) is associated with a rule which satisfies the Taylor principle. Accordingly, evidence obtained from estimated interest rate rules is often used to argue that a distinct change in the conduct of monetary policy played a key role in explaining the contrast between the instability during the 1970s and the subsequent tranquillity of the 1980s and 1990s. From the perspective of the forward-looking NK model, this amounts to the claim that the economy went from a state of indeterminacy – which must presumably include the possibility of sunspot-driven nominal explosions – to one free of indeterminacy problems.

1.1.2 Interest Rate Rules, the NK Model and Monetary policy without 'M'

One notable feature of the NK modelling framework is that it assigns no prominent role to monetary aggregates (e.g. Woodford, 2008, pp.1566-1567). This represents a significant departure from prominent schools-of-thought which assign a central role to monetary relationships for the analysis of monetary policy (Friedman, 1960; Friedman and Schwartz, 1963, to name but two eminent contributions). Although the central bank is required to conduct money market interventions in order to deliver the rule-implied nominal interest rate, such

⁶ Technically, the requirement is that the rule's coefficients must, when taken in combination with the other parameters of the model, satisfy the Blanchard and Kahn (1980) conditions (Woodford, 2003, p.685.) Strictly speaking, the 'rule-of-thumb' described in the text holds exactly when the interest rate rule contains a term in inflation only. However, under a standard calibration the reaction to the output gap in a rule which features such a term is not important to the outcome. The coefficient on the output gap is often multiplied by $(1-\beta)$ in the determinacy condition, where β is the discount factor and is typically calibrated to be close to one (see Woodford, 2008, p.1569, eq.7, for example).

interventions are considered to be an operational detail and of little interest in-and-of-themselves. Changes in the supply of money therefore take place 'off-stage' and are not modelled explicitly. As Woodford makes clear from the outset:

“While the implied evolution of the money supply is sometimes discussed, the question is often ignored. Some of the time, I do not bother to specify policy (or an economic model) in sufficient detail to determine the associated path of the money supply, or even to tell if one can be uniquely determined in principle.” (Woodford, 2003, p.25)

Furthermore, Woodford (2003, pp.299-311; 2008) adapts the structural relationships underpinning the three equation NK system by adding a (non-separable) term in money balances to the utility function. Woodford finds that the omission of monetary aggregates comes at no material cost' in terms of the quantitative predictions of the model (see also: McCallum, 2001; Nelson, 2008a, p.1799). Appending monetary variables to the NK framework in this way readily leads to the conclusion that monetary aggregates are superfluous. However, an interest rate rule is still used to characterise monetary policy even for the extended money-in-utility model. Therefore, the money supply is still infinitely elastic, i.e. purely demand determined, and so money enters the adapted model somewhat superficially.

The de-emphasis of money in the NK model is, however, consistent with an analogous de-emphasis in practice in many developed countries. Three prominent examples of the de-emphasis of monetary variables in the conduct of U.S. monetary policy are provided by the abolition of formal M1 targeting in 1987, Chairman Greenspan's July 1993 testimony to Congress that Federal Reserve officials intended to reduce their reliance on the M2 money supply as a “reliable indicator of financial conditions in the economy” (Greenspan's testimony is cited by Asso et al., 2007, p.4) and the decision to cease publication of measures of 'broad money' (M3) from March 2006 onwards (see Meyer, 2001; Bernanke, 2006; Kahn and Benolkin, 2007).

Aside from the justification that monetary policy seems to be implemented without reference to money in practice, there may be several other advantages to

a modelling approach which omits monetary aggregates. For one, using a nominal interest rate as the instrument of monetary policy reduces the need for policymakers to possess an accurate model of money demand. Under an interest rate rule, a well-specified money demand function is not necessary because shifts in money demand are implicitly accommodated by adjustments in the supply of money to the extent required to maintain the target interest rate. This would be particularly appealing to those who view money demand as erratic and inherently difficult to model (e.g. Goldfeld, 1976; Goldfeld and Sichel, 1990), thus obfuscating the relationship between monetary aggregates and the variables that the central bank is ultimately concerned about (e.g. Friedman, 1988; Friedman and Kuttner, 1992; De Grauwe and Polan, 2005). Goldfeld and Sichel (1990, p.300) describe a stable demand for money as being, “a prerequisite for the use of monetary aggregates in the conduct of policy” and Beck and Wieland (2008, p.53) similarly acknowledge that sudden shifts in the velocity of money – a corollary of an unstable money demand function – are “the Achilles heel of traditional monetary targeting”. The reasoning applied here is reminiscent of Poole (1970), who demonstrated that it is optimal for the monetary authority to use the nominal interest rate as the instrument of monetary policy if ‘LM shocks’ – i.e. shocks to money demand/velocity – are quantitatively large relative to other – ‘IS’ or demand – shocks.⁷ Under an interest rate rule, it is argued that policymakers need not worry about abrupt shifts in money demand.

However, as Canova and Menz (2011, p.578) point out, others reject the notion that monetary policy can be conducted and analysed without reference to money. Alvarez et al. (2001), for example, outline an alternative ‘segmented markets’ approach which assigns a prominent role to monetary variables. Their paper begins as follows:

“A consensus has emerged among practitioners that the instrument of monetary policy ought to be the short-term interest rate, that policy should be focused on the control of inflation, and that inflation can be reduced by increasing short-term interest rates. At the center of this consensus is a

⁷ See Collard and Dellas (2005) for a translation of Poole’s analysis into a ‘modern’, micro-founded model.

rejection of the quantity theory. Such a rejection is a difficult step to take, given the mass of evidence linking money growth, inflation, and interest rates: increases in average rates of money growth are associated with equal increases in average inflation rates and interest rates.” (Alvarez et al., 2001, p.219)⁸

The empirical evidence linking money growth to inflation and, in turn, inflation to interest rates is seemingly clear in its conclusion that money growth and inflation are inextricably linked, at least at low frequencies (e.g. Lucas, 1996; McCandless and Weber, 1995; Monnet and Weber, 2001; Haug and Dewald, 2012).

Many other studies have also investigated the importance of money from an empirical perspective. For example, Meltzer (2001) applies regression techniques to U.S. data and finds support for the hypothesis that monetary quantities – represented by (the growth rate of) the monetary base in his study – have a distinct effect on aggregate demand over-and-above that exerted through the real interest rate. Nelson (2002) generalises Meltzer’s (2001) specification in order to provide a closer correspondence with the ‘IS type’ specification adopted by Rudebusch and Svensson (2002). He uses U.S. and U.K. data to demonstrate that (the growth rate of) the monetary base enters Rudebusch and Svensson’s specification, “sizably, positively, and significantly” (Nelson, 2002, p.693), whereas the original study found no additional role for real monetary relationships. Hafer et al. (2007) apply similar regression techniques to various empirical specifications which seek to account for the dynamics observed in the data and subsequently find that a measure of broad money (M2) has an important role to play in explaining observed fluctuations in the output gap. Using an empirical VAR, Leeper and Roush (2003) question the ability of a theoretical model which excludes money to generate an observed ‘expected inflation effect’ following a shock to monetary policy. Similarly, Favara and Giordani (2009) use

⁸ Nelson (2008a) takes issue with the claim that the modelling approach taken by the NK framework represents a “rejection of the quantity theory” on the basis that quantity-theoretic principles still determine the rate of inflation at lower frequencies (see the discussion below). However, Woodford (2003, p.49) describes the ‘neo-Wicksellian’ approach adopted in his treatise as a, “non-quantity-theoretic analytical framework”, relevant, he argues, to “a world of purely fiat currencies in which central banks adjust their operating targets for nominal interest rates in response to perceived risks of inflation, but pay little if any attention to the evolution of monetary aggregates.”

an 'identified VAR' to show that exogenous shocks to money demand can have a material impact upon the dynamics of output, prices and interest rates. Bordo and Filardo (2007) use a novel empirical approach to argue that the recent de-emphasis of monetary aggregates is an overreaction to the claim that interest rate rules offer a satisfactory description of monetary policy during the Great Moderation period. Their empirical results uncover a, "robust correlation between the monetary aggregates and macroeconomic developments, even when controlling for real interest rates" (p.521) for G7 time series data. D'Agostino and Surico (2009) show that a measure of G7-country liquidity can markedly improve the accuracy of U.S. inflation forecasts in an international context, while Castelnuovo (2012) employs full-system estimation methods and finds that output reacts significantly and positively to money demand shocks.

Given the abundance of empirical evidence in support of the relevance of money to fluctuations in key macroeconomic variables such as inflation and output, it would seem to be remiss of a central bank seeking to promote stability in these variables to wholly disregard monetary variables as an additional source of information. As Nelson (2008a, p.1794) concludes:

"One can take one's pick among recent empirical studies of money... but whichever of these studies one finds most convincing, I believe that between them they have established that money has explanatory power for output and inflation beyond what the standard New Keynesian model predicts money should have, and exhibits this power across a number of different monetary policy regimes."

To state the obvious, it is difficult to see how the aforementioned empirical findings can be fully accounted for by an economic model which omits monetary relationships or, equivalently, a model which assigns only a residual role to the supply of money as a means to meet an interest rate target with no further quantitatively significant impact on the predictions of the model.

There are also several plausible reasons to doubt whether a Taylor-type interest rate constitutes a 'complete' description of monetary policy from a theoretical perspective. Nelson (2008a), for example, demonstrates that in the absence of

monetary relationships, policymakers in the NK framework lack a plausible means of ‘selecting’ the long-term (trend) rate of inflation.⁹ If prices are fully flexible in the long-run as nominal rigidities dissipate then the claim that the central bank can determine the steady-state rate of inflation using an interest rate rule represents a “high-level assumption”, in Nelson’s (2008a, p.1803) terminology. He argues that given the strong empirical relationship between money growth and inflation at lower frequencies, along with the fact that the central bank ordinarily possesses monopoly control over money creation, money supply growth is the natural candidate to fill this ‘gap’ in the model. Reynard (2007) presents empirical evidence which supports the notion that an interest rate rule is incapable of determining trend inflation. He also finds that peaks in inflation are invariably preceded by peaks in velocity-adjusted money growth for U.S., Eurozone and Swiss data.¹⁰ Therefore, monetary relationships may have an important role to play, even in the NK model which, technically, can be analysed without reference to money.

Christiano and Rostagno (2001), Christiano et al. (2007) and Minford and Srinivasan (2011a,b) also identify potentially useful roles for monetary relationships in the canonical NK model. Christiano and Rostagno (2001) and Christiano et al. (2007) consider a framework in which monetary policy is conducted using a nominal interest rate rule in the normal course of events but switches to a constant money growth rule if the quantity of money necessary to meet the rule-implied rate deviates outside of some pre-specified range. They argue that this commitment to enact a monetary ‘escape clause’ if necessary might be sufficient to prevent money growth from getting out of control to begin with

⁹ Similarly, Assenmacher-Wesche and Gerlach (2007, pp.535-536) reject the notion that policymakers can appropriately view a long-run time horizon as a series of short-run horizons and thus continue to operate via an interest rate rule without reference to money. In other words, one must consider the lower frequency determinants of inflation as a separate matter, not as an extension of higher frequency considerations.

¹⁰ According to this view, it is not the money supply *per se* that is important for economic outcomes, and inflation in particular, but the excess of the money supply over that necessary to support economic activity (i.e. the transactions demand for money). Similar logic underlies so-called ‘P-star models’ (e.g. Hallman et al., 1991) and related empirical studies which seek to identify incipient inflationary pressures via an assessment of the ‘monetary overhang’ or ‘money gap’ – essentially, money supply less money demand (e.g. Friedman, 2003; Masuch et al., 2003; Siklos, 2010, for Canadian data).

(Christiano et al., 2007, p.6).¹¹ Consequently, although the central bank may appear to adhere to a conventional interest rate rule, monetary variables form a crucial element of the monetary policy framework. In a similar vein, Minford and Srinivasan (2011a,b) argue that the process for the money supply must come to the fore in certain circumstances in order to prevent explosive paths which are otherwise ruled out only by assumption in the NK model (as Cochrane, 2011a, has argued). They diagnose the NK model as lacking an explicit terminal condition to preclude such paths and suggest that regulation of money supply growth can offer an economically valid reason to exclude non-stable equilibria. As with Christiano et al. (2007), the mere possibility that the conventional interest rate rule may be overridden by a money supply rule prevents the latter from ever having to be deployed and in practice the central bank appears to adhere to a conventional interest rate rule.

While it is undoubtedly true that many countries have de-emphasised the role of money for practical purposes, monetary policymakers seem to be divided as to whether monetary aggregates can be completely disregarded in the conduct of monetary policy. For example, 'monetary analysis' forms one of the ECB's 'two pillars' of monetary policy (e.g. European Central Bank, 2000; Gerlach, 2004; Kahn and Benolkin, 2007; Beck and Wieland, 2007), while the Bundesbank and the Swiss National Bank have also retained the view that inflation is ultimately a monetary phenomenon (Bordo and Filardo, 2007, p.511) and hence that monetary aggregates are still worthy of study. Even leading figures within central banks which ordinarily frame monetary policy decisions in terms of a nominal interest rate have expressed concerns about an analytical framework completely devoid of money. For example, Mervyn King, a Deputy Governor of the Bank of England at the time, documents three dangers of completely disregarding monetary aggregates in the conduct of monetary policy (King, 2002). Firstly, monetary aggregates might hold an important influence over risk and term premia; secondly, models without a prominent role for money might give rise to the false impression that a permanent inflation-output trade-off exists; and

¹¹ They compare this to the way in which government-run deposit protection schemes seldom need to be drawn-upon because the very existence of the scheme is often sufficient to prevent a bank-run from occurring in the first place.

thirdly, framing monetary policy without reference to money might foster the mistaken belief that it is within the gift of the monetary authority to offset *any* shock that might hit the economy (King, 2002, p.169).

James Bullard, President of the Federal Reserve Bank of St. Louis, raises a further practical problem with the convention of framing monetary policy exclusively in terms of a nominal interest rate: The rule-implied nominal interest rate cannot be realised if it falls below zero, as it seems to have done in the U.S. recently (e.g. Rudebusch, 2009). Bullard (2009) notes that:

“...the setting of nominal interest rate targets as a monetary policy tool will be off the table for some time. In this environment the implementation of monetary policy has to be refocused. The new focus should be on quantitative measures of policy.”

This is the so-called ‘zero lower bound problem’ and Laidler (2006) also highlights this flaw in a review of the NK framework. Bullard (2009) subsequently defines ‘quantitative measures of policy’ as, “starting with the monetary base” and advocates the use of “quantitative targets for monetary policy” in order to provide the requisite nominal anchor that the interest rate rule is temporarily incapable of supplying. Although Bullard makes it clear that in normal times he deems an interest rate rule to work well, this nevertheless leaves the zero lower bound as a reason for policymakers to question the use of models which use the nominal interest rate as the instrument of monetary policy to the exclusion of all other viable policy instruments.¹² Some have even discussed the “complacency” engendered by the apparent success of interest rate rules in generating stable macroeconomic outcomes during the Great Moderation period (Bordo and Filardo, 2007, p.521). Others have similarly suggested that policymakers had previously neglected monetary variables to the extent that there now exists a dearth of statistical information and detailed analysis pertaining to such quantities (e.g. Smith, 2010) or possible flaws in published monetary statistics

¹² It should be pointed-out, however, that Cúrdia and Woodford (2011) and Gertler and Karadi (2011) have studied extensions to the NK model which seek to incorporate ‘unconventional’ monetary policy.

(e.g. Dutkowsky and Cynamon, 2003) at precisely the time when this knowledge and information is required.

Many researchers have also questioned the notion that the demand for money cannot be modelled as a 'stable function' over time. This, we recall, is one justification for framing monetary policy exclusively in terms of the nominal interest rate. Several studies have argued that, in fact, progress can be made in modelling secular trends in the velocity of money (e.g. Lucas, 1988a; McGrattan, 1998; Ball, 2001; Gillman and Otto, 2007) and indeed short-run fluctuations too (Ball, 2012). In turn, these well-specified money demand functions could be used to derive policy recommendations from models which exhibit quantity theoretic principles (e.g. Alvarez et al., 2001).

In light of the discussion in this section, it seems that plausible roles for monetary aggregates can be identified on empirical, theoretical and practical grounds. In light of their empirical results, Hafer et al. (2007, p.953), for example, conclude that it may be "premature" to suggest that one can meaningfully conduct monetary policy analysis without reference to money. We next investigate the link between the type of interest rate rules which have become ubiquitous in the contemporary literature and the money supply rules which were traditionally used to depict the monetary policy process in previous generations of models and certain contemporary models.

1.2 'Implicit' Interest Rate Rules

Fixed money growth rules (i.e. a Friedman, 1960, k -percent rule) and interest rate rules with feedback (Taylor-type rules) seemingly constitute very different prescriptions for monetary policy. On the one hand, the money growth rule is expressed in terms of a measure of the money supply and involves no feedback on the state of the economy; on the other hand, the Taylor-type rule is expressed in terms of the nominal interest rate and *must* feedback on the state of the economy in order to preclude 'endogenous fluctuations'. However, as Nelson (2008b) argues, these two policy regimes share several common characteristics. Firstly, and most obviously, they both fall into the category of 'rules for monetary policy'

in the sense that each stands opposed to policy-making by unfettered discretion.¹³ Secondly, Nelson argues that both prescriptions embody Milton Friedman's famous and oft-quoted maxim that *inflation is always and everywhere a monetary phenomenon* in that both emphasise the primacy of monetary policy over fiscal policy for keeping inflation under control.¹⁴ Thirdly, both imply that monetary policy should 'lean against the wind' – i.e. seek to counteract business cycle fluctuations – to some degree. This latter point is clear for a conventional 'reaction function' but, as we demonstrate below, a money supply rule also possesses this property to a certain extent. Indeed, the organising principle of Taylor's (1999) analysis is that a lengthy period of historical U.S. monetary policy (1879-1997) can be characterised by an interest rate rule of the type proposed by Taylor (1993) which differs by its 'reaction coefficients'. The constant money growth rule merely constitutes one of several monetary policy regimes that Taylor 'translates' into interest rate rule form (see also, Orphanides, 2003a) and he describes how his interest rate rule "is closely connected to the quantity equation" (Taylor, 1999, p.322). Similarly, Clarida et al. (1998) reinterpret the Bundesbank's stated policy of money targeting in terms of a (forward-looking) interest rate rule; the brief adoption of direct monetary targeting in the U.S. during the early 1980s has also been interpreted as a way of justifying an interest rate rule which placed strong emphasis on inflation at the expense of the output gap (e.g. Mishkin and Eakins, 2009, p.191).

The suggested correspondence between money growth and interest rate rules clearly raises the question as to the precise details of the connection between the two. Asso et al. (2007) report a quote from an interview conducted with John Taylor which sheds some light on the nature of this relationship:

¹³ Nelson (2008b, p.10) notes that Taylor recognised this particular similarity early on in his research: "Activist and constant-growth-rate policy rules have much more in common with each other than do activist policy rules and discretionary policy. Both types of policy rules involve commitments and lead to the type of policy analysis suggested by the rational expectations approach." (Taylor, 1986, p.157).

¹⁴ However, Hetzel (2000) and Alvarez et al. (2001) question whether the modelling framework in which conventional interest rate rules are most commonly employed – the NK framework (e.g. Woodford, 2003) – fully reflects this sentiment.

“This [the similarity between an interest rate rule and the quantity theory of money] actually goes back to the inverted money demand equation in my 1968 paper. Such an inverted equation can *generate interest rate behavior with similar characteristics to interest rate rules*. When GDP rises, the interest rate also rises, for example.” (Asso et al., 2007, p.17, emphasis added)¹⁵

The money growth rule might therefore be said to *imply* a particular type of interest rate rule.¹⁶ In such a framework, a separately-specified interest rate rule would be superfluous thus reversing the situation in the NK framework where the model can be solved without the need to specify monetary relationships. This suggestion also carries implications for empirical studies which evaluate conventional interest rate rules. Econometric exercises which seek to obtain estimated interest rate rule coefficients from time series data simply recover aggregate relationships between the nominal interest rate and whichever variables the researcher chooses to include on the right hand side of the rule. The researcher’s estimating equation might well be motivated by a conventional interest rate rule but a similar relationship would be obtained from a model in which a separately-specified interest rate rule does not feature. As Hetzel warns:

“What the economist sees is only the correlations between economic activity and the funds rate that emerge out of the policy process... Even if one assumes that a functional form like the Taylor rule successfully predicts the behavior of the funds rate, what has one learned about the behavior of the FOMC? Unfortunately the answer is ‘nothing’ unless one has solved the identification (simultaneous equation bias) problem. One must determine that the functional form is a structural rather than a reduced form relationship... a reduced form is an amalgam of structural relationships embodying both the behavior of the FOMC and the public.” (Hetzel, 2000, p.3)

Accordingly, estimates obtained from interest rate rules might not be as conclusive as they seem despite the obvious intuitive appeal of the results

¹⁵ Taylor (1968, eq.5), adapting his original notation, is: $\bar{R} = \bar{R}^* + \mu(\log P + \log Y_A - \log M)$, where, \bar{R} is the nominal interest rate, \bar{R}^* is a constant, Y_A is the actual level of income (output) and μ is simply defined as the, “influence of price level, actual income, and money supply on interest rate”. The following description accompanies this expression: “Such a relationship represents an economy where the demand for cash balances is a function of money income (PY_A) and the interest rate”.

¹⁶ In some sense, even a conventional (“Taylor-type”) interest rate rule is ‘implicit’ because no central bank has ever declared that they adhere to such a rule in a mechanical way but our intended meaning here is different.

obtained (e.g. Clarida et al., 2000, as discussed above). The interest rate rule account of the historical record has come to define the conventional wisdom. However, Friedman (2003) characterises the change in the conduct of monetary policy not in terms of an interest rate rule but in terms of the way in which monetary policymakers have controlled the supply of money:

“Prior to the 1980s, the Fed got into trouble because it generated wide fluctuations in monetary growth per unit of output. Far from promoting price stability, it was itself a major source of instability... Yet since the mid '80s, it has managed to control the money supply in such a way as to offset changes not only in output but also in velocity.” (Friedman, 2003)

The shift in monetary policy conventionally documented by an interest rate rule is now reinterpreted as a transition to a judicious rule for the money supply. As the quotation from Friedman (2003) suggests, the post-transition rule appears to have satisfied the aforementioned quantity-theoretic requirement for a stable price level – that money supply growth should be set equal to the real output growth rate less the growth rate of the velocity of money (the inverse of money per unit of output). Similarly, Chowdhury and Schabert (2008) propose a rigorous ('micro-founded') model in which the monetary policy process is stated in terms of a forward-looking rule for 'high-powered money' (non-borrowed reserves) rather than a rule for the short-term nominal interest rate. Using this alternative specification for monetary policy, they uncover a “reversed Taylor principle” in which the quantity of non-borrowed reserves is required to decrease with an increase in the rate of inflation. This reversed Taylor principle is found to be satisfied for post-1979 data but not for pre-1979 data, similar to the way in which Clarida et al. (2000) report a shift in their (forward-looking) interest rate rule at around the same point in time. Moreover, when applied in the context of a standard economic model, the rule for non-borrowed reserves delivers determinate outcomes both pre- and post-1979 whereas Clarida et al.'s (2000) result implies indeterminate outcomes ('endogenous fluctuations') in the standard NK model for the pre-1979 period.

We now proceed to examine a series of implicit interest rate rules in the context of several different economic models. In keeping with the discussion in this

section, these expressions involve relationships between the nominal interest rate and key macroeconomic variables which often feature in conventional interest rate rules but they emerge from underlying models which do not directly incorporate such a rule.

1.2.1 A Conventional Interest Rate Rule

We begin by presenting a general conventional interest rate rule which will serve as a useful point of comparison for the implicit rules discussed below. This general rule is:

$$\bar{R}_t^R \equiv \bar{R}_t = \bar{r}^* + E_t \bar{\pi}_{t+s} + \beta_\pi (E_t \bar{\pi}_{t+s} - \bar{\pi}^*) + \beta_y (E_t \bar{y}_{gap,t+q}), \quad (1.1)$$

where over bars denote net rates, \bar{R}_t^R denotes the rule-implied nominal interest rate, \bar{r}^* is usually interpreted as the natural (or ‘Wicksellian’) real rate of interest, s measures the policy horizon with respect to inflation deviations from target, $\bar{\pi}_{t+s}$ denotes the percentage change in the price level over this horizon, β_π measures the ‘strength’ of the interest rate response to deviations of inflation from target (i.e. ‘reaction coefficient’), q measures the policy horizon with respect to output deviations from potential, $\bar{y}_{gap,t+q}$ represents a measure of the average output gap over this horizon in (net) percentage terms, β_y measures the ‘strength’ of the policy response to the output gap and E_t is the expectations operator conditional upon information available at time t . Equation (1.1) can equivalently be written as:

$$\bar{R}_t^R \equiv \bar{R}_t = \bar{r}^* + \bar{\pi}^* + (1 + \beta_\pi)(E_t \bar{\pi}_{t+s} - \bar{\pi}^*) + \beta_y (E_t \bar{y}_{gap,t+q}). \quad (1.2)$$

One particularly well-known parameterisation of (1.2) is due to Taylor (1993) – he effectively sets $s=q=0$ and adopts the calibration $\beta_\pi=0.5$, $\beta_y=0.5$, $\bar{r}=\bar{\pi}^*=2\%$. With both policy horizons set to zero, the expectations operators disappear from (1.1) and (1.2) and policymakers simply react to deviations of current inflation from target by adjusting the nominal interest rate by one-and-a-half times as much and

react to deviations of current output from its potential level by adjusting the nominal interest rate by half as much. Taylor (1999) also considered an alternative calibration in which $\beta_y=1.0$, with all other coefficients as per Taylor (1993). As Taylor and Williams (2010, p.10) emphasise, this suggested calibration of (1.2) satisfies the ‘Taylor principle’ whereby an increase in the rate of inflation is met by a more than proportional increase in the nominal interest rate in order to, “slow the economy and reduce inflationary pressures” through a ‘stabilising’ increase in the real interest rate.

Many extensions have since been made to Taylor’s original rule. These include: *i*) allowing independent variables to enter in a forward-looking manner, i.e. $s, q \geq 1$ in equation (1.1), as per Clarida et al. (1998, 2000), Batini and Haldane (1999) and Mehra (1999), for example; *ii*) estimating the coefficients of the rule using econometric procedures rather than resorting to calibration (e.g. Taylor, 1999, Table 7.1; Clarida et al., 1998, 2000; Rudebusch, 2009); *iii*) allowing lagged dependent variable terms to appear on the right hand side of the rule in order to incorporate the notion of ‘interest rate smoothing’. The implied nominal interest rate series derived from such rules are often found to provide a better fit to the observed nominal interest rate (e.g. Carlstrom and Fuerst, 2008, figure-1); *iv*) including other potentially relevant variables to stand either in place of or alongside inflation and the output gap. For example, Mankiw (2001) replaces the output gap with the unemployment rate and Clarida et al. (2000, Table III) and Rudebusch (2009) replace the output gap with the ‘unemployment gap’; Bernanke and Gertler (1999, 2001), Cecchetti et al. (2000), Filardo (2001) and Gilchrist and Leahy (2002) allow for an interest rate reaction to ‘asset price bubbles’; Borio and Lowe (2004) specify a rule in which policymakers are assumed to take credit conditions into account when deciding upon the appropriate setting for the nominal interest rate; Mishkin (2007) allows monetary policy to respond to housing market conditions; and Ball (1999) and Cecchetti et al. (2000) consider whether a reaction to the exchange rate is appropriate for a small, open economy.

Each of these modifications builds upon the contribution of Taylor (1993) and other seminal studies conducted during the early 1990s. Each modification is readily incorporated into the interest rate rule framework because the rule stands as an exogenously specified entity in the context of a wider economic model. The researcher therefore acquires a certain degree of freedom as to the structure of the rule. On the other hand, the functional form of the implicit interest rate rules presented below emanate from an underlying structural model. One starts with a model in which some alternative monetary policy regime applies, e.g. a constant money growth rule, and the behaviour of the nominal interest rate generated by this alternative regime is then derived in 'rule' form. Implicit rules therefore represent an equilibrium condition – or a combination of several equilibrium conditions – of an underlying model.¹⁷ The underlying model will also place certain restrictions upon the coefficients of the implicit interest rate rule, as we shall now demonstrate for several different models.

1.2.2 A Quantity-Theory-Based Implicit Rule

We first consider a simple 'textbook' derivation based on the Quantity Theory of Money (QTM). Sørensen and Whitta-Jacobsen (2005, pp.502-505) – SWJ henceforth – consider a model in which the central bank adheres to a constant money growth rule as opposed to a conventional interest rate rule. They pose the question: "What does the constant money growth rule imply for the formation of interest rates?" The following derivation represents their answer to this question.¹⁸ They begin by specifying the following function for the demand for real money balances (SWJ, 2005, p.503):

¹⁷ The inclusion of variables not considered by Taylor (1993) in a conventional interest rate rule might be justified, somewhat superficially, by appending additional variables to the 'central bank loss function'. This modification would subsequently be justified if the newly introduced variable helps to produce a nominal interest rate series which better tracks the observed series or if the new variable is estimated to be statistically significant using an appropriate econometric procedure.

¹⁸ Similarly, Taylor (1999, p.322) describes how: "The policy rule is, of course, quite different from the quantity equation of money, but it is closely connected to the quantity equation. In fact, it can be easily derived from the quantity equation." Taylor (1999, Section-7.1.1) then describes how to conduct this derivation but does not provide a full exposition. We therefore present SWJ's (2005) derivation, although similar QTM-based derivations can also be found in Edey (1997), Orphanides (2003a, pp.990-991), Cochrane (2011b, p.7) and Gerberding et al. (2007). The latter study uses the resulting expression – which is more complex than the implicit rule derived by SWJ because it features interest rate smoothing and allows for measurement error – to analyse German data over

$$\frac{M_t}{P_t} = L^D(y_t, \bar{R}_t) = \eta_0 y_t^{\eta_y} e^{-\eta_R \bar{R}_t}, \quad (1.3)$$

where M represents nominal money balances, P represents the price level, \bar{R} is a short-term net nominal interest rate which corresponds to the opportunity cost of money, $\eta_0 (>0)$ is a constant term, $\eta_y (>0)$ is the income (output) elasticity of money demand, i.e. the percentage increase or decrease in real money demand for a one percent increase or decrease in income, y is real output and $\eta_R (>0)$ is the interest semi-elasticity of money demand, i.e. the percentage increase or decrease in real money demand for a one *percentage point* decrease or increase in the nominal interest rate. According to (1.3), the income elasticity of money demand is constant at η_y and the interest elasticity of money demand, which we shall define as λ_R , varies and can be calculated as the product of the constant semi-elasticity and the nominal interest rate ($\lambda_R \equiv \eta_R \bar{R}$).

Using the following definitions, $P_t \equiv (1 + \bar{\pi}_t)P_{t-1}$ and $M_t \equiv (1 + \bar{\sigma})M_{t-1}$, where $\bar{\pi}_t$ is the net rate of inflation and $\bar{\sigma}$ is the constant net money supply growth rate, equation (1.3) can be expressed as:

$$\frac{(1 + \bar{\sigma})M_{t-1}}{(1 + \bar{\pi}_t)P_{t-1}} = \eta_0 y_t^{\eta_y} e^{-\eta_R \bar{R}_t}. \quad (1.4)$$

Assuming that the economy was in its long-run equilibrium state in the previous period and assuming zero growth in real output, the demand for real money balances must also have been constant in the previous period. This, in turn, implies that the rate of inflation is constant at the money supply growth rate in the long-run equilibrium. This can be seen by rewriting (1.3) and (1.4) as, $(1 + \bar{\sigma})/(1 + \bar{\pi}_t) = (P_{t-1}/M_{t-1})(M_t/P_t)$, which, for constant real money demand ($M_{t-1}/P_{t-1} = M_t/P_t = M/P$) leads to the long-run equilibrium condition, $\bar{\pi} = \bar{\sigma}$.

the period 1979-1998 and finds it to be a suitable characterisation of the way in which the Bundesbank has behaved.

Although SWJ do not emphasise this point, their model evidently possesses ‘quantity-theoretic foundations’ because writing the QTM relationship in first difference form, $\bar{\sigma} + \bar{g}_V = \bar{\pi} + \bar{g}_y$, also shows that with real output and velocity constant, the rate of inflation is determined by the rate of growth of the money supply.¹⁹ Accordingly, the equilibrium condition of SWJ’s model is consistent with Orphanides’ (2007, pp.2-3) interpretation of Friedman’s *k*-percent rule, and the policy recommendation of Snyder (1935) that if money demand is stable, price stability can be achieved by setting the rate of growth of the money supply equal to the real output growth rate. Under the assumption of zero real output growth, we note from (1.3) and (1.4) that perfect price stability is achieved if the money supply is constant (i.e. $\bar{\sigma} = 0$ gives $\bar{\pi} = 0$). Alternatively, SWJ (2005, p.504, footnote-7) report that the equilibrium rate of inflation with non-zero output growth would be $\pi^* = \bar{\sigma} - \eta_y \bar{g}_y$, where \bar{g}_y is the real output growth rate. Perfect price stability would therefore require the money growth rate to match the real output growth rate, as long as $\eta_y = 1$, hence replicating Snyder’s recommendation and Orphanides’ (2007) interpretation of the *k*-percent rule.

Substituting the long-run equilibrium relationship, $\bar{\pi} = \bar{\sigma}$, and the fact that the real interest rate is constant if the nominal interest rate and the rate of inflation are constant into the standard representation of the Fisher relation ($\bar{R} = \bar{r} + \bar{\pi}$) gives an expression for the constant nominal interest rate consistent with the long-run equilibrium:

¹⁹ Strictly speaking, the money demand function must have a ‘velocity specification’ in order for the ‘*V*’ in $MV=PQ$ to be interchangeable with inverse money demand. The ‘velocity specification’ is more-appropriately thought of as a special case in which the income elasticity of money demand is unity in functions such as (1.3) (e.g. Poole, 1988; McGrattan, 1998; Haug and Tam, 2007). In general, the relationship between money demand and velocity is, $\ln V_t = -\ln \eta_o + \eta_R \bar{R}_t + (1 - \eta_y) \ln y_t$ and the ‘velocity specification’ is recovered only when $\eta_y = 1$. Lucas (1988a) extends the data period considered by Meltzer (1963) and verifies Meltzer’s finding that the income elasticity is approximately unity for U.S. data (also McGrattan, 1998). However, other studies contradict this result. Friedman and Kuttner (1992), for example, argue that a stable money demand relation cannot be found using non-stationary time series methods, hence calling into question whether these elasticities can be estimated at all, while Haug and Tam (2007) use similar methods and report an income elasticity of 0.86 and an interest elasticity of -0.44. Ball (2001) finds a stable relationship between the nominal interest rate and “quasi-velocity” (with $\eta_y < 1$) for post-war U.S. data but not between the nominal interest rate and the conventional velocity measure (with $\eta_y = 1$).

$$\bar{R} = \bar{r} + \bar{\sigma}. \quad (1.5)$$

Given the assumption that the model was in its long-run equilibrium state in the previous period and using the long-run condition (1.5), the first lag of the money demand function (1.3) is:

$$\frac{M_{t-1}}{P_{t-1}} = \eta_0 (y^*)^{\eta_y} e^{-\eta_R(\bar{r} + \bar{\sigma})}, \quad (1.6)$$

where y_{t-1} has been replaced by trend output y^* which is also assumed to be constant for simplicity. Taking the natural log of (1.4) and using the approximation that $\ln(1 + x) \simeq x$, for sufficiently small x :

$$\bar{\sigma} - \bar{\pi}_t + \ln L^{D*} = \ln \eta_0 + \eta_y \ln y_t - \eta_R \bar{R}_t, \quad (1.7)$$

where L^{D*} denotes that the economy is assumed to have been in its long-run equilibrium in the previous period. Substituting the natural log of (1.6) into (1.7) for $\ln L^{D*}$ and solving for the nominal interest rate gives the ‘interest rate rule’ implicit in SWJ’s QTM-based model:

$$\bar{R}_t = \bar{r} + \bar{\pi}_t + \left(\frac{1 - \eta_R}{\eta_R} \right) (\bar{\pi}_t - \bar{\sigma}) + \frac{\eta_y}{\eta_R} (\ln y_t - \ln y^*). \quad (1.8)$$

The timing of the variables in this expression is found to be consistent with Taylor’s (1993) specification in which s and q are set to zero in (1.1). Equation (1.8) is interpreted to show:

“how the short-term nominal interest rate $[\bar{R}]$ will react to changes in inflation and output if monetary policy aims at securing a constant growth rate $[\bar{\sigma}]$ of the nominal money supply.” (SWJ, p.505).

Gerberding et al. (2007, p.6) similarly interpret the terms in inflation and output in their QTM-based implicit rule to represent the nominal interest rate responses to the determinants of money demand. This is consistent with the reasoning set-out by Carlin and Soskice (2006, ch.8.4) that the variation in the nominal interest rate documented by an expression such as (1.8) describes that which is required to equate the supply of and demand for money.

Equation (1.8) shows that the nominal interest rate varies positively with inflation so long as $0 < \eta_R < 1$. Furthermore, rewriting (1.8) in terms of the real interest rate $(\bar{R}_t - \bar{\pi}_t)$ makes it clear that the nominal interest rate increases sufficiently with inflation to raise the real interest rate so long as $(1 - \eta_R) / \eta_R > 0$. One could compare this requirement for the coefficient on inflation in (1.8) to the rule-of-thumb Taylor principle in the context of a conventional interest rate rule such as (1.1), where the correspondence between the two expressions is $(1 - \eta_R) / \eta_R \equiv \beta \pi$. The nominal interest rate also varies positively with the output gap in (1.8) – this replicates the correlation between the nominal interest rate and the output gap found in the conventional rule (1.1). The money supply growth rate also enters (1.8) as a separate term and carries the same coefficient as inflation but with the opposite sign. Therefore, the nominal interest rate will fall as the money supply increases, so long as $(1 - \eta_R) / \eta_R > 0$. Alternatively, the money supply growth rate could be interpreted as the trend (long-run equilibrium) rate of inflation in keeping with the quantity-theoretic principles of SWJ's model, or as the central bank's inflation target. Adopting this interpretation and adding and subtracting a term in $(\pi_t - \pi^*)$ to (1.8) yields an expression comparable to the conventional interest rate rule (1.2):

$$\bar{R}_t = \bar{r} + \bar{\pi}^* + \frac{1}{\eta_R} (\bar{\pi}_t - \bar{\pi}^*) + \frac{\eta_Y}{\eta_R} (\ln y_t - \ln y^*), \quad (1.9)$$

where \bar{r} is equivalent to the equilibrium natural rate of interest in (1.2). If the money demand function is restricted to take a 'velocity specification' ($\eta_Y = 1$) then the coefficients on inflation and output gaps must take the same numerical value

in (1.9), but SWJ's expression clearly generalises to the case where the coefficients may differ ($\eta_y \neq 1$). To reproduce Taylor's original (1993) calibration in equation (1.9), we would require $\eta_R = 2/3$ and $\eta_y = 1/3$. Alternatively, $\eta_R = \eta_y = 2/3$ would replicate Taylor's (1999) alternative calibration. Therefore, we find that under a money demand function which has a valid 'velocity specification' ($\eta_y = 1$), the coefficients on inflation and output gaps in (1.9) would take the same magnitude.

The implicit interest rate rules (1.8) and (1.9) show that the parameters of the money demand function play a crucial role in the QTM-based derivation. Hetzel (2000, p.7), for example, argues that an interest rate rule approximates, "moderate growth in money" so long as the demand for money is, "stable and relatively interest inelastic." Indeed, SWJ interpret Friedman's favoured prescription for monetary policy rule in terms of the stability of the demand for money:

"In an influential book published in 1960, the American economist Milton Friedman argued that a constant money supply growth rate would in practice ensure the highest degree of macroeconomic stability which could realistically be achieved... This argument was based on Friedman's belief in a *stable* money demand function with a *low interest elasticity*." (SWJ, 2005, pp.503-504, emphasis added)

Firstly, the 'stability' of the money demand function is important because, at best, erratic variation in η_R and η_y in (1.8) and (1.9) could mean that the implied interest rate rule switches unpredictably between $(1-\eta_R)/\eta_R > 0$ and $(1-\eta_R)/\eta_R < 0$ or, worse still, could mean that the money demand function (1.3) is simply misspecified. Secondly, even if the stability of the money demand function can be established, the constant money growth rule may imply an 'undesirable' interest rate rule with too small a coefficient on inflation if η_R is 'too large'. The coefficients of equation (1.9) are therefore comparable to the calibrated coefficients of a conventional interest rate rule to a certain extent. However, the crucial difference between the coefficient $1/\eta_R$ in equation (1.9) and $(1+\beta\pi)$ for the conventional rule (1.2) is that the latter is 'chosen' by policymakers whereas the former is not in their gift:

“Under the constant money growth rule the coefficients in the equation for the interest rate depend on the parameters $[\eta_y]$ and $[\eta_R]$ in the money demand function. In contrast, under the Taylor rule the parameters $[\beta_\pi]$ and $[\beta_y]$ in [(1.1) or (1.2)] are chosen directly by policymakers, depending on their aversion to inflation and output instability.” (SWJ, 2005, p.506)

This clearly represents a fundamental distinction between an equilibrium condition such as (1.9) and an exogenously specified interest rate rule.

1.2.3 Implicit Rules for the NK Model

The SWJ ‘textbook’ derivation, although useful from an intuitive perspective, is based upon a non-forward-looking, reduced form model rather than a forward-looking, structural model and is therefore potentially subject to the Lucas (1976) critique. We therefore proceed to derive a set of implicit interest rate rules from several structural economic models, in keeping with the ‘Modern Macro’ approach (e.g. Gillman, 2011). To begin with we consider two ways in which an implicit interest rate rule can be derived from the NK model under two alternative specifications for monetary policy – the first is where the standard interest rate rule is replaced by ‘strict inflation targeting’ and the second is where it is replaced by a money supply (growth) rule.

Consider the following two equations of the simplest version of the NK model (as presented by Woodford 2003, p.246):

$$\bar{y}_{gap,t} = E_t \bar{y}_{gap,t+1} - \omega(\bar{R}_t - E_t \bar{\pi}_{t+1} - \bar{r}_t^*); \quad (1.10)$$

$$\bar{\pi}_t = \kappa \bar{y}_{gap,t} + \beta E_t \bar{\pi}_{t+1}, \quad (1.11)$$

where $\omega (>0)$ is the intertemporal elasticity of substitution (the inverse of the coefficient of relative risk aversion) from the underlying utility function, $\kappa (>0)$ is an amalgam of parameters which reflects, amongst other things, the assumed degree of nominal rigidity emanating from the price-setting behaviour of firms

(i.e. the Calvo, 1983, ‘reset probability’), β ($0 < \beta < 1$) is the discount factor and all other terms have been defined elsewhere.²⁰

Adopting the usual terminology, equation (1.10) represents the ‘New Keynesian IS equation (NKIS)’, which is essentially an intertemporal Euler equation expressed in terms of the output gap rather than consumption and $y=c$ in this simple model, and equation (1.11) represents the ‘New Keynesian Phillips Curve’ (NKPC) which documents the trade-off between inflation and the output gap engendered by the nominal rigidities incorporated into the model. Unlike the original Phillips curve, the NKPC takes inflation expectations into account so that the Phillips curve shifts with expected future inflation. This two-equation system requires a representation of the monetary policy process to close the model. Usually a Taylor-type rule such as (1.2) would be added but following Woodford (2003, p.290), suppose that the central bank commits to deliver the target rate of inflation (π^*) – a ‘strict inflation targeting’ regime – but still using the nominal interest rate as its policy instrument. Woodford explains that:

“Under such a specification of the policy rule, the central bank’s explicit commitment is to the achievement of the target criterion, which *need not involve any explicit reference to the desired path of the nominal interest rate*, even though this is the central bank’s policy instrument.” (Woodford, 2003, p.290, emphasis added)

In this sense there is an interest rate rule implicit in the NK model under this alternative policy regime. To derive the precise form for this implicit rule, begin by substituting the NKIS equation for the output gap (1.10) into the NKPC (1.11) to give (this derivation is presented and discussed by Woodford, 2003, pp.290-295):

$$\bar{\pi}_t = (\beta + \kappa\omega)E_t\bar{\pi}_{t+1} + \kappa E_t\bar{y}_{gap,t} - \kappa\omega(\bar{R}_t - \bar{r}_t^*). \quad (1.12)$$

²⁰ Equations (1.10) and (1.11) are written in deviation-from-steady-state form. Woodford (2003) often employs this sort of approximation hence his analysis applies to situations in which variables do not ‘stray too far’ from their steady-state values. Further note that steady-state inflation is usually set equal to zero (Woodford, 2003, p.79); Coibion and Gorodnichenko (2011) generalise the model to allow for trend inflation.

Further suppose that the central bank has full knowledge of the ‘correct’ model of the economy so that it is able to evaluate period t inflation as a function of its interest-rate decision. In this case, the nominal interest rate that would lead it to project an inflation rate consistent with the target (π^*) is obtained by equating the left-hand side of (1.12) with the inflation target and solving for the nominal interest rate. Also using the steady-state counterpart to the NKPC, $\bar{y}_{gap} \equiv \bar{\pi}^*(1 - \beta)/\kappa$, we obtain:

$$\bar{R}_t = \bar{r}_t + \bar{\pi}^* + \left(1 + \frac{\beta}{\kappa\omega}\right) (E_t \bar{\pi}_{t+1} - \bar{\pi}^*) + \frac{1}{\omega} (E_t \bar{y}_{gap,t+1} - \bar{y}_{gap}), \quad (1.13)$$

which represents the interest rate rule implicit in ‘strict inflation targeting’ according to Woodford’s (2003, p.246) model. It differs from Taylor’s original rule and equation (1.9) for SWJ’s derivation because it features forward-looking terms but is similar in that it includes terms in inflation and output gaps. Equation (1.13) shows that the coefficient on (expected future) inflation deviations from target exceeds unity since $\beta, \kappa, \omega > 0$ and that the coefficient on the (expected future) output gap is positive and will usually be smaller than the coefficient on inflation in a manner consistent with conventional rules which typically prescribe more decisive responses to inflation than to output. As Woodford (2003, p.294) notes, this means that the coefficients of (1.13) would satisfy the ‘Taylor principle’ if it were to be interpreted as a conventional rule. For example, under a ‘standard’ calibration of $\beta=0.99$, $\kappa=0.024$ and $\omega^{-1}=0.16$ (Woodford, 2003, p.341), the coefficient on inflation in (1.13) would take a value of 7.60 and the coefficient on the output gap would take a value of 0.16. Under this calibration, the inflation coefficient takes a magnitude substantially higher than the value of 1.5 that Taylor (1993) assigned to β_π in his contemporaneous rule (1.2) or the inflation coefficient of 2.15 that Clarida et al. (2000, Table II) obtain for a ‘Volcker-Greenspan’ sample of U.S. data.²¹ On the other hand, the magnitude of the output

²¹ Clarida et al. (2000) evaluate an interest rate rule which accounts for ‘interest smoothing’ by including a lagged dependent variables in the estimating equation. The estimate of 2.15 refers to their long-term coefficient estimate, i.e. once the protracted adjustment process has fully played out. We return to this issue in Chapter-IV when conducting similar estimation exercises to theirs.

gap coefficient is substantially smaller than Taylor’s calibration of 0.5 or Clarida et al.’s (2000, Table II) ‘Pre-Volcker’ estimate of 0.83. Consistent with Woodford’s (2003, p.294) interpretation of (1.13) as the interest rate rule which “implements” strict inflation targeting in the NK model, policymakers react more decisively to inflation deviations from target and less decisively to the output gap than a conventional interest rate rule usually requires. It is difficult to compare equation (1.13) with SWJ’s equation (1.9) because the model used to derive the former doesn’t contain a money demand function and the model used to derive the latter doesn’t contain structural parameters such as β , κ and ω . For the time being, we simply note that the coefficients on both inflation and the output gap in (1.13) vary inversely with the intertemporal elasticity of substitution, ω .

Although Woodford’s derivation yields some intuitively appealing results, his derivation still takes place in a model in which the short-term nominal interest rate is assumed to be the instrument of monetary policy. Minford (2008), on the other hand, presents a modified NK model which frames the monetary policy process in terms of a monetary aggregate instead.²² He derives an implicit Taylor-type rule by combining the money-supply-based approach taken in the SWJ derivation with the micro-founded nature of Woodford’s derivation. Just like the standard NK framework, his model consists of a NKIS equation and a NK Phillips Curve but a money growth rule is then added to represent monetary policy and a money demand function is also specified in order to form equilibrium in the money market. The modified NK model is as follows:

$$y_t = \alpha E_{t-1} y_{t+1} - \omega \bar{r}_t + \varepsilon_{1,t}; \tag{1.14}$$

$$\bar{\pi}_t = \kappa \bar{y}_{gap,t} + \zeta E_{t-1} \bar{\pi}_{t+1} + (1 - \zeta) \bar{\pi}_{t-1} + \varepsilon_{2,t}; \tag{1.15}$$

$$\Delta m_t = \bar{\sigma} + \varepsilon_{3,t}; \tag{1.16}$$

²² The derivation presented here is closely related to Minford et al. (2002).

$$m_t - p_t = \eta_y E_{t-1} y_{t+1} - \lambda_R \bar{R}_t + \varepsilon_{4,t} ; \quad (1.17)$$

$$\bar{R}_t = \bar{r}_t + E_{t-1} \bar{\pi}_{t+1} , \quad (1.18)$$

where (1.14), the NKIS equation, is similar to (1.10) above but it features the level of output rather than the output gap and it does not restrict the parameter on expected future output to take a value of unity. The NKPC (1.15) is similar to (1.11) except that it allows for some degree of ‘backward indexation’. The two equations relating to money supply and money demand (1.16) and (1.17) do not feature in Woodford’s derivation and the latter now contains a constant interest elasticity of money (λ_R) as opposed to the constant *semi*-elasticity (η_R) which featured in equation (1.3), and the Fisher relation (1.18) provides the link between real and nominal variables.

In order to derive the model’s implicit interest rate rule, Minford (2008) sets the first difference of the money demand function (1.17) equal to the exogenous process for the money supply (1.16), where the term in the first difference of output is eliminated using the first difference of the NKIS equation (1.14) to give:

$$\lambda_R \Delta \bar{R}_t = \bar{\pi}_t - \bar{\sigma} + \frac{\eta_y}{\alpha} (\Delta y_t + \omega \Delta \bar{r}_t - \Delta \varepsilon_{1,t}) + \Delta \varepsilon_{4,t} - \varepsilon_{3,t} . \quad (1.19)$$

Using the first difference of the Fisher relation (1.18) to eliminate $\Delta \bar{r}_t$ and adding steady-state values in first-difference form (there is no trend growth in any of the variables so the latter take a value of zero) gives:

$$\begin{aligned} \left(\lambda_R - \frac{\omega \eta_y}{\alpha} \right) \Delta (\bar{R}_t - \bar{R}^*) &= \bar{\pi}_t - \bar{\sigma} + \frac{\eta_y}{\alpha} \Delta (y_t - y^*) \\ &- \frac{\omega \eta_y}{\alpha} \Delta E_{t-1} \bar{\pi}_{t+1} + \Delta \varepsilon_{4,t} - \varepsilon_{3,t} - \frac{\eta_y}{\alpha} \Delta \varepsilon_{1,t} . \end{aligned}$$

Rewriting this expression by expanding the $\Delta\bar{R}$ term and applying the steady-state Fisher relation ($\bar{R}^* = \bar{r}^* + \bar{\pi}^*$) to one of the two \bar{R}^* terms contained in $\Delta\bar{R}^*$ gives:

$$\begin{aligned} \bar{R}_t = & [(\bar{r}^* + \bar{\pi}^*) + \alpha\chi^{-1}(\bar{\pi}_t - \bar{\sigma}) + \eta_y\chi^{-1}(y_t - y^*)] + \{(\bar{R}_{t-1} - \bar{R}^*) \\ & - \eta_y\chi^{-1}[\omega\Delta E_{t-1}\bar{\pi}_{t+1} - (y_{t-1} - y^*)] - \eta_y\Delta\varepsilon_{1,t} + \alpha\chi^{-1}(\Delta\varepsilon_{4,t} - \varepsilon_{3,t})\}, \end{aligned} \quad (1.20)$$

where $\chi \equiv \alpha\lambda_R - \omega\eta_y$. The expression in square brackets takes the same form as a conventional interest rate rule such as (1.2) if the steady-state condition $\bar{\sigma} = \bar{\pi}^*$ is applied. The remaining terms are collected in braces and would form a ‘composite error term’ if one was to try and estimate a conventional interest rate rule from model-simulated data. Using the definition of χ provided above, the coefficient on inflation in (1.20) is:

$$\alpha\chi^{-1} \equiv \frac{\alpha}{\alpha\lambda_R - \omega\eta_y}. \quad (1.21)$$

The magnitude of this coefficient depends inversely on the interest elasticity of money demand and positively on the income elasticity of money demand whereas the coefficient associated with inflation in (1.9) for the SWJ model depended only on the former. The coefficient on inflation also depends positively on the intertemporal elasticity of substitution, ω ; this differs from equation (1.13) derived from the NK model under strict inflation targeting. The coefficient on inflation in Woodford’s (2003) implicit rule also depends upon the parameters of the NKPC but these do not feature in (1.21). Applying the Rotemberg and Woodford (1997) calibration to (1.21), the ratio of the structural parameters of the IS equation (α/ω) is found to be equal to 0.16.²³ Therefore, under a ‘velocity specification’ ($\eta_y=1$), (1.21) exceeds unity if λ_R is smaller than 0.86

²³ Specifically, $\alpha=1$ and $\omega=6.25$. However, this calibration may not be entirely appropriate because Rotemberg and Woodford (1997) and Woodford (2003) use Calvo contracts to generate nominal rigidities whereas as Minford (2008) uses Fischer contracting instead – i.e. ‘sticky wages’ (Fischer) rather than ‘sticky prices’ (Calvo).

(approximately). As discussed in the context of the SWJ derivation, a money supply rule generates an interest rate rule which mimics a ‘desirable’ interest rate rule if money demand is not too sensitive to the nominal interest rate – i.e. if the elasticity λ_R is ‘small’.

Using the definition of χ provided above, the coefficient on the output gap in (1.20) is:

$$\eta_y \chi^{-1} \equiv \frac{\eta_y}{\alpha \lambda_R - \omega \eta_y}. \tag{1.22}$$

This is found to depend upon the ratio of income and interest elasticities in the same way that the corresponding coefficient in (1.9) did for the QTM-based model but, again, this coefficient can now be linked back to structural parameters of the intertemporal IS equation. The intertemporal elasticity of substitution is found to enter (1.22) with the opposite sign to Woodford’s (1.13), where the coefficients on both inflation and the output gap depended negatively upon ω .

The composition of the term in braces in (1.20) is also particularly interesting because it features a lagged dependent variable with a coefficient of unity, as found in interest rate rule written in first differences. It also features a lagged output gap term, as found in ‘speed-limit’ interest rate rules (e.g. Walsh, 2003b) and a term in expected future inflation, as one would find in a forward-looking interest rate rule (e.g. Clarida et al., 2000). Equation (1.20) could be rewritten so that any of these terms are extracted from the error term and placed into the systematic component in square brackets. The complex nature of the error term also suggests that estimating (1.20) would be challenging from an econometric perspective. In summary, this derivation shows that either a contemporaneous (Taylor, 1993) rule or one of the several prominent descendants of the original rule can be generated as an implicit rule derived from a NK model in which the central bank uses the money supply as the instrument of monetary policy.

1.2.4 Euler-Equation-Based Implicit Rules

The micro-founded nature of the models considered by Woodford (2003) and Minford (2008) show the importance of the structural parameters of the intertemporal Euler equation to the magnitude of the coefficients of the implicit interest rate rules derived from each model. The intertemporal Euler equation also plays a central role in implicit interest rate rules derived from structural models which do not feature nominal rigidities. For example, Fève and Auray (2002) specify a flexible price, cash-in-advance (CIA) model in which the monetary authority uses the money supply as the instrument of policy and show that they can recover a ‘Taylor rule’ by applying conventional estimation techniques to model-simulated data. They note that their estimated inflation coefficient takes a similar magnitude to the coefficient obtained by Clarida et al. (2000) for U.S. time series data. However, as Fève and Auray (2002) acknowledge in their concluding remarks, their implicit interest rate rule lacks a real variable, such as the output gap, which conventional rules routinely include as a “lean against the wind” term (Taylor and Williams, 2010, p.10). Of course, for an exogenously specified interest rate rule a real term could simply be added to the specification but this is not permitted for an implicit rule given that it is an equilibrium condition of an underlying structural model. The structural equations must themselves be modified in order to generate a different implicit rule.

Salyer and Van Gaasbeck (2007) make progress in this regard in that they derive an implicit interest rate rule which features an output gap term from a ‘limited participation’ model in which monetary policy is implemented via a money supply rule. However, they find that their estimation results cannot match the coefficients reported by Clarida et al. (2000) for actual data. The estimated coefficients on inflation are ‘too small’ in comparison and the estimated coefficients on the output gap carry the wrong sign. Schabert (2003) follows a similar approach to Fève and Auray (2002). He investigates the correspondence between money supply and interest rate rules in a flexible price, CIA model in which the monetary authority follows a money growth rule. Once again, the intertemporal Euler equation plays a key role in the derivation of the model’s implicit interest rate rule and Schabert (2003), like Salyer and Van Gaasbeck

(2007), is able to derive an expression for the nominal interest rate which contains a real term alongside the term in inflation. The implicit rule derived from this framework can also replicate either contemporaneous or forward-looking rules; the outcome depends upon a subtle timing assumption, as we shall demonstrate below. The model that Schabert (2003) considers is sufficiently succinct that we express his maximisation problem in-full here. The representative consumer's/household's problem is to:

$$\begin{aligned} \max: & \sum_{t=0}^{\infty} \beta^t u(c_t, l_t) \\ & - \lambda_{1,t} \left[c_t + b_t + m_t - \frac{(1 + \bar{R}_t)}{(1 + \bar{\pi}_t)} b_{t-1} - \frac{m_{t-1}}{(1 + \bar{\pi}_t)} - w_t l_t - \frac{T_t}{P_t} - \Pi_t \right] \\ & - \lambda_{2,t} \left[c_t - \frac{m_{t-1}}{(1 + \bar{\pi}_t)} - \frac{T_t}{P_t} \right], \end{aligned}$$

by choosing c_t , l_t , m_t and b_t , where utility depends positively upon consumption and negatively upon hours worked, m_t represents real money holdings acquired in the current period, m_{t-1} represents money holdings brought forward from the previous period (expressed in real terms), b_t represents government (risk-free) bonds purchased today (expressed in real terms), b_{t-1} represents nominal bonds brought forward from the previous period (expressed in real terms and adjusted for interest earned and inflation), $w_t l_t$ is labour income, Π_t represents (real terms) profit repatriated from a representative firm which the representative consumer is assumed to own, T_t denotes a nominal transfer from the government and λ_1 and λ_2 are Lagrangian multipliers. The expectations operator does not feature in Schabert's model because he assumes perfect foresight and output growth and consumption growth are interchangeable because he models a closed economy without capital ($y=c$).

The maximisation problem above has the following first-order conditions:

$$\begin{aligned} c_t: & \quad u_c(c_t, l_t) - \lambda_{1,t} - \lambda_{2,t} = 0 ; \\ l_t: & \quad -u_l(c_t, l_t) + w_t \lambda_{1,t} = 0 ; \end{aligned}$$

$$\begin{aligned}
m_t: & -\lambda_{1,t} + (1 + \bar{\pi}_{t+1})^{-1} \beta (\lambda_{1,t+1} + \lambda_{2,t+1}) = 0; \\
b_t: & -\lambda_{1,t} + (1 + \bar{\pi}_{t+1})^{-1} \beta \lambda_{1,t+1} (1 + \bar{R}_{t+1}) = 0.
\end{aligned}$$

Solving for $(\lambda_{1,t+1} + \lambda_{2,t+1})$ from the first order condition for m_t and substituting this into the first order condition for c_t gives, $u_c(c_{t+1}, l_{t+1}) = \beta^{-1} \lambda_{1,t} (1 + \bar{\pi}_{t+1})$. Evaluating this over two consecutive time periods, $u_c(c_{t+1}, l_{t+1}) / u_c(c_t, l_t) = (\lambda_{1,t} / \lambda_{1,t-1}) [(1 + \bar{\pi}_{t+1}) / (1 + \bar{\pi}_t)]$. Substituting out for the ratio of Lagrangian multipliers $(\lambda_{1,t} / \lambda_{1,t-1})$ from the first order condition for government bonds gives: $u_c(c_{t+1}, l_{t+1}) / u_c(c_t, l_t) = [\beta^{-1} (1 + \bar{\pi}_t) / (1 + \bar{R}_t)] [(1 + \bar{\pi}_{t+1}) / (1 + \bar{\pi}_t)]$, which subsequently yields the following intertemporal consumption Euler equation (Schabert, 2003, eq.7):

$$\frac{u_c(c_t, l_t)}{u_c(c_{t+1}, l_{t+1})} \equiv \left(\frac{c_{t+1}}{c_t} \right)^\theta = \beta \left(\frac{1 + \bar{R}_t}{1 + \bar{\pi}_{t+1}} \right), \tag{1.23}$$

where the separable CRRA utility function $u(c_t, l_t) = [c_t / (1 - \theta)]^{1 - \theta} - [l_t / (1 + \zeta)]^{1 + \zeta}$ has been applied (θ is the constant coefficient of relative risk aversion – the inverse of the intertemporal elasticity of substitution – and ζ^{-1} is the of the Frisch elasticity of labour supply). Taking a log approximation of (1.23) and rearranging the resulting expression in terms of the net nominal interest rate yields the following equilibrium relationship:

$$\bar{R}_t \simeq \rho + \bar{\pi}_{t+1} + \theta \bar{g}_{c,t+1}, \tag{1.24}$$

where ρ is the rate of time preference and $\bar{g}_{c,t+1}$ is consumption growth in the next period $(c_{t+1} / c_t - 1)$, which in the context of this model is equivalent to the output growth rate. We interpret equation (1.24) as the interest rate rule implicit in Schabert's (2003) CIA model, although it simply corresponds to a standard consumption Euler equation written in terms of the nominal interest rate. Equation (1.24) stipulates that the nominal interest rate varies one-for-one with future inflation and positively with future consumption growth. The fact that

forward-looking terms in inflation and consumption growth feature on the right hand side of (1.24) shows that the interest rate rule implicit in Schabert's (2003) CIA economy replicates the timing of a forward-looking interest rate rule, such as equation (1.2) with $s=1$ (for inflation) or the rule considered by Clarida et al. (2000). In the context of a conventional interest rate rule, forward-looking terms are interpreted to reflect the fact that monetary policymakers ought to, or in practice do, respond to (expected) future rather than current economic conditions in order to take appropriate account of the lags inherent in the monetary transmission mechanism (e.g. Batini and Haldane, 1999; Bernanke, 2003, p.209).

It is also possible to provide intuition for the forward-looking terms in (1.24) by tracing the timing structure back to a subtle but important assumption applied in the underlying structural model. Carlstrom and Fuerst (2001) document the fundamental difference between the timing convention typically adopted in money-in-the-utility-function (MIUF) models and the timing convention typically adopted in CIA models.²⁴ MIUF models typically assume that agents derive utility from end-of-period real money balances (e.g. Walsh, 2003a, p.47). However, this standard MIUF timing assumption – which Carlstrom and Fuerst (2001) describe as ‘cash-when-I’m-done’ (CWID) timing – is not intuitively appealing in the context of a CIA model because it would imply that money balances net of *current* consumption matter for *current* period transactions or, as Carlstrom and Fuerst (2001, p.288) put it, “what aids in current transactions is the money I leave the supermarket with not the money I entered the market with.” Walsh (2003a, p.101) interprets this in terms of the order in which the goods and financial markets open – under CWID timing the goods market opens before the financial market in each period. Carlstrom and Fuerst (2001) demonstrate that different timing assumptions imply different consumption Euler equations. Rearranging their equation-6 for the nominal interest rate shows that CWID timing produces an expression analogous to (1.23) above in which the (net) nominal interest rate is dated at time t .

²⁴ Carlstrom and Fuerst (2001, footnote 4) note that Feenstra (1986) showed that any transactions cost model can be expressed as a MIUF model and that CIA models are “extreme versions” of a transactions cost model.

Under the alternative assumption that ‘the asset market opens first and then the goods market opens’,²⁵ the first order condition with respect to government bonds (b_t) would be:

$$b_t: \quad -(\lambda_{1,t} + \lambda_{2,t}) + (1 + \bar{\pi}_{t+1})^{-1} \beta (1 + \bar{R}_{t+1}) (\lambda_{1,t+1} + \lambda_{2,t+1}) = 0,$$

which is also implied by Schabert’s (2003, p.10) ‘including net bonds trading’ budget constraint which he briefly considers as an alternative to his baseline model. The representative consumer can now ‘ease’ the CIA constraint in any given period by adjusting its financial holdings so that a relatively smaller/larger proportion of total wealth is held as nominal bonds and a relatively larger/smaller proportion is held as real money balances. In order to do this, the consumer must have access to financial markets, of course, hence the importance of the assumption about the order in which markets open. The modified first order condition yields an expression for $(\lambda_{1,t} + \lambda_{2,t}) / (\lambda_{1,t+1} + \lambda_{2,t+1})$ which can be substituted into the first order condition with respect to consumption to give the following consumption Euler equation (Schabert, 2003, p.10):

$$\frac{u_c(c_t, l_t)}{u_c(c_{t+1}, l_{t+1})} \equiv \left(\frac{c_{t+1}}{c_t} \right)^\theta = \beta \left(\frac{1 + \bar{R}_{t+1}}{1 + \bar{\pi}_{t+1}} \right). \tag{1.25}$$

This is consistent with Carlstrom and Fuerst (2001, eq.8), which they derive from CIA rather than CWID timing. The key difference between (1.25) and (1.23) is that the nominal interest rate now enters with a lead.²⁶ As Carlstrom and Fuerst (2001, p.290) state, “one manifestation of our CIA timing is that one can use the

²⁵ This is consistent with Carlstrom and Fuerst’s (2001, p.287) description of the conventional CIA timing convention as, “the money available to satisfy consumption needs is the money the household has left after leaving the bond market but before entering the goods market.”

²⁶ Carlstrom and Fuerst (2001, p.289) show that the timing convention adopted also determines whether the model’s equilibrium conditions imply that the opportunity cost of money is $\bar{R}_t / (1 + \bar{R}_t)$ for CWID timing or whether it is simply the net interest rate, \bar{R}_t for standard CIA timing; see also, Walsh (2003a, p.47, pp.90-91). Carlstrom and Fuerst (2001) proceed to demonstrate that this timing convention also affects the conditions required for the model to deliver a determinate (unique) solution. They conclude that (p.295), “we need to think much more carefully about basic modelling assumptions when writing down monetary models. A lot depends on apparently trivial assumptions.”

traditional Fisher expression [1.23] but with the nominal rate scrolled forward one period.” Taking a log approximation of (1.25), solving for the nominal interest rate and lagging the resulting expression by one period yields an implicit interest rate rule in which all variables are evaluated at time t as follows:

$$\bar{R}_t \simeq \rho + \bar{\pi}_t + \theta \bar{g}_{c,t} . \tag{1.26}$$

A subtle modification to the timing convention employed in Schabert’s (2003) initial CIA model therefore yields an equilibrium condition with a timing convention more in-keeping with the original Taylor (1993) rule ($s=0$ for the inflation term, for instance). However, this implies that the forward-looking rules considered in the NK framework cannot be replicated under the appropriate CIA timing convention.

The ‘textbook’ treatment of the Fisher relation usually states that the nominal interest rate is equal to the contemporaneous real interest rate plus expected future inflation (e.g. Wickens, 2008, p.353, eq.13.1). This would seem to imply that (1.23) is the appropriate form because (1.24) then gives the current period nominal interest rate as a function of future inflation. However, in order to derive this from the flexible price CIA model considered by Schabert (2003) one would need to adopt a counter-intuitive timing assumption. Carlstrom and Fuerst’s (2001, p.288) argue that in the context of a CIA model: “It is very difficult to justify CWID timing on theoretical grounds.” On the other hand, one could derive (1.23) from a MIUF model in which the representative consumer derives utility from end-of-period real money balances but this would appear to be an arbitrary feature of such models. It is not clear how to decide *a priori*, without working backwards from the appropriate Fisher relation, which assumption is most appropriate in the MIUF framework. Of course, written as a long-run or steady-state condition, this timing issue can be avoided by dropping the time subscripts in the Fisher relation altogether (e.g. Wickens, 2008, p.353, eq.13.2).

Aside from this matter, the implicit rules (1.24) and (1.26) are otherwise similar. Each contains a constant term representing the rate of time preference, a term in inflation and a term in consumption growth. Inflation enters with a coefficient of unity so there is a one-for-one relationship between the rate of inflation and the nominal interest rate, so long as consumption growth is controlled for. Equation (1.26) corresponds to Arnwine and Yigit's (2008) "augmented Fisher relation", for example, and they argue that the term in consumption growth is essential in order to capture both Fisher's original meaning from a theoretical perspective and in order to account for the pro-cyclical nature of the real interest rate empirically.²⁷ The coefficient on the term in consumption growth corresponds to the representative consumer's coefficient of relative risk aversion ($\theta > 0$). It follows that the coefficient on the real variable in the interest rate rule implicit in the CIA model varies negatively with the intertemporal elasticity of substitution ($\theta \equiv \omega^{-1}$). This feature of (1.24) is consistent with the relationship between the intertemporal elasticity of substitution and the coefficient on the real term in Woodford's (2003) implicit rule (1.13), although we have consumption growth rather than an output gap as the real term here.

Unlike the conventional and implicit rules considered up to this point, equation (1.24) makes no reference to potential consumption (or output) and thus the real term enters in growth rate rather than 'gap' form. Conventional interest rate rules do not usually disregard cumulative output losses in this manner. In terms of the implicit rules, we note that trend (potential) output enters equation (1.13) by virtue of the assumption that the model was in long-run equilibrium in the previous period. Effectively, (1.13) could be interpreted as containing a term in output growth where lagged output coincides with trend output and thus the output growth rate coincides with the output gap. However, given the reduced form nature of the QTM-based model used to derive (1.13), the structural reason for the appearance of the output gap remains somewhat vague. This, of course, is

²⁷ Specifically, Arnwine and Yigit cite Fisher (1930) as representative of Fisher's original theoretical proposition and refer to Levi and Makin (1978), VanderHoff (1984) and Dotsey et al. (2003) as studies which find statistically significant coefficients on real variables in estimated Fisher-type relationships. They proceed to use equation (1.26) as a long-run cointegrating relationship in an error correction model.

the fundamental criticism of reduced form models. On the other hand, the emergence of a non-zero output gap in (1.9) and (1.13) can be traced back to the fact that the underlying structural models assume that prices are not fully flexible. The whole notion of a 'gap' between actual and potential output is of limited relevance in a flexible-price model; indeed, the output gap is often defined as the deviation of observed output from its flexible-price level (e.g. Goodfriend and King, 1997, p.261; Clarida et al., 1999, p.1665).

However, certain classes of conventional interest rate rule have considered growth rates of real terms rather than deviations from potential/trend levels. For example, Walsh (2003b) considers a class of 'speed-limit rules' motivated by statements made by U.S. monetary policymakers which suggest that they respond to the excess of output growth over potential output growth; Peel et al. (2004) find empirical support for such a rule using quarterly U.S data between 1960 and 2003. This type of interest rate rule is appealing from a theoretical perspective because it introduces an element of 'history dependence' into the monetary policymaking process (Woodford, 1999) and is also appealing from an operational perspective because it does not require policymakers to possess knowledge of the level of potential output but merely its growth rate which seems to be less prone to subsequent revision (e.g. Orphanides and van Norden, 2002, 2005; Orphanides, 2003b; Walsh, 2003b). McCallum and Nelson (1999a) also consider a form of conventional interest rate rule which features the growth rate of output. This rule, they argue, is consistent with a policy regime of 'nominal GDP targeting' under which the central bank uses all means at its disposal to deliver a 'target path' for nominal GDP.

Even though (1.24) and (1.26) are 'micro-founded' because they are derived from very similar consumption (or output) Euler equations which link back to the representative consumer's utility function, they lack the connection to the money demand function offered by the implicit interest rate rules derived from the QTM (1.9) and the NK model with money (1.20). This stems from the fact that (1.24) and (1.26) are derived from simple CIA models in which the velocity of money, $Y/M (=C/M)$ in nominal terms, is constant at unity. This shows that although the

standard CIA model successfully provides a reason for economic agents to hold a positive quantity of return-dominated money, it restricts the demand for money to be a constant proportion of consumption (or output). Walsh (2003a, pp.107-108) argues that this feature of the original CIA model is unsatisfactory because velocity is observed to vary over time. This inconsistency between the data and the implications of the model has motivated researchers to consider ways in which the “tight link between c and m ” can be broken (Walsh, 2003a, p.107).

Walsh (2003a, p.101) refers to the importance of the timing assumption in terms of how economic agents learn about shocks that hit the economy. For example, under Svensson’s (1985) timing assumption consumers must decide upon the level of money balances to hold *prior to* observing such shocks. As such, consumers may wish to hold ‘excess’ money balances in order to take advantage of an unexpectedly positive state of the world. This modelling approach, Svensson argues, means that he obtains, “a more reasonable demand for money with variable velocity” (Svensson, 1985, p.922). Furthermore, the velocity of money will vary positively with the nominal interest rate because consumers will trade-off the potential benefits derived from holding ‘excess’ money balances against the interest foregone from potentially holding more money than is required to support consumption. An alternative way to break the link between c and m is to stipulate that certain goods must be purchased using money balances while other goods must be purchased using a money alternative such as exchange credit. In this case, the CIA constraint only applies to a certain subset of consumption goods (e.g. Lucas and Stokey, 1987) and consumers respond to higher inflation by substituting away from ‘cash goods’ and towards ‘credit goods’ because the money balances required to support the former attract an opportunity cost equal to the nominal interest rate which increases with inflation through the Fisher relation. The (consumption) velocity of money will also vary positively with the nominal interest rate in this model as consumers adjust their consumption patterns between the cash and credit goods. The demand for money generated in this setting is purely transactional (i.e. there is no precautionary component) if we revert back to the assumption that shocks are observed prior to portfolio decisions being taken (as in Lucas and Stokey, 1987). As such, the velocity of

money would be expected to exceed unity in general or equal unity as a special case in which the ‘credit good’ is not used (i.e. $m \leq c$). On the other hand, the velocity of money may either fall below or exactly equal unity under Svensson’s (1985) timing assumption because there is no alternative to money but actual (nominal) consumption may fall below the quantity of (nominal) money balances held because of the precautionary element of money demand induced by the timing of the shocks ($m \geq c$).²⁸

In the next section we consider a variant on the Euler-equation-based approach derived from the structural model of Benk et al. (2008, 2010). In their model, velocity is allowed to vary endogenously and the properties of the resulting implicit rule are found to share similar properties with some of the conventional interest rate rules proposed in the literature but also some notable differences.

1.3 The ‘Taylor Condition’

We label the implicit interest rate rule derived from the model of Benk et al. as the ‘Taylor Condition’ in order to reflect its similarities with the class of interest rate rule described in Section 1.1 and stated as equations (1.1) and (1.2) above but to simultaneously acknowledge its status as an equilibrium condition of a broader model rather than an exogenously specified rule for monetary policy. The monetary policy regime modelled directly is one in which the central bank sets the long-run (balanced growth path) rate of money growth in order to (implicitly) meet the fiscal requirements of the government but where the money supply is also subject to transitory stochastic shocks in the short-run.

Unlike the QTM-based implicit rule (presented in Section 1.2.2), the derivation is based upon a micro-founded, structural model of the economy, and unlike the derivations which take place in the NK framework (presented in Section 1.2.3) it takes place within a flexible price CIA framework in which monetary variables play a fundamental role. As with Schabert’s (2003) CIA-based derivation

²⁸ Hromcová (1998) extends Svensson’s (1985) model to include capital investment. She finds that the (output/income) velocity of money can exceed unity in this extended model because a certain proportion of output is now channelled towards capital investment.

(presented in Section 1.2.4), the Taylor Condition is based upon the intertemporal Euler equation but contrary to the simple CIA model presented above the velocity of money is now permitted to vary. However, unlike Lucas and Stokey (1987), consumption goods are not exogenously divided into ‘cash’ and ‘credit’ categories in the Benk et al. model. The representative consumer is instead permitted to choose between using either money or intratemporal credit to support consumption purchases hence (normalised) money demand (m/c), and therefore the velocity of money (c/m), is endogenously determined. The use of money to support consumption incurs the conventional opportunity cost equal to the nominal interest rate (the ‘inflation tax’) while the use of the credit alternative attracts a service fee. The credit service is nevertheless potentially attractive to the representative consumer because it effectively serves as an inflation tax avoidance mechanism; non-interest-yielding real money balances, on the other hand, lose purchasing power over time due to inflation. Naturally, the credit alternative becomes more attractive to the consumer as inflation increases because the nominal interest rate rises in unison through the Fisher effect.

The derivation begins from a modified intertemporal Euler equation of the form:²⁹

$$1 = \beta E_t \left\{ \frac{u_c(c_{t+1}, x_{t+1})}{u_c(c_t, x_t)} \left(\frac{1 + \tilde{R}_t}{1 + \tilde{R}_{t+1}} \right) \frac{1 + \bar{R}_{t+1}}{1 + \bar{\pi}_{t+1}} \right\}, \quad (1.27)$$

where the underlying utility function contains arguments in real consumption (c_t) and leisure time (x_t) and, with the exception of \tilde{R} , all other variables have been defined elsewhere in this chapter. We note that (1.27) features a “nominal rate scrolled forward one period” in a manner consistent with Carlstrom and Fuerst’s (2001, p.290) ‘CIA timing’ Euler equation (1.25) rather than the ‘CWID timing’ form (1.23) which they reject for CIA models. The unconventional terms in \tilde{R} feature in (1.27) because of the endogenous money-credit choice. These terms are defined as:

²⁹ See Chapter-III, Section 3.2 for a full exposition of the model.

$$\tilde{R}_t = \left(1 - \frac{q_t}{c_t}\right) \bar{R}_t + \left(\frac{q_t}{c_t}\right) \gamma \bar{R}_t, \quad (1.28)$$

where γ is the coefficient on the effective labour input in the (Cobb-Douglas) credit production function assigned to the banking sector, q_t/c_t is the fraction of consumption financed by credit and $(1-q_t/c_t)$ is the fraction of consumption financed by non-interest bearing money balances. Equation (1.28) can be interpreted as a “shadow cost of exchange” averaged over the two means of payment, where \bar{R} is the opportunity cost of money and $\gamma\bar{R}$ is the average cost of credit production (Gillman and Kejak, 2011, p.268). The usual inflation tax distortion, \bar{R}_{t+1} , is found in equation (1.27), in keeping with (1.25) above for ‘CIA timing’, but the nominal interest rate also enters indirectly through the terms in \tilde{R} , in accordance with (1.28). In this case, the ‘inflation tax’ distortion encourages substitution away from money-financed-consumption and towards leisure in the usual way but also towards credit-financed-consumption. Therefore, a given increase in inflation induces less substitution away from consumption than would be the case if the money-alternative did not exist because consumers now have an additional way in which to avoid the inflation tax other than through simply forgoing consumption and/or taking more leisure time.

After substituting out for the functional form of the representative consumer’s (CRRA) utility function and log-linearizing around the balanced growth path (BGP) equilibrium we arrive at the following expression for the deviation of the (net) nominal interest rate from its BGP equilibrium value (\bar{R}):

$$\begin{aligned} \bar{R}_t - \bar{R} = & \Omega E_t(\bar{\pi}_{t+1} - \bar{\pi}) + \Omega \theta E_t(\bar{g}_{c,t+1} - \bar{g}) + \Omega \psi (1 - \theta) \frac{l}{1-l} E_t \bar{g}_{l,t+1} \\ & - \Omega_v E_t \bar{g}_{v,t+1} - (\Omega - 1) E_t(\bar{R}_{t+1} - \bar{R}), \end{aligned} \quad (1.29)$$

where ψ is a parameter governing the consumer’s preference for leisure from the underlying CRRA utility function, $E_t \bar{g}_{v,t+1}$ is the expected future growth rate of the consumption velocity of money (c/m), $E_t \bar{g}_{l,t+1}$ is the expected future growth

rate of non-leisure time – time can be spent accumulating human capital, working in the banking (credit) sector, working in the goods sector or on leisure – and variables without time-subscripts denote *BGP* values (i.e. 1.29 is presented in absolute-deviation-from-*BGP* form). The model also incorporates endogenous growth, so the *BGP* terms are not exogenously specified as the inflation target in the general Taylor rule (1.2) would be, for example. The coefficients of the implicit rule (1.29) can be related to the structural parameters and steady state equilibrium values of the underlying model as follows:

$$\Omega \equiv 1 + \frac{(1 - \gamma)(1 - \frac{m}{c})}{(1 + \bar{R})[1 - (1 - \gamma)(1 - \frac{m}{c})]} ; \quad (1.30)$$

$$\Omega_v \equiv \frac{\bar{R}}{1 + \bar{R}} \left[\frac{(1 - \gamma)\frac{m}{c}}{1 - (1 - \gamma)(1 - \frac{m}{c})} \right], \quad (1.31)$$

where m/c is the steady-state (consumption-normalised) demand for money and $(1-\gamma)$ is the power attached to deposits in the credit production function.³⁰ The Taylor Condition features forward-looking terms in inflation and consumption growth, as did (1.24) under CWID timing, but is nevertheless derived from a CIA model which adheres to Carlstrom and Fuerst's (2001) 'CIA timing', as shown by the forward-looking nominal interest rate term in (1.27). In addition, equation (1.29) also features a term in the growth rate of leisure time, although this would drop out under the log utility specification ($\theta=1$) considered as part of Benk et al.'s (2010) baseline calibration. Non-leisure time growth features in the Taylor Condition, similar to the way in which conventional interest rate rules sometimes feature (un)employment in place of output (e.g. Clarida et al., 2000, Table III; Mankiw, 2001; Rudebusch, 2009).

³⁰ Whether the demand for money is normalised by consumption, m/c , or by income (output), m/y , depends upon whether investment is incorporated into the cash-in-advance constraint (à la Stockman, 1981) or not. So long as the consumption (income) elasticity of real money demand is unity, either version of money demand (m/c or m/y) can be inverted to yield an expression in terms of the consumption (income) velocity of money.

Equation (1.29) differs from both the conventional interest rate rule and the implicit interest rate rules studied thus far in that it also features terms in the velocity of money and the lead of the nominal interest rate.³¹ The consumption velocity of money (c/m) is important to the Taylor Condition in two ways – its steady-state level features as part of the coefficients associated with inflation, the consumption growth rate, the leisure growth rate and the future nominal interest rate and its growth rate enters as an independent variable in its own right. The lead dependent variable introduces a dynamic element into the Taylor Condition. Several prominent studies (e.g. Kozicki, 1999; Mehra, 1999; Clarida et al., 2000) posit a dynamic interest rate rule which includes lagged dependent variable(s) to capture ‘interest rate smoothing’ and the interest rate rule implicit in equation (1.20) derived from the modified NK framework also featured such a term as part of its ‘residual’. In the context of a conventional interest rate rule, this gradual adjustment process is justified on the grounds that policymakers wish to avoid implementing rapid adjustments to the nominal interest rate for fear of destabilising financial markets (e.g. Goodfriend, 1991; Cukierman, 1992; Lowe and Ellis, 1997).³² However, equation (1.29) represents an ‘expectational’ intertemporal relationship rather an ‘inertial’ relationship (in the terminology of McCallum, 2010) hence the conventional interest rate smoothing interpretation is not entirely appropriate for (1.29). We return to this issue in further detail in Chapters-III and -IV when evaluating the Taylor Condition using econometric techniques.

According to (1.30), the theoretical coefficient on expected future inflation in the Taylor Condition exceeds unity in general. For example, we obtain $\Omega=2.125$ under Benk et al.’s (2010) calibration (see Chapter-III, Section 3.4 for the full

³¹ The Taylor Condition also lacks a constant term because of the log-linear approximation method used to derive it. This is a minor difference however and we could employ an empirical specification which includes a constant term and test for its significance. Furthermore, the constant term could also turn out to be zero empirically for a conventional interest rate rule. The following estimating equation is often used to evaluate equation (1.2): $\bar{R}_t = [\bar{r} - (1 + \beta_\pi)\bar{\pi}^*] + (1 + \beta_\pi)\bar{\pi}_t + \beta_y y_{gap,t} + error_t$. This is more convenient than (1.2) because it avoids the need to subtract an inflation target from $\bar{\pi}_t$. Written this way, an estimate of zero for the term in square brackets does not seem to be implausible given the structure of the composite constant term (in square brackets).

³² Srouf (2001) reviews many other reasons as to why policymakers may wish to implement interest rate adjustments in a protracted way but the interest rate smoothing interpretation has been challenged by Rudebusch (2002), for example.

calibration). As such, (1.29) adheres to the rule-of-thumb Taylor principle which empirical studies in the Taylor rule tradition often seek to recover from time series data. This empirical result can clearly not be supported for equations (1.24) and (1.26); a one-for-one relationship between the nominal interest rate and inflation holds for the equilibrium condition of the unit-velocity CIA model. However, one would recover an equivalent parameterisation of $\Omega=1$ for the Taylor Condition at the Friedman (1969) optimum nominal interest rate of zero. In this case, the representative consumer has no incentive to use the costly credit service because money carries no opportunity cost therefore $q/c=0$. To see the basis for this result, note that the money demand function derived from the model is (Benk et al., 2008, eq.13):

$$\frac{m}{c} = 1 - A_F^{\frac{1}{1-\gamma}} \left(\frac{\gamma \bar{R}}{w} \right)^{\frac{\gamma}{1-\gamma}}, \quad (1.32)$$

where A_F represents the productivity of the banking sector and w represents the real wage.³³ With $\bar{R}=0$, money holdings incur no opportunity cost and $m/c=1$. Consulting the definition of \tilde{R} , (1.28) above, we find that with $q/c=0$, the terms in \tilde{R} would drop-out of (1.29) and the coefficient on inflation would assume a value of unity. Furthermore, the forward interest rate term would drop out of (1.29) given that it carries a coefficient of $(\Omega-1)$, as would the term in g_v because velocity is constant at one so long as $\bar{R}=0$. The Friedman optimum special-case of (1.29) is therefore:

$$\bar{R}_t - \bar{R} = E_t(\bar{\pi}_{t+1} - \bar{\pi}) + \theta E_t(\bar{g}_{c,t+1} - \bar{g}) + \psi(1 - \theta) \frac{l}{1-l} E_t \bar{g}_{l,t+1}, \quad (1.33)$$

which is similar to (1.24) except for the fact that (1.33) is written in deviation-from-steady-state form, features expectations operators and contains a term in

³³ These terms feature in the credit production function: $q_t = A_F (l_{F,t} h_t)^\gamma d_t^{1-\gamma}$, where h indexes the stock of human capital and d represents the level of (bank) deposits. Labour and deposits are required to produce credit but physical capital is not (Benk et al., 2010). However, this assumption can be generalised (see Gillman and Kejak, 2011). Full details are provided in Chapter-III.

the growth rate of leisure time. However, Schabert (2003) uses a separable function in consumption and leisure; the growth rate of leisure would drop out of (1.33) under a separable, logarithmic ($\theta=1$) form for the generally non-separable CRRA utility function specified by Benk et al. (2010). The implicit interest rate rule of the unit-velocity CIA model therefore represents a special case of (1.29). This shows that variation in the velocity of money, modelled here as endogenous via the inclusion of exchange credit as an alternative to money, is crucial to the Taylor Condition's ability to replicate the 'Taylor principle', $\Omega > 1$.

The definition of Ω above further implies that the coefficient on inflation in (1.29) cannot fall below one and is therefore incapable of replicating empirical estimates which suggest that the Taylor principle was violated during the pre-c.1980 period of high and variable inflation (e.g. the 'pre-Volcker', 1960q1-1979q2, period examined by Clarida et al., 2000). This result can be interpreted in (at least) two ways. Firstly, it might be indicative of bias in the estimated coefficients reported in the empirical literature. As discussed above, conventional interest rate rule typically overlook terms such as the growth rate of velocity and the forward interest rate term which feature in (1.29), as indeed equations (1.1) and (1.2) above do. Including such terms may increase the magnitude of these estimated inflation coefficients to such an extent that the Taylor principle holds. We explore this possibility in Chapter-IV. Secondly, given the specification for monetary policy modelled by Benk et al., this finding might signify a correspondence between the constant (long-run) money growth rule and a 'desirable', or 'stabilising', interest rate rule. This would be consistent with the interpretation of Woodford's (2003) implicit rule, (1.13) above, where the coefficient on inflation (expected deviations from target) exceeded one in contrast to the inflation coefficients in the implicit rules derived from the QTM (1.9), or the implicit rule derived from the NK model with money (1.20), where in each case the coefficient on inflation can, in principle, take a magnitude greater than, equal to or less than one.

We previously showed that the theoretical coefficient on inflation in equation (1.9) derived from the QTM depended inversely on the interest (semi-) elasticity

of money demand and that the same result carried over to the inflation coefficient in equation (1.20) for the NK model with money. A similar relationship also existed between the coefficient on the output gap and this same elasticity parameter. In order to evaluate this aspect of equation (1.29), we use the money demand function (1.32) to derive the following expression for the interest elasticity of (consumption-normalised) money demand (see Gillman and Otto, 2007, p.8, for example):

$$\lambda_R = \frac{\partial\left(\frac{m}{c}\right)}{\partial\bar{R}} \frac{\bar{R}}{\left(\frac{m}{c}\right)} = -\left(\frac{\gamma}{1-\gamma}\right) \left(\frac{1-\frac{m}{c}}{\frac{m}{c}}\right). \quad (1.34)$$

The interest elasticity of money demand is found to be negative because $0 < \gamma < 1$ (e.g. $\gamma=0.11$ in Benk et al., 2010) and because m/c is a positive fraction as long as $\bar{R} > 0$ (e.g. $\bar{R}=0.38$ in Benk et al., 2010). This elasticity is also a function of the nominal interest rate, just as the interest elasticity of money demand ($\lambda_R \equiv \eta_{R\bar{R}_t}$) is in the reduced form money demand function (1.3) used for the SWJ's derivation. Specifically, the elasticity (1.34) becomes more negative as the nominal interest rate increases as consumers' demand for money balances becomes 'more sensitive' to the inflation tax, i.e. the costly credit service becomes ever-more attractive as inflation rises.³⁴ Re-arranging (1.34) yields the following reduced form expression for $(1-m/c)$ in terms of the interest elasticity of money, λ_R :

$$\left(1 - \frac{m}{c}\right) = 1 + \frac{\gamma}{(1-\gamma)\lambda_R - \gamma}. \quad (1.35)$$

Using (1.35) to substitute out for $(1-m/c)$, the coefficient on inflation (1.30) can now be expressed as:

³⁴ For completeness, we note that the consumption elasticity of money demand is unity by construction because (1.33) is expressed as a fraction of (is normalised by) real consumption; (1.32) is therefore assured to have a '(consumption) velocity specification'.

$$\Omega = 1 + \frac{(1 - \gamma) \left(1 + \frac{\gamma}{(1-\gamma)\lambda_R - \gamma}\right)}{(1 + \bar{R}) \left[1 - (1 - \gamma) \left(1 + \frac{\gamma}{(1-\gamma)\lambda_R - \gamma}\right)\right]}, \quad (1.36)$$

which shows that $\partial\Omega/\partial\lambda_R < 0$. The inflation coefficient in (1.29) therefore varies inversely with the interest elasticity of consumption-normalised money demand in a manner consistent with (1.9) and (1.21). The coefficient on consumption growth in (1.29) is simply $\Omega\theta$. With $\theta > 0$, the parameter on the real term in (1.29) also depends negatively on the interest elasticity of money demand, just as the coefficient on the output gap did in (1.9) and (1.22). However, since the money demand function (1.32) is normalised by consumption, the income elasticity of money demand is restricted to be unity and hence the coefficients of (1.29) do not depend on the income elasticity of money demand. However, unlike equation (1.9) with $\eta_y = 1$, the coefficient on consumption growth may still differ from the coefficient on inflation because of the presence of θ , although the CRRA utility function would clearly need to be non-separable ($\theta \neq 1$).

1.3.1 The 'Long-Run Taylor Condition'

An expression akin to Schabert's (2003) equation (1.24) and similar to the Friedman optimum special case (1.33) can be derived as a long-run counterpart to the full Taylor Condition (1.29). In the long-run equilibrium, terms in (1.33) which are expressed as fractions – the growth rates of non-leisure time and the consumption velocity of money – must be zero because they cannot expand or contract into perpetuity. Further, combining the terms in the current end expected future nominal interest rate in (1.29) as follows, $\bar{R}_t - \bar{R} = E_t(\bar{R}_{t+1} - \bar{R})$, yields the following expression:

$$\bar{R}_t - \bar{R} = E_t(\bar{\pi}_{t+1} - \bar{\pi}) + \theta E_t(\bar{g}_{c,t+1} - \bar{g}), \quad (1.37)$$

where the coefficient on inflation takes a value of unity and the coefficient on consumption growth is simply the coefficient of relative risk aversion in keeping

with (1.24). The forward-looking nature of (1.37) is consistent with the forward-looking nature of the ‘textbook’ Fisher relation but unlike (1.24) it has been derived from an Euler equation consistent with Carlstrom and Fuerst’s (2001) “cash-in-advance” timing. The long-run form (1.37) is also consistent with the “standard preferences” Euler equation presented by Canzoneri et al. (2007) in terms of the magnitudes of the coefficients.

1.4 The Remainder of the Thesis

In the remainder of the thesis we focus on the class of Euler-equation-based implicit rules in particular. As demonstrated in this chapter, these generalise the ‘implicit interest rate rule’ to apply to modelling frameworks which abstract from the assumed nominal rigidities which are central to the operation of a conventional interest rate rule.

Chapter-II compares the contemporaneous equilibrium relationship derived from the constant velocity cash-in-advance model under Carlstrom and Fuerst’s (2001) favoured ‘CIA timing’ to a contemporaneous interest rate rule of the Taylor (1993) form; Chapter-III presents a full derivation of the Taylor Condition and analyses ‘short-run’ (high frequency) model-simulated data; Chapter-IV shows how the Taylor Condition unifies the Taylor principle and the long-run Fisher relation; and Chapter-V provides a general conclusion.

CHAPTER-II: CALIBRATION EXERCISES

2.1 Contemporaneous Rules

In this chapter we compare the empirical fit of a conventional interest rate rule with that of the implicit interest rate rule derived from a constant velocity cash-in-advance (CIA) model using some of the simple empirical exercises conducted in the literature (e.g. Taylor, 1993; Kozicki, 1999; Orphanides, 2001). In particular, we consider a restricted version of equation (1.2) of Chapter-I in which $s=q=0$:

$$\bar{R}_t^T \equiv \bar{R}_t = \bar{r}^* + \bar{\pi}^* + (1 + \beta_\pi)(\bar{\pi}_t - \bar{\pi}^*) + \beta_y \bar{y}_{gap,t} , \quad (2.1)$$

where \bar{R}_t^T represents the rule-implied nominal interest rate, \bar{R}_t is a short-term nominal interest that policymakers closely control and use as the instrument of monetary policy, \bar{r}^* is the 'natural' real rate of interest, $\bar{\pi}_t$ denotes the current rate of inflation in (net) percentage terms, β_π is the 'reaction coefficient' for inflation deviations from target, $\bar{y}_{gap,t}$ represents a measure of the current output gap expressed in (net) percentage-deviation-from-potential-output terms and β_y is the 'reaction coefficient' for the output gap. Equation (2.1) is chosen to represent a conventional interest rate rule because it corresponds to the original Taylor (1993) rule which is often found to fit the data well for the stable post-c.1980 (Great Moderation) era. We therefore label (2.1) as the 'Taylor Rule'.¹

This conventional rule shall be compared to the implicit rule derived from a unit-velocity CIA model, equation (1.26) of Chapter-I:

$$\bar{R}_t^I \equiv \bar{R}_t \simeq \rho + \bar{\pi}_t + \theta \bar{g}_{c,t} , \quad (2.2)$$

¹ Taylor (1993) actually used rolling averages of the annualised quarterly rate of inflation over the previous four quarters. Therefore, it would be more appropriate to state that Taylor (1993) effectively sets $s < 0$. Nevertheless, the key point is that early formulations of the rule were not forward-looking.

where \bar{R}_t^l represents the net nominal interest rate generated by this expression, \bar{R}_t again represents a short-term nominal interest rate, but recall that monetary policymakers use the money supply as the policy instrument in the structural model which underpins (2.2), ρ is the rate of time preference, which appears in the underlying CRRA utility function and varies inversely with the discount factor (β), θ is the constant coefficient of relative risk aversion, which also features in the utility function and $\bar{g}_{c,t}$ is the consumption growth rate. Further recall that consumption and output coincide ($y=c$) in the simple CIA model presented in Chapter-I, so $\bar{g}_{c,t}=\bar{g}_{y,t}\equiv\bar{g}_t$. As Fuhrer and Rudebusch (2004, p.1135) point out, this latter simplification only applies “in an economy without capital, durable goods, investment, foreign trade, or a government.” Equation (2.2) is chosen because it is derived from ‘CIA timing’ rather than the theoretically questionable ‘CWID timing’ (Carlstrom and Fuerst, 2001) and because it conveniently replicates the contemporaneous timing of Taylor’s original rule. We label equation (2.2) as the ‘Implicit Rule’ in this chapter but as we saw in Chapter-I, analogous expressions can be obtained from a variety of different underlying models.

In order to compare (2.1) and (2.2) empirically, we use quarterly U.S. time series data for the period 1960q1-2011q1 as inputs and plot the implied path for the nominal interest rate obtained from each expression.² The absence of the expectations operator in (2.1) and (2.2) allows for the application of simple calibration techniques for the purposes of this analysis. The aim is to demonstrate the empirical similarity between the two implied interest rate series despite the fact that they carry fundamentally different interpretations – the Taylor Rule is an exogenously specified description of, or prescription for, monetary policy whereas the Implicit Rule is as an equilibrium condition of a fully-specified structural model in which the central bank adheres to a money growth rule.

We calibrate the conventional rule (2.1) according to either Taylor (1993), the ‘original’ calibration, or Taylor (1999) and Orphanides (2003c), a ‘revised’ calibration. The coefficient on inflation in the Implicit Rule is constant at unity and

² 1960 is chosen as a starting point in order to coincide with the beginning of the Clarida et al. (2000) sample period. This will also be convenient for Chapters-III and -IV.

may not be calibrated but we allow the coefficient on the real term, consumption (output) growth, to take values of 0.5 and 1 in order to match the ‘original’ and ‘revised’ calibrations respectively. The coefficient on inflation in the Taylor Rule is held at 1.5 under both calibrations in order to retain the greater than one-for-one reaction to inflation often taken to define a ‘desirable’ interest rate rule, i.e. the ‘Taylor principle’ is satisfied. Table 2.1 documents the calibration used.

[Table 2.1 here]

It is worth emphasising from the outset that the exercises conducted here are not fully-fledged counterfactual exercises. As Taylor (2009a) explains when adopting a similar procedure, the implied series:

“... shows what the interest rate would have been had the Fed followed the kind of policy that had worked well during the period of economic stability called the Great Moderation, which began in the early 1980s” (Taylor, 2009a, pg.2).

A fully-fledged counterfactual exercise would require the construction of a full alternative history for each of the variables on the right hand side of the Taylor Rule and the Implicit Rule because these variables would in all likelihood have followed a different course had the nominal interest rates implied by (2.1) and (2.2) actually been implemented.³ The task here is more modest. Similar to the empirical analysis conducted by Taylor (1999), Kozicki (1999) and Orphanides (2001), for example, we simply document how far the actual nominal interest rate deviates from the rate implied by the conventional Taylor Rule (2.1) and the Implicit Rule (2.2) under two alternative calibrations for each.

2.1.1 Data

The data are obtained from the Federal Reserve Bank of St Louis FRED database and have been seasonally adjusted at source where appropriate. The data is evaluated at a quarterly frequency and monthly readings are converted using

³ For example, Orphanides (2003c) employs an atheoretical VAR to calculate a full alternative history of the variables fed into the interest rate rule and Ireland (2007) uses a structural model for a similar purpose.

three-month averages where necessary. Several different measures of inflation are considered as a robustness check. These are: the ‘headline’ (all items) Consumer Prices Index [FRED series code: CPIAUCSL]; the ‘core’ CPI index [CPILFESL] which excludes food and energy; the GDP deflator [GDPDEF]; and the ‘headline’ [PCECTPI] and ‘core’ [JCXFE] Personal Consumption Expenditures (PCE) price indices. The inflation rate is calculated as the year-over-year percentage change in each measure.⁴ As ever, the output gap is problematic because it requires an estimate of unobservable ‘potential output’. Two measures of potential output are used for the Taylor Rule (2.1) – a log-linear (exponential) trend is fitted to real GDP [GDPC96] as the first measure and Congressional Budget Office estimates [GDPPOT] are used as an alternative.⁵ The consumption growth term in (2.2) is represented by the year-over-year percentage change in real GDP [GDPC96] since $y=c$.

The implied interest rate derived from each expression is subsequently compared to the effective federal funds rate [FEDFUNDS] in order to calculate a ‘discrepancy’ series; this is $(\bar{R}_t^T - \bar{R}_t)$ for (2.1) and $(\bar{R}_t^I - \bar{R}_t)$ for (2.2). We restrict attention to a ‘contemporaneous information’ specification in which right-hand side variables are dated at time t .⁶ Furthermore, we do not follow Orphanides (2001, 2003a, 2003b, 2003c), who argues that historical analysis should be conducted using the first vintage (‘unrevised’) data that policymakers would have

⁴ ‘Core’ series are considered because empirical studies have often found that the ‘Greenspan Fed’ focused on this type of measure (e.g. Mankiw, 2001; Blinder and Reis, 2005, and Mehra and Minton, 2007). Policymakers in the U.S. seem to pay particularly close attention to the PCE index (e.g. Bernanke, 2010, p.7) hence we consider this as an alternative to the CPI index. Goodfriend (2004) interprets “price stability” to mean a *core* PCE inflation rate in the 1-2% range.

⁵ The log-linear trend is an *ex post* measure because it uses information from the entire sample period to estimate potential output at each point in time. Therefore, a policymaker could not possibly have constructed such a series in real time. An alternative approach would be to estimate potential output recursively as more information accumulates over time. A Hodrick-Prescott filter was also considered as a third measure but this technique suffers from a well-known ‘end point problem’ whereby the most recent data points in the series hold undue influence over the estimated trend (see Bruchez, 2003, for example). This issue is particularly problematic for the present sample because the 2007-2009 recession occurs towards the end of this period. Results obtained from the Hodrick-Prescott filter are therefore not reported.

⁶ The ‘contemporaneous specification’ is natural for the Implicit Rule but this is not necessarily so for the Taylor Rule because it implies that policymakers receive and respond to endogenous variables without delay. Such rules have been criticised as ‘non-operational’ by McCallum (1993), for example.

had access to at the time; instead we use the most recent vintage of data, as many empirical studies do.⁷

Figure 2.1 plots the data over the full sample period. The NBER Business Cycle Dating Committee's recession periods, April 1960–February 1961; December 1969–November 1970; November 1973–March 1975; January 1980–July 1980; July 1981–November 1982; July 1990–March 1991; March 2001–November 2001; and December 2007–June 2009, are marked as shaded areas. Table 2.2 defines each empirical specification using labels *a* to *j*.

[Figure 2.1 here]

[Table 2.2 here]

Along with the 'full sample' period (1960q1-2011q1), we also consider a subsample of 1987q1–1992q4 because this coincides with Taylor's (1993) original period of study. He found that the 'original' calibration performed well against the observed nominal interest rate over this six year period.

2.1.2 Issues of Interpretation for the Taylor Rule

Extending this analysis beyond Taylor's original period of study raises some important issues of interpretation. For instance, one would not expect the original Taylor (1993) rule to track the observed nominal interest rate series particularly closely over the full sample. To the extent that the conduct of monetary policy is related to economic outcomes, it would be surprising to find that policymakers followed a 'good', or 'desirable', rule during the 1970s, for example, given the high and variable rates of inflation at that time (see Figure 2.1). This would be documented in two different ways within the Taylor rule framework: Firstly the actual nominal interest rate would differ substantially from that implied by the

⁷ The use of revised data might be defended on the grounds that policymakers perhaps view first release data with an appropriate degree of scepticism and look to other, harder to measure, factors when reaching their monetary policy decisions. This may negate some of the 'revision bias' associated with first release data. Moreover, Taylor (2000) is sceptical about the quality of the real-time data used by Orphanides (2003c).

Taylor (1993) rule, thus generating larger discrepancies between actual and implied interest rates. Equivalently, econometric procedures would generate estimates for the rule's coefficients which differ substantially from those of the benchmark calibration (e.g. Taylor's, 1999 exercise). The former approach retains the Taylor (1993) calibration as a *normative* benchmark while the latter attempts to obtain the magnitude of the 'reaction coefficients' consistent with the data in a *positive* manner. Deviations from a 'desirable' interest rate rule, or equivalently estimated coefficients which depart substantially from Taylor's (1993) calibration, are often interpreted to be a contributing factor to the less-than-satisfactory economic performance during the 1970s; in contrast, judicious monetary policy post-c.1980 is argued to have helped foster the Great Moderation (e.g. Taylor, 1999; Mankiw, 2001; Clarida et al., 2000). In this chapter we focus on the former manifestation of 'undesirable' monetary policy and return to the alternative, estimation-based method in Chapters-III and -IV.

2.2 Implied Nominal Interest Rate and Discrepancy Series

Figure 2.2 presents the implied nominal interest rate series generated by Taylor Rule 'b' and Implicit Rule 'a=b' and Figure 2.3 plots the corresponding 'discrepancy' series, $(\bar{R}_t^T - \bar{R}_t)$ and $(\bar{R}_t^I - \bar{R}_t)$ respectively.⁸ Taylor's 1987q1-1992q4 sample period is denoted by the shaded region in Figure 2.3.⁹

[Figure 2.2 here]

[Figure 2.3 here]

As expected, the Taylor Rules are found to fit to the actual nominal interest rate particularly well between 1987 and 1992 but less so outside of this period, especially prior to c.1980. The nominal interest rate produced by the Implicit Rule under the 'original' calibration is also found to follow the rules quite closely over

⁸ Specification 'b' is plotted for illustrative purposes. This is not intended to show favour for this particular empirical specification, although the CBO output gap may well be preferable to the log-linear trend, as we shall show.

⁹ The log-linear potential output series is not recalculated for the Taylor subsample. We simply use a segment of the full sample measure of potential output.

the 1987-1992 period but departs further from the other three series under the 'revised' calibration.

2.2.1 Summary Statistics

In order to provide a more objective assessment of how well these implied interest rate series fit the observed series, we also calculate a set of simple summary statistics. The performance of the Taylor Rule (2.1) and the Implicit Rule (2.2) are evaluated using mean absolute deviation statistics, as in Kozicki (1999) for a conventional interest rate rule, along with the mean of the discrepancy series, its standard deviation and minimum and maximum values, as in Orphanides (2001) also for a conventional rule, and the correlation coefficient between the implied and observed nominal interest rates, as in Canzoneri et al. (2007, Table 1) for a consumption Euler equation. Table 2.3 presents these summary statistics for the Taylor Rule and the Implicit Rule under both calibrations, for each empirical specification, over both the full sample period and Taylor's (1993) subsample:

[Table 2.3 here]

Unsurprisingly, the summary statistics show that the fit of the nominal interest rate series implied by both calibrations of the Taylor Rule deteriorates substantially when extended from the 1987-1992 subsample to the full sample. This is readily apparent from the mean absolute deviation statistics but the correlation coefficient also declines for all ten rule specifications under both the original and revised specifications. There is also a noticeable alternating pattern in the performance of the Taylor Rules, particularly under the revised specification. Rules (b), (d), (f), (h) and (j) tend to provide a better (level) fit than rules (a), (c), (e), (g) and (i) respectively; although rule (e) sometimes provides an exception. This feature of the summary statistics, in combination with the fact that it is not replicated to the same extent for the Implicit Rule, suggests that the exponential trend measure of potential output harms the empirical fit of the Taylor Rules which use this rather than the CBO estimates. In terms of the calibration adopted, the nominal interest rate series derived from the original

calibration of the Taylor Rule have a lower mean absolute deviation than those derived from the revised calibration (without exception), a higher correlation coefficient (without exception) and a lower standard deviation (without exception) for the subsample period. This seemingly justifies Taylor's (1993) initial calibration over the revised alternative, at least in positive (descriptive) terms. This result is also found to extend to the full sample period in terms of the mean absolute discrepancy.

Similar patterns can be found in the summary statistics for the Implicit Rule. Mean absolute deviations and mean discrepancies generally increase when the sample period is extended, although perversely the correlation coefficients tend to increase at the same time. More importantly, comparing the Taylor Rule to the Implicit Rule reveals that the former generally tends to provide a closer fit to the data over the 1987-1992 period. In particular, the Taylor Rules tend to produce lower mean discrepancies, lower mean absolute discrepancies, lower standard deviations and higher correlation coefficients than their Implicit Rule counterparts under both the 'original' and 'revised' calibrations. However, under certain empirical specifications the equilibrium condition also seems capable of providing a 'reasonable' description of the observed series for the Taylor (1993) subsample period. A similar result carries-over to the full sample period.

It is also apparent that the mean discrepancy statistics for the Implicit Rules tend to be similar to the mean absolute discrepancy statistics while the latter tend to be materially larger than the former for the Taylor Rules. This result is indicative of the fact that the Implicit Rules show a greater propensity to overstate the actual nominal interest rate – i.e. generate a positive discrepancy – than the Taylor Rules do. Taking the empirical specifications plotted in Figures 2.2 and 2.3 as representative examples, the Taylor Rule produces a negative discrepancy for 77 out of the 205 quarters considered while the Implicit Rule does so on only 39 occasions.¹⁰

¹⁰ Excluding the period 1980q4-1987q1 – an interval admittedly chosen on an arbitrary basis but one which corresponds to the 'Volcker disinflation' period during which both (2.1) and (2.2) record negative discrepancies – reveals that Taylor Rule (*b*) produces a negative discrepancy on 54 occasions while Implicit Rule (*a=b*) does so on just 14 occasions.

2.2.2 Divergence

It is straightforward to identify the source of the difference between the nominal interest rate implied by (2.1) and (2.2). We refer to this as a ‘divergence’ rather than a ‘discrepancy’ since the latter term is reserved for the difference between implied and actual rates. Figure 2.4 plots the divergence between Taylor Rule (b) and Implicit Rule ($a=b$) under both the original and revised calibrations ($\bar{R}_t^T - \bar{R}_t^I$).

[Figure 2.4 here]

The Taylor-rule-implied nominal interest rate rarely exceeds the rate generated by the Implicit Rule for the post-c.1982 period and even when a positive divergence does emerge the magnitudes involved are significantly smaller than those observed prior to c.1982. Two large positive divergences stand-out in the pre-1982 period; the first reaches a maximum of 4.68 percentage points in 1974q4 and the second reaches a maximum of 5.29 percentage points in 1980q1 (both under the original calibration). The three post-1982 peaks for the original calibration are considerably smaller and reach only 1.01 percentage points (1990q4), 0.79 percentage points (2001q2) and 0.62 percentage points (2008q3) while the divergence series for the revised calibration hardly registers a positive value at all post-1982. The positive divergence series track each other closely during the 1970s but when the divergence falls below zero (i.e. the Implicit Rule exceeds the Taylor Rule) the revised series fall further than the original series. For example, the divergence series reaches a (local) minimum of -2.12 percentage points under the original calibration (1971q4) but stands at -5.02 percentage points for this same quarter under the revised calibration. A similar phenomenon is observed during other periods of negative divergence.

To shed light on these patterns, we can simply subtract (2.2) from (2.1) in order to obtain an expression for the divergence, denoted Δ_R :

$$\Delta_R = [(\bar{r}^* + \bar{\pi}^*) - (\rho + \bar{\pi}^*)] + \beta_\pi(\bar{\pi}_t - \bar{\pi}^*) + (\beta_y \bar{y}_{gap,t} - \theta \bar{g}_t). \quad (2.3)$$

Applying the original calibration ($\rho=\bar{\pi}^* = \bar{r}=2$ and $\theta=\beta_{\pi}=\beta_y=0.5$) to (2.3) reveals that the Taylor-Rule-implied nominal interest rate will exceed that of the Implicit Rule in any given quarter if:

$$(\bar{\pi}_t - 2) > (\bar{g}_t - y_{gap,t}) . \tag{2.4}$$

This explains why the nominal interest rate obtained from the Taylor Rule often exceeds the rate obtained from the Implicit Rule during the pronounced surges in inflation during the 1970s (see Figure 2.1). The high rate of inflation quantitatively dominates the difference between the growth rate and the output gap plus the inflation target (2%) during that period and the Taylor Rule places a higher weight on inflation deviations from target. Following the ‘Volcker disinflation’ of the 1980s, the right hand side of (2.4) shows a greater propensity to dominate the left-hand side, in part because the high rates of inflation suffered during the 1970s have not been experienced since.

The divergence series also depends upon the difference between the output gap and the output growth rate. Figure 2.5 evaluates the terms in inequality (2.4) by plotting CPI inflation less the inflation target (assumed to be constant at 2%), the difference between the output growth rate and the output gap derived from CBO estimates of potential output, along with the difference between rules (b) and (a=b) for the original calibration (as in Figure 2.4).

[Figure 2.5 here]

The divergence series is found to be negative between 1960q1 and 1966q3. This is because inflation was running close to ‘target’ – CPI inflation averaged 1.48% on a year-over-year basis compared to the 2% target implicit in the rule – so that the ‘CPI less 2%’ series is barely visible on the chart. In this case, the sign of the divergence between the Taylor Rule and the Implicit Rule is effectively determined by the difference between the output gap and the GDP growth rate, which was negative during this period.

The divergence subsequently fluctuates between negative and positive values during the late 1960s, the 1970s and into the early 1980s. In contrast to the 1960-1966 period, large positive divergences at this time are associated with periods in which observed inflation differs substantially from the 2% 'target' and with output growth rates which are approximately equal in magnitude to the output gap. Accordingly, the left-hand side of (2.4) determines the overall sign of the divergence. The lengthy period during the 1990s (1991q3-2000q2) for which R^I exceeds R^T shares certain similarities with the 1960-1966 period. A negative divergence is generated because inflation is reasonably close to the 2% target (although not as close to target as during the early 1960s) while the output growth rate consistently exceeds the output gap, perhaps due to the well-documented productivity gains of that decade (e.g. Jorgenson et al., 2008) which may have served to increase potential output.

One of the more dramatic features of Figure 2.4 is the precipitous decline in the divergence series from a (global) maximum of 5.29 percentage points to a (global) minimum of -4.93 percentage points over the course of just sixteen quarters between 1980q1 and 1983q4. This is associated with an abrupt decline in the inflation rate from nearly 15% to below 5% (see Figure 2.1). The policy measures required to bring about the disinflation also induced a recession, which appears in Figure 2.1 as a short, sharp decline in the GDP growth rate and a protracted period for which output falls below its potential level. This combination of events clearly impinges upon both sides of equation (2.4). The rapid decline in inflation would, all else equal, make $\Delta_R < 0$ the more likely outcome. The asymmetry between the ephemeral period of negative output growth and the protracted period of output below potential produces a situation in which $\bar{g}_t - \bar{y}_{gap,t} > 0$ and this exerts the same influence on Δ_R as the decline in inflation.

Similarly, applying the revised calibration to (2.3) gives the following analogue to (2.4): $(\bar{\pi}_t - 2) > 2(\bar{g}_t - \bar{y}_{gap,t})$. This helps to explain why the revised Taylor Rule very rarely exceeds the Implicit Rule during the post-1980 era (even on these rare occasions, the maximum gap observed is 0.92 percentage points compared to a peak of 5.00 percentage points in 1974q2, for example). The requirements

stipulated by the inequality for the divergence series to exceed zero are now doubly 'demanding' compared to the situation under the original calibration. As Figure 2.4 shows, such was the extremity of the 1970s inflation that even this more stringent inequality was satisfied.

This decomposition highlights the importance of the difference between the output gap and the output growth rate. Figure 2.6 plots the GDP growth rate, the CBO output gap, the difference between the two and the difference between Taylor Rule (b) and Implicit Rule ($a=b$) (plotted as bars this time).

[Figure 2.6 here]

We observe that downward movements in the output growth rate, i.e. when output growth is falling but not necessarily below zero, are closely followed by downward movements in the output gap. A decline in real GDP against a (relatively) stable level of potential output will reduce the output gap. However, the output growth rate 'recovers' to positive territory faster than the output gap. This difference between the output gap and the output growth rate in the aftermath of a recession has an important impact upon the nominal interest rates obtained from the Taylor Rule and the Implicit Rule – the latter will start to rise sooner than the former as output recovers. This is apparent from Figure 2.6, because we often observe negative divergence readings in conjunction with positive 'growth-less-gap' readings, most prominently as the economy emerges from periods of recession. In other words, if interpreted (erroneously) as a conventional interest rate rule, one would find that the Implicit Rule begins to 'tighten' relatively quickly following a period of recession, perhaps 'too quickly' from a reaction function perspective (Clarida et al., 1999, p.1700).

Clearly, the treatment of discrepancy and divergence series hitherto has amounted to little more than an accounting exercise. The next section proceeds to consider in more detail the question of *why* the series obtained from the Taylor Rule might differ from the observed series over the full sample period.

2.2.3 Taylor Rule Discrepancies: An ‘Historical Approach’

As is common in the interest rate rule literature, Taylor (1999, p.336) interprets discrepancies between the observed nominal interest rate and the rate implied by his “preferred policy rule” as indicative of “policy mistakes” and draws a link between such mistakes and unstable economic outcomes.¹¹ Similarly, Taylor (2011) argues that the degree of discretion in monetary policymaking has waxed and waned in distinct cycles over the course of U.S. economic history. For example, Taylor (1999, Figures 7.4-7.6) focuses on three subsample periods (c.1960-1974; c.1975-1986; c.1987-1997) in linking his notion of ‘policy mistakes’ to interest rate discrepancies. It is also common-practice to divide the post-war period into numerous subsamples when estimating Taylor-type rules. This allows the researcher to document the way in which the conduct of monetary policy has changed over time using changes in the coefficients of the rule. Judd and Rudebusch (1998), for example, split their 1970-1997 sample according to the tenure of Federal Reserve Chairmen and Clarida et al. (2000) similarly split their sample into ‘pre-Volcker’ (1960q1-1979q2) and ‘Volcker-Greenspan’ (1979q3-1996q4) periods. With these studies in mind, Figure 2.7 reproduces Figure 2.3 for the Taylor Rules but demarks four different ‘policy eras’. These eras shall be referred to as: ‘pre-Volcker’ (1960q1-1979q2); ‘Volcker disinflation’ (1979q3-1987q2); ‘Greenspan-Bernanke’ (1987q3-2007q3) and the ‘crisis period’ (2007q4-2011q1).

[Figure 2.7 here]

Figure 2.7 reveals a pattern of generally positive discrepancies during the ‘pre-Volcker’ period; negative discrepancies during the ‘Volcker disinflation’; a fairly even distribution of positive and negative discrepancies in the first half of the ‘Greenspan-Bernanke’ era but persistent positive discrepancies in the second half; and strong positive followed by strong negative discrepancies during the ‘crisis

¹¹ Despite the designated label, Taylor emphasises that such assessments are made with the benefit of hindsight and do not necessarily indicate that policymakers had the ability to set policy in a more appropriate manner in real time. Indeed, there are times when policymakers have had legitimate reason to err from rules-based policy due to unforeseen events. The 9/11 terrorist attacks provide one such example (e.g. McAndrews and Potter, 2002; Neely, 2004; Martin, 2009).

period'. The timing of these patterns is also broadly consistent with Taylor's recent analysis with regards to what he views as 'cycles' of discretionary and rules-based monetary (and fiscal) policy (Taylor, 2011).

Taylor (1999) identifies two distinct 'policy mistakes' during the 'pre-Volcker' era. The first is during the early 1960s when he argues that monetary policy was "too tight" (Taylor, 1999, p.338). This episode can possibly be attributed to the monetary policy initiative often referred to as 'Operation Twist', where policymakers attempted to raise short-term interest rates in order to preserve the value of the U.S. dollar (see Bernanke et al., 2004, p.24). The second, quantitatively larger discrepancy begins in the late 1960s and persists throughout the 1970s, essentially up until Volcker's appointment and the associated shift in policy emphasis. The conduct of monetary policy during the late 1960s and into the 1970s is often thought to have been a contributing factor to the Great Inflation which dominated the subsequent decade. The reason for this policy mistake has been the subject of much discussion – the Great Depression may have still been fresh in the minds of policymakers, instilling them with a severe aversion to output below potential which resulted in interest rates that were lower than appropriate (DeLong, 1997); policymakers possibly miscalculated the 'true' level of potential output in real time (Orphanides, 2003a); or may have placed undue faith in the notion of a permanent inflation-output trade off (Bernanke, 2003, pp.209-210).

Figure 2.8 focuses on the pre-Volcker era for the original and revised calibration of rule (b) in levels and also plots the effective federal funds rate and the inputs to rule (b).

[Figure 2.8 here]

The 'policy mistake' during the early 1960s identified by Taylor (1999) is more pronounced for the revised calibration because this places greater emphasis on the output gap which is found to be negative at this time. This first policy mistake is dwarfed by the mistake which subsequently follows. This is shown by the large,

persistent discrepancies which persist for the remainder of the pre-Volcker period (Figure 2.7). The discrepancy for rule (b) peaks at 9.05 percentage points in 1975q1 for the original rule and at 8.23 percentage points in 1979q3 for the revised rule. The lingering effect of the 1973q4-1975q1 recession in terms of a protracted negative output gap forces the implied series towards the observed interest rate and thereby reduces the size of the discrepancy by more than one would expect from looking at the rate of inflation alone. The period towards the end of the pre-Volcker era, during which the discrepancy begins to pick up again, further demonstrates that policymakers exhibited a lax attitude towards inflation at this time. Empirical studies which attempt to estimate the coefficients of the interest rate rule applicable to this period often find that a rule with a lower coefficient on inflation and a higher coefficient on the output gap better-describes the data than the benchmark Taylor (1993) rule (e.g. Taylor, 1999, Table 7.1). Taylor (1999, p.339) infers that the lesson is that: "If a policy closer to the baseline were followed, the rise in inflation may have been avoided." This illustrates the 'Taylor rule interpretation' of the historical record.

Evidently, the transition to the 'Volcker Fed' was a significant event in U.S. economic history. Goodfriend (2007, pg.47), for example, refers to Volcker's appointment as a "turning point", Clarida et al. (1998, pp.1042-1044) identify October 1979 as a break point for their estimation exercises because the newly appointed Federal Reserve Chairman "clearly signalled his intention to reign [*sic.*] in inflation" and Gavin and Kydland (1999) identify 1979q3 as an important break point in U.S. data for nominal variables. In direct reference to the type of interest rate rule considered here, Allan Meltzer describes an October 1979 FOMC meeting chaired by the newly appointed Volcker as the point at which the Fed, "implicitly changed the weights on unemployment and inflation" (Meltzer, 2010a, pp.1033-1034). Figure 2.7 shows that the Volcker era, though short, produces a dramatic change in the nature of the discrepancy series. The discrepancy series for the 'original' rule, for example, falls from 7.93 percentage points in 1979q3 to a low of -6.99 percentage points in 1983q3. Figure 2.9 plots the interest series derived from rule (b) along with the effective federal funds rate and the rule's inputs for the Volcker disinflation period.

[Figure 2.9 here]

This rapid decline in the discrepancy series can be explained by a near-simultaneous rise in the observed effective federal funds rate and a decline in both the original and revised rule-implied interest rates. The increase in the observed effective federal funds rate reflects the Volcker Fed's determination to disinflate. The Taylor-rule-implied rates fall as the disinflation materialises and as a result of the two periods of recession which occurred during this interval (1980q1-1980q3 and 1981q3-1982q4). The second of these two recessions was the more severe and was also the more protracted in terms of the lingering effects of a negative output gap. As Figure 2.9 shows, policymakers did not reverse course in the wake of the 1981q3-1982q4 recession. The 'Volcker disinflation' era might therefore be thought of as a time during which monetary policymakers resolved to 'correct' the monetary policy mistakes (accumulated discrepancies) committed during the pre-Volcker era by acting aggressively to permanently reduce the rate of inflation. Perhaps because of this, Taylor (1999, p.339) views this period from the perspective that the Fed was, "in a transition between policy rules" so that, "this period has less claim to being a 'policy mistake' than the other two periods." Similarly, Hetzel (2006, p.268) distinguishes between reaction functions which assume credibility and those which seek to restore credibility; the latter is analogous to a rule which attempts to 'correct' past mistakes.

At the conclusion of this 'Volcker disinflation' subsample, Taylor-rule-implied and observed nominal interest rates coincide almost exactly. The success of the disinflationary effort is striking: CPI inflation has reduced almost four-fold since the beginning of the sample period and the output gap, despite becoming strongly negative in the intervening period, has almost completely closed by the end of Volcker's tenure. Having progressed from a 'bad rule' during the pre-Volcker era, to a 'corrective rule' during the Volcker Disinflation, the final step in the progression towards the interest rate rule account of the Great Moderation involves a transition to a 'desirable' interest rate rule. Such a rule is required in order to ensure that the progress made in the 1980s, which plainly came at a high price in terms of output below potential, is not swiftly undone.

Figure 2.7 shows that the discrepancy series during the Greenspan-Bernanke era are condensed into a discernibly tighter range (within approximately +4 to -3 percentage points) than for the other eras. We observe that the range of the discrepancy series is especially narrow – within approximately ± 2 percentage points – and fairly evenly distributed between positive and negative discrepancies up until c.2000, whereupon the discrepancy jumps to approximately +4 percentage points and exhibits a very strong propensity to exceed zero, signifying that the observed nominal interest rate is lower than the Taylor Rule would recommend. Taylor (1999) directly associates the more favourable economic outcomes of the post-Volcker era – less frequent and shorter-lived recessions, strong and sustained output growth and lower and less variable inflation – to a change in the policy rule. Figure 2.10 presents the Greenspan-Bernanke era in isolation and shows that the empirical fit of the Taylor (1993) rule extends further than Taylor’s endpoint of 1992 (Judd and Trehan, 1995, showed that the rule could be extended to cover 1993 and 1994; similarly, Taylor, 1999, Figure 7.6).

[Figure 2.10 here]

Taylor-type interest rate rules became increasingly influential among policymakers during the Greenspan-Bernanke era, at least according to anecdotal accounts (e.g. Yellen, 2007; Kohn, 2007).¹² This growing influence followed from early studies which popularised simple interest rate rules by demonstrating their empirical relevance (e.g. Taylor, 1993) which also attracted the attention of financial market participants (e.g. Goldman Sachs, 1997; HSBC, 1997).

¹² Janet Yellen: “When I became a Governor back in 1994, I was privy to little analysis that used monetary policy rules. At the time, I argued that the FOMC should, at a minimum, routinely monitor the recommendations of Taylor-type policy rules as a check on its judgmental decisions... Nowadays, I am pleased to say, such analysis is routinely provided and discussed.” (Yellen, 2007). Similarly, Kohn (2007): “Federal Reserve policymakers are shown several versions of Taylor rules in the material we receive before each meeting of the Federal Open Market Committee (FOMC). I always look at those charts and tables and ask myself whether I am comfortable with any significant deviation of my policy prescription from those rules.” Taylor (2011, p.80) also gains this impression from the published minutes of FOMC meetings.

It is possible to identify several unanticipated events which gave monetary policymakers cause to deviate from the rule, as Rudebusch (2006, Figure 5) does. A prominent example of an extreme, unforeseen event for U.S. monetary policy would be the 9/11 terrorist attacks in 2001. U.S. monetary policymakers responded to this event by rapidly easing their monetary policy stance to support the financial system (e.g. McAndrews and Potter, 2002; Neely, 2004; Martin, 2009). A standard interest rate rule would have provided no basis for this loosening of monetary policy but it was lauded by the proponents of rules-based policy nevertheless (e.g. Taylor, 2009b, pp.65-66). This unexpected event was swiftly followed by a 'deflation scare' (Rudebusch, 2006, Figure 5) which helps to explain why the positive discrepancy in Figure 2.10 persists until c.2006. Policymakers have defended this extended period of ease partly by appealing to alternative rules which are more supportive of their policy stance than Taylor's original rule. The coefficients of the rule can be altered, for example, or different measures of inflation, or forward-looking variants on (2.1) can be employed (e.g. Bernanke, 2010). However, given that one of the most important features of a policy rule is that it stands diametrically opposed to discretionary policy making, policymakers ought to be cautious about making modifications to the rule to rationalise a particular course of policy after the fact.

Despite the justifications issued by policymakers, Taylor (2009a, 2011) views the period from c.2003 onwards, after which the impact of 9/11 and the subsequent worries about deflation should have receded, as a major policy error. He labels this episode 'the Great Deviation', clearly linking this discrepancy with policy errors associated with other major economic events such as the Great Depression of the 1930s and the Great Inflation of the 1970s (also, Meltzer, 2010a). The Great Deviation, Taylor (2011) argues, contributed to the bubble in the housing market which contributed to the financial crisis of 2007 and the subsequent recession (although Bernanke, 2010, disputes this claim). Taylor's protest emanates from the fact that policymakers did not 'normalise' the stance of policy appropriately once the immediate danger to the financial system posed by 9/11 had dissipated. Under rules-based policy, policymakers may legitimately depart from the rule for a time in order to react to unforeseen events but should then seek to return to it

as swiftly as possible. The Great Deviation appears to draw to a close in 2006 when the rule-implied interest rate begins to fall towards the effective federal funds rate due to a decline in inflation and a gradually receding output gap. At the conclusion of the Greenspan-Bernanke era there is very little difference between the rule-implied rates and the effective federal funds rate. In 2007q3, the effective federal funds rate stood at 5.07% and rule (b) reads 4.65% under the original calibration and 4.78% under the revised calibration. However, the big ‘policy mistake’ of the Greenspan-Bernanke era has arguably already been committed.

The 2007q4-2011q1 period still forms part of the Greenspan-Bernanke era, of course, but it is perhaps more appropriate to treat this as a distinct period. The ‘crisis period’ has exposed one of the biggest problems of framing monetary policy purely in terms of a nominal interest rate – it is not possible for the nominal interest rate to fall below zero in a fiat money system because the return on paper money provides a floor for the nominal interest rate. Lenders would rather simply hold onto zero-interest bearing money than pay for the privilege of lending. This is often referred to as the ‘zero lower bound problem’ (e.g. Laidler, 2006) and on rare occasions it can impinge upon monetary policy decisions. As Figure 2.11 shows, the rule implied nominal interest rate falls below zero for almost one year from 2008q4 under the original calibration and is still below zero at the end of the sample period under the revised calibration.

[Figure 2.11 here]

Clearly, the combination of close-to-target inflation and a strongly negative output gap conspire to generate the negative readings on the policy rules. Rudebusch (2009) also reports significant negative readings, in the region of -5%, for his (estimated) rule during this same period. To further illustrate how unusual it is for the Taylor Rule rates to fall below zero, Figure 2.12 follows Taylor (2001, 2009b) in plotting two ‘zero lower bound frontiers’, one for each of the calibrations provided in Table 2.1, and adds to Taylor’s diagrams by including scatter points to represent inflation: output gap combinations throughout the full sample period.

[Figure 2.12 here]

Points to the southwest of each frontier imply a negative nominal interest rate under each calibration and the plots show that such points occur exclusively towards the negative output gap region of the frontiers rather than the positive output gap region.¹³ The slopes of the frontiers differ; this shows that it is 'easier' to violate the zero lower bound for the revised rule than it is for the original rule because the former places twice the weight on the (negative) output gap than the latter. We observe that most violations of the zero lower bound for the revised rule occur during the 'crisis period' while all such violations occur during this era for the original rule. The non 'crisis period' quarters for which the implied nominal interest rate from the revised rule falls below zero occurred during the early 1960s and the early 1980s but were quantitatively less significant.¹⁴ The effective federal funds rate fell from approximately 2% in 2008q3, to 0.5% in 2008q4, to 0.18% in 2009q1 and has not risen above 0.2%, effectively zero, since. In other words, the observed nominal interest rate appears to track the Taylor Rule rates as far as possible, beyond which it remains 'stuck' at zero. Although, the observed rate briefly reached 1% in late 2003 and early 2004 as fears of deflation mounted, one would have to look back to the Great Depression or to Japan during the 1990s to find comparable episodes; the 'crisis period' represents uncharted territory for the post-1960 sample studied here.

Reaching the zero lower bound introduces a further complication to the 'policy mistakes' interpretation of the discrepancy series because policymakers could not possibly have followed the recommendations of the interest rate rule even if they had wanted to. However, U.S. monetary policymakers did attempt to ease

¹³ The frontier for the original rule is: $\bar{\pi} = -\frac{1}{3}(\bar{y}_{gap,t}) - \frac{2}{3}$ and for the revised rule it is: $\bar{\pi} = -\frac{2}{3}(\bar{y}_{gap,t}) - \frac{2}{3}$.

¹⁴ Revised rule (b) falls below zero for three consecutive quarters during the early 1960s (1960q4-1961q2), taking values of -0.21, -0.45 and -0.59 respectively and for two consecutive quarters during the early 1980s (1982q4-1983q1), taking values of -0.04 and -0.84 respectively. Original rule (b) does not fall below zero outside of the 'crisis period'. However, the negative readings recorded during the 2007q4-2011q1 period are much larger than those for the previous episodes: The original rule takes a negative value for three consecutive quarters (2009q1-2009q3), reading -2.36%, -3.88% and -4.85%, and the revised rule takes a negative reading for ten consecutive quarters (2008q4-2011q1), reaching a minimum of -8.30% in 2009q3, and closing on a value of -0.92% in the final quarter of the sample.

monetary policy further by resorting to ‘unconventional’ monetary policy. The policy initiative known as ‘quantitative easing’ is the most prominent of these measures.¹⁵ A natural question to ask of the Taylor Rule is: ‘Do policymakers gain any useful information from points which lie below the frontiers?’ Taylor (2009b) seems to suggest that they might:

“For the area below the line [zero lower bound frontier], the interest rate is zero and policymakers must look at some quantity, such as the money supply or the monetary base; this is the region of quantitative easing. In this lower region, policymakers could use Milton Friedman’s famous constant growth rate rule, or the money base rule proposed by McCallum... [Figure 2.12] illustrates that one should not think of quantitative easing as a separate or different framework for monetary policy, but rather as part of a broader framework.” (Taylor, 2009b, p.64, emphasis added)

In essence, Taylor (2001, 2009b) attempts to extend the Taylor (1999) ‘historical approach’ to incorporate unconventional monetary policy at the zero lower bound. However, it would seem that the Taylor rule is only able to provide at most a binary indicator of whether unconventional monetary policy is required because the mapping from negative nominal interest rate to unconventional monetary policy is not fully articulated in Taylor (2001, 2009b).¹⁶ The interest rate rule interpretation is therefore found to provide an intuitive account of the historical record but is not without its limitations.

2.2.4 Implicit Rule Discrepancies

As documented in Figure 2.3, the discrepancy series produced by the ‘interest rate rule’ implicit in the unit-velocity CIA model shares similar features to the

¹⁵ The first round of quantitative easing (announced in December 2008) included the purchase of \$1.25 trillion in mortgage-backed securities and \$300 billion in long-term treasury bonds and the second round (announced in November 2010) involved the purchase of another \$600 billion in long-dated Treasury bonds.

¹⁶ Chung et al. (2011) express policymakers’ attempts to influence long-term interest rates in terms of the short term rate, even though the latter is ‘stuck’ at zero. To do so they regress quarterly changes in the 10-year Treasury yield on quarterly changes in the federal funds rate for the period 1987-2007 and find that a 100 basis point reduction in the short term rate is equivalent to a 25 basis point reduction in long term yields. In this way they translate ‘unconventional’ monetary policy back into ‘conventional’ form. Similarly, Rudebusch (2010, Figure 3) provides an estimate as to what extent the discrepancy between rule-implied and actual nominal interest rate should be adjusted to take account of the attempts to ease monetary policy by ‘unconventional’ means. He argues that: “If the Fed’s purchases reduced long rates by $\frac{1}{2}$ to $\frac{3}{4}$ of a percentage point, the resulting stimulus would be very roughly equal to a $1\frac{1}{2}$ to 3 percentage point cut in the funds rate”.

discrepancy series generated by a conventional interest rate rule. Given the fundamental difference between the Taylor Rule (2.1) and the Implicit Rule (2.2), it would plainly be inappropriate to interpret the discrepancy series obtained from the latter as indicative of ‘policy mistakes’ in the same manner as Taylor’s (1999) ‘historical approach’. We therefore interpret the discrepancy series derived from (2.2) with reference to Lucas (2003), who poses the question as to whether the data supports a “*stable real rate plus inflation premium, à la Irving Fisher?*” or a “*Central Bank policy response to inflation?*” His answer to this question is, “100% Fisher” and he concludes that: “[*the*] figure contains no information on central bank interest rate policy rules” (2003, slide-10). While the Implicit Rule (2.2) does feature a one-for-one relationship between the nominal interest rate and inflation in a manner consistent with the Fisher relation, it also features a term in consumption growth. This is consistent with Arnwine and Yigit’s (2008) “augmented Fisher relation”. They insist that empirical applications of the Fisher relation should make allowance for changes in consumption (or output if $y=c$) to account for pro-cyclical fluctuations in the real interest rate and that the expected one-for-one relation should only be expected to hold if such provision is made.

Figure 2.13 adapts the figure presented by Lucas (2003, slide 9) to apply to the Implicit Rule (2.2) by considering the rate of inflation plus one half times the growth rate along the horizontal axis in accordance with the ‘original’ calibration above. We also adjust the gap between the 45-degree line and the dashed line to be 2 percentage points ($\rho=2$) rather than 2.5 percentage points (which was Lucas’ assumed “stable real rate”) and distinguish between the various monetary policy regimes defined above.¹⁷

[Figure 2.13 here]

¹⁷ It is not clear which precise series Lucas (2003) plots or what frequency and time period he considers but for the purposes of Figure 2.13 we interpret Lucas’ “Short-term Interest Rate” to be the effective federal funds rate and his “Inflation Rate (CPI)” to be the year-on-year percentage change in the CPI index, consistent with the quantitative analysis presented above.

Figure 2.13 contains three regions, each of which can be defined by the following inequalities: $\bar{R} > \rho + (\bar{\pi} + \theta \bar{g})$ for plots to the northwest of the solid line; $\bar{R} < \bar{\pi} + \theta \bar{g}$ for plots to the southeast of the dashed line; and $\rho + (\bar{\pi} + \theta \bar{g}) > \bar{R} > (\bar{\pi} + \theta \bar{g})$ for plots lying between the solid and dashed lines. Historical periods characterised by relatively small discrepancies from the parallel lines could be characterised as periods for which the modified Fisher relation holds. In this way, we apply a (augmented) Fisher relation interpretation to the data which does not depend upon ‘Taylor rule logic’. Treating the rate of time preference (ρ) as analogous to the equilibrium real interest rate, Figure 2.13 shows the tendency for low (<2%) and often negative ex-post real interest rates during the pre-Volcker era and relatively high (>2%) real interest rates during the Volcker disinflation. Observations relating to the Greenspan-Bernanke era usually fall within or reasonably close to the 2 percentage point region thus indicating a low and stable real interest rate of interest in the 0-2% range. Negative ex-post real interest rates are observed for the crisis period because with the nominal interest rate close to zero, only a modest rate of inflation is required to generate a negative ex-post real rate.

Alternatively, the Implicit Rule (2.2) can be interpreted in the context of a consumption (output) Euler equation. As shown in Chapter-I, the Implicit Rule above is essentially a re-arranged Euler equation. Canzoneri et al. (2007) document the inability of conventional intertemporal Euler equations to track observed *ex post* real interest rates.¹⁸ Figure 2.14 plots the equivalent to their “Fig. 1” in terms of the real interest rate, $\bar{R}_t - \bar{\pi}_t$, but uses the simpler expression (2.2) which does not include uncertainty.

[Figure 2.14 here]

Canzoneri et al. (2007) suggest that this poor empirical fit stems partly from the fact that the real interest rate derived from Euler equations such as (2.2) cannot capture the ‘liquidity effect’ associated with monetary policy adjustments. They point to two historical episodes in particular to illustrate their point (Fig. 1, p.1867): Firstly, during the late 1970s when the Euler-equation-implied real rate

¹⁸ See also Collard and Dellas (2012).

fell at a time when policymakers actually ‘tightened’ monetary policy by engineering increases in the short-term real interest rate (‘the Volcker tightening’, as they describe it); and secondly, in c.2001 when the model-implied real rate increased although monetary policy was actually ‘loosened’ (‘the Greenspan easing’). These two episodes are also observed in Figure 2.14 – the former episode generates large negative discrepancies between the observed and model-implied real interest rate while the latter generates large positive discrepancies (as shown by the highlighted regions).

Reynard and Schabert (2009) also consider the link (or lack thereof) between short-term interest rates and Euler-equation-implied rates. They apply a similar conditional log-normality assumption but express their figure (p.6) in terms of the nominal rather than the real rate of interest. Therefore, their ‘Standard Euler interest rate’ is analogous to the series labelled as ‘IR ($a=b$) original’ and ‘IR ($a=b$) revised’ in Figure 2.2 above. They show that the spread between the model-implied nominal rate and the observed nominal rate often varies inversely. Figure 2.15 shows that this result also emerges from the simplified expression (2.2).¹⁹

[Figure 2.15 here]

Reynard and Schabert (2009) proceed to construct a model which abstracts from the assumption that the nominal interest rate used to implement monetary policy and the nominal interest rate which enters the Euler equation coincide.

2.3 Inflation Misperceptions

Although equation (2.2) is derived from the appropriate ‘cash-in-advance timing’ advocated by Carlstrom and Fuerst (2001), it is notable in that it differs from the usual Fisher relation form which conventionally features *expected future* inflation on the right hand side rather than the current rate of inflation.²⁰ In Chapter-I, we

¹⁹ The discrepancy series shown in Figure 2.15 are the same as those plotted in Figure 2.3.

²⁰ The Fisher equation of interest rates is generally stated as $\bar{R} = \bar{r} + \bar{\pi}^e$. If actual and expected inflation are taken to be interchangeable and if the real interest rate is taken to be ‘stable’ at 2.5% as a long-run condition then this is simply $\bar{R} = 2.5 + \bar{\pi}$, which is the relationship plotted by the solid line in Figure 2.13.

examined a 'long-run Taylor Condition' (as equation 1.37). Assuming perfect foresight for the moment, this expression takes the following form:

$$\bar{R}_t = \bar{\pi}_{t+1} + \theta \bar{g}_{c,t+1}, \quad (2.5)$$

which is written in 'levels' as opposed to deviation-from-BGP form in order to compare with equation (2.2) above. As discussed in Chapter-I, this expression reflects the forward-looking nature of the Fisher relation but is nevertheless derived from an Euler equation which is compatible with Carlstrom and Fuerst's (2001) 'cash-in-advance timing'. In principle, we could obtain discrepancy series from different calibrations of (2.5) and analyse them in the same manner as those obtained for equations (2.1) and (2.2) above. However, the perfect foresight assumption is likely to be dubious for more turbulent historical periods, such as the Great Inflation during the 1970s. For instance, DeLong (1997) writes:

"One of the striking features of the inflation of the 1970s was that increases in inflation were almost always unanticipated... In every single year in the 1970s, the consensus forecast made late in the previous year *understated* the actual value of inflation. Moreover, in every year inflation was expected to fall." (DeLong, 1997, pg.266, emphasis present in the original)

The oil price shocks of the 1970s may account for some proportion of these forecast errors (e.g. Blinder and Rudd, 2008) but monetary policy was also seemingly more intent on maintaining low unemployment than containing inflationary pressures (DeLong, 1997, p.250).

Goodfriend and King (2005) also point to rising long-term bond yields during Chairman Volcker's time in office as indicative of scepticism over whether policymakers would actually deliver on their intentions. As such, inflation expectations were likely to have been overstated during this time. This scepticism was understandable given the frequency with which the Federal Reserve's operational independence had been encroached upon in the recent past (Abrams,

2006; Abrams and Butkiewicz, 2012).²¹ Such doubts were justified in March 1980, shortly after Volcker commenced his program of monetary tightening, when the Carter administration imposed credit controls in an attempt to offset the impact of the high nominal interest rates required to deliver the disinflation. This intervention was counterproductive because the Fed ended up having to expand the money supply in order to ameliorate the damage caused by this misguided policy step at the cost of postponing its effort to disinflate (Meltzer, 2010b, p.290). Goodfriend and King (2005, p.1000) argue that Reagan's victory in 1980 was an important turning point in the fight against inflation because his administration gave Volcker the 'political umbrella' he needed to administer his anti-inflationary medicine without fear of political reprisals.

This historical background therefore suggests that the perfect foresight assumption applied to arrive at (2.5) would be questionable during these periods. One way to demonstrate the impact on the implied nominal interest rate is to rewrite equation (2.5) as:

$$\bar{R}_t^{LRTC} \equiv \bar{R}_t \simeq \rho + \bar{\pi}_{t+1} + \theta \bar{g}_{c,t+1} + \Lambda_t . \quad (2.6)$$

The 'error' term here would provide a measure of the impact of inappropriately assuming perfect foresight, $\Lambda_t \equiv (\bar{\pi}_{t+1}^e - \bar{\pi}_{t+1}) + \theta(\bar{g}_{c,t+1}^e - \bar{g}_{c,t+1})$. If equation (2.5) was considered instead of equation (2.6) then unanticipated inflation, for example, would imply $\Lambda_t < 0$ and clearly bias the nominal interest rate implied by

²¹ These studies focus on the relationship between the Nixon Administration and the Burns Fed immediately prior to the 1972 General Election. They use the conversations documented by 'the Nixon Tapes' as evidence that the Federal Reserve was subject to heavy political interference from the Nixon administration during Burns' tenure. The recordings show that the administration threatened to diminish the Fed's independence by appointing candidates sympathetic to the president's objectives to the Federal Reserve Board without the Chairman's approval. Nixon to [Director of the OMB] George P. Shultz, July 3rd, 1971: "I'll tell you what I've done. I've told [Treasury Secretary] Connally to find the easiest money man he can find in the country. And one that will do exactly what Connally wants and one that will speak up to Burns... and Connally is searching the god damn hills of Texas, California, Ohio. We'll get a populist senator on that board one way or another... If you know of someone that's that crazy then let me know too... I want a man on that Board that I can control. I really do..." (Abrams and Butkiewicz, 2012, p.393).

(2.5) upwards. However, Λ_t could also be said to incorporate all of the *BGP* conditions placed upon the full Taylor Condition to obtain equation (1.37).

In order to assess the quantitative importance of inflation misperceptions in particular, we use Survey of Professional Forecasters (SPF) data, which is available from 1969q1 (for one-quarter-ahead forecasts) and 1979q2 (for four-quarter-ahead forecasts), to calculate the forecast errors made by survey participants over time.²² Figure 2.16 plots the one- and four-quarter-ahead forecast errors calculated from the median SPF forecast together with the discrepancy series generated from equation (2.5) for empirical specification ($e=f$) under the ‘original’ calibration ($\rho=2, \theta=0.5$).²³ We follow the convention in the literature (e.g. Croushore, 1998) and define the misperception series to be actual inflation minus expected inflation ($-\Lambda_t$) and the raw forecast data has been realigned so that the x -axis in Figure 2.16 denotes the period that the forecast applies to rather than the date that the forecast was initially made. Figure 2.16 also marks the monetary policy eras defined in the previous section: pre-Volcker (1969q1-1979q2, now reduced in length owing to limited SPF data coverage); Volcker disinflation (1979q3-1987q2); Greenspan-Bernanke (1987q3-2007q3); crisis period (2007q4-2011q1).

[Figure 2.16 here]

²² While market-based measures of inflation expectations – e.g. spreads between nominal and indexed-linked government securities (TIPS) – may generally be preferable to survey-based measures, it is not possible to apply these measures to the historical periods of greatest interest in terms of inflation misperceptions because indexed-linked securities were only launched by the U.S. Treasury in January of 1997.

²³ The ‘actual inflation’ series used to calculate the inflation misperceptions is taken directly from the file entitled ‘Data for error statistics (projections and realizations)’ which is available from the SPF section of the Federal Reserve Bank of Philadelphia website. Prior to 1992, respondents were asked to forecast the GNP deflator, they were then asked to forecast the GDP deflator between 1992 and 1996 and finally the GDP price index from 1997 onwards. The ‘realised series’ used to calculate the forecast error is constructed to reflect these changes in the survey methodology. The growth rate of the price indices has been calculated by using compounding to annualise quarter-on-quarter changes in the index, as suggested by the FRBP documentation accompanying the survey data. There is a missing observation for 1975q3 for the four-quarter-ahead inflation forecast. This has been dealt with by taking an average of the four-quarter-ahead forecasts for 1975q2 (3.50%) and 1975q4 (6.57%) to impute a value for 1975q3 (5.04%). There is no corresponding missing value for the one-quarter-ahead forecast. Figure 2.16 uses empirical specification $e=f$ because this uses the GDP deflator as the measure of inflation.

Consistent with DeLong (1997), we find substantial and persistent under-predictions of inflation ($\bar{\pi}_t - \bar{\pi}_t^e > 0$) during the pre-Volcker era. This is followed by a period of less extreme, but similarly persistent, over-predictions of inflation during the Volcker disinflation ($\bar{\pi}_t - \bar{\pi}_t^e < 0$), consistent with Goodfriend and King's (2005) account. A lengthy run of smaller over-predictions then follow during the first half of the Greenspan-Bernanke era, consistent with Croushore's (1998, p.5) observation that "forecasters have been forecasting an upturn in inflation in the 1990s that hasn't happened". This can perhaps be explained by productivity gains, i.e. "positive supply shocks" (Jorgenson et al., 2008, p.4), which arose during the mid-1990s or it could be that financial markets and the general public were doubtful that the Greenspan Fed would be capable of securing Volcker's legacy. A run of similar-sized under-predictions then follow from c.2000 until the financial crisis of 2007/08. These under-predictions are possibly associated with a 'productivity slowdown' which placed upward pressure on the rate of inflation (e.g. Yellen, 2005). During the 'crisis period', inflation tended to be lower than predicted by survey respondents as observed (headline) inflation fell towards zero as the financial crisis transformed into a severe recession (Figure 2.1). Alternatively, SPF participants possibly saw the unprecedented expansion of the Federal Reserve's balance sheet as a precursor to inflation but as yet this has not materialised.

In sum, we find that over the 1969-2011 period inflation usually turned out to be lower than expected between c.1980 and c.2000 (although to different extents) and higher than expected outside of this interval. This conclusion is consistent with Thomas (1999) who studies the forecasting performance of four different measures of expected inflation – the SPF Survey, the Livingston Survey, the Michigan survey, and a model-based 'Fisher forecast' – and concludes that:

"Agents exhibit a strong propensity to underestimate inflation when it is relatively high and to overestimate inflation when it is low" Thomas (1999, p.142)

Figure 2.16 also shows that the discrepancy series generated from (2.5), $(\bar{R}_t^{LRTC} - \bar{R}_t)$, tends to track the inflation misperception series, especially during

the pre-Volcker Great Inflation, the Volcker Disinflation period and during the c.2001 period, which Canzoneri et al. (2007) highlight as a period when a conventional Euler equation provides a poor fit to the data (see Figure 2.14 above). Although the correspondence is by no means perfect, this suggests that the nominal interest rate given by (2.5) is biased upwards when Λ_t in (2.6) is negative and biased downwards when Λ_t is positive, as expected. Allowing for the rate of inflation that people expected rather than the observed inflation rate in (2.5) might provide a nominal interest rate series which fits the data better. Instead of the ‘policy mistake’ explanation employed in the Taylor rule literature, what we perhaps require is a more satisfactory model of expectation formation and in particular the phenomenon described by Thomas (1999) above.

2.3.1 Unexpected Inflation and the Taylor Rule

The discussion in the previous section raises the question as to how forward-looking terms and expectations are dealt with in the interest rate rule framework. Equation (2.1) is a contemporaneous rule but it is common to instead specify a forward-looking variant. Equation (1.2) of Chapter-I with $s=q=1$, gives the forward-looking interest rate rule considered by Galí (2008, p.79), for example:

$$\bar{R}_t^R \equiv \bar{R}_t = \bar{r}^* + \bar{\pi}^* + (1 + \beta_\pi)(E_t \bar{\pi}_{t+1} - \bar{\pi}^*) + \beta_y(E_t \bar{y}_{gap,t+1}). \quad (2.7)$$

The standard interpretation of the forward-looking relationship between the central bank’s policy instrument and the variables that it reacts to is that policymakers must allow for lags in the monetary transmission mechanism.²⁴ As Batini and Haldane (1999, p.159) explain, the inflation forecast horizon of the policy rule (‘s’ in Chapter-I) can also be thought of as a ‘choice variable’ for policymakers, and they may therefore seek to optimally select ‘s’.

²⁴ Chairman Greenspan, testifying before the United States Senate Committee on the Budget, stated that: “Because monetary policy works with a lag, it is not the conditions prevailing today that are critical but rather those likely to prevail six to twelve months, or even longer, from now. Hence, as difficult as it is, we must arrive at some judgement about the most probable direction of the economy and the distribution of risks around that expectation.” (Chairman Greenspan testifying before the Senate Committee on the Budget, January 21st 1997, as quoted by Orphanides, 2001, p.978).

In empirical applications, these forward looking terms are dealt with either by using central bank or private sector forecast information (e.g. Orphanides, 2001; Siklos and Wohar, 2005) or by appealing to the rational expectations hypothesis and assuming that agents use all available information efficiently in order to generate unbiased forecasts on average (e.g. Clarida et al., 1998, 2000). In the former case, expectational errors would naturally be interpreted as central bank forecast errors and unanticipated inflation would lead to a lower nominal interest rate than an *ex post* Taylor rule would deem to be appropriate, similar to equation (2.6) above. In the latter case, *realised* future values stand in place of expected future values and conditional forecast errors are collected in a composite error term which has an expected value of zero.²⁵

2.4 Summary and Implications for Remaining Chapters

In this chapter we have applied the simple calibration exercises considered by Taylor (1993), Kozicki (1999) and Orphanides (2001) to the Taylor (1993) rule and the interest rate rule implicit in a standard, constant velocity CIA model. Although the simple summary statistics presented suggest that the Taylor Rule (2.1) generally provides a better fit to the observed nominal interest rate series during Taylor's 1987-1992 sample period, the Implicit Rule (2.2) is also able to offer a reasonable fit to the observed series during this time (Figures 2.2 and 2.3). Outside of this six year period, both of these expressions offer a substantially less satisfactory fit to the observed series.

Discrepancies between the nominal interest rate derived from the Taylor Rule and the observed nominal interest rate are usually interpreted to reflect 'policy mistakes' on the part of the monetary authority. In a similar exercise to Taylor (1999), we demonstrated that Taylor rule discrepancies have an intuitive interpretation in terms of four 'policy eras' which corresponded to: a 'pre-Volcker' era during which policymakers adhered to an 'undesirable' interest rate rule; a 'Volcker disinflation' era which required a rule to 'correct for' the mistakes of the previous era; a Greenspan-Bernanke era during which a 'desirable' rule was adopted; and finally a 'crisis' period where the conventional rule called for a

²⁵ See Chapter-IV for more on the Clarida et al. (1998, 2000) method.

negative nominal interest rate which could not be implemented in practice. We required an alternative interpretation for the discrepancy series obtained from the Implicit Rule, however, because the underlying structural model assumes that monetary policy is conducted according to a constant money growth rule. As such, we took the long-run Fisher relation as a benchmark and demonstrated that the discrepancy series generated by the Implicit Rule maps to the four 'policy eras' used to interpret the predictions of the Taylor Rule.

The Fisher relation interpretation raises the issue of the timing structure of the Implicit Rule, as discussed in Chapter-I. We subsequently considered a forward-looking variant (2.5) of the contemporaneous Implicit Rule (2.2), where the former was interpreted as the 'long-run Taylor Condition' obtained from the structural model of Benk et al. (2010). For this more conventional, forward-looking statement of the Fisher relation, we found that discrepancies were linked to inflation misperceptions. The model-implied interest rate tends to overstate the nominal interest rate when private sector forecasters underestimate future inflation, the 1970s being the prime example, and conversely the model tends to understate the nominal interest rate when private sector forecasters overestimate future inflation, the Volcker disinflation being the prime example in this case.

In Chapters-III and -IV we consider the more general Taylor Condition which, in addition to inflation and consumption growth, also features terms in the growth rate of productive time, the growth rate of the velocity of money and the expected future nominal interest rate. Rather than applying the simple calibration exercises considered in this chapter, we turn to estimation procedures which have routinely been adopted in the empirical literature.

CHAPTER-III: AN ANALYSIS OF THE TAYLOR CONDITION

3.1 Introduction¹

It is conventional to view interest rate rules as ‘reaction functions’ which represent the way in which monetary policymakers adjust a short-term nominal interest rate in response to the state of the economy. The coefficients of such rules are subsequently interpreted to reflect policymakers’ preferences towards key macroeconomic variables such as deviations of inflation from target or the output gap (e.g. Taylor, 1993). An interest rate rule of this type forms one of the three core equations of the prominent New Keynesian (NK) modelling framework (e.g. Woodford, 2003; Clarida et al., 1999; Galí, 2008). One well-known normative result in this literature is that monetary policymakers should adhere to an interest rate rule which satisfies the ‘Taylor principle’ whereby an increase in inflation above target is met by a more-than-proportional increase in the short-term nominal interest rate, which leads to an increase in the real interest rate, which reduces inflation back towards target.²

A corresponding empirical literature has found that the Taylor principle is satisfied for U.S. data during the Federal Reserve chairmanships of Paul Volcker and Alan Greenspan but that it was violated for a pre-Volcker sample, during which policymakers accommodated inflation by initiating interest rate responses which were insufficient to raise the real rate of interest as inflation increased (e.g. Taylor, 1999; Clarida et al., 2000; Mankiw, 2001).³ Since the pre-Volcker era is associated with unstable economic outcomes, particularly with regards to

¹ This chapter forms the basis for the research paper, *Deriving the Taylor Principle when the Central Bank Supplies Money*, with Max Gillman (Cardiff Business School) and Michal Kejak (CERGE-EI, Prague). Distributed as: Cardiff Business School Working Paper ref. E2012/20; Central European University Working Paper ref. 2012/13; Hungarian Academy of Sciences, Discussion Paper ref. MT-DP 2012/25.

² Strictly speaking, the Taylor principle is a determinacy condition and is therefore model-specific. However, for a conventionally calibrated NK model, determinacy turns out to rest primarily upon the magnitude of the rule’s inflation coefficient (e.g. Woodford, 2003, 2008). Accordingly, empirical studies tend to focus on the relationship between the nominal interest rate and inflation while the coefficients on additional terms such as the output gap play only a peripheral role. The requirement on the inflation coefficient described in the text can be thought of as a ‘rule-of-thumb Taylor principle’.

³ Cochrane (2011a, p.566) questions whether this “‘old-Keynesian’, stabilizing logic” can be meaningfully applied to the forward-looking NK framework.

inflation, and the Volcker-Greenspan era coincides with the Great Moderation, it is clearly tempting to link the benign economic conditions of the latter period with an improvement in the conduct of monetary policy – i.e. adherence to the Taylor principle.

From an alternative perspective, an historical strand of literature dating back to Poole (1970) – and more recently Alvarez et al. (2001), Collard and Dellas (2005) and Chowdhury and Schabert (2008), amongst others – considers interest rate rules and money supply rules as two ways of implementing the same monetary policy stance. This chapter perhaps most closely follows Alvarez et al. (2001) by deriving an equilibrium condition for the nominal interest rate from a general equilibrium economy in which the central bank conducts monetary policy by supplying money at a fixed long-run (steady state) rate of growth in order to satisfy the government's fiscal needs. This equilibrium condition is labelled a 'Taylor Condition' in order to reflect its similarities with conventional interest rate rules but also its status as an equilibrium condition rather than an exogenously specified rule *per se*. Instead of granting only an exogenously-set fraction of agents access to the bond market, as Alvarez et al. (2001) do, here the consumer purchases goods with an endogenous fraction of intratemporal credit produced by the banking sector. This credit service is costly but nevertheless potentially attractive because it allows the representative consumer to avoid the inflation tax on exchange.

This cash-in-advance (CIA) framework is also extended to include endogenous growth and endogenous velocity, as in Benk et al. (2010). The resulting equilibrium condition for the nominal interest rate 'nests' a standard interest rate rule within a more general forward-looking setting, one which assigns a prominent role to traditional monetary elements such as the velocity of money, as in Alvarez et al. (2001), or money demand, as in McCallum and Nelson (1999b). The endogenous growth aspect of the Benk et al. (2010) model means that the 'target terms' of the Taylor Condition, such as the 'inflation target', correspond to the balanced growth path (BGP) equilibrium value of each variable. In addition, the coefficients of the Taylor Condition are shown to be a function of the model's

utility and technology parameters along with the *BGP* money supply growth rate, in essence fulfilling Lucas's (1976) aim of postulating policy rules with coefficients that depend explicitly upon 'deep parameters' and a key policy choice, in this case the *BGP* rate of money supply growth.

The analytical form for the Taylor Condition provides a fundamental theoretical result: the coefficient on inflation exceeds one for any given non-Friedman (1969) optimum *BGP* money supply growth rate and equals one only at the Friedman optimum. Furthermore, this coefficient cannot fall below one. Equivalently, the inflation coefficient always exceeds one when (endogenously-determined) velocity exceeds one and velocity exceeds one for any rate of money supply growth which is not compatible with the Friedman optimal nominal interest rate. In general, the inflation coefficient rises with the level of *BGP* velocity. Another key result is that expected velocity growth enters the Taylor Condition as an additional term. This contrasts with standard Taylor rules which often sit within economic models in which monetary relationships play only a peripheral role (e.g. Woodford, 2003, 2008 in support and Alvarez et al., 2001, for a criticism of this approach).

Having derived the Taylor Condition, we then estimate its coefficients against artificial data simulated from the Benk et al. (2010) model. We apply three conventional estimation procedures to one thousand samples of simulated data, where the data is passed through one of three standard statistical filters prior to estimation. The results verify the theoretical form of the Taylor Condition along several key dimensions. In particular, the coefficient on inflation is greater than one and close to its theoretical magnitude for all three estimation techniques under all three filters. We subsequently explore the impact of estimating two alternative, arbitrarily misspecified estimating equations which diverge from the 'true' theoretical expression: the first modifies just one of the variables in the Taylor Condition while the second implements a standard Taylor rule which involves multiple misspecification errors. Using the same artificial data, the two misspecified models produce an estimated coefficient on inflation which falls below one and thus constitutes an inadmissible estimate in the context of the

model from which the simulated data is obtained. In the context of actual data, this result would typically be interpreted as a violation of the Taylor principle, i.e. that monetary policymakers are 'passive' towards, or 'accommodative' of, inflation. The illusion of a 'Taylor rule' emerges even though the central bank simply sets a fixed long-run money growth rate in order to implicitly satisfy the government's fiscal needs through the inflation tax. It would therefore be spurious within this economy to interpret the Taylor Condition as a 'reaction function'. The empirical result which suggests that the Taylor principle is violated emerges simply as a product of a misspecified estimating equation.

It is perhaps unsurprising to find a link between the contemporary notion of an interest rate rule and a traditional money supply rule. For example, Taylor (1999) alludes to the possibility that an interest rate rule can be derived from the quantity theory of money; Sørensen and Whitta-Jacobsen (2005, pp.502-505) present such a derivation under the assumption of constant money growth whereby the coefficients of the 'rule' relate to elasticities of money demand rather than the preferences of policymakers; Fève and Auray (2002) and Schabert (2003) consider the link between money supply rules and interest rate rules in standard CIA models with velocity constant at unity. Alternatively, this chapter could be viewed in the context of Canzoneri et al. (2007) account of the shortcomings of estimated Euler equations because it shows how the latter can be used to derive an equilibrium Condition which shares certain similarities with the interest rate rules that seem to have provided a close fit to the data during the post-Volcker era (e.g. Taylor, 1993, 1999).

The remainder of this chapter is structured as follows: Section 3.2 describes the model of Benk et al. (2010); Section 3.3 derives the model's 'Taylor Condition'; Section 3.4 provides details of the baseline calibration; Section 3.5 describes the econometric methodology applied to model-simulated data and presents the corresponding estimation results; Section 3.6 briefly discusses two alternative forms for the Taylor Condition; and Sections 3.7 and 3.8 provide a discussion and a conclusion.

3.2 Stochastic Endogenous Growth with Banking

The representative agent model considered here is as described in Benk et al. (2008, 2010) but adds a decentralised banking sector that produces credit, as in Gillman and Kejak (2011). By combining the business cycle with endogenous growth, stationary inflation lowers the output growth rate, as reported empirically by Gillman et al. (2004) and Fountas et al. (2006), for example. Furthermore, money supply shocks can cause changes in the rate of inflation at lower frequencies, as documented by Sargent and Surico (2008, 2011) and Haug and Dewald (2012), which can lead to output growth effects if the shocks are persistent and repeated. This allows shocks over the business cycle to cause changes in long-run growth rates and in stationary ratios. The shocks to the goods sector productivity and the money supply growth rate are standard in the literature, while the third shock to credit sector productivity exists by virtue of the model's endogenous velocity of money. Exchange credit is produced via a functional form used extensively in the financial intermediation literature starting with Clark (1984) and adopted by Berger and Humphrey (1997) and Inklaar and Wang (2013), for example. Specifically, shocks to goods sector productivity (z_t), the money supply growth rate (u_t) and bank sector productivity (v_t) materialise at the beginning of each period, are observed by the consumer before the decision making process commences and follow a vector first-order autoregressive process of the form:

$$Z_t = \Phi_Z Z_{t-1} + \varepsilon_{Zt}, \quad (3.1)$$

where $Z_t = [z_t \ u_t \ v_t]'$, the autocorrelation matrix is $\Phi_Z = \text{diag}\{\varphi_z, \varphi_u, \varphi_v\}$ where $\varphi_z, \varphi_u, \varphi_v \in (0,1)$ are autocorrelation parameters and the shock innovations are $\varepsilon_{Zt} = [\varepsilon_{zt} \ \varepsilon_{ut} \ \varepsilon_{vt}]' \sim N(0, \Sigma)$. The general structure of the second-order moments is given by the variance-covariance matrix Σ . These shocks affect the model as described below and are calibrated in accordance with Benk et al. (2010).

3.2.1 The Consumer's Problem

A representative consumer derives utility from the consumption of goods (c_t) and leisure time (x_t). Utility is assumed to be given by the Constant Relative Risk Aversion (CRRA) form (expressed in expected present value terms):

$$U = E_0 \sum_{t=0}^{\infty} \beta^t \frac{(c_t x_t^\psi)^{1-\theta}}{1-\theta}, \quad (3.2)$$

where $\beta \in (0,1)$ is the discount factor, $\psi > 0$ is a leisure preference parameter and $\theta > 0$ is the (constant) coefficient of relative risk aversion. Output of goods (y_t) and accumulation of human capital must be produced with physical capital and effective labour, each in Cobb-Douglas fashion; the bank sector produces exchange credit using labour and deposits as inputs. The terms s_{Gt} and s_{Ht} denote the fractions of physical capital used in goods production (G) and human capital investment (H), whereby:

$$s_{Gt} + s_{Ht} = 1. \quad (3.3)$$

The representative consumer allocates a time endowment of one between leisure (x_t), time spent working in the goods sector (l_{Gt}), time spent accumulating human capital (l_{Ht}) and time spent working in the banking sector (l_{Ft}):

$$l_{Gt} + l_{Ht} + l_{Ft} + x_t = 1. \quad (3.4)$$

Output of goods can be converted into physical capital (k_t) without cost and is thus divided between consumption goods and investment (i_t) net of capital depreciation. The capital stock available in the next period is given by the standard physical capital accumulation equation:

$$k_{t+1} = (1 - \delta_k)k_t + i_t = (1 - \delta_k)k_t + (y_t - c_t). \quad (3.5)$$

Human capital investment is produced using capital $s_H k_t$ and effective labour $l_H h_t$ such that the human capital accumulation equation is:

$$h_{t+1} = (1 - \delta_h)h_t + A_H (s_H k_t)^{1-\eta} (l_H h_t)^\eta, \quad (3.6)$$

where $A_H > 0$ and $\eta \in [0, 1]$. The consumer receives income through wages and rental income from capital, $P_t w_t (l_{Gt} + l_{Ft}) h_t$ and $P_t r_t s_{Gt} k_t$ in nominal terms, where w_t and r_t denote the real wage and the real interest rate respectively, through a nominal transfer from the government (T_t) and through dividends from the bank. The consumer acquires shares in the bank by depositing funds. Akin to a mutual bank, each dollar deposited buys one share at a fixed price of one and the residual profits of the bank are returned to the consumer as dividend income in proportion to the number of shares owned. Accordingly, the consumer receives a nominal dividend income of $P_t R_{Ft} d_t$, where d_t denotes the real quantity of deposits and R_{Ft} denotes the dividend per unit of deposits. The consumer must also pay the bank a fee for using the credit service, where one unit of credit service is required for each unit of consumption that the consumer chooses to fund using this money alternative. The representative consumer pays $P_{Ft} q_t$ in credit fees, where P_{Ft} denotes the nominal price of each unit of credit and q_t the real quantity of credit used for exchange purposes.

Incorporating expenditure on goods, $P_t c_t$, physical capital investment, $P_t k_{t+1} - P_t (1 - \delta_k) k_t$, acquisition of money, $M_{t+1} - M_t$, and investment in nominal bonds, $B_{t+1} - B_t R_t$, where R_t is the gross nominal interest rate, the consumer's budget constraint is:

$$\begin{aligned} P_t w_t (l_{Gt} + l_{Ft}) h_t + P_t r_t s_{Gt} k_t + P_t R_{Ft} d_t + T_t &\geq P_{Ft} q_t + P_t c_t \\ + P_t k_{t+1} - P_t (1 - \delta_k) k_t + M_{t+1} - M_t + B_{t+1} - B_t R_t &. \end{aligned} \quad (3.7)$$

Money (M_t) and credit ($P_t q_t$ in nominal terms) are fungible for exchange purposes. The consumer's exchange technology (CIA constraint) is therefore:

$$M_t + T_t + P_t q_t \geq P_t c_t , \quad (3.8)$$

where the lump sum government transfer (T_t) arrives at the beginning of each period. Since all money ultimately emanates from deposits at the bank and since credit purchases are paid off at the end of each period out of these same deposits, total deposits must be equal to total consumption:

$$d_t = c_t . \quad (3.9)$$

The consumer maximises utility subject to the budget, exchange and deposit constraints (3.7)-(3.9), given k_0, h_0 and the evolution of M_t ($t \geq 0$), which shall be specified below.

3.2.2 The Banking Intermediary's Problem

The bank produces the credit service which is available to the consumer as an alternative to money for exchange purposes and determines the quantity to produce by maximising profit subject to the production technology. Credit is produced using a constant returns to scale technology with effective labour and deposits as inputs:

$$q_t = A_F e^{v_t} (l_{Ft} h_t)^\gamma d_t^{1-\gamma} , \quad (3.10)$$

where $A_F > 0$, $\gamma \in (0,1)$ and $A_F e^{v_t}$ is stochastic factor productivity. The bank maximises profit (Π_{Ft}):

$$\Pi_{Ft} = P_{Ft} q_t - P_t w_t l_{Ft} h_t - P_t R_{Ft} d_t , \quad (3.11)$$

by choosing labour (l_{Ft}) and deposits (d_t) subject to (3.10). The resulting first order conditions imply that in equilibrium:

$$w_t = \left(\frac{P_{Ft}}{P_t}\right) \gamma A_F e^{v_t} \left(\frac{l_{Ft} h_t}{d_t}\right)^{\gamma-1} ; \quad (3.12)$$

$$R_{Ft} = \left(\frac{P_{Ft}}{P_t}\right) (1 - \gamma) A_F e^{v_t} \left(\frac{l_{Ft} h_t}{d_t}\right)^{\gamma} . \quad (3.13)$$

Equation (3.12) implies that the marginal cost of credit, P_{Ft}/P_t , is equal to the marginal factor price divided by the marginal factor product, or:

$$\left(\frac{P_{Ft}}{P_t}\right) = \frac{w_t}{\gamma A_F e^{v_t} \left(\frac{l_{Ft} h_t}{d_t}\right)^{\gamma-1}} , \quad (3.14)$$

and equation (3.13) implies that the dividend paid on deposits is equal to a fraction of marginal cost:

$$R_{Ft} = \left(\frac{P_{Ft}}{P_t}\right) (1 - \gamma) \left(\frac{q_t}{d_t}\right) . \quad (3.15)$$

3.2.3 The Goods Producer's Problem

Goods output is produced using a standard Cobb-Douglas production in effective labour and capital:

$$y_t = A_G e^{z_t} (s_{Gt} k_t)^{1-\alpha} (l_{Gt} h_t)^{\alpha} , \quad (3.16)$$

where $A_G > 0$, $\alpha \in (0,1)$ and $A_G e^{z_t}$ is stochastic factor productivity. The firm maximises profit (Π_{Gt}):

$$\Pi_{Gt} = y_t - w_t l_{Gt} h_t - r_t s_{Gt} k_t , \quad (3.17)$$

by choosing labour (l_{Gt}) and capital (k_t) subject to (3.16). The resulting first order conditions imply the standard expressions:

$$w_t = \alpha A_G e^{z_t} \left(\frac{s_{Gt} k_t}{l_{Gt} h_t} \right)^{1-\alpha} ; \quad (3.18)$$

$$r_t = (1 - \alpha) A_G e^{z_t} \left(\frac{s_{Gt} k_t}{l_{Gt} h_t} \right)^{-\alpha} , \quad (3.19)$$

which equate marginal factor prices to marginal factor products for labour and capital inputs respectively.

3.2.4 Monetary Policy

It is assumed that government policy involves a sequence of nominal transfers given by:

$$T_t = \Theta_t M_t = (\Theta^* + e^{u_t} - 1) M_t , \quad (3.20)$$

where Θ_t is the growth rate of the money supply, $(M_t - M_{t-1}) / M_{t-1}$, and Θ^* is its stationary (gross) growth rate. This monetary policy regime can be interpreted as one in which the money supply growth rate is set so as to satisfy the government's fiscal objectives, which it implements using the lump-sum transfer T .

3.2.5 Definition of the Competitive Equilibrium

The representative agent's optimisation problem can be written recursively as:

$$V(s) = \max \{u(c, x) + \beta EV(s')\}, \quad (3.21)$$

through choice of $c, x, l_G, l_H, l_F, s_G, s_H, q, d, k', h', M'$, subject to the conditions (3.3) to (3.9), where the state of the economy is denoted by $s=(k, h, M, B; z, u, v)$ and primes (') denote next-period values. A competitive equilibrium consists of a set of policy functions $c(s), x(s), l_G(s), l_H(s), l_F(s), s_G(s), s_H(s), q(s), d(s), k'(s), h'(s), M'(s), B'(s)$, pricing functions $P(s), w(s), r(s), R_F(s), P_F(s)$ and a value function $V(s)$, such that:

- (i) The consumer maximises utility, given the pricing functions and the policy functions, so that $V(s)$ satisfies equation (3.21);
- (ii) The bank maximises profit according to (3.11) subject to technology (3.10), with the resulting equilibrium conditions for w and R_F given by equations (3.12) and (3.13) respectively;
- (iii) The goods producer similarly maximises profit according to (3.17) subject to technology (3.16), with the resulting equilibrium conditions for w and r given by equations (3.18) and (3.19) respectively;
- (iv) The goods, money and credit markets clear, in equations (3.7) and (3.16) and in equations (3.8), (3.20) and (3.10).

3.3 The General Equilibrium Taylor Condition

We now derive the 'Taylor Condition' as an equilibrium condition of the Benk et al. (2010) model described in the previous section. Beginning from the first-order conditions of the model, we obtain:

$$1 = \beta E_t \left\{ \frac{c_{t+1}^{-\theta} x_{t+1}^{\psi(1-\theta)}}{c_t^{-\theta} x_t^{\psi(1-\theta)}} \left(\frac{1 + \tilde{R}_t}{1 + \tilde{R}_{t+1}} \right) \frac{R_{t+1}}{\pi_{t+1}} \right\}, \quad (3.22)$$

where R and π are gross rates of nominal interest and inflation, respectively. The term \tilde{R}_t represents a ‘weighted average cost of exchange’ as follows:

$$\tilde{R}_t = \frac{m_t}{c_t}(R_t - 1) + \gamma \left(1 - \frac{m_t}{c_t}\right) (R_t - 1), \quad (3.23)$$

where a weight of m/c is attached to the opportunity cost of money and a weight $(1-m/c)$ is attached to the average cost of credit, $\gamma(R_t-1)$, where m_t/c_t is the consumption normalised demand for money expressed in real terms (i.e. the inverse of the consumption velocity of money). In effect, equation (3.22) augments a standard consumption Euler equation with (the growth rate of) the weighted average cost of exchange (3.23). If all goods purchases are conducted using money ($m_t/c_t=1$) then equation (3.22) would revert back to the familiar consumption Euler equation and would constitute an equilibrium condition of a standard, unit velocity CIA model without a money alternative (e.g. Schabert, 2003).

For any variable z_t , define $\hat{z}_t \equiv \ln z_t - \ln z$, where the absence of a time subscript denotes a *BGP* stationary value, and define $\hat{g}_{z,t+1} \equiv \ln z_{t+1} - \ln z_t$, which approximates the growth rate at time $t+1$ for sufficiently small Δz_{t+1} . Consider a log-linear approximation of (3.22) taken around the *BGP*:

$$0 = E_t \{ \theta \hat{g}_{c,t+1} - \psi(1 - \theta) \hat{g}_{x,t+1} + \hat{g}_{\tilde{R},t+1} - \hat{R}_{t+1} + \hat{\pi}_{t+1} \}. \quad (3.24)$$

Rearranging this expression in terms of \hat{R}_t gives the Taylor Condition written in terms of log-deviations from the *BGP* equilibrium:

$$\begin{aligned}\hat{R}_t = E_t \left\{ \Omega \hat{\pi}_{t+1} + \Omega \theta \hat{g}_{c,t+1} - \Omega \psi (1 - \theta) \hat{g}_{x,t+1} \right. \\ \left. + \frac{(1 - \gamma) \left(1 - \frac{m}{c}\right)}{R \left[1 - (1 - \gamma) \left(1 - \frac{m}{c}\right)\right]} \left[(R - 1) \left(\frac{m}{1 - \frac{m}{c}}\right) \hat{g}_{\frac{m}{c},t+1} - \hat{R}_{t+1} \right] \right\},\end{aligned}\tag{3.25}$$

where:

$$\Omega \equiv 1 + \frac{(1 - \gamma) \left(1 - \frac{m}{c}\right)}{R \left[1 - (1 - \gamma) \left(1 - \frac{m}{c}\right)\right]} \geq 1.$$

The Taylor Condition (3.25) can now be expressed in net rates (which we denote by over-barred terms) and absolute deviations from the *BGP* equilibrium, as summarised by the following proposition.

Proposition 1: *An equilibrium condition of the Benk et al. (2010) model takes the form of a ‘Taylor Rule’ which expresses deviations of the short-term nominal interest rate from a baseline path in proportion to deviations of variables from their ‘target values’:*

$$\begin{aligned}\bar{R}_t - \bar{R} = \Omega E_t (\bar{\pi}_{t+1} - \bar{\pi}) + \Omega \theta E_t (\bar{g}_{c,t+1} - \bar{g}) - \Omega \psi (1 - \theta) E_t \bar{g}_{x,t+1} \\ + \frac{(1 - \gamma) \left(1 - \frac{m}{c}\right)}{(1 + \bar{R}) \left[1 - (1 - \gamma) \left(1 - \frac{m}{c}\right)\right]} \left[\bar{R} \left(\frac{m}{1 - \frac{m}{c}}\right) E_t \bar{g}_{\frac{m}{c},t+1} - E_t (\bar{R}_{t+1} - \bar{R}) \right],\end{aligned}\tag{3.26}$$

where $\Omega \geq 1$ and where the ‘target values’ correspond to *BGP* equilibrium values.

Proof: *Since the BGP solution for normalised money demand is:*

$$0 \leq \frac{m}{c} = 1 - A_F \left[\frac{\gamma A_F \bar{R}}{w} \right]^{\frac{\gamma}{1-\gamma}} \leq 1,$$

then:

$$\Omega \equiv 1 + \frac{(1 - \gamma)(1 - \frac{m}{c})}{(1 + \bar{R})[1 - (1 - \gamma)(1 - \frac{m}{c})]} \geq 1,$$

and given $w, \frac{\partial \Omega}{\partial R} \geq 0$ and $\frac{\partial \Omega}{\partial A_F} \geq 0$. ■

The term $\bar{\pi}$ in (3.26) is comparable to the inflation target term that features in many interest rate rules (e.g. Taylor, 1993; Clarida et al., 2000). This is usually set as an exogenous constant for a conventional rule but represents the *BGP* rate of inflation in the Taylor Condition.⁴ The term in consumption growth is similar, but not identical to, the first difference of the output gap that features in the so-called ‘speed limit’ rule proposed by Walsh (2003b).⁵ Alternatively, the term in the growth rate of leisure time can be compared to the unemployment rate, which sometimes features in conventional interest rate rules in place of the output gap.⁶ However, equation (3.26) also contains two terms which are not usually found in standard monetary policy reaction functions. Firstly, there is a term in the growth rate of the real (consumption normalised) demand for money whereas interest rate rules are typically considered as part of a broader framework which omits monetary relationships and thus money demand does not enter the model directly.⁷ Secondly, the Taylor Condition contains a term in the expected future nominal interest rate. This stands in contrast to the lagged nominal interest rate terms which are often used to capture ‘interest rate smoothing’ in conventional rules (e.g. Clarida et al., 2000).

Proposition 1 shows that in general the coefficient on inflation in (3.26) exceeds unity ($\Omega > 1$). This replicates the ‘Taylor principle’ whereby the nominal interest

⁴ Although see Ireland (2007) for an example of a conventional interest rate rule with a time-varying inflation target.

⁵ Also see Taylor and Wieland (2010).

⁶ For example, Mankiw (2001) includes the unemployment rate and Clarida et al. (2000, Table III) and Rudebusch (2009) include an ‘unemployment gap’.

⁷ Specifically, shifts in the demand for money are perfectly accommodated by adjustments to the money supply in order to maintain the rule-implied nominal interest rate. This, it is sometimes claimed, renders the evolution of the money supply an operational detail which need not be modelled directly (e.g. Woodford, 2003, 2008, for the NK model).

rate responds more than one-for-one to (expected future) inflation deviations from target. However, the inflation coefficient in the Taylor Condition does not reflect policymakers' preferences; rather, it is a function of the *BGP* nominal interest rate (R), the consumption normalised demand for real money balances (m/c) and the efficiency with which the banking sector transforms units of deposits into units of the credit service, as reflected by the magnitude of $(1-\gamma)$. Furthermore, higher productivity in the banking sector (A_F) causes a higher velocity of money and implies a larger inflation coefficient in (3.26). The magnitude of Ω clearly does not reflect a response to inflation in the conventional 'reaction function' sense.⁸

Equation (3.26) can alternatively be rewritten in terms of the consumption velocity of money, $V_t \equiv c_t/m_t$, and the productive time, or 'employment', growth rate ($l \equiv l_G + l_H + l_F = 1 - x$). Using the fact that $\hat{x}_t = -\frac{1-x}{x} \hat{l}_t$:

$$\begin{aligned} \bar{R}_t - \bar{R} &= \Omega E_t(\bar{\pi}_{t+1} - \bar{\pi}) + \Omega \theta E_t(\bar{g}_{c,t+1} - \bar{g}) + \Omega \psi(1 - \theta) \frac{l}{1-l} E_t \bar{g}_{l,t+1} \\ &- \Omega_V E_t \bar{g}_{V,t+1} - (\Omega - 1) E_t(\bar{R}_{t+1} - \bar{R}), \end{aligned} \tag{3.27}$$

where over-barred terms again denote net rates and:

$$\Omega_V \equiv \frac{\bar{R}}{1 + \bar{R}} \left[\frac{(1 - \gamma) \frac{m}{c}}{1 - (1 - \gamma)(1 - \frac{m}{c})} \right].$$

Proposition 2: *For the Taylor Condition (3.27), it is always the case that $0 \leq \Omega_V \leq 1 \leq \Omega$.*

⁸ Unlike Sørensen and Whitta-Jacobsen's (2005, pp.502-505) quantity-theory-based equilibrium condition, the inflation coefficient in (3.26) exceeds unity for any (admissible) interest elasticity of money demand. In their expression, the inflation coefficient falls below unity if the interest (semi) elasticity of money demand exceeds one in absolute value. In the Benk et al. (2010) model, the coefficient on inflation would exceed unity even in this case but the central bank would not wish to increase the money supply growth rate to this extent because seigniorage revenues would begin to recede as the interest elasticity of money increases beyond this point.

Proof:

$$\Omega \equiv 1 + \frac{(1 - \gamma)(1 - \frac{m}{c})}{(1 + \bar{R})[1 - (1 - \gamma)(1 - \frac{m}{c})]} \geq 1;$$

$$\frac{m}{c} = 1 - A_F^{\frac{1}{1-\gamma}} \left[\frac{\gamma \bar{R}}{w} \right]^{\frac{\gamma}{1-\gamma}} \leq 1;$$

$$1 \geq (1 - \gamma) \left(1 - \frac{m}{c} \right) \geq 0;$$

$$0 \leq \Omega_V \equiv \frac{\bar{R}}{1 + \bar{R}} \left[\frac{(1 - \gamma) \frac{m}{c}}{1 - (1 - \gamma)(1 - \frac{m}{c})} \right] \leq 1;$$

$$0 \leq \Omega_V \leq 1 \leq \Omega. \blacksquare$$

At the Friedman (1969) optimum (gross) nominal interest rate ($R=1$) there is no incentive to avoid the inflation tax and so $m/c=1$, which from the parameter definitions above implies that $\Omega=1$ and $\Omega_V=0$, so that the forward interest rate and velocity growth terms drop out of (3.27). However, for m/c below one (i.e. velocity above one), which would be the general case, the model's equivalent of the 'Taylor principle' ($\Omega>1$) holds.

Corollary 3: *Given w , then $\frac{\partial \Omega}{\partial R} \geq 0$, $\frac{\partial \Omega_V}{\partial R} \geq 0$, $\frac{\partial \Omega}{\partial A_F} \geq 0$, $\frac{\partial \Omega_V}{\partial A_F} \leq 0$.*

Proof: *This comes directly from the parameter definitions above. ■*

A higher target nominal interest rate can be accomplished by a higher *BGP* money supply growth rate. This would in turn make the inflation and consumption growth coefficients larger and the forward interest rate and velocity coefficients more negative. A higher credit productivity factor A_F , and so a higher velocity, leads to a higher inflation coefficient and a more negative response to the

forward-looking interest term but a less negative coefficient on the velocity growth term.

The Taylor Condition above would look identical under exogenous growth. However, for exogenous growth the ‘target’ inflation rate and *BGP* growth rate of the economy would be independent of each other. Under endogenous growth, on the other hand, the targets are instead the endogenously-determined *BGP* values for inflation, the output growth rate and the nominal interest rate and each of these are determined, in part, by the long-run (*BGP*) money supply growth rate Θ^* . In turn, Θ^* translates into a long-run ‘inflation target’ and appears in the Taylor Condition in a similar manner to the inflation targets often incorporated into conventional interest rate rules (for example, Taylor, 1993).

3.3.1 Misspecified Taylor Condition with Output Growth

It is not surprising to find that the consumption growth rate appears in (3.27) rather than the output growth rate given that the derivation of the Taylor Condition begins with the (augmented) consumption Euler equation (3.22). However, the Taylor Condition can be rewritten to include an output growth term and hence correspond more closely to standard Taylor rule specifications, in particular the ‘speed limit’ rule proposed by Walsh (2003b). To derive this alternative rule, consider that the identity $y_t = c_t + i_t$ implies that $\hat{y}_t = \frac{c}{y}\hat{c}_t + \frac{i}{y}\hat{i}_t$, where $\hat{i}_t = \frac{k}{i}[\hat{k}_t - (1 - \delta)\hat{k}_{t-1}]$. The growth rate of investment can be interpreted as the growth of the capital stock gross of depreciation and the Taylor Condition can be legitimately rewritten as:

$$\begin{aligned} \bar{R}_t - \bar{R} = & \Omega E_t(\bar{\pi}_{t+1} - \bar{\pi}) + \Omega\theta \left[\frac{y}{c} E_t(\bar{g}_{y,t+1} - \bar{g}) - \frac{i}{c} E_t(\bar{g}_{i,t+1} - \bar{g}) \right] \\ & + \Omega\psi(1 - \theta) \frac{l}{1-l} E_t \bar{g}_{l,t+1} - \Omega_V E_t \bar{g}_{V,t+1} - (\Omega - 1) E_t(\bar{R}_{t+1} - \bar{R}). \end{aligned} \quad (3.28)$$

A term in investment growth does not appear in standard Taylor rules but plays a role as part of what might be interpreted as the growth rate of the ‘output gap’ in (3.28). This alternative expression for the Taylor Condition forms the basis for the

two misspecified estimating equations considered in Section 3.5. The first simply replaces the consumption growth term in equation (3.27) with an output growth term as follows:

$$\begin{aligned}\bar{R}_t - \bar{R} &= \Omega E_t(\bar{\pi}_{t+1} - \bar{\pi}) + \Omega \theta E_t(\bar{g}_{y,t+1} - \bar{g}) \\ &+ \Omega \psi(1 - \theta) \frac{l}{1-l} E_t \bar{g}_{l,t+1} - \Omega_V E_t \bar{g}_{V,t+1} - (\Omega - 1) E_t(\bar{R}_{t+1} - \bar{R}).\end{aligned}\tag{3.29}$$

Comparing equation (3.29) to equation (3.28) shows that the former erroneously overlooks the weighting on the output growth rate (y/c) and omits the term in the investment growth rate. Replacing consumption growth with output growth without the additional term in investment therefore misrepresents the structure of the underlying Benk et al. (2010) model and as such equation (3.29) is misspecified. Note that with no physical capital in the model, equation (3.29) would be a valid equilibrium condition (i.e. the national income identity would be $y=c$, as per the simple ‘three equation’ NK model).

3.3.2 Misspecified as a ‘Taylor Rule’

The second misspecified form imposes the same erroneous restrictions used to arrive at equation (3.29) but also spuriously omits the terms in productive time and velocity:

$$\bar{R}_t - \bar{R} = \Omega E_t(\bar{\pi}_{t+1} - \bar{\pi}) + \Omega \theta [E_t(\bar{g}_{y,t+1} - \bar{g})] - (\Omega - 1) E_t(\bar{R}_{t+1} - \bar{R}).\tag{3.30}$$

This can be interpreted as a conventional forward-looking interest rate rule with a forward-looking nominal interest rate term rather than the lagged dependent variable term often used to capture ‘interest rate smoothing’. The additional restriction that $\Omega=1$ would replicate a standard interest rate rule without interest rate smoothing. Once again, equation (3.30) does not accurately represent an equilibrium condition of the Benk et al. (2010) model and is therefore misspecified. Equation (3.30) with $\Omega=1$ would be the appropriate equilibrium

condition if the underlying model featured neither physical capital nor exchange credit and would then resemble a standard Euler equation with $y=c$ (e.g. Schabert, 2003).

3.4 Calibration, Target Values and Implied Theoretical Predictions

We follow Benk et al. (2010) in using post-war U.S. data to calibrate the model (Table 3.1) and calculate a series of ‘target values’ consistent with this calibration (Table 3.2):

[Table 3.1 here]

[Table 3.2 here]

Subject to this calibration, we derive a set of theoretical ‘predictions’ for the coefficients of the Taylor Condition (3.27). We shall subsequently compare these predictions to the estimated coefficients obtained from model-simulated data. Consider first the inflation coefficient (Ω). According to the calibration and target values presented in Tables 3.1 and Table 3.2 respectively, its predicted value is:

$$\Omega = 1 + \frac{(1 - 0.11)(1 - 0.38)}{1.0944[1 - (1 - 0.11)(1 - 0.38)]} = 2.125 ,$$

and for $R=1$, only money is used to support transactions so that $m/c=1$ and Ω reverts to its minimum value of 1. This would also be the case with zero credit productivity ($A_F=0$), in which case the credit sector is effectively ‘shut off’ and m/c is bound to equal one.

Except for the velocity growth coefficient, the remaining coefficients are simple functions of the inflation coefficient. The consumption growth coefficient is $\Omega\theta$, which with $\theta=1$ for log-utility should simply take the same magnitude as the coefficient on inflation ($\theta\Omega=2.125$). Even though the leisure preference parameter is calibrated to be 1.84 and ‘target’ productive time ($1-x\equiv l$) is taken to be 0.45, the coefficient on the growth rate of productive time would be 0 because $\theta=1$.

Given the magnitude of the inflation coefficient, the predicted value of the coefficient on the forward interest term is simply $-(\Omega-1)=-1.125$ and the predicted value for the velocity coefficient is -0.065 . At the Friedman (1969) optimum ($R=1$) we would obtain $\Omega_V=0$, as discussed above. In this case the omission of the term in velocity growth when evaluating the Taylor Condition empirically would be innocuous but this is not true in general.

3.5 Analysis of Model-Simulated Data

The Benk et al. (2010) model presented in Section 3.2 is simulated using the calibration provided in Table 3.1 in order to generate 1000 alternative ‘joint histories’ for each of the variables in (3.27), where each history is 100 periods in length. To do so, 100 random sequences for the shock vector innovations are generated and control functions of the log-linearized model are used to compute sequences for each variable. Each time period within a given history may be thought of as an annual period given the frequency of the Benk et al. (2010) model and the associated calibration and target values. The dataset used to estimate the coefficients of the Taylor Condition can therefore be interpreted to comprise of 1000, 100 ‘year’, samples of artificial data.

3.5.1 Methodology

This section presents the results of estimating a ‘correctly specified’ estimating equation based upon the true theoretical relationship (3.27) against artificial data generated from the Benk et al. (2010) model.⁹ In a similar manner, two alternative estimating equations are evaluated using the same dataset. Since these alternative estimating equations differ from the expression based upon the true theoretical relationship, they necessarily constitute misspecified empirical models.

⁹ The exercise conducted here is similar to that of Fève and Auray (2002), for a standard CIA model, and Salyer and Van Gaasbeck (2007), for a ‘limited participation’ model. We acknowledge that using a full information maximum likelihood estimation that uses all of the equilibrium conditions of the model, it should be possible to estimate the theoretical coefficients of the Taylor Condition almost exactly. But the purpose of the exercise is to employ the simpler econometric procedures that have often been applied in the interest rate rule literature.

Prior to estimation, the simulated data is passed through one of three statistical filters in order to reflect the deviation-from-*BGP* form of (3.27): either 1) a Hodrick-Prescott (HP) filter with a smoothing parameter selected in accordance with Ravn and Uhlig (2002); 2) a 3-8 period ('year') Christiano and Fitzgerald (2003) band pass filter for 'business cycle frequencies'; or 3) a 2-15 year Christiano and Fitzgerald (2003) band pass filter which retains more of the lower frequency trends in the data than the 3-8 year filter. Of these, the 2-15 band pass filter might be regarded as the most relevant to the underlying theoretical model because shocks in the Benk et al. model can cause lower frequency fluctuations over the business cycle.¹⁰ Nevertheless, all three filters extract 'high frequency' fluctuations from the data relative to the filters considered by Comin and Gertler (2006), say. It is at these frequencies that we would expect the Taylor Condition to mimic the Taylor Principle.

We first consider a simple Ordinary Least Squares (OLS) procedure, as used by Taylor (1999) in the context of a contemporaneous interest rate rule. However, if expected future variables are correlated with the error term then a suitable set of instruments must be used to proxy for the forward-looking terms on the right hand side of the estimating equation.¹¹ Two instrumental variables (IV) techniques are considered and each differs by the instrument set employed. The first is a Two Stage Least Squares (2SLS) estimator under which the first lag of inflation, consumption growth, productive time growth and velocity growth and the second lag of the nominal interest rate are used as instruments. Adding a constant term to the instrument set provides an 'exactly identified' 2SLS estimator. By using lagged variables as instruments, we exploit the fact that such terms are pre-determined and thus not susceptible to the simultaneity problem which motivates the use of IV techniques to begin with. The 2SLS procedure applies a Newey-West adjustment for heteroskedasticity and autocorrelation

¹⁰ Standard ADF and KPSS tests suggest that the simulated data is stationary prior to filtering (full test results presented in Chapter-IV). Accordingly, the filters do not implement a de-trending procedure.

¹¹ Empirical studies usually deal with expected future terms either by replacing them with realised future values and appealing to rational expectations for the resulting conditional forecast errors (e.g. Clarida et al., 1998, 2000) or by using private sector or central bank forecasts as empirical proxies (e.g. Orphanides, 2001; Siklos and Wohar, 2005).

(HAC) to the coefficient covariance matrix. The second IV procedure is a generalised method of moments (GMM) estimator (Hansen, 1982).¹² Three additional lags of inflation, consumption growth, productive time growth and velocity growth and two further lags of the nominal interest rate are added to the instrument set.¹³ Expanding the instrument set in this manner comes at the cost of reducing the sample size available for each of the 1000 simulated histories but means that over-identifying restrictions can now be used to test the validity of the instrument set via the Hansen J-test. The GMM estimator employed iterates on the weighting matrix in two steps and applies a HAC adjustment to the weighting matrix using a Bartlett kernel with a Newey-West fixed bandwidth.¹⁴ A similar HAC adjustment is also applied to the covariance weighting matrix.

The results are presented according to the statistical filter applied. Alongside estimates derived from an ‘unrestricted’ estimating equation, each table also reports estimates from a ‘restricted’ form which omits the forward interest rate term ($\beta_5=0$). This arbitrary restriction helps to demonstrate the importance of the dynamic term to equation (3.27). Each table of results reports mean coefficient estimates obtained from the 1000 simulated samples along with the standard error of these estimates (as opposed to the mean standard error). The figures in square brackets report the number of coefficients estimated to be statistically different from zero at the 5% level of significance; this count is used as an indication of the precision with which the coefficients are estimated. An “adjusted mean” figure is also reported for each coefficient; this is obtained by setting non-statistically-significant coefficient estimates to zero when calculating the mean

¹² The GMM procedure is based upon Clarida et al. (1998, 2000) for a forward-looking interest rate rule and is described in full in Chapter-IV.

¹³ Carare and Tchaidze (2005, p.15) note that the four-lags-as-instruments approach is standard in the interest rate rule literature (e.g. Orphanides, 2001). These instruments will be ‘relevant’ if the simulated series are persistent but this does not necessarily mean that lagged terms need to be added to the estimating equation itself. On the other hand, Clarida et al. (2000, p.153) use a GMM estimator “with an optimal weighting matrix that accounts for possible serial correlation in [the error term]” for actual data but they also add two lags of the dependent variable to their estimating equation on the basis that this “seemed to be sufficient to eliminate any serial correlation in the error term.” (p.157), suggesting that the GMM correction was not sufficient for this purpose.

¹⁴ Jondeau et al. (2004, p.227) state that: “To our knowledge, all estimations of the forward-looking reaction function based on GMM have so far relied on the two-step estimator.” They proceed to consider more sophisticated GMM estimators but nevertheless identify advantages to the “simple approach” (p.238) adopted in the literature.

estimate. The tables also report mean R-squared and mean adjusted R-squared statistics along with the mean P-value for the F-statistic for overall significance (these cannot be computed for the GMM estimator), the mean P-value for the Hansen J-statistic which tests the validity of the instrument set (these can only be calculated for the GMM estimator) and the mean Durbin-Watson (D-W) statistic which tests for autocorrelation in the residual series generated from the estimation procedure. The number of occasions upon which the null hypothesis of the J-statistic is *not* rejected – i.e. the instrument set is not found to be invalid – is reported alongside its mean P-value and the number of simulated series for which the D-W statistic exceeds its upper critical value – i.e. the null hypothesis that the residuals are serially uncorrelated *cannot* be rejected – is reported alongside the mean D-W statistic.¹⁵ These counts are therefore presented in a ‘the higher the better’ form.

3.5.2 General Taylor Condition

The left hand side of Tables 3.3-3.5 present estimates obtained from using the estimation procedures described above to evaluate the following ‘correctly specified’ estimating equation:

$$\bar{R}_t = \beta_0 + \beta_1 E_t \bar{\pi}_{t+1} + \beta_2 E_t \bar{g}_{c,t+1} + \beta_3 E_t \bar{g}_{l,t+1} + \beta_4 E_t \bar{g}_{v,t+1} + \beta_5 E_t \bar{R}_{t+1} + \varepsilon_t , \quad (3.31)$$

against HP, 3-8 band pass and 2-15 band pass filtered data respectively. Expected future values are obtained from the model simulation procedure and are used directly under the OLS estimator or are instrumented for under the IV techniques, as described above.

[Table 3.3 here]

[Table 3.4 here]

¹⁵ The D-W count excludes cases for which the test statistic falls in the inconclusive region of the test’s critical values.

[Table 3.5 here]

The key result in Tables 3.3-3.5 is that the mean inflation coefficient consistently exceeds unity for the estimating equation (3.31) which accurately reflects the underlying theoretical relationship (3.27); furthermore, the magnitude of these estimates is broadly consistent with the theoretical prediction derived in Section 3.4 ($\Omega=2.125$), subject to the caveat that the coefficients are estimated precisely. This result is found to be robust to both the statistical filter applied to the data and to the econometric procedure employed to generate the estimates. Generally speaking, the OLS and GMM estimators produce a greater number of statistically significant coefficient estimates than the 2SLS estimator. In Table 3.5 for the 2-15 filter, for example, the 2SLS estimator provides a statistically significant estimate for the inflation coefficient for only 580 of the 1000 simulated samples whereas the OLS and GMM estimators both return 1000 statistically significant estimates. The OLS and GMM procedures generate reasonably large R-squared and adjusted R-squared statistics (greater than 0.77 in all cases), whereas negative R-squared statistics are repeatedly obtained for the 2SLS estimator. The OLS estimator also rejects the null hypothesis of the F-statistic more frequently than the 2SLS estimator (1000 vs. 907 rejections in Table 3.5, for example). However, one might be wary of the low number of D-W null hypothesis non-rejections produced by the OLS estimator. The results for the 3-8 band pass filter (Table 3.4) are unusual in the sense that all three estimation procedures produce a high number of D-W test rejections; for the other two filters this undesirable result is confined to the OLS estimator. On the whole, one might therefore be inclined to favour the GMM estimates out of the three alternatives. Furthermore, the instrument set used for the GMM estimator shows no signs of being invalid since 1000 non-rejections of the null hypothesis of the J-statistic for instrument validity are obtained across all three filters. Under the GMM procedure, the mean inflation coefficients are estimated to be 2.299, 2.423 and 2.306 in Tables 3.3, 3.4 and 3.5 respectively; these estimates compare favourably to the predicted value of 2.125.

The forward interest rate term is found to be an important element of the estimating equation (3.31) in terms of generating an inflation coefficient which is

consistent with the underlying Benk et al. (2010) model. The right hand side of Tables 3.3, 3.4 and 3.5 show that the mean estimate of the inflation coefficient falls below unity for the OLS and GMM estimators under the $\beta_5=0$ restriction. Precise mean estimates of 0.614 and 0.963 (adjusted mean for 999 statistically significant coefficients) are obtained from the OLS and GMM procedures under the 2-15 filter, for example. Similar estimates are obtained for the inflation coefficient under the two alternative filters in Tables 3.3 and 3.4, both in terms of the mean coefficient estimates for the unrestricted specification and in terms of the decline in magnitude induced by the arbitrary restriction, although the GMM estimate for the inflation coefficient tends to be smaller under the HP and 3-8 band pass filters at 0.614 (adjusted mean for 925 statistically significant estimates) and 0.679 (for 974 estimates).

In contrast to the inflation coefficients, the estimated coefficients for consumption growth and productive time growth diverge from their theoretical predictions for the unrestricted estimating equation (3.31). Under log utility ($\theta=1$), the former should take the same magnitude as the coefficient on inflation and the latter should take a value of zero. The coefficient estimates obtained can be used to 'back-out' an estimate of the coefficient of relative risk aversion (θ). Firstly, using the mean GMM estimate for the coefficient on consumption growth of 0.302 (Table 3.5) and the corresponding estimate of 2.306 for Ω , an implied estimate of θ can be calculated as $\beta_2/\beta_1=0.131$, which is substantially smaller than the baseline calibration of $\theta=1$. Alternatively, the relationship $\beta_3=\beta_1\psi(1-\theta)l/(1-l)$, which is obtained from equation (3.27) with Ω replaced by its estimate β_1 , can also be used to obtain an implied estimate of θ . Using the estimates presented in Table 3.5, the implied estimate would be $\theta=1.103$, which is much more in keeping with the calibrated value. Table 3.5 also reports that both the OLS and GMM procedures generate 1000 statistically significant estimates for the coefficient on velocity growth under the unrestricted estimating equation and that the mean estimate is correctly signed for both estimators. The mean coefficient estimates are reported as -0.196 and -0.269 for OLS and GMM estimators respectively; these estimates are somewhat smaller than the theoretical prediction of -0.065. Similar mean coefficient estimates are obtained from the HP and 3-8 filters. Finally, Table

3.5 reports mean estimates of -1.761 and -1.729 (OLS and GMM respectively) for the forward interest rate coefficient compared to a theoretical prediction of -1.125. The mean estimates are therefore correctly signed but, again, somewhat smaller than the theoretical prediction.

For a standard interest rate rule, the magnitude of the coefficient on inflation is deemed to reflect the strength of monetary policymakers' dislike of inflation deviations from target and a magnitude above one, in particular, is deemed to satisfy the Taylor principle. However, this interpretation is not applicable to the Taylor Condition. The result that the estimated coefficient on inflation exceeds unity in (3.31) is a consequence of a money growth rule, not an interest rate rule. Similarly, the break-down of the Taylor principle under the 'restricted' estimating equation ($\beta_5=0$) cannot be interpreted as a softening of policymakers' attitude towards inflation; this result simply emanates from model misspecification.

Unlike the estimates obtained from filtered data, each of the three econometric procedures described above generates an estimated inflation coefficient which falls below unity when equation (3.31) is evaluated against the simulated data in unfiltered form. Specifically, the OLS procedure generates a mean coefficient estimate of 0.837 (1000 statistically significant coefficient estimates), the 2SLS procedure generates a mean coefficient estimate of 0.101 (adjusted mean for 107 statistically significant coefficient estimates) and the GMM procedure produces a mean coefficient estimate of 0.478 (adjusted mean for 804 statistically significant coefficient estimates).¹⁶ Under the restriction on the forward interest rate term considered previously ($\beta_5=0$), all three procedures generate a mean inflation coefficient of less than one in a manner consistent with a conventional interest rate rule which violates the Taylor principle (OLS: 0.702 for 1000 statistically significant coefficient estimates; 2SLS: 0.729, adjusted mean for 905 statistically significant coefficient estimates; GMM: 0.782 for 1000 statistically significant coefficient estimates). Again, this Taylor principle interpretation does not apply in the present context. One cannot draw inferences about the conduct of monetary policy from these estimates because they are generated simply as a product of a

¹⁶ Full results are reported in an appendix table (Table 3.8).

misspecified estimating equation. Monetary policy continues to be characterised by the money growth rule described in Section 3.2.4.

We interpret the low estimated inflation coefficients obtained from unfiltered data as a reflection of the fact that all frequency components of the simulated data are considered jointly if a filter is not applied. On the other hand, the ‘high frequency filters’ used in this chapter isolate the ‘short-run relationship’ between the nominal interest rate and inflation, a relationship which is typically interpreted as an ‘interest rate rule’ when recovered from actual time series data. In Chapter-IV we adjust the calibration of the band pass filter in order to retain lower frequency trends in the simulated data. To preview the results obtained there, these extended frequency ranges allow us to identify a long-run Fisher relation in the simulated data. However, as Table 4.7 of Chapter-IV will show, if the frequency range considered is extended beyond a certain point (approximately 50 periods or ‘years’) then the mean estimated inflation coefficient falls below one, as is the case when the simulated data is evaluated in unfiltered form. As one would expect, the effect of the filters used in this chapter is to isolate the high frequency relationship between the nominal interest rate and inflation and the nominal interest rate and the other terms which feature in the Taylor Condition (3.27).

3.5.3 Taylor Condition with Output Growth

The same procedure is now applied to an estimating equation which replaces the consumption growth term in (3.31) with output growth as follows:

$$\bar{R}_t = \beta_0 + \beta_1 E_t \bar{\pi}_{t+1} + \beta_2 E_t \bar{g}_{y,t+1} + \beta_3 E_t \bar{g}_{l,t+1} + \beta_4 E_t \bar{g}_{v,t+1} + \beta_5 E_t \bar{R}_{t+1} + \varepsilon_t . \quad (3.32)$$

However, the simulated data remains unchanged, hence (3.31) continues to be the correct estimating equation, meaning that (3.32) constitutes a misspecified empirical model. In particular, equation (3.32) can be seen to correspond to the misspecified theoretical expression (3.29).

The results obtained from estimating equation (3.32) are broadly similar across the HP, the 3-8 band pass and the 2-15 band pass filters and since the latter generally yields the greatest number of statistically significant coefficient estimates only estimates derived from the 2-15 filter are presented (as Table 3.6).¹⁷ Comparing the general features of the results to those presented in Tables 3.3-3.5, there has been a decline in the precision with which the coefficients are estimated, a decline in the magnitude of the R-squared and adjusted R-squared statistics and a decline in the number of rejections of the null hypothesis of the F-statistic for joint significance for both the OLS and 2SLS estimators. This is perhaps not surprising given that an element of misspecification has now been introduced into the estimating equation.

[Table 3.6 here]

The estimated inflation coefficients are found to increase relative to those obtained from the 'correctly specified' estimating equation (3.31). For instance, the GMM estimate for the unrestricted estimating equation rises from 2.306 in Table 3.5 to 5.235 in Table 3.6 (adjusted mean for 961 statistically significant estimates). Similarly, the corresponding OLS estimate increases from 2.179 to 4.185 (adjusted mean for 971 estimates).¹⁸ The estimates clearly diverge from the theoretical prediction of $\Omega=2.125$ under this particular form of misspecification. The misspecified estimating equation (3.32) also induces a substantial decrease in the estimated coefficients for the productive time growth rate and the forward nominal interest rate. The estimated coefficient on the productive time growth rate decreases from -0.294 to -2.073 (both adjusted means) between Tables 3.5 and 3.6 according to the OLS estimator and from -0.359 to -2.790 according to the GMM estimator; the estimates therefore diverge further from their predicted value of $\beta_3=0$. The OLS estimates of the forward interest rate term also decrease from -1.761 in Table 3.5 to -3.767 in Table 3.6 (adjusted means where

¹⁷ The instrument sets used for the 2SLS and GMM estimators are modified by replacing consumption growth with output growth but remains unchanged in terms of the number of lags included.

¹⁸ Similar upward shifts in the estimated inflation coefficient are found for the 3-8 band pass filter (results not reported in full) and even larger increases are found for HP filtered data (results not reported in full).

appropriate) and the corresponding GMM estimate falls from -1.729 to -4.372. Again, the estimates diverge further from the theoretical prediction of $\beta_5 = -1.125$ under both estimators. On the other hand, the estimated coefficients for output growth in Table 3.6 are similar to those for consumption growth presented in Table 3.5, despite the impact that the misspecification has on the other estimates. For example, the OLS estimate for β_2 is 0.300 (adjusted mean for 967 estimates) in Table 3.6 compared to the corresponding estimate of 0.277 in Table 3.5. For the GMM estimator the coefficient on output growth is 0.402 (adjusted mean for 940 estimates) in Table 3.6 compared to the corresponding estimate of 0.302 reported in Table 3.5. The velocity growth term is estimated precisely by the GMM estimator even after the modification to the estimating equation. Estimates of β_4 retain the correct sign and are of a similar magnitude as under the correctly specified estimating equation; for example, a GMM estimate of -0.190 (adjusted mean for 970 estimates) in Table 3.6 compared to a corresponding estimate of -0.269 in Table 3.5.

For the restricted ($\beta_5 = 0$) counterpart to (3.32), the estimates undergo similar changes as observed for the 'correct' estimating equation (3.31) with $\beta_5 = 0$. The OLS estimator, for example, generates a mean inflation coefficient which falls below unity in a manner incompatible with the theoretical model from which the Taylor Condition is derived.

In short, estimates obtained from applying equation (3.32) to the simulated data show that adapting the correct estimating equation (3.31) in a seemingly minor way can have a substantial impact upon the coefficient estimates obtained. The results produced by this misspecified estimating equation provide an illustration of the fundamental difference between the Taylor Condition and a conventional interest rate rule. Unlike a Taylor rule, the Taylor Condition cannot be modified in an *ad hoc* manner.¹⁹ In order to make the progression from (3.31) to (3.32) in a legitimate manner, one would need to alter the underlying model by excluding

¹⁹ Conventional interest rate rules are exogenously specified and thus amenable to arbitrary modifications. Clarida et al. (1998), for example, add the exchange rate to the standard Taylor rule and Cecchetti et al. (2000) and Bernanke and Gertler (2001) consider whether policymakers should react to asset prices in addition to inflation.

physical capital so that $y=c$, for example. A new set of artificial data would then need to be simulated from this alternative model prior to re-running the estimation procedure.

3.5.4 A ‘Taylor Rule’

We now apply the three estimation procedures to the following estimating equation:

$$\bar{R}_t = \beta_0 + \beta_1 E_t \bar{\pi}_{t+1} + \beta_2 E_t \bar{g}_{y,t+1} + \beta_5 E_t \bar{R}_{t+1} + \varepsilon_t, \quad (3.33)$$

which corresponds to the misspecified representation of the Taylor Condition with output growth instead of consumption growth, plus further restrictions on the terms in productive time and the velocity of money; see equation (3.30). Equation (3.33) can be interpreted as a ‘dynamic forward-looking Taylor rule’ for $\beta_5 \neq 0$ or a ‘static forward-looking Taylor rule’ under the restriction $\beta_5 = 0$. Notably, the term in velocity growth is absent from this expression. This omission might be expected to have a significant bearing on the estimates because the correctly specified estimating equation (3.31), and even the misspecified form (3.32), consistently generated a large number of statistically significant estimates for the velocity growth coefficient, at least using the OLS and GMM estimators.

The results obtained from (3.33) are again similar across the HP and band pass filters and so only the 2-15 band pass results are presented here (as Table 3.7).²⁰ The quality of the results is generally found to deteriorate in terms of the number of statistically significant estimates produced and in terms of the magnitude of the mean R-squared and adjusted R-squared statistics. Notably, the mean coefficient on inflation does not exceed unity for any of the three estimators considered. The results are also comparatively poor in terms of the frequency with which the null hypothesis of the F-statistic is rejected for the OLS and 2SLS estimators and in

²⁰ The instrument set now comprises of four lags of expected future inflation, four lags of expected future output growth, the second, third and fourth lags of the nominal interest rate and a constant term for the GMM estimator or just the shortest lag of each of these and a constant term for the exactly identified 2SLS estimator.

terms of the number of non-rejections of the null hypothesis of the Hansen J-test for the GMM estimator. The latter finding calls into question the validity of the instrument set used for the GMM estimator for the first time. However, the inflation coefficients are estimated surprisingly precisely for the non-dynamic rule (3.33 with $\beta_5=0$) but these estimates differ quite substantially between the different estimating procedures. The mean estimate is 0.317 (adjusted mean for 926 statistically significant estimates) for the OLS estimator compared to 0.892 for the GMM estimator (adjusted mean for 981 estimates), although both fail to satisfy the Taylor principle so both estimates would be inadmissible in the Benk et al. (2010) model from which the simulated data was generated.

[Table 3.7 here]

In short, imposing a 'conventional Taylor rule' on the simulated data restricts the true estimating equation to such an extent that the theoretical prediction that the coefficient on expected inflation exceeds unity cannot be verified. An estimated inflation coefficient of this magnitude might erroneously be interpreted to signify that the Taylor principle is violated but this result is simply the product of a misspecified estimating equation in the present context. Only if the model excluded physical capital and if velocity was set to one, by excluding exchange credit for example, would such an estimating equation be appropriate but as it stands, the estimates reported in Table 3.7 cannot be used to conclude that the conduct of monetary policy has changed for the worse. Monetary policy continues to operate in the manner described in Section 3.2.4.

3.6 Alternative Forms for the Taylor Condition

We now briefly consider two alternative representations of the Taylor Condition – a backward-looking form and an alternative which features the quantity of credit.

3.6.1 A Contemporaneous Taylor Condition

Firstly, the Taylor Condition can be reformulated to feature a lagged dependent variable on the right hand side instead of the lead dependent variable which

appears in equation (3.27). This yields a similar expression written in terms of R_{t+1} instead of R_t :

$$\begin{aligned} \bar{R}_{t+1} - \bar{R} &= \left(\frac{\Omega}{\Omega-1}\right) E_t(\bar{\pi}_{t+1} - \bar{\pi}) + \left(\frac{\Omega\theta}{\Omega-1}\right) E_t(\bar{g}_{c,t+1} - \bar{g}) \\ &+ \Omega\psi(1-\theta)\frac{l}{1-l}E_t\bar{g}_{l,t+1} - \Omega_V E_t\bar{g}_{V,t+1} - (\Omega-1)E_t(\bar{R}_t - \bar{R}). \end{aligned} \quad (3.34)$$

While equation (3.34) compares more favourably to forward-looking interest rate rules which feature a lagged dependent variable on the right hand side as an ‘interest rate smoothing’ term (Clarida et al., 2000), it differs from a standard rule because the lead nominal interest rate stands as the dependent variable. As such, (3.34) is more akin to a forecasting equation for the nominal interest rate than a conventional interest rate rule. This restatement of the Taylor Condition also raises the fundamental issue discussed by McCallum (2010). He argues that the equilibrium conditions of a structural model stipulate whether any given dynamic relationship is forward-looking (“expectational”) or backward-looking (“inertial”) and that the researcher is not free to alter the direction of causality implied by the model at will.

3.6.2 A Credit Interpretation

Christiano et al., (2010) have considered how the growth rate of credit might be included as part of a Taylor rule so that “allowing an independent role for credit growth (beyond its role in constructing the inflation forecast) would reduce the volatility of output and asset prices.” The term in velocity growth can be rewritten as the growth rate of credit (g_q) in the following way:

$$\begin{aligned} \bar{R}_t - \bar{R} &= \Omega E_t(\bar{\pi}_{t+1} - \bar{\pi}) + \Omega\theta E_t(\bar{g}_{c,t+1} - \bar{g}) + \Omega\psi(1-\theta)\frac{l}{1-l}E_t\bar{g}_{l,t+1} \\ &- \Omega_q E_t\bar{g}_{q,t+1} - (\Omega-1)E_t(\bar{R}_{t+1} - \bar{R}), \end{aligned} \quad (3.35)$$

where the coefficient on the credit term (Ω_q) is:

$$\Omega_q \equiv \frac{(R-1)(1-\gamma)\left(\frac{m_t}{c_t}\right)^2}{(1-\gamma)^2} \frac{(1-\gamma)\left(1-\frac{m_t}{c_t}\right)}{R\left[1-(1-\gamma)\left(1-\frac{m_t}{c_t}\right)\right]} \geq 0.$$

A positive expected credit growth rate decreases the current net nominal interest rate, \bar{R}_t . With velocity set to one as in a standard CIA model, neither credit nor velocity would enter the Taylor Condition since the credit service does not exist and velocity does not vary over time.

3.7 Discussion

This chapter has derived an expression which resembles a conventional interest rate rule as an equilibrium condition of an endogenous growth model with endogenous velocity in which monetary policy is characterised not by an interest rate rule but by a stochastic money supply rule. The theoretical model from which this equilibrium condition is derived (Benk et al., 2010) implies that the coefficient on inflation exceeds one in general, takes a value of one as a special case at the Friedman (1969) optimum, but that it may not fall below one. Simulation exercises support the theoretical restriction placed on this coefficient, so long as the estimating equation accurately reflects the equilibrium condition.

Our analysis can be interpreted in several ways. Firstly, the Taylor Condition could be said to constitute an ‘equivalence proposition’ between the ‘interest rate rule’ which emerges as an equilibrium condition of the model and the money supply process actually specified. This would be similar to the interpretation offered by Alvarez et al. (2001), Végh (2002), Fève and Auray (2002) and Schabert (2003). Fève and Auray (2002), for example, generate simulated data from a simple CIA model and demonstrate that an ‘interest rate rule’ can be spuriously recovered from this artificial data even though monetary policy is expressly modelled in terms of a money growth rule.

Secondly, and closely related to the previous point, the Taylor Condition could be interpreted as the interest rate rule which indirectly enacts the money supply

process, i.e. the long-run (*BGP*) rate of money growth, θ^* . As Bernanke (2003, p.213) notes:

"... the fact that the Federal Reserve and other central banks actively manipulate their instrument interest rates is not necessarily inconsistent with their providing a stable monetary background, as that manipulation might be necessary to offset shocks that would otherwise endanger nominal stability."

Our analysis has shown one way in which providing (long-run) monetary stability can engender interest rate-rule-like behaviour in the nominal interest rate. As shown in Chapter-I, Woodford similarly derives the interest rate rule which "implements" strict inflation targeting in the NK model (Woodford, 2003, pp.290-295). However, in contrast to the Benk et al. (2010) model, monetary variables do not play a prominent role in the NK model and so fluctuations in the velocity of money cannot be meaningfully incorporated into the interest rate rule in order to correct for potential downward bias in the inflation coefficients reported in the empirical literature.

Thirdly, the Taylor Condition is, in principle, similar to the class of Euler equation studied by Canzoneri et al. (2007, p.1866), for example. However, such expressions typically carry an (expected future) inflation coefficient of unity.²¹ For post-1966 U.S. data, Canzoneri et al. show that the Euler-equation-implied interest rate provides a poor fit to U.S. time series data. On the other hand, a conventional Taylor rule with a coefficient on inflation in excess of unity has often been found to fit the observed nominal interest rate rather well, particularly since c.1980 (for example, Taylor, 1993). The Taylor Condition (3.27) therefore represents an equilibrium condition which contains a coefficient on inflation consistent with empirical results which find evidence for the 'Taylor principle', while suggesting that estimates which fail to find support for the Taylor principle might omit potentially important variables such as the velocity of money.

²¹ Their expression is a log-normal approximation to a standard Euler equation and is written in terms of the inverse of the gross nominal interest rate (Canzoneri et al., 2007, eq.3). The coefficient on expected future inflation therefore carries a coefficient of *minus* one and their expression also features second moment terms which are lost during the log linearization process used to arrive at equation (3.27) above.

The derivation of the Taylor Condition also relates to Hetzel (2000), who warns that reduced form empirical correlations between a short-term interest rate and macroeconomic variables such as output and inflation cannot be interpreted to reveal an underlying policy rule unless the relationship obtained is a structural one. Similarly, Lucas (2003) questions whether estimated rule coefficients really reveal any meaningful information about the monetary policy rule or whether such estimates can already be explained by well-established theory.²² This point also speaks to Cochrane (2011a), who argues that the Taylor rule suffers from an identification problem in the NK model. Our contribution has been to offer one particular explanation of an alternative neoclassical monetary model, extended to include endogenous growth and endogenous velocity, in order to shed light upon the structural relationships which might underpin the reduced form expressions to which Hetzel (2000) refers.

3.8 Conclusion

In this chapter we have derived a dynamic general equilibrium condition for the nominal interest rate from a constant relative risk aversion economy with a labour-leisure choice, Lucas (1988b) endogenous growth and endogenous velocity in which monetary policymakers use the money supply as the instrument of monetary policy as opposed to an interest rate rule (Benk et al., 2010). Velocity is endogenised in the model according to the financial intermediation microeconomic literature, where financial services are produced via a Cobb-Douglas production function which includes deposits as an input. This equilibrium condition – labelled a ‘Taylor Condition’ – shares certain key similarities with the interest rate rules examined in the extant literature (e.g. Taylor, 1993, 1999; Clarida et al., 1998, 2000; Woodford, 2003, 2008; Galí, 2008). In particular, it features a coefficient on inflation which exceeds unity in keeping with such rules.

As recognised by Mehrling (2006), expressing the monetary policy process in terms of an interest rate rule carries the advantage of reconciling the language of

²² Lucas (2003) mentions the Fisher relation, in particular. We previously discussed this interpretation in Chapter-II and shall pursue it further in Chapter-IV.

economists, who have traditionally cast the money supply as the instrument of monetary policy, with the language of central bankers, who are more accustomed to communicating in terms of a short-term interest rate. However, Alvarez et al. (2001) caution that modelling monetary policy solely in terms of a short-term interest rate rejects the quantity theory despite the strong empirical link between money growth, inflation and, interest rates (e.g. McCandless and Weber, 1995; Lucas, 1996; Haug and Dewald, 2012). The fundamental role for monetary variables within the Benk et al. (2010) framework and the importance of the velocity of money to the Taylor Condition is consistent with the prominent role assigned to velocity by Reynard (2004, 2006). The presence of an alternative to money for exchange purposes is crucial to the analytical derivation of the 'Taylor principle'. We demonstrate that a simple CIA model without an alternative to money, in which velocity is necessarily constant at unity, would produce a coefficient of one on the Taylor Condition's term in (expected future) inflation and the Taylor principle result would be lost.

The primary focus in this chapter is to show that if the researcher searches for a conventional interest rate rule in model-simulated data then although he may succeed, the inference that the central bank adheres to such a rule would be spurious since monetary policy is actually conducted through control of the money supply growth rate. The Taylor Condition is simply an equilibrium condition of the model in which the central bank adjusts the money supply growth rate to finance government spending, effectively using the 'inflation tax' to do so (wartime spending, for example). To illustrate the point, we use conventional estimation techniques and standard statistical filters in order to extract 'high frequency' fluctuations from model-simulated data and generate estimates of the coefficients of the Taylor Condition and several misspecified estimating equations. The estimation results provide support for the theoretical prediction for the inflation coefficient under a correctly-specified estimating equation but misspecified estimating equations lead to bias in the estimated coefficients. The fact that our framework assigns a central role to money also implies that it can potentially offer guidance to policymakers at times when the conventional monetary policy instrument reaches the zero lower bound, as is the

case at the present time, during which conventional interest rate rules have been calling for negative nominal interest rates (e.g. Rudebusch, 2009) which cannot actually be implemented.

CHAPTER-IV: A UNIFIED ACCOUNT OF THE TAYLOR PRINCIPLE AND THE FISHER RELATION

4.1 Introduction

The long-run relationship between the nominal interest rate and the rate of inflation is often interpreted in terms of Fisher (1896). A rise in expected future inflation is followed by a proportional increase in the nominal interest rate which leaves the real rate of interest rate unchanged. Faced with this 'neutrality', monetary policymakers should harbour only modest long-run ambitions with regards to real economic quantities (e.g. Friedman, 1968). Empirical studies have sought to validate the Fisher relation using a variety of econometric techniques. For instance, statistical filters have been used to remove high frequency fluctuations from the data to leave filtered series which should exhibit the predicted one-for-one relationship between the nominal interest rate and the rate of inflation (e.g. Summers, 1982).¹ Alternatively, the Fisher relation has been modelled as a cointegrating relationship using error correction methods. Under this approach, the one-for-one relationship stands as a long-run equilibrium condition which may break-down temporarily but is subsequently restored ('corrected') over time (e.g. Mishkin, 1992; Crowder and Hoffman, 1996; Crowder, 2003; Arnwine and Yigit, 2008). However, in searching for a long-run Fisher relation these empirical studies lack a structural account of the short-run relationship between the nominal interest rate and inflation – high frequency fluctuations are simply discarded by the statistical filters and a reduced form process is used to characterise short-run dynamics under the error correction approach.

It has become increasingly common to interpret the short-run relationship between the nominal interest rate and inflation as an 'interest rate rule'. These rules seek to express the way in which policymakers adjust, or ought to adjust, a short-term nominal interest rate in response to inflation deviations from target and a real variable such as the output gap. Taylor (1993, 1999), for instance, fits

¹ Summers (1982) actually fails to find evidence for the Fisher relation using this approach; possible explanations for this are discussed in the next section.

calibrated and estimated interest rate rules to U.S. data while Clarida et al. (1999), Woodford (2003), Galí (2008), and many others, incorporate a forward-looking interest rate rule into the canonical New Keynesian (NK) model as an alternative to a money supply rule. A prominent normative result established in the NK framework is that policymakers should adhere to an interest rate rule with an inflation coefficient which exceeds unity (e.g. Woodford, 2003), thus adhering to the so-called ‘Taylor principle’.² Complementary empirical studies have often found that historical periods characterised by such a rule are also associated with stable macroeconomic outcomes (e.g. Taylor, 1999; Clarida et al., 2000; Mankiw, 2001). However, Alvarez et al. (2001) argue that models which take the nominal interest rate to be the instrument of monetary policy overlook the long-run link between money growth, the nominal interest rate and inflation stipulated by the Quantity Theory of Money. Nelson (2008a) makes the related point that the NK model lacks a plausible account of how the central bank determines the rate of inflation in the long-run.³

Empirically orientated investigations into the long-run Fisher relation therefore remain agnostic about the short-run on the one hand while the NK model arguably lacks a fully coherent account of the long-run on the other. This chapter provides a structural explanation of both the short-run ‘Taylor principle’ and the long-run ‘Fisher relation’ within a unified theoretical framework. In Chapter-III we have shown that an ‘interest rate rule’ can be derived from the structural model of Benk et al. (2010) in which the central bank uses the money supply as its policy instrument, thus heeding both the Lucas (1976) critique of policy evaluation and Alvarez et al.’s (2001) criticism of the NK approach. The pseudo-

² Formally, the Taylor principle is a determinacy condition but for a conventionally calibrated NK model it turns out that the magnitude of the interest rate rule’s inflation coefficient is the key parameter and that it should exceed one for a determinate (unique) equilibrium (e.g. Woodford, 2003). The requirement that the inflation coefficient exceeds one can therefore be thought of as a ‘rule-of-thumb Taylor principle’.

³ Nelson’s point can be summarised as follows: In the NK model, nominal rigidities allow a change in the nominal interest rate, which is taken to be the instrument of monetary policy, to feed-through to a change in the real interest rate and hence through to the optimal intertemporal allocation of consumption via the NKIS (intertemporal Euler) relation and finally through to inflation via the NK Phillips curve. However, these nominal rigidities must presumably dissipate over time, ostensibly rendering the central bank without a means of delivering its desired (target) rate of inflation. The question then arises as to who or what determines the rate of inflation in the long-run.

rule – labelled a ‘Taylor Condition’ – is not an interest rate rule of the conventional kind but an equilibrium condition akin to the Euler equations analysed by Canzoneri et al. (2007). Unlike an Euler equation, but consistent with a ‘stabilising’ interest rate rule, the Taylor Condition features a coefficient on (expected future) inflation which exceeds unity in general.

Contrary to the canonical NK model and conventional interest rate rules, monetary relationships play a fundamental role in the Taylor Condition. Indeed, Nelson (2008a) concludes that control of the money supply is the obvious means to ensure long-run determination of the rate of inflation because policymakers can closely control the supply of (base) money and because of the well-documented empirical link between inflation and money growth at low frequencies (e.g. McCandless and Weber, 1995; Lucas, 1996; Reynard, 2007; Assenmacher-Wesche and Gerlach, 2007; Haug and Dewald, 2012). However, it remains the case that monetary relationships play only a peripheral role in the NK model because an interest rate rule still characterises the monetary policy process. Monetary relationships are ‘superfluous’ in that framework because the interest rate rule implies a certain path for the money supply (Woodford, 2003, 2008); i.e. the money supply curve is perfectly elastic. Not only does the central bank use the money supply rather than a short-term interest rate as the instrument of monetary policy in the Benk et al. (2010) model but the long-run velocity of money features as a component of the coefficient on expected future inflation in the Taylor Condition derived from this model and the growth rate of the velocity of money enters the Taylor Condition as a separate term.

The econometric exercises conducted in this chapter first extend the findings of the previous chapter to show that the ‘Taylor principle’ result in terms of the coefficient on inflation holds for a ‘medium-term cycle’ in the spirit of Comin and Gertler (2006) as well as for the ‘high frequency filters’ considered previously, although the medium-term cycle is initially specified to be shorter than their original calibration. The Taylor principle result also holds for an expression akin to a conventional, non-dynamic Taylor rule at this extended frequency range. The relationship between the nominal interest rate and expected inflation tends

towards the Fisher relation under three scenarios. The first is when the Taylor Condition is estimated using simulated data which retains cycles with a periodicity of up to approximately 50 years consistent with Comin and Gertler's (2006) original 'medium-term cycle'; the second is when the estimating equation is arbitrarily restricted to omit a forward-looking nominal interest rate term; and the third is when the true estimating equation is restricted to form a 'long-run Taylor Condition' which features terms in inflation and consumption growth only. The first two scenarios employ econometric methods commonly used in the Taylor rule literature while the final scenario requires an error correction framework in keeping with the econometric techniques typically employed by empirical studies in the Fisher relation tradition.

4.1.1 Empirical Evidence and Theoretical Rationalisations

Empirical studies in both the Fisher relation and the Taylor rule traditions have found evidence in favour of a less-than-proportional, a more-than-proportional and a one-for-one relationship between the nominal interest rate and inflation. For example, Summers (1982) finds evidence for a less-than-proportional relationship for post-war U.S. data, Crowder and Hoffman's (1996) results imply a greater-than-proportional relationship and Mishkin (1992) and Arnwine and Yigit's (2008) estimates support the expected one-for-one relationship.^{4,5} From a Taylor rule perspective, Taylor (1999), for example, evaluates the Taylor (1993) rule against a lengthy span of U.S. data using simple econometric techniques and shows that the nominal interest rate varies more-than-proportionally with inflation – i.e. the estimated inflation coefficient exceeds unity and the Taylor principle is satisfied – between 1987q1 and 1997q3 but that a less-than-proportional response is found for other historical periods (1879q1-1914q4 and 1960q1-1979q4). In a well-known paper, Clarida et al. (2000) extend Taylor's original formulation to incorporate the forward-looking nature of monetary policy decisions and the notion of 'interest rate smoothing' and report similar

⁴ It is not claimed that the present discussion constitutes an exhaustive review of either the Fisher relation or the Taylor rule literatures. Rather, the intention is to demonstrate that a range of coefficient estimates have been found in each strand of the literature and to consider some the common theoretical explanations for this diverse range of estimates.

⁵ Crowder (2003) extends Crowder and Hoffman (1996) to cover a panel of 8 industrialised nations and obtains similar results for 7 out of the 8 countries examined.

results. They estimate a pre-Volcker (1960q1-1979q2) inflation coefficient of 0.83 and a Volcker-Greenspan (1979q3-1996q4) inflation coefficient of 2.15 (Clarida et al., 2000, Table II).

Several theoretical explanations have been proposed to explain the absence of a Fisher relation in the aforementioned empirical studies. Darby (1975), for example, argues that a greater-than-proportional relationship would be expected if interest income is taxed because agents' behaviour will then be influenced by the after-tax relationship between inflation and the nominal interest rate. In this case, researchers should expect to find evidence for an 'after tax Fisher relation'; Crowder and Hoffman (1996) interpret their empirical findings in this manner. However, Tanzi (1980) suggests that a less-than-proportional relationship could be indicative of a form of investor irrationality in which agents do not fully account for the tax effect when deciding upon their asset holdings.⁶ Indeed, Summers (1982, p.46) notes that Fisher himself considered the possibility that nominal interest rates might fail to fully adjust to (expected) inflation because of some form of 'money illusion' and Summers interprets his estimates in this manner. Alternatively, Tobin (1965, 1969) argues that a less-than-proportional relationship would be expected if investors rationally substitute away from nominal assets and towards real assets as inflation increases, thus driving the price of nominal bonds down, the price of real assets up and weakening the Fisher relation. For an interest rate rule, variation in the estimated inflation coefficient is interpreted to reflect changes in policymakers' preferences towards inflation. An inflation coefficient below one signifies that the central bank accommodates inflation by failing to increase the nominal interest rate sufficiently to raise the real rate of interest when inflation, or forecasted (expected) inflation, increases. In this case, monetary policymakers fail in their (presumed) desire to act as a stabilising force on the economy. On the other hand, an inflation coefficient in excess of unity is said to be 'stabilising' because policymakers would then engineer an increase in the real interest rate as (forecasted) inflation increases.⁷

⁶ Crowder and Wohar (1999) discount this "fiscal illusion" effect because they consistently find that the nominal interest rate response to a change in the rate of inflation is larger for taxed U.S. government bonds than it is for tax-exempt municipal bonds.

⁷ Although recall Cochrane (2011a).

Clarida et al. (2000), for example, interpret their empirical estimates as indicative of a positive change in the conduct of monetary policy subsequent to Paul Volcker's appointment as Chairman of the Federal Reserve (in August of 1979).

The interpretation of the relationship between the nominal interest rate and expected inflation depends upon whether one considers the short- or long-run relationship. The emphasis in the literature has shifted over time as researchers have sought to reconcile the way in which economic models represent monetary policy with the way in which monetary policymakers communicate their decisions (Mehrling, 2006). Accordingly, it is now more common to consider the relationship between the nominal interest rate and inflation as a product of policymakers' interest rate response to deviations of inflation from target. However, as discussed in Chapter-II, Lucas (2003) questions the interest rate rule interpretation of the empirical relationship between the nominal interest rate and expected inflation.⁸ In Lucas' view, U.S. time series data provides no information about the interest rate rule followed by the Federal Reserve. Rather, the standard Taylor rule relationship could simply be a "misinterpretation of behavior that Fisher has already explained." (Lucas, 2003, slide 12).

Islam and Ali (2012) have recently made the connection between empirical studies which find evidence in favour of a long-run Fisher relation and studies which take a short-run interest rate rule perspective. They confirm that regressing the nominal interest rate on inflation produces an inflation coefficient consistent with the Fisher relation for a lengthy post-war sample of U.S. data (1957-2010) and that an inflation coefficient consistent with the Taylor (1993) rule is obtained for a 1981-2010 subsample.⁹ Although these results have been established elsewhere in the disparate empirical literatures, their contribution is to make the intellectual link between the short-run Taylor rule and the long-run Fisher relation. However, Islam and Ali (2012) do not attempt to derive their

⁸ Lucas expresses this view in a presentation given to the Federal Reserve Bank of Minneapolis in November of 2003. Workshop proceedings are available online (see References for details).

⁹ They find that the nominal interest rate and inflation are integrated of order one and cointegrated over the full sample, thus the full-sample estimates are generated using error correction methods. The data is found to be stationary for the post-1980 period hence standard estimation methods are used for this subsample.

estimating equations within a unified theoretical framework hence it is not clear from a structural perspective how or why the Fisher relation applies at lower frequencies but the Taylor principle emerges at high frequencies. This is the issue we address in this chapter, building upon the analysis presented in Chapter-III.

The remainder of this chapter is structured as follows: Section 4.2 briefly restates the Taylor Condition, which is derived more comprehensively in Chapter-III, along with an explanation of two misspecified theoretical forms and a ‘long-run Taylor Condition’ which are evaluated empirically at a later stage; Section 4.3 restates the calibration and target values used to simulate the Benk et al. (2010) model; Section 4.4 shows that the Taylor principle result can be obtained from a ‘correctly specified’ estimating equation by applying standard econometric procedures to model-simulated data and from an estimating equation which resembles a standard Taylor rule. The full Taylor Condition is also evaluated against a sample of post-war U.S. data in order to provide a comparison with the estimates derived from model-simulated data. Section 4.5 considers the circumstances under which the ‘Taylor principle’ result reverts to the long-run ‘Fisher relation’, firstly by extending the frequencies incorporated into the ‘medium-term cycle’ and subsequently by restricting the full Taylor Condition in one arbitrary and one economically meaningful way. Section 4.6 concludes.

4.2 The Taylor Condition

A full derivation of the Taylor Condition is provided in Chapter-III so for present purposes we simply restate the full Taylor Condition along with several misspecified forms. The full Taylor Condition in proportional-deviation-from-target form is:

$$\begin{aligned} \bar{R}_t - \bar{R} = & \Omega E_t(\bar{\pi}_{t+1} - \bar{\pi}) + \Omega\theta E_t(\bar{g}_{c,t+1} - \bar{g}) + \Omega\psi(1 - \theta)\frac{l}{1-l}E_t\bar{g}_{l,t+1} \\ & - \Omega_V E_t\bar{g}_{V,t+1} - (\Omega - 1)E_t(\bar{R}_{t+1} - \bar{R}), \end{aligned} \tag{4.1}$$

where \bar{R} denotes the nominal interest rate, $\bar{\pi}$ is the rate of inflation, \bar{g}_c is the consumption growth rate, \bar{g}_l is the growth rate of non-leisure ('productive') hours – which includes time spent working in the goods sector (l_G), time spent working in the banking sector (l_F) and time spent accumulating human capital (l_H) – and \bar{g}_v denotes the growth rate of the consumption velocity of money (c/m). Over-barred terms denote net rates of interest or growth.

As shown in Chapter-III, the coefficients in equation (4.1) are defined as:

$$\Omega \equiv 1 + \frac{(1 - \gamma)\left(1 - \frac{m}{c}\right)}{(1 + \bar{R})\left[1 - (1 - \gamma)\left(1 - \frac{m}{c}\right)\right]};$$

$$\Omega_v \equiv \frac{\bar{R}}{1 + \bar{R}} \left[\frac{(1 - \gamma)\frac{m}{c}}{1 - (1 - \gamma)\left(1 - \frac{m}{c}\right)} \right],$$

with associated restrictions:

$$0 \leq \Omega_v \leq 1 \leq \Omega. \quad (4.2)$$

For the general case in which m/c falls below one (velocity rises above one), the model's analogue to the Taylor principle ($\Omega > 1$) holds. As such, and unlike a standard Euler equation, the coefficient on inflation in equation (4.1) generally exceeds unity and thus resembles a 'stabilising' interest rate rule. However, at the Friedman (1969) optimum nominal interest rate ($\bar{R} = 0$) there is no incentive to avoid the inflation tax and hence no reason to utilise the costly intratemporal credit service. As such, all goods purchases are conducted using money ($m/c=1$), which from the above parameter definitions implies that $\Omega=1$ and $\Omega_v=0$. Equation (4.1) would collapse to:

$$\bar{R}_t - \bar{R} = E_t(\bar{\pi}_{t+1} - \bar{\pi}) + \theta E_t(\bar{g}_{c,t+1} - \bar{g}) + \psi(1 - \theta) \frac{l}{1-l} E_t \bar{g}_{l,t+1}, \quad (4.3)$$

which implies a proportional relationship between the nominal interest rate and (expected) inflation. The velocity growth and forward interest rate terms only enter the Taylor Condition when the nominal interest rate differs from the Friedman (1969) optimum and fluctuates.

4.2.1 Misspecification: Output Growth Replaces Consumption Growth

The Taylor Condition can be rewritten to include an output growth term instead of a consumption growth term and hence correspond more closely to the Taylor rule specifications found in the literature. Consider that the identity $y_t = c_t + i_t$ implies that $\hat{c}_t = \frac{y}{c}\hat{y}_t - \frac{i}{c}\hat{i}_t$, where $\hat{i}_t = [\hat{k}_t - (1 - \delta)\hat{k}_{t-1}]$, then the Taylor Condition (4.1) can be legitimately re-expressed as:

$$\begin{aligned} \bar{R}_t - \bar{R} = & \Omega E_t(\bar{\pi}_{t+1} - \bar{\pi}) + \Omega\theta \left[\frac{y}{c} E_t(\bar{g}_{y,t+1} - \bar{g}) - \frac{i}{c} E_t(\bar{g}_{i,t+1} - \bar{g}) \right] \\ & + \Omega\psi(1 - \theta) \frac{l}{1-l} E_t \bar{g}_{l,t+1} - \Omega_V E_t \bar{g}_{V,t+1} - (\Omega - 1) E_t(\bar{R}_{t+1} - \bar{R}) . \end{aligned} \quad (4.4)$$

However, simply replacing consumption growth in equation (4.1) with output growth to give:

$$\begin{aligned} \bar{R}_t - \bar{R} = & \Omega E_t(\bar{\pi}_{t+1} - \bar{\pi}) + \Omega\theta E_t(\bar{g}_{y,t+1} - \bar{g}) \\ & + \Omega\psi(1 - \theta) \frac{l}{1-l} E_t \bar{g}_{l,t+1} - \Omega_V E_t \bar{g}_{V,t+1} - (\Omega - 1) E_t(\bar{R}_{t+1} - \bar{R}) , \end{aligned} \quad (4.5)$$

erroneously overlooks the weighting on the output growth rate (y/c) and the term in the investment growth rate in (4.4). As such, equation (4.5) is misspecified.

4.2.2 Misspecification: A Conventional Taylor Rule

The second misspecified model imposes the same restrictions used to arrive at equation (4.5) but also omits the terms in productive time and velocity growth in order to provide an even closer correspondence to a conventional interest rate rule:

$$\bar{R}_t - \bar{R} = \Omega E_t(\bar{\pi}_{t+1} - \bar{\pi}) + \Omega\theta[E_t(\bar{g}_{y,t+1} - \bar{g})] - (\Omega - 1)E_t(\bar{R}_{t+1} - \bar{R}). \quad (4.6)$$

This can be interpreted as a forward-looking interest rate rule (e.g. Clarida et al., 2000). There are, however, two substantial differences between equation (4.6) and the rule estimated by Clarida et al. (2000). Firstly, an output growth term enters instead of the conventional output gap term and secondly, a forward interest rate term enters rather than a lagged partial adjustment – ‘interest rate smoothing’ – term. However, the former is comparable to the real variable used in Walsh’s (2003b) ‘speed limit’ rule. Once again, equation (4.6) does not accurately represent an equilibrium condition of the Benk et al. (2010) model and is therefore misspecified.

4.2.3 The ‘Long-Run Taylor Condition’

The model’s equivalent of the long-run Fisher relation can be derived by combining the terms in the current end expected future nominal interest rate in equation (4.1), i.e. $\bar{R}_t - \bar{R} = E_t(\bar{R}_{t+1} - \bar{R})$, as follows:

$$\bar{R}_t - \bar{R} = E_t(\bar{\pi}_{t+1} - \bar{\pi}) + \theta E_t(\bar{g}_{c,t+1} - \bar{g}), \quad (4.7)$$

where the coefficient on inflation now takes a value of unity and the coefficient on consumption growth is simply the coefficient of relative risk aversion.¹⁰ Equation (4.7) shares certain similarities with the Friedman optimum special case (4.3) but here the growth rate of the fraction of time spent in non-leisure activities (\bar{g}_l) is also taken to be constant because it cannot trend upwards or downwards without limit. The same argument applies to the growth rate of the fraction of consumption purchases financed by money and therefore g_v , which is also absent from (4.7).

¹⁰ The coefficient on inflation is $\Omega/(1+\Omega-1)$ and the coefficient on consumption growth is $\Omega\theta/(1+\Omega-1)$.

Equation (4.7) is analogous to a forward-looking version of Arnwine and Yigit's (2008) "augmented Fisher relation" which contains terms in both inflation and consumption growth and is modelled as a long-run equilibrium relationship within their econometric framework. It is also similar to the "standard preferences" Euler equation estimated by Canzoneri et al. (2007). The magnitudes of the coefficients on the inflation and consumption growth terms in equation (4.7) are consistent with the expressions analysed by these studies.¹¹

4.3 Calibration, Target Values and Implied Theoretical Predictions

The calibration and target values adopted in Chapter-III are applied again here. These are re-stated in Tables 4.1 and 4.2 for convenience.

[Table 4.1 here]

[Table 4.2 here]

The calibration presented in Table 4.1 and the target values presented in Table 4.2 can be used to derive a set of theoretical 'predictions' for the coefficients of the Taylor Condition. These predictions shall subsequently be compared to the coefficients obtained from model-simulated data. Using the parameter definitions presented above, the 'predicted' value for Ω is 2.125. However, if the representative consumer finds it optimal to fund all consumption using money, as would be the case at the Friedman optimum $\bar{R}=0$ for example, then $(m/c)=1$ and Ω reverts to its lower bound of one. This would also be the case without credit production (i.e. $A_F=0$), in which case only money is available for exchange.

Except for the velocity growth coefficient, the remaining coefficients are simple functions of the inflation coefficient. The consumption growth coefficient is $\Omega\theta$, which with $\theta=1$ for log-utility should simply take the same magnitude as the coefficient on inflation ($\theta\Omega=2.125$). With $\theta=1$, the coefficient on the growth rate of

¹¹ See Arnwine and Yigit's (2008) equation (6) and the inverse of Canzoneri et al.'s (2007) equation (3). The constant term included in Arnwine and Yigit's (2008) expression and the second moment terms which feature in Canzoneri et al.'s (2007) expression are both absent due to the log-linear approximation used to derive equation (4.1).

productive time should be 0. Given the magnitude of the inflation coefficient, the coefficient on the forward interest term is simply $-(\Omega-1)=-1.125$ and the velocity coefficient is -0.065 . The velocity coefficient would take a value of zero at the Friedman (1969) optimum nominal interest rate, in which case the term in velocity would not be needed when estimating the Taylor Condition.

4.4 Empirical Analysis: The Taylor Principle

For this section we adopt an econometric framework that has often been applied in the interest rate rule literature because we wish to establish whether the Taylor principle result holds for the Taylor Condition. In particular, the econometric methodology employed follows the well-known procedure of Clarida et al. (2000), who use Generalised Method of Moments (GMM) techniques (Hansen, 1982) to estimate the coefficients of a forward-looking interest rate rule against U.S. time series data.¹² Also recall that in Chapter-III the GMM technique tended to produce better (i.e. more precise) estimates for model-simulated data than either Ordinary Least Squares or Two Stage Least Squares. Following Clarida et al. (2000), equation (4.1) is rewritten in terms of realised instead of expected future values:

$$\begin{aligned} \bar{R}_t - \bar{R} &= \Omega(\bar{\pi}_{t+1} - \bar{\pi}) + \Omega\theta(\bar{g}_{c,t+1} - \bar{g}) + \Omega\psi(1 - \theta)\frac{l}{1-l}\bar{g}_{l,t+1} \\ &- \Omega_V\bar{g}_{V,t+1} - (\Omega - 1)(\bar{R}_{t+1} - \bar{R}) + \mu_t, \end{aligned} \tag{4.8}$$

where the additional term μ_t consists of a linear combination of the forecast errors associated with each variable. Mathematically, μ_t simply reconciles equation (4.8) with equation (4.1) as follows:

¹² Clarida et al.'s (1998, 2000) procedure has often been used to estimate conventional interest rate rules but also has wider applications: for example, Jondeau et al. (2004) experiment with the specific type of GMM estimator used by Clarida et al. (2000); Dolado et al. (2004) estimate a non-linear interest rate rule; Fuhrer and Rudebusch (2004) estimate an 'output Euler equation'; Galí and Gertler (1999) estimate a 'new (Keynesian) Phillips curve'; and Gabriel et al. (2009) evaluate a 'Calvo-type rule'. The latter study refers to Clarida et al.'s econometric procedure as "the now standard strategy" (Gabriel et al., 2009, p.93).

$$\begin{aligned}
\mu_t \equiv & -\left\{ \Omega[(\bar{\pi}_{t+1} - \bar{\pi}) - E_t(\bar{\pi}_{t+1} - \bar{\pi})] + \Omega\theta[(\bar{g}_{c,t+1} - \bar{g}) - E_t(\bar{g}_{c,t+1} - \bar{g})] \right. \\
& + \Omega\psi(1 - \theta)\frac{l}{1-l}[\bar{g}_{l,t+1} - E_t\bar{g}_{l,t+1}] - \Omega_V[\bar{g}_{V,t+1} - E_t\bar{g}_{V,t+1}] \\
& \left. - (\Omega - 1)[(\bar{R}_{t+1} - \bar{R}) - E_t(\bar{R}_{t+1} - \bar{R})] \right\}.
\end{aligned} \tag{4.9}$$

Equation (4.8) cannot be evaluated using a standard estimating procedure such as OLS because the resultant error term would contain forecast errors which are correlated with the regressors. Coefficient estimates derived from this procedure would be biased and inconsistent. Clarida et al. (2000) use a GMM estimator to overcome this problem and hence require a suitable set of instruments. The validity of the chosen instrument set can be tested so long as over-identifying restrictions are specified. Formally, the GMM procedure derives coefficient estimates from the following moment condition:

$$\begin{aligned}
E \left\{ \left[(\bar{R}_t - \bar{R}) - \Omega(\bar{\pi}_{t+1} - \bar{\pi}) - \theta\Omega(\bar{g}_{c,t+1} - \bar{g}) - \Omega\psi(1 - \theta)\frac{l}{1-l}\bar{g}_{l,t+1} \right. \right. \\
\left. \left. + \Omega_V\bar{g}_{V,t+1} + (\Omega - 1)(\bar{R}_{t+1} - \bar{R}) \right] \mathbf{z}_t \right\} = 0,
\end{aligned} \tag{4.10}$$

where \mathbf{z}_t is a vector of instruments. The specific GMM procedure adopted below iterates on the weighting matrix in two steps and applies heteroskedasticity and autocorrelation (HAC) adjustments to the weighting matrix using a Bartlett kernel with a Newey-West fixed bandwidth.¹³ A similar adjustment is also applied to the covariance weighting matrix. The instrument set shall consist of a constant and four lags of the dependent and independent variables, a standard approach in the empirical literature.¹⁴ Forecast errors are therefore assumed to be orthogonal to past information which implies that all relevant information is utilised when the forecast is made (i.e. forecasts are formed rationally). The over-identifying

¹³ It is not clear precisely which GMM estimator Clarida et al. (2000) use in their seminal paper but in reviewing the empirical literature Jondeau et al. (2004, p.227) state that: "To our knowledge, all estimations of the forward-looking reaction function based on GMM have so far relied on the two-step estimator." We therefore consider a GMM estimator of this type.

¹⁴ Carare and Tchaidze (2005, p.15) describe four lags as "the usual suspects" for the instrument set in the context of interest rate rule estimation. Nelson (2000, Table B), Orphanides (2001) and Rudebusch (2002) also follow this approach, for example. Nelson (2000) also adds a constant term to the instrument set.

restrictions implied by the chosen instrument set can be used to test the validity of this orthogonality assumption. Clarida et al. (2000) also include as part of their instrument set three variables which do not feature in the theoretical model which complements their empirical analysis. The instrument set considered for present purposes shall comprise only of lags of variables that can be generated by the underlying theoretical model; Jondeau et al. (2004) limit their instrument set in this manner for a similar reason.

4.4.1 Estimating Equations

Using the econometric methodology outlined above, we begin by evaluating a ‘correctly specified’ estimating equation which is designed to faithfully reflect the structure of equation (4.1):

$$\bar{R}_t = \beta_0 + \beta_1 E_t \bar{\pi}_{t+1} + \beta_2 E_t \bar{g}_{c,t+1} + \beta_3 E_t \bar{g}_{l,t+1} + \beta_4 E_t \bar{g}_{v,t+1} + \beta_5 E_t \bar{R}_{t+1} + e_t , \quad (4.11)$$

where e_t represents a residual series. This expression is first evaluated against simulated data – similar to the exercise conducted in Chapter-III but using only the GMM estimator and different statistical filters, as discussed below – and against quarterly U.S. time series data over the post-war period 1960q1-2011q1. As in Chapter-III, for simulated data we also consider a misspecified version of equation (4.1) in which output growth replaces consumption growth. This misspecified estimating equation corresponds to equation (4.5) above.

We also consider an estimating equation which corresponds to equation (4.6). This is interpreted to represent the analogue to a standard forward-looking ‘Taylor rule’ and is implemented empirically using the estimating equation:

$$\bar{R}_t = \beta_0 + \beta_1 E_t \bar{\pi}_{t+1} + \beta_2 E_t \bar{g}_{y,t+1} + \beta_5 E_t \bar{R}_{t+1} + e_t . \quad (4.12)$$

Imposing the restriction $\beta_5=0$ on equation (4.12) forms a ‘non-dynamic Taylor rule’ in which the dependent variable appears only on the left-hand side of the

estimating equation. This restriction addresses the discrepancy between the forward-looking nominal interest rate term in equation (4.6) and the lagged nominal interest rate term which features in standard rules to allow for ‘interest rate smoothing’ (e.g. Clarida et al., 2000). The estimates obtained from equation (4.12) and its counterpart with $\beta_5=0$ can be compared to estimates derived from the standard Taylor rules found in the literature, although these studies typically use the output gap rather than the output growth rate as a real term to stand alongside inflation.

4.4.2 The Taylor Condition for Model-Simulated Data

The model of Benk et al. (2010) described above is now simulated using the target values presented in Tables 4.1 and 4.2. We construct 1000 ‘joint histories’ for each of the variables which enter the Taylor Condition (4.1) along with the output growth series required to evaluate equation (4.5). The simulation procedure involves generating one hundred pseudo-random sequences for the exogenous shock innovations and feeding these back into the model; control functions of the log-linearized model are then used to compute sequences for each variable. A burn-in period is applied in order to allow the model to converge on its stationary state. Given the frequency of the underlying model, each observation within a particular history may be interpreted as an annual period in calendar time; thus the dataset comprises of 1000, 100 ‘year’ samples of simulated data.

The band pass filter (e.g. Christiano and Fitzgerald, 2003) is applied to the simulated data prior to estimation to account for the fact that the Taylor Condition is expressed in deviation-from-*BGP* form. This type of filter is selected in particular because it allows the periodicities consigned to the ‘trend component’, and hence the periodicities retained as part of the ‘cyclical component’, to be precisely specified. The band pass filter is used to extract a ‘medium-term cycle’ from the data in the spirit of Comin and Gertler (2006). In essence, a smoother trend is applied to the data than would be the case under a conventional ‘business cycle filter’, such as the Hodrick-Prescott filter. In practice, the medium-term cycle is constructed as the combination of standard business cycle fluctuations (a ‘high-frequency component’) and lower periodicity

fluctuations (a ‘medium-frequency component’); these component frequency ranges are considered jointly to allow for the possibility that they are not orthogonal to each other.¹⁵

Subsequent to Comin and Gertler’s (2006) original contribution, different studies have used a variety of filter settings for the medium-term cycle depending upon a several factors, including the length of the time series available (e.g. Basu et al., 2012) and the frequency of the data under consideration (e.g. Haug and Dewald, 2012). The ‘medium-term cycle’ considered here initially truncates Comin and Gertler’s (2006) original specification. In particular, the ‘high-frequency component’ is assumed to consist of cycles of 2-8 periods (‘years’) and the ‘medium-frequency component’ is assumed to consist of cycles of 8-20 years; the ‘medium-term cycle’ therefore comprises of cycles of 2-20 years compared to Comin and Gertler’s 2-200 quarter specification.¹⁶ We first establish that the Taylor principle result holds for this truncated filter specification before exploring the consequences of converging towards Comin and Gertler’s definition of the medium-term cycle in Section 4.5.

Comin and Gertler (2006, p.526) note that the majority of their series are non-stationary and explain that they take log differences of the data *prior to* applying the band pass filter. This suggests that they intend to apply the band pass filter to stationary series. The statistical tests employed by Österholm (2005) indicate that the vast majority of the series simulated from the Benk et al. (2010) model are stationary (Table 4.3). In light of these results, and consistent with Basu et al. (2012), the band pass filter applied does not use a de-trending procedure.

[Table 4.3 here]

¹⁵ The nomenclature adopted here follows Comin and Gertler (2006). Alternatively, Basu et al. (2012) decompose their data into four frequencies labelled “high frequency”, “business cycle”, “low frequency” and “medium term” while Haug and Dewald (2012) use band pass filters to identify a “longer-term component” and a “short-run business-cycle component”.

¹⁶ Our ‘high-frequency component’ is consistent with Haug and Dewald’s (2012) “short-run business-cycle component” for annual data; they base this choice upon Stock and Watson (1998). Comin and Gertler’s specification cannot be replicated precisely because cycles of less than two periods are inadmissible.

Table 4.4 presents the coefficient estimates obtained from the ‘correctly specified’ estimating equation (4.11) and a misspecified form which includes output growth instead of consumption growth.¹⁷ The table reports mean coefficient estimates over the 1000 simulated samples along with a measure of the dispersion of the estimates (“standard error”), the number of statistically significant estimates at the 5% level (in square brackets) and an “adjusted mean” which sets non-statistically-significant estimates equal to zero when calculating the mean estimate. The table also reports mean R-squared and adjusted R-squared statistics, mean P-values for the Hansen J-statistic to test the validity of the instrument set and mean Durbin-Watson (D-W) statistics and P-values for the Q-statistic to test for autocorrelated residuals. The number of estimation runs for which the null hypothesis of the J-statistic is *not* rejected – i.e. the instrument set is *not* found to be invalid – is reported alongside its mean P-value, the number of estimation runs for which the D-W statistic exceeds its upper critical value – i.e. the null that the estimated residuals are serially uncorrelated *cannot* be rejected – is reported alongside the mean D-W statistic and the number of estimations for which the Q-statistic *cannot* be rejected – under the null hypothesis of no autocorrelation – is reported alongside its P-value.¹⁸

For the correctly specified estimating equation, the key inflation coefficient compares favourably to the theoretical prediction of 2.125 for the high-frequency component (mean estimate of 2.221) and the medium-term cycle (mean estimate of 2.068) but is substantially smaller than the theoretical prediction for the medium-frequency component (adjusted mean estimate of 0.191). Furthermore, estimates of the coefficient on inflation are estimated precisely for the high frequency component and for the medium-term cycle – 1000 statistically significant coefficient estimates are obtained at both frequencies – but only 596 out of 1000 estimates are statistically significant at the 5% level for the medium-frequency component. In terms of the coefficient on inflation, the results

¹⁷ The instrument set is modified to include lagged output growth terms instead of lagged consumption growth terms for this misspecified estimating equation.

¹⁸ The D-W count excludes cases which lie in the inconclusive region of the test’s critical values so that only decisive rejections of the null hypothesis are included.

presented in Table 4.4 therefore confirm (high-frequency component) and extend (medium-term cycle) the results presented in Tables 3.3-3.5 of Chapter-III.

[Table 4.4 here]

Estimated coefficients for velocity growth are found to be statistically significant and correctly signed for all 1000 simulated samples under each of the three filters but the mean point estimate is smaller than the theoretical prediction of -0.065 in each case. The forward interest rate coefficients are estimated with a high degree of precision and the mean estimates are correctly signed for the high-frequency component and the medium-term cycle but both estimates are smaller than the theoretical prediction, which is -1.125.

Under log utility ($\theta=1$), the coefficient on consumption growth would be expected to take the same magnitude as the coefficient on inflation and the coefficient on productive time growth would be expected to take a value of zero. This is plainly not the case at the high frequency component or at the medium-term cycle, even though reasonable estimates are produced for the coefficient on inflation at these frequencies. The estimated coefficients on consumption growth are statistically significant for all 1000 samples but the mean estimate is only around one tenth of the size of the mean estimate for the inflation coefficients, while more than 99% of the coefficients on productive time are estimated to be significantly different from zero. These results can also be assessed by calculating implied estimates of the structural coefficient of relative risk aversion (θ) from these direct GMM estimates. For example, the mean consumption growth coefficient implies an estimate of θ of 0.126 ($=0.279/2.221$) for the high-frequency component and an estimate of 0.142 ($=0.293/2.068$) for the medium-term cycle.¹⁹ Clearly, both of these implied estimates are substantially smaller than the calibrated value ($\theta=1$). Alternatively, the relationship $\beta_3=\beta_1\psi(1-\theta)l/(1-l)$, which comes from equation (4.1), can be used to obtain an estimate of θ . These implied estimates are 1.102

¹⁹ The estimated coefficient on consumption growth takes the wrong sign for the medium-frequency component so the implied estimate for θ is not discussed.

and 1.097 for the high-frequency component and medium-term cycle respectively, both of which are more in keeping with the calibration adopted.

In terms of the general features of the results derived from equation (4.11), the null hypothesis for the J-statistic cannot be rejected for all 1000 samples across all three frequency ranges, indicating that the instrument set used is consistently 'valid'. The mean R-squared statistic is reasonably high across all frequencies and the D-W statistics suggest that the estimated residual series do not suffer from autocorrelation for the high and medium-term frequencies. However, some caution is required in terms of the medium-frequency component because the combination of high mean R-squared and low mean D-W statistic might indicate a 'spurious regression' problem of the Granger and Newbold (1974) type. The presence of autocorrelation at the medium-frequency component is perhaps not surprising because Comin and Gertler (2006, Table 3) show that while their high frequency filter produces series which are not highly serially correlated, their medium-term cycle filter generates "significantly greater persistence for each series" (Comin and Gertler, 2006, p.530).²⁰ Therefore, the low D-W statistics for the medium-frequency component are likely to stem from the fact that high frequency fluctuations are discarded by the 8-20 filter. Reassuringly, the same high R-squared, low D-W combination is not apparent when the high- and medium-term components are combined to form the medium-term cycle.

Turning to the misspecified estimating equation, the right-hand side of Table 4.4 reports an upward shift in the mean inflation coefficient for the high-frequency component and for the medium-term cycle, again extending the result obtained from the high frequency filter in Table 3.6 of Chapter-III to the medium-term cycle.²¹ This shift is particularly apparent for the high-frequency component as the mean estimate more than quadruples in magnitude. A similar upward shift is

²⁰ Unfortunately, Comin and Gertler do not present analogous autocorrelation statistics for the medium-frequency component alone. However, given their findings for the other two frequency bands, it is reasonable to suppose that the persistence found at the medium-term cycle emanates from the medium-frequency component.

²¹ The discussion focuses on the estimated inflation coefficient for the misspecified estimating equations because we are primarily interested in the 'Taylor principle implications' of these alterations to the correctly specified form.

evident but less pronounced for the medium-term cycle, for which the mean estimate for the inflation coefficient increases by approximately 50%. These larger coefficient estimates cannot be attributed to the fact that the central bank takes a particularly 'tough stance' against inflation deviations from target, as one might conclude from a Taylor rule perspective, but arise because the estimating equation no longer accurately reflects the data generating process. Model misspecification of this form generally leads to a small decline in the precision with which the coefficients are estimated and yields substantially smaller mean R-squared statistics at the high and medium-term frequencies. The medium-frequency component once again yields a high mean R-squared statistic and low D-W statistic so one would need to treat these estimates with caution.

4.4.3 The Taylor Condition for U.S. Time Series Data

The econometric techniques used to evaluate model-simulated data are now applied to a post-war sample of U.S. data. The data are obtained from the Federal Reserve Bank of St. Louis Economic Data (FRED) directory and have been seasonally adjusted at source where applicable. The full sample comprises of 205 quarterly observations between 1960q1 and 2011q1. Quarterly data is used both in order to comply with empirical studies in the Taylor rule tradition and in order to provide a reasonably large sample of data for the estimation techniques to exploit. Inflation is calculated from the GDP deflator [FRED series code: GDPDEF], consumption growth is calculated from the Personal Consumption Expenditure [PCE] index, non-leisure hours are represented by the civilian employment-to-population ratio [EMRATIO] and the consumption velocity of money is constructed by taking the ratio of nominal consumption expenditures [PCE] to the M1 money supply [M1SL]. Growth rates are calculated as year-over-year percentage changes in the level of the relevant series. We follow the interest rate rule literature and use the effective federal funds rate [FEDFUNDS] as the dependent variable. The intuition behind this choice is clear in an interest rate rule setting where policymakers are deemed to implement their policy decisions by 'selecting' an appropriate level for a short-term nominal interest rate.

Empirical studies in the interest rate rule tradition typically treat the data as stationary without undertaking a rigorous analysis to formally verify this approach. Clarida et al. (2000, p.154), for example, cite the low power of conventional unit root tests as justification for this assumption.²² Accordingly, the data are initially analysed using conventional econometric methods which require stationary series. Also in keeping with the empirical literature, actual data is analysed in unfiltered form, unlike the model-simulated data studied previously. Following Clarida et al. (2000), the data is split into pre-Volcker (1960q1-1979q2) and Volcker-Greenspan (1979q3-onwards) subsamples, where Paul Volcker's appointment as Chairman of the Federal Reserve is used as an arbitrary break-point.²³ Three endpoints are considered for the post-Volcker subsample: the first is consistent with Clarida et al.'s (2000) Volcker-Greenspan subsample which ends in 1996q4 (denoted "CGG post-Volcker"), the second ends in 2000q3 in order to incorporate Taylor's (2009a) claim that monetary policy veered "off track" during the early 2000s ("Taylor post-Volcker") and the third utilises the remainder of the sample ("extended post-Volcker", 1979q3-2011q1).²⁴ Coefficient estimates are also obtained for the 'full sample' period of 1960q1-2011q1, although Clarida et al. (2000) do not consider an estimation period of comparable length.

The forward-looking interest rate rule proposed by Clarida et al. (2000) is first estimated as a preliminary check on the econometric procedure employed. The GMM technique described above is used to evaluate an empirical specification in which the nominal interest rate is regressed on a constant, expected future inflation, the expected output gap and up to two lags of the nominal interest

²² Siklos and Wohar (2005) and Österholm (2005) are critical of the empirical literature for not adequately addressing the time series properties of the data. We consider this issue in greater detail in Section 4.5 when assessing the Fisher relation; in that literature it is common to establish formally whether the data is stationary or not as a preliminary step.

²³ It would, of course, be more rigorous to use a formal econometric procedure (e.g. Bai and Perron, 1998) to identify the appropriate break-point in the data. However, the purpose of the current exercise is to evaluate the Taylor Condition within Clarida et al.'s (2000) econometric framework given that it has been frequently applied in the empirical literature. Furthermore, Gavin and Kydland (1999) identify 1979q3 as an important break-point in U.S. data for nominal variables, noting that the Federal Reserve announced a major change in operating procedures in favour of control of the money supply at the end of this quarter.

²⁴ The 'Taylor post-Volcker' subsample coincides with Jondeau et al.'s (2004) 'Volcker-Greenspan' sample.

rate.²⁵ These lagged dependent variable terms are often interpreted to capture ‘interest rate smoothing’ behaviour on the part of policymakers (e.g. Clarida et al., 2000, p.152) but from an econometric perspective they simply serve to relieve the estimated residuals of serial correlation.²⁶ The Q-statistic and the statistical significance of the coefficients on the lagged dependent variable terms are used to judge the appropriate lag length and the most parsimonious specification is always preferred.²⁷ As with the simulated data above, the instrument set comprises of lagged variables, but unlike Clarida et al. (2000) it does not include variables which do not otherwise feature in the estimating equation. Coefficient estimates obtained for Clarida et al.’s (2000) interest rate rule using our dataset – results not reported in full – show that the ‘pre-Volcker’ subsample is characterised by an interest rate rule with an inflation coefficient of 0.80 (compared to CGG’s estimate of 0.83), an output gap coefficient of 0.39 (CGG: 0.27) and a sum of lagged dependent variable coefficients of 0.75 (CGG: 0.68). The ‘CGG post-Volcker’ subsample yields an estimated inflation coefficient of 2.17 (CGG: 2.15), an output gap coefficient of 0.94 (CGG: 0.93) and an estimated coefficient of 0.78 on the lagged dependent variable (CGG: 0.79).²⁸ Overall, the econometric procedure replicates Clarida et al.’s point estimates rather well, despite the slight difference in the instrument set used.

The same econometric techniques are now applied to the ‘correctly specified’ Taylor Condition for U.S. time series data. The results are presented in Table 4.5. Specification tests suggest that one lagged dependent variable term is required for the ‘pre-Volcker’ period but that lagged terms are not required for the post-Volcker subsamples, or for the full sample period.²⁹ Table 4.5 reports a point estimate of 1.170 for the inflation coefficient during the ‘pre-Volcker’ period and a

²⁵ The output gap is calculated using the CBO’s estimate of potential output [GDPPOT].

²⁶ The interest rate smoothing interpretation of such lagged dependent variable terms is not universally accepted (e.g. Rudebusch, 2002).

²⁷ The Q-statistic is now used because the Durbin-Watson statistic is not appropriate for testing for autocorrelated residuals if the estimating equation contains lagged dependent variable terms.

²⁸ Only one lagged dependent variable was found to be necessary to relieve the estimated residuals of serial correlation for the ‘CGG post-Volcker’ subsample as opposed to Clarida et al.’s (2000) specification which includes two lags.

²⁹ The pre-Volcker specification with no lagged dependent variable terms produces a D-W statistic of 1.580 (critical values 1.482-1.769) and a Q-statistic P-value of 0.068. The estimated coefficient on inflation is not statistically significant for this specification.

point estimate of 1.973 for the ‘CGG post-Volcker’ subsample. Extending the post-Volcker subsample to 2000q3 yields an estimated inflation coefficient of 1.955 and further extending this subsample to 2011q1 yields an inflation coefficient of 1.747. It is apparent that the statistical significance of the coefficients on consumption growth, productive time growth and velocity growth diminish for the ‘extended post-Volcker’ subsample, whereas all variables are found to be statistically significant to at least the 5% level for the two post-Volcker subsamples which stop short of the point at which the Federal Reserve allegedly departed from a stabilising interest rate rule (Taylor, 2009a). Nevertheless, the point estimate for the inflation coefficient remains above unity and is statistically significant to at least the 5% level for all subsamples. In short, the ‘Taylor principle’ is satisfied. Over the full sample period the point estimate for the inflation coefficient is estimated to be 0.919. However, the P-value for the Q-statistic is 0.010, so we reject the null hypothesis of no serial correlation in the estimated residual series at the 5% level of significance; the D-W statistic concurs given that it falls below its critical range.³⁰ Although serial correlation in the error term does not bias the reported estimates, it can lead to an understatement of the standard errors and thus provide unwarranted confidence about the precision with which the coefficients are estimated. We address this problem by using alternative econometric techniques to analyse the full sample period at a later stage.

Concerns about serial correlation do not apply to the subsamples, however. The result that the inflation coefficient exceeds one for the pre-Volcker subsample differs from Clarida et al.’s (2000) well-known and oft-replicated result that monetary policy progressed from violating the Taylor principle during the pre-Volcker era to adhering to it for the post-Volcker period. Moreover, for the pre-Volcker subsample the coefficients on velocity growth and the forward interest rate – terms which do not feature in conventional interest rate rules – are found to be statistically significant at the 1% level, thus pointing to the potential importance of these terms to the unconventional result in terms of the inflation

³⁰ Adding lagged dependent variables to the full sample specification does not ameliorate this serial correlation: Pr(Q) falls to 0.001 with one lag and 0.000 with two lags (results not reported in full).

coefficient. The forward interest rate term in particular is found to be statistically significant at the 1% level across all estimation periods. This latter finding motivates one of the specification restrictions considered in Section 4.5.

[Table 4.5 here]

4.4.4 A ‘Taylor Rule’ for Model-Simulated Data

Table 4.6 presents estimates obtained from a ‘standard Taylor rule’ with and without the forward interest rate term. Including a term in the forward interest rate – as in equation (4.6) – produces inadmissible estimates of the inflation coefficient at all three frequencies. According to the underlying model the coefficient on inflation, Ω in equation (4.1), cannot fall below one. The results also raise concerns about the validity of the instrument set given the low number of J-statistic non-rejections. The combination of high R-squared and low D-W statistic is again apparent for the medium-frequency component estimates. Forming a ‘non-dynamic Taylor rule’ by omitting the forward interest rate term ($\beta_5=0$) generally improves the precision of the coefficient estimates and the mean inflation coefficient for the medium-term cycle now stands at 1.265 (adjusted mean). A researcher unaware of the true data generating process might conclude that the central bank is following a Taylor rule which violates the Taylor principle in the unrestricted ($\beta_5 \neq 0$) case and a Taylor rule which satisfies the Taylor principle in the restricted ($\beta_5=0$) case, similar to the way in which the empirical results obtained by Taylor (1999) or Clarida et al. (2000) are conventionally interpreted. Indeed, Mankiw (2001, Table 7) suggests that the behaviour of the Federal Reserve was consistent with a non-dynamic interest rate rule with an inflation coefficient of 1.39 during the 1990s and attributes the stability of inflation at that time to this ‘desirable’ policy response. However, neither estimate presented in Table 4.6 is derived from an empirical model which accurately represents the true data generating process hence no inferences can be made about the conduct of monetary policy; monetary policy continues to be described by the money growth rule described in Chapter-III, Section 3.2.4.

[Table 4.6 here]

4.5 Empirical Analysis: The Fisher Relation

Having obtained estimates for the coefficient on inflation consistent with the Taylor principle, we now consider the circumstances under which this result reverts to the one-to-one relationship stipulated by the Fisher relation. Firstly, the estimating equation remains in its ‘correctly specified’ form (4.11) but the periodicity of the medium-term cycle, assumed to comprise of cycles of 2-20 ‘years’ in Section 4.4, shall be extended towards and beyond Comin and Gertler’s (2006) 2-200 quarter specification. Secondly, the filter specifications used in the previous section are retained but the estimating equation shall be restricted to exclude the forward interest rate term ($\beta_5=0$) and to conform to the ‘long-run Taylor Condition’ introduced above ($\beta_3=\beta_4=\beta_5=0$). Thirdly, the ‘long-run Taylor Condition’ (4.7) is cast as a long-run equilibrium relationship and an alternative econometric framework shall be introduced to facilitate this.

4.5.1 Extending the Medium-Term Cycle for Model-Simulated Data

Up until this point the upper periodicity used to define the medium-term cycle has been shorter than Comin and Gertler’s (2006) upper periodicity of 200 quarters. Table 4.7 shows how the estimated coefficients change as the upper periodicity is varied between 15 and 75 periods. The upper periodicity of 25 periods (‘years’) corresponds to Basu et al.’s (2012) 2-100 quarter “medium term” filter and the upper periodicity of 50 periods corresponds to Comin and Gertler’s (2006) 2-200 quarter filter.³¹

[Table 4.7 here]

The results show that the mean estimated inflation coefficient declines as the window length is extended. At the upper periodicity consistent with Basu et al.’s ‘medium-term’, the coefficient on expected inflation takes a mean value of 1.840 (with 1000 statistically significant estimates) which, although lower than the

³¹ The filter specifications adopted here come as close as possible to those used by Basu et al. and Comin and Gertler but we face the constraint that cycles of less than two periods cannot be extracted from the data. Since a ‘period’ is interpreted as a year for present purposes but corresponds to a quarter in these studies, the correspondence between our filters and theirs is not exact at the high frequency (low periodicity) end.

predicted value ($\Omega=2.125$), is still compatible with the ‘Taylor principle’. The remaining coefficients are also estimated precisely at this 2-25 frequency – 1000 statistically significant estimates are generated for expected consumption growth, 921 for expected productive time growth, 1000 for expected velocity growth and 951 for the forward interest rate.

Comin and Gertler’s (2006) upper periodicity of 50 years, on the other hand, produces a mean estimated inflation coefficient of approximately unity (1.089, adjusted mean for 977 statistically significant estimates). This estimate is consistent with the one-to-one relationship between the nominal interest rate and (expected future) inflation implied by the Fisher relation, although (4.11) features more variables than an estimating equation used to verify the conventional Fisher relation typically would. However, the number of statistically significant estimates for the productive time growth and forward interest rate terms falls sharply when the upper periodicity is increased from 25 to 50 years, possibly signifying that these terms are superfluous at this frequency band. Only the terms in inflation, consumption growth and velocity growth generate a reasonable number of statistically significant estimates at Comin and Gertler’s ‘medium-term cycle’. The fact that an approximately unit coefficient on inflation is obtained as the upper periodicity is extended in this way would be consistent with the notion that the Fisher relation holds as a ‘long-run’, lower frequency relationship in the model. We explore this point formally using appropriate econometric methods at a later stage.

4.5.2 Restricted Estimating Equations

For model-simulated data we consider two alternative versions of the ‘correctly specified’ estimating equation (4.11). Firstly, we impose the restriction $\beta_5=0$ so that the forward interest rate term is omitted. The estimating equation is therefore:

$$\bar{R}_t = \beta_0 + \beta_1 E_t \bar{\pi}_{t+1} + \beta_2 E_t \bar{g}_{c,t+1} + \beta_3 E_t \bar{g}_{l,t+1} + \beta_4 E_t \bar{g}_{v,t+1} + e_t , \quad (4.13)$$

and secondly the restriction $\beta_3=\beta_4=\beta_5=0$ is imposed so that terms in the growth rate of productive time, velocity growth and the forward interest rate term are omitted, as follows:

$$\bar{R}_t = \beta_0 + \beta_1 E_t \bar{\pi}_{t+1} + \beta_2 E_t \bar{g}_{c,t+1} + e_t . \tag{4.14}$$

This second restriction produces an estimating equation which reflects the ‘long-run Taylor Condition’ presented as equation (4.7) above. As noted at that point, second moment terms, which reflect the extent to which nominal bonds act as suitable ‘insurance’ against periods of low consumption growth and which feature in Canzoneri et al.’s (2007) empirical specification, are absent from equation (4.7) due to the log-linearization procedure used to derive the Taylor Condition (4.1). Crowder and Hoffman (1996) also drop second moment terms from their analysis of the Fisher relation on the basis that previous empirical studies have found such terms to be only marginally significant while Arnwine and Yigit (2008, p.194) argue that the omission of such terms is justifiable for “a low inflation risk economy”.³²

Table 4.8 shows the consequences of imposing these two sets of restrictions upon the correctly specified estimating equation.³³ The first restriction ($\beta_5=0$) yields a lower mean inflation coefficient for both the high frequency component and for the medium-term cycle relative to the estimates reported above for the ‘correctly specified’ empirical model. The mean estimate for the medium-term cycle now takes a value of 1.025 compared to 2.068 previously (Table 4.4) and these coefficients are estimated no less precisely under this restriction (1000 statistically significant estimates). This estimate is similar to the GMM estimate of 0.963 presented on the right hand side of Table 3.5 in Chapter-III for the same

³² Crowder and Wohar (1999) also omit these second moment terms and Crowder and Hoffman (1996, p.106) state that: “The evidence given by Shome, Smith, and Pinkerton (1988) implies that the effects of the risk premium on the “Fisher effect” estimates are inconsequential.” However, they subsequently caution that: “rejections of the implications of the textbook Fisher relation may suggest that these factors are indeed important.” (ibid).

³³ Once again, the instrument set is appropriately adapted to reflect each modification to the estimating equation.

restricted estimating equation under a 2-15 band pass filter. The high-frequency component (adjusted) mean estimate of 0.370 would now be inadmissible in the context of the Benk et al. (2010) model, for which Ω may not fall below one, whereas the corresponding estimate stood at 2.221 in Table 4.4, well in excess of unity. Not surprisingly given that the estimating equation is now misspecified, the estimated inflation coefficient no longer resembles the theoretical prediction. The forward interest rate term turns out to be a crucial element of the full estimating equation (4.11), as was established in Chapter-III. Finally, the estimated inflation coefficient for the medium-frequency component ($\beta_1=0.949$) is now similar to the medium-term cycle estimate but, as with Table 4.4, one would need to treat this estimate with caution because of the high R-squared, low D-W statistic combination which continues to characterise the results obtained from this frequency band.

[Table 4.8 here]

Table 4.8 also shows that an (adjusted) mean inflation coefficient of 0.916 is obtained from the medium-term cycle under the second restricted estimating equation ($\beta_3=\beta_4=\beta_5=0$), as is consistent with theoretical prediction of Canzoneri et al.'s (2007, p.1866) Euler equation and Arnwine and Yigit's (2008, eq.6) "augmented Fisher relation". On the other hand, the mean consumption growth coefficient, which in principle now provides a direct estimate of the coefficient of relative risk aversion, is substantially smaller (0.128, adjusted mean) than the calibrated value ($\theta=1$). However, it should be noted that the validity of the instrument set now appears to deteriorate and the estimated residual series show symptoms of autocorrelation according to both the D-W and Q statistics. The latter finding might indicate that the 'long-run Taylor Condition' (4.7) is better thought of as a long-run equilibrium condition for model-simulated data. This suggestion shall be explored using alternative econometric techniques later on in this section.

Considering the first of the two restricted specifications ($\beta_5=0$) against U.S. time series data, the point estimate for the coefficient on inflation is found to traverse

one for the pre- and post-Volcker subsamples in a similar manner to Clarida et al.'s (2000) findings for a forward-looking interest rate rule (Table 4.9). The 'pre-Volcker' estimate of 0.89 for the inflation coefficient is comparable to Clarida et al.'s estimate of 0.83, while the 'CGG post-Volcker' estimate of 1.97 compares to their estimate of 2.15 for this same period (Clarida et al., 2000, Table II).³⁴ It is also apparent from Table 4.9 that omitting the forward interest rate term leads to coefficients on consumption growth which are not statistically significant but that the coefficients on the 'productive time' term remain significant at the 1% level for all estimation periods.

[Table 4.9 here]

Turning to the second restricted specification for the 'long-run Taylor Condition', this estimating equation produces a higher pre-Volcker estimate for the inflation coefficient compared to the first restriction (Table 4.10).³⁵ Consequently, although the coefficient on inflation does increase when moving from pre- to post-Volcker subsamples in keeping with Clarida et al.'s (2000) estimates, the pre-Volcker point estimate no longer falls decisively below unity. The pre-Volcker point estimate for the coefficient on inflation is 1.048 and the post-Volcker point estimates all exceed two. Over the full sample period, the point estimate for the coefficient on inflation takes a value of unity in keeping with the 'long-run Taylor Condition'. However, the estimated residual series is potentially autocorrelated over the full sample because the Q-statistic produces a P-value of 0.052 and so only marginally fails to reject at the 5% level of significance, even with two lagged dependent variable terms added to the specification. This is similar to the

³⁴ Diagnostic tests suggest that two lagged dependent variable terms are required for the 'pre-Volcker' subsample but that one lagged dependent variable term is sufficient for all other estimation periods. 'Pre-Volcker': a zero lag specification produces a D-W statistic of 0.532 and a Pr(Q) statistic of 0.000; adding one lagged dependent variable produces Pr(Q)=0.045. 'CGG-post': D-W=0.573 and Pr(Q)=0.000 for a zero lag specification; 'Taylor-post': D-W=0.546, Pr(Q)=0.000; 'extended-post': D-W=0.272, Pr(Q)=0.000; full sample: D-W=0.140, Pr(Q)=0.000.

³⁵ Two lagged dependent variable terms are now required for the 'pre-Volcker' and 'full sample' periods and one lagged dependent variable is required for each of the post-Volcker subsamples. 'Pre-Volcker': a zero lag specification produces a D-W statistic of 0.405 and a Pr(Q) of 0.000; adding one lagged dependent variable gives Pr(Q)=0.001; 'CGG-post': D-W=0.575 and Pr(Q)=0.000 for a zero lag specification; 'Taylor-post': D-W=0.588, Pr(Q)=0.000; 'extended-post': D-W=0.316, Pr(Q)=0.000; 'full sample': D-W=0.156 and Pr(Q)=0.000 with zero lags and Pr(Q)=0.004 with a single lag.

autocorrelation reported for the same estimating equation for model-simulated data in Table 4.8. To deal with such concerns we next consider an alternative econometric framework which casts (4.7) as a long-run equilibrium condition.

[Table 4.10 here]

4.5.3 Error Correction Model

We now adopt the econometric framework of Mehra (1991, 1993), who uses an error correction model (ECM) to estimate a money demand function, in order to cast the 'long-run Taylor Condition' as a long-run equilibrium condition. Crowder and Hoffman (1996) and Arnwine and Yigit (2008) have applied similar techniques to evaluate the Fisher relation. Mehra's (1991, 1993) procedure is particularly useful if the postulated long-run relationship contains a mixture of stationary and non-stationary series. This is potentially relevant for present purposes because one might reasonably expect inflation to be a non-stationary series for actual data (e.g. Pivetta and Reis, 2007; Russell, 2011) but consumption growth to be stationary (e.g. Arnwine and Yigit, 2008). In this case, the simple 'two-step method' cannot be applied because least squares coefficient estimates obtained from the estimating equation (4.14) would be inconsistent at the first stage.³⁶ The two-step method is also inappropriate if the estimated residuals are serially correlated at the first stage because conventional standard errors are not then suitable for hypothesis testing (Mehra, 1991, p.6). Both of these problems potentially apply to the restricted estimating equation (4.14) but can be overcome within Mehra's framework.

Adapting Mehra's approach in a manner consistent with Arnwine and Yigit (2008), the 'long-run Taylor Condition' (4.7) is cast as an equilibrium relationship of the form:

³⁶ The two-step method is as follows (Mehra, 1991, p.5): first, use a consistent estimating procedure to evaluate the long-run relationship (this will be equation 4.15) and second, use the residuals from step 1 to estimate the short-run dynamics (these will be governed by equation 4.16).

$$\bar{R}_t = \rho_0 + \rho_1 \bar{\pi}_t + \rho_2 \bar{g}_{c,t} + \zeta_t, \quad (4.15)$$

where ζ_t represents an error term and short-run fluctuations about this long-run relationship are assumed to take the following, 'error-correction' form:

$$\Delta \bar{R}_t = \varphi_0 + \sum_{s=0}^{\tau_1} \varphi_{1,s} \Delta \bar{\pi}_{t-s} + \sum_{s=0}^{\tau_2} \varphi_{2,s} \Delta \bar{g}_{c,t-s} + \sum_{s=1}^{\tau_3} \varphi_{3,s} \Delta \bar{R}_{t-s} + \varphi_4 \zeta_{t-1} + \epsilon_t, \quad (4.16)$$

where the lag lengths τ_1 , τ_2 and τ_3 must be selected by the user, (ϵ_t) is a short-run random disturbance term and the coefficient φ_4 governs the speed at which the long-run relationship is restored in the event that it failed to hold in the previous period (i.e. if $\bar{R}_{t-1} - \rho_0 - \rho_1 \bar{\pi}_{t-1} - \rho_2 \bar{g}_{c,t-1} \neq 0$). Eliminating ζ_{t-1} from equation (4.16) using the long-run relationship (4.15) yields the following 'reduced form' in the first difference of the nominal interest rate:

$$\begin{aligned} \Delta \bar{R}_t &= \chi_0 + \sum_{s=0}^{\tau_1} \chi_{1,s} \Delta \bar{\pi}_{t-s} + \sum_{s=0}^{\tau_2} \chi_{2,s} \Delta \bar{g}_{c,t-s} + \sum_{s=1}^{\tau_3} \chi_{3,s} \Delta \bar{R}_{t-s} \\ &\quad - \chi_4 \bar{\pi}_{t-1} - \chi_5 \bar{g}_{c,t-1} + \chi_6 \bar{R}_{t-1} + \epsilon_t, \end{aligned} \quad (4.17)$$

where $\chi_0 = (\varphi_0 - \varphi_4 \rho_0)$, $-\chi_4 = \varphi_4 \rho_1$, $-\chi_5 = \varphi_4 \rho_2$ and χ_6 now indicates the speed at which (4.15) is restored (i.e. $\chi_6 = \varphi_4$). Equation (4.17) allows short- and long-run coefficients to be evaluated jointly and estimates of the structural parameters can be obtained from the reduced form estimates as, $\rho_1 = -\chi_4 / \chi_6$ and $\rho_2 = -\chi_5 / \chi_6$.³⁷ The standard errors associated with these implied structural estimates shall be calculated using the delta method in order to account for the fact that they are formed as non-linear combinations of directly estimated reduced form

³⁷ Mehra (1993, p.456) states that an implied estimate cannot be calculated for the structural constant term (ρ_0) but Arnwine and Yigit (2008) suggest that ρ_0 can be approximated as $-\chi_0 / \chi_6$. The tables of results below report estimates of ρ_0 using this approximation for completeness but they will not be discussed or interpreted in detail.

coefficients (e.g. Mihailov, 2006). Following Mehra (1993) and Arnwine and Yigit (2008), equation (4.17) is estimated using OLS and an instrumental variables technique (GMM) which allows for correlation between the regressors and the error term.

As Mehra (1991) explains, the reduced form (4.17) is only appropriate if the error term in (4.15), ζ_t , is stationary. If this is not the case then the model should be estimated in first difference form (i.e. $\varphi_4=0$). However, a standard first differences specification is inappropriate if ζ_t is stationary because potentially useful information would be discarded during the differencing process. It follows that if any of the series in the long-run relationship (4.15) are found to be non-stationary then cointegration between these variables is required in order for (4.17) to represent a valid empirical specification. Following Mehra (1991), we adopt the procedure of Engle and Granger (1987) and first test whether each of the variables in the long-run relationship is stationary over the full sample period. Secondly, the residuals obtained from the simple regression of (4.15) in levels are tested to see whether they are stationary. If evidence in favour of non-stationarity is found at the first stage but not at the second, this would suggest that a cointegrating relationship exists between the non-stationary variables in equation (4.15).

4.5.4 Fitting the ECM to U.S. Time Series Data

This time we begin by applying the ECM described above to U.S. time series data over the 'full sample' period (1960q1-2011q1) and consider the simulated data in the next section. While it is natural to use the federal funds rate to represent the nominal interest rate in the context of a Taylor-type interest rate rule (e.g. Clarida et al., 2000), empirical studies in the Fisher relation tradition often use a short-run Treasury bill rate to represent the nominal interest rate instead (e.g. Crowder and Hoffman, 1996; Arnwine and Yigit, 2008; see Neely and Rapach, 2008, for a review). We therefore consider the 3 month Treasury bill rate [FRED series code:

TB3MS] in addition to the effective federal funds rate when implementing the ECM described above.³⁸

As with Table 4.3 for simulated data, we apply one unit root test (ADF) and one stationarity test (KPSS) to each of the variables belonging to the long-run relationship (4.15); Mehra (1991) only considers an ADF test but we wish to implement a second test as a check on the results. The tests are applied to the nominal interest rate, the rate of inflation and the consumption growth rate and the first difference of each variable in order to explore the possibility that they might be $I(2)$. The tests indicate that both the nominal interest rate series and the inflation series are $I(1)$ – the KPSS tests in the top panel of Table 4.11 reject the null hypothesis that these two series are stationary in levels and the ADF test does not reject the null hypothesis that they are integrated of order one; the ADF tests in the bottom panel reject the null that the first difference of the nominal interest rate and inflation are $I(1)$ and the KPSS test cannot reject the null that the first differences are stationary.³⁹ Clearly, these findings immediately pose a further problem for the full sample estimates presented in Tables 4.5, 4.9 and 4.10. However, the tests are not so decisive with respect to the consumption growth rate – while both tests seem to agree that \bar{g}_c is not $I(2)$, two of the ADF tests reject the null of a unit root at the 90% level of significance and the KPSS test with a constant and a trend fails to reject the null of stationarity. On balance, these test statistics suggest that the consumption growth rate is stationary over the full sample period. Given the mixed results for \bar{g}_c , it would seem prudent to adopt Mehra’s econometric framework which allows stationary and non-stationary variables to enter the long-run equilibrium relationship simultaneously.⁴⁰

[Table 4.11 here]

³⁸ The correlation coefficient between FEDFUNDS and TB3MS is 0.990 over the full sample period.

³⁹ The tax adjusted interest rates in Tables 4.11 and 4.12 should be ignored for the time being.

⁴⁰ As discussed in the previous section, the seminal study of Clarida et al. (2000) cites the unsatisfactory nature of such tests as grounds for omitting a formal analysis of the stationarity of the data.

In light of the results reported in Table 4.11, we require cointegration between the non-stationary variables in (4.15) in order for equation (4.17) to represent a valid empirical specification. To evaluate this, we perform a series of ‘cointegrating regressions’ using the non-stationary variables; if the residual series from such regressions are found to be stationary then this suggests that a linear combination of the non-stationary series are stationary, i.e. the series are cointegrated. Following Mehra (1991, Table 2), we regress both empirical proxies for the nominal interest rate on inflation and also perform the regression with the dependent and independent variables reversed. Table 4.12 reports the slope coefficient obtained from this procedure along with ADF and KPSS test results for the residuals of the cointegrating regression, ζ_t .⁴¹ The ADF test suggests that the null hypothesis that the estimated residual series has a unit root can be rejected at either the 90% or the 95% level depending on whether the nominal interest rate or inflation is used as the dependent variable for the cointegrating regression, while the KPSS test suggests that the null hypothesis that the estimated residual series is stationary cannot be rejected at conventional levels of significance. These results are not materially affected by whether the effective federal funds rate or the 3 month Treasury bill rate is used as the empirical proxy for the nominal interest rate. Overall, there is evidence to suggest that the nominal interest rate and inflation are cointegrated over the full sample of U.S. data considered here.

[Table 4.12 here]

Having confirmed that the pre-requisites for the ECM are satisfied for our sample of post-war U.S. data, we are now able to estimate the reduced form model (4.17) using OLS and GMM procedures. One issue we face is in selecting the lag lengths τ_1 , τ_2 and τ_3 . Mehra (1991, 1993) is not clear as to how this feature of the specification is determined. For present purposes, we apply a grid search over 27 empirical specifications which allow τ_1 , τ_2 and τ_3 to vary between 0 and 2. For the

⁴¹ Mehra (1991, Table 2) considers only the ADF test. He omits the constant and the trend when testing the residuals from the cointegrating regression despite the fact that he includes a constant and a trend when testing the stationarity of the series (Mehra, 1991, Table 1). As such, the trend is also omitted from the KPSS test here but the constant term cannot be dispensed with.

OLS estimator, the 'preferred specification' is deemed to be the one which minimises the Akaike Information Criterion. However, information criterion such as these cannot be applied under the GMM procedure so the lag structure is chosen simply in order to relieve the estimated residuals of serial correlation. The GMM selection therefore inevitably involves a greater degree of judgement but we shall show that estimates of the key inflation coefficient (ρ_1) are not sensitive to the estimation technique adopted. Following Mehra (1993) and Arnwine and Yigit (2008), the instrument set for the GMM estimator comprises of a constant, two lagged first differences of the nominal interest rate, four lagged first differences of inflation, four lagged first differences of consumption growth and one lagged level of the nominal interest rate, inflation and consumption growth.

Table 4.13 presents the results obtained from the OLS and GMM estimators, using both the effective federal funds rate and the 3 month Treasury bill rate as the empirical proxy for the nominal interest rate. The estimates of primary interest are those for the coefficients of the long-run equilibrium condition, ρ_1 and ρ_2 in equation (4.15); these estimates can be found in the uppermost portion of Table 4.13. The results show that the estimated coefficient on inflation is similar regardless of whether the federal funds rate or the Treasury bill rate is used to represent the nominal interest rate and regardless of whether the OLS or GMM estimator is employed. Furthermore, the Q-statistic suggests that the estimated residual series is not afflicted by serial correlation and the J-statistic suggests that the instrument set used for the GMM procedure is valid. The R-squared statistics are in the region of 0.20-0.25, which is rather low, but consistent with the R-squared statistics reported by Arnwine and Yigit (2008, Table 1) for a similar regression.

[Table 4.13 here]

The estimates for ρ_1 and ρ_2 presented in Table 4.13 can be compared to the analytical form for the 'long-run Taylor Condition', equation (4.7). Take the GMM estimates produced using the 3 month Treasury bill as the empirical proxy for the nominal interest rate for example, the estimated coefficient on the constant term

is not statistically significant, the estimated coefficient on inflation is 1.210 and the estimated coefficient on consumption growth is 1.040. The estimates for ρ_0 and ρ_2 therefore conform to equation (4.7) with $\theta \approx 1$ but, at first sight, the point estimate for the coefficient on inflation appears to be 'too high'. But as discussed in the introduction, an inflation coefficient in excess of one would be consistent with a long-run Fisher relation if tax effects are important. Disregarding the form of investor irrationality suggested by Tanzi (1980), if capital income is subject to taxation then investors have an incentive to adjust their asset portfolios up until the point at which a one-for-one relationship exists between the *after tax* nominal interest rate and inflation. As Crowder and Wohar (1999, p.310) explain, in this case the coefficient on inflation in the Fisher relation would not take a value of unity but $(1-\xi_k)^{-1}$, where ξ_k is the tax rate on capital income (the return on nominal government bonds here). As such, Neely and Rapach (2008, p.614) note that estimates in the region of 1.3-1.4 for the coefficient on inflation would be reasonable because estimates of this order imply a plausible tax rate in the region of 20%-30%. Similarly, Summers (1982) and Crowder and Hoffman (1996) state that one would expect a coefficient estimate in the range of 1.3-1.5 if no provision is made for taxation.

Upon obtaining an estimated inflation coefficient of this magnitude, some studies conclude with the conjecture that the results are consistent with a 'tax adjusted Fisher relation' (e.g. Crowder, 2003) but others attempt to calculate the appropriate adjustment to apply to the nominal interest rate in order to test for the expected one-for-one relation in tax adjusted data (e.g. Crowder and Hoffman, 1996). We estimate the appropriate tax adjustment by following the procedure set out by Padovano and Galli (2001). Although they did not examine the Fisher relation per se, others have used their estimates in this context (see Neely and Rapach, 2008, for a review). We prefer to calculate our own tax rates rather than adopt Padovano and Galli's estimates for two reasons: firstly, because they do not produce estimates beyond 1990 and secondly, because we wish to include only federal tax receipts in the calculation given that U.S. Treasury bills are exempt from state and local taxes. To estimate the appropriate tax adjustment to apply to the nominal interest rate, we regress annual federal tax receipts on a constant and

the level of annual real GDP using OLS.⁴² The estimated coefficient on real GDP subsequently provides an estimate of the change in tax revenue due to a change in aggregate income, i.e. the ‘effective marginal tax rate’ (Padovano and Galli, 2001). Separate regressions are run for each decade and the marginal tax rate obtained is applied to all quarters within that decade. Although this approach severely limits the sample size, the results (Table 4.14) show that the coefficient on real GDP is statistically significant at the 1% level and that the regression produces a high R-squared statistic for all decades with the exception of the final period (2000-2011). We therefore adjust the nominal interest rate series using our estimates for the first four decades of the sample period and use the average tax rate (revenue-to-GDP ratio) to make this adjustment for the 2000-2011 period.⁴³ ⁴⁴ Overall, our estimated marginal tax rates are smaller than Padovano and Galli’s (2001) estimates, which seems reasonable if they have included tax revenues at all levels of government whereas we have considered federal tax receipts only.⁴⁵

[Table 4.14 here]

We now re-estimate (4.17) using the tax adjusted nominal interest rate series. The same pre-requisites for the ECM must also apply to these new series. Table

⁴² Tax revenue data are obtained from OMB Historical Table 1.3 and are expressed in 2005 dollars. This data is only available on an annual basis, hence the frequency used for the regressions. Real GDP is FRED series GDPC1. For simplicity we omit the dummy variables used by Padovano and Galli (2001) to account for major tax reforms. Theirs is a multi-country study but for the U.S. they apply a dummy variable only to the 1980s. This appears to have a quantitatively small impact upon their estimated tax rate.

⁴³ Padovano and Galli (2001) note that empirical studies routinely use the revenue-to-GDP ratio to proxy for the effective tax rate. They argue that the effective *marginal* tax rate is a more appropriate measure theoretically. We use their preferred measure where it has been possible to produce a statistically significant estimate (1960s, 1970s, 1980s, 1990s) but revert to the revenue-to-GDP ratio where this has not been possible (2000-2011). Using the revenue-to-GDP ratio for the whole period would provide an estimated tax rate which varies very little because this ratio has been remarkably stable for post-war U.S. data, despite notable declines in top marginal and average tax rates. Gillman and Kejak (2013) offer a theoretical explanation for this apparent contradiction.

⁴⁴ There is a discrepancy between the revenue-to-GDP ratio calculated from OMB and FRED data and the receipts-to-GDP ratio reported in Historical Table 1.3. Table 4.14 reports both of these figures for each decade for completeness. However, for 2000-2011, the period for which we use the revenue-to-GDP ratio instead of the estimated marginal tax rate to adjust the nominal interest rate, there is only a trivial difference between the two estimates (0.171 and 0.173).

⁴⁵ It is unclear whether their measure of tax revenue includes state and local taxes. The only information they provide is that their series are obtained from the IMF's Government Financial Statistics and International Financial Statistics database.

4.11 considers the time series properties of the tax adjusted nominal interest rate and Table 4.12 presents a new set of cointegrating regressions. The tax adjustment makes no material difference to the conclusions drawn from the unadjusted series. The final step is to re-run the ECM (4.17) using both measures of the nominal interest rate and the same two econometric procedures. As Table 4.15 shows, the estimated inflation coefficient is now consistent with the Fisher relation but only if the 3 month Treasury bill rate is used as the empirical proxy for the nominal interest rate. Taking the OLS estimate under the 3 month rate, for example, the constant term is not statistically significant, the estimate of ρ_1 is 1.070 and the estimate of ρ_2 is 1.052. In the context of the 'long-run Taylor Condition', equation (4.7), these estimates would again correspond to a log utility function (CRRA with $\theta=1$). The estimate for ρ_2 falls slightly to 0.820 under the GMM estimator but the coefficient on inflation is still consistent with the Fisher relation ($\rho_1=1.041$). On the other hand, the estimates for ρ_1 obtained using the federal funds rate fall only slightly compared to the estimates presented in Table 4.13 for the unadjusted nominal interest rate and are thus still 'too high' relative to the predicted Fisher relation. Other aspects of this tax adjusted regression – including R-squared statistics, Q statistics and J statistics for instrument validity – remain satisfactory and similar to the results presented in Table 4.13.

[Table 4.15 here]

4.5.5 Fitting the ECM to Model-Simulated Data

The ECM is now applied to the 1000 samples of artificial data simulated from the Benk et al. (2010) model. The econometric framework is analogous to that of the previous section except for the fact that the long-run equilibrium condition is now specified to be:

$$\bar{R}_t = \rho_0 + \rho_1 \bar{\pi}_{t+1} + \rho_2 \bar{g}_{c,t+1} + \zeta_t , \quad (4.18)$$

in a manner consistent with the ‘long-run Taylor Condition’, equation (4.7) above but where the simulated data is now considered in unfiltered form so as not to remove any trends in the series.

The application of the ECM to simulated data might be questioned on the basis that Table 4.3 suggests that the majority of the simulated series are stationary. Firstly, out of the seven variables tested in Table 4.3, the nominal interest rate and inflation series are the ‘most likely’ to be non-stationary because they produce the smallest number of ADF rejections and KPSS non-rejections. Nevertheless, treating the simulated series as stationary, as we did in Section 4.4, still seems to be reasonable based upon the absolute number of rejections and non-rejections obtained. Secondly, the key requirement for the ECM is that the error term (ζ_t in equation 4.18) is stationary. If any of the variables in the long-run equilibrium (4.18) are non-stationary then cointegration is required for this to be true but if all of the series in (4.18) are stationary then ζ_t is also guaranteed to be stationary. It is not necessarily the case that ECMs can only be used with non-stationary data.⁴⁶ We therefore proceed to apply the ECM on the understanding that the simulated data is in all likelihood stationary but that this econometric framework can still be legitimately applied and might indeed be useful for ameliorating the autocorrelation reported in Table 4.8 (right-hand side).

As with the actual data, we must first investigate whether the two ‘non-stationary’ series are cointegrated. Table 4.16 repeats for simulated data the exercise conducted in Table 4.12 for actual data. The results indicate that the residual series derived from a simple regression of the nominal interest rate on inflation are stationary, as are the residuals obtained from this regression with dependent and independent variables reversed. The null hypothesis for the ADF test – that the residual series in question is integrated of order one – is rejected for 993 out

⁴⁶ De Boef and Keele (2008) have argued for wider use of error correction methods in their field, political science, where the data are often persistent but unlikely to be integrated. They state that: “ECMs suffer from benign neglect in stationary time series applications in political science. Intimately connected with and applied almost exclusively to cointegrated time series, it seems analysts have concluded that ECMs are only suited to estimating statistical relationships between two integrated time series. In fact, ECMs may be used with stationary data to great advantage.” (p.189).

of the 1000 samples while the null hypothesis for the KPSS test – that the residual series in question is stationary – is not rejected for 848 out of 1000 samples. Of course, this result would also be expected if we were to regress one stationary series on another stationary series. Either way, we may proceed to implement the ECM (4.17) for the long-run relationship (4.18). We also note the difference between the coefficient estimate derived from this cointegrating relationship and the coefficient obtained from the estimates derived from the levels regression in the right-hand side of Table 4.8. The consumption growth term would appear to be important for obtaining the Fisher relation result for the simulated data, as Arnwine and Yigit (2008) argue, given that the regression without \bar{g}_c produces a smaller mean coefficient estimate.

[Table 4.16 here]

The final step is to estimate the ECM for each of the 1000 simulated samples. As for the actual data above, we consider a GMM procedure along with a simple OLS estimator.⁴⁷ In order to choose an appropriate lag length we again search across 27 different specifications by varying τ_1 , τ_2 and τ_3 between 0 and 2. The residuals obtained from the OLS procedure exhibit a high degree of serial correlation for all prospective specifications but Table 4.17 presents the ‘preferred specification’ based on the AIC. On the other hand, the GMM estimator successfully ameliorates the autocorrelation problem and the resulting point estimate for the coefficient on inflation, ρ_1 in (4.18), is 1.033. This estimate is consistent with a one-to-one Fisher relation. However, the estimate for the coefficient on consumption growth is lower than the equivalent estimated presented in Table 4.15; 0.447 compared to (approximately) one previously. Other features of the GMM estimation appear to be satisfactory – the R-squared is reasonably high (0.806) and the instrument set satisfies the J-test for 933 out of 1000 samples.

[Table 4.17 here]

⁴⁷ As was the case for actual data, the instrument set for the GMM estimator consists of a constant, two lagged first differences of the nominal interest rate, four lagged first differences of inflation, four lagged first differences of consumption growth and one lagged level of the nominal interest rate, inflation and consumption growth.

4.6 Conclusion

It has become increasingly common to interpret the short-run relationship between the nominal interest rate and inflation as an interest rate rule. This interpretation has the advantage of conforming to the way in which prominent central banks around the world communicate their monetary policy decisions to the public (Mehrling, 2006). However, Lucas (2003) has questioned whether such rules offer any new insight given that the Fisher relation already explains the link between the nominal interest rate and (expected future) inflation. In recent empirical work, Islam and Ali (2012) have drawn a connection between well-known empirical results in the distinct Taylor rule and Fisher relation literatures. In this chapter, we use the structural model of Benk et al. (2010), outlined in detail in Chapter-III, to provide a unified theoretical framework for the relationship between these two literatures.

In essence, the standard consumption Euler equation, which we have shown in Chapter-I to be central to the 'equivalence' between interest rate rules and money supply rules in a flexible price environment, is augmented by a term which reflects the endogenous money-credit choice modelled by Benk et al. (2010). From this, we derive the interest rate rule implicit in the model, which we label as the Taylor Condition. As shown in Chapter-III, in general the 'Taylor principle' holds in the short-run in that the coefficient on inflation in the Taylor Condition exceeds one and reverts to its minimum value of one at the Friedman (1969) optimum, at which the net nominal interest rate is zero and money balances carry no opportunity cost. A coefficient of one on inflation is also obtained for the 'long-run Taylor Condition' introduced in this chapter and, as such, this long-run form corresponds to Arnwine and Yigit's (2008) 'augmented Fisher relation' which links the nominal interest rate to inflation and consumption growth.

For model-simulated data, we have extended the results of the previous chapter to apply to statistical filters which retain some of the lower frequency fluctuations that the standard 'business cycle' filters applied previously would have discarded. As described in Section 4.4, we extend the band pass filter in order to construct a 'medium-term cycle', similar in the spirit to Comin and Gertler (2006), although

initially using a narrower filter window than the one they initially specified. The Taylor principle result holds for extended filter windows of 2-20 and 2-25 years but the one-for-one relationship between the nominal interest rate and (expected future) inflation emerges as the window extended to conform to their original, 2-50 year, medium-term cycle. The Fisher relation is also found to hold for simulated data when the estimating equation is restricted to conform to the 'long-run Taylor Condition'.

Support for the theoretical restrictions implied by the underlying structural model has also been provided for U.S. time series data. One particularly striking result is that the variation in the coefficient on inflation reported by Clarida et al. (2000), and which is central to the New Keynesian account of the historical record, is not replicated for the Taylor Condition implicit in the Benk et al. (2010) model. Instead, the Taylor principle holds for both 'pre-Volcker' and 'post-Volcker' subsamples of our full, 1960-2011, period of study, as long as the correct empirical model is specified. In addition, we replicate the well-known result in the Fisher relation literature that there exists a one-for-one relationship between the nominal interest rate and inflation over the full 51 year period. To do so, however, we needed to resort to error correction methods to deal with the non-stationary nature of the nominal interest rate and inflation series over this lengthy time period and also applied a tax adjustment to the nominal interest rate series.

Our unified approach to the Taylor and Fisher relations has involved a careful consideration of monetary variables. Nelson (2008a) argues that the New Keynesian model cannot offer a coherent account of the long-run without reference to monetary variables. Similarly, we have shown that a variable velocity of money is crucial to the account of the short-run offered by our framework. More broadly, our alternative framework casts further doubt upon the notion that estimated interest rate rule can be used to reveal the underlying behaviour of policymakers.

CHAPTER-V: GENERAL CONCLUSION

5.1 Contribution

In this thesis we have provided a structural framework to account for empirical results consistent with both the Taylor principle and the Fisher relation. In so doing, we have questioned the conventional 'reaction function' interpretation of the relationship between the nominal interest rate and inflation, motivated by theoretical, empirical and practical reservations as to whether monetary policy analysis can be conducted without reference to monetary variables.

5.1.1 The Taylor Condition and the Taylor Principle

Building upon previous contributions to the literature, we have demonstrated how an expression which resembles a conventional interest rate rule can be derived as an equilibrium condition of a flexible price, cash-in-advance model (Benk et al., 2008, 2010) in which the monetary policy process is modelled as a money growth rule. We label this equilibrium condition the 'Taylor Condition' in order to reflect its similarities with a conventional interest rate rule yet its status as an equilibrium condition of an underlying model which makes no direct reference to such a rule. The Taylor Condition is stated in terms of the current period nominal interest rate and in full it features forward-looking terms in inflation, consumption growth, productive (non-leisure) time growth, velocity growth and the nominal interest rate (see equation 1.29 of Chapter-I). Two features of the Benk et al. model in particular enhance the resemblance between the Taylor Condition and a conventional interest rate rule. Firstly, their model incorporates endogenous growth which means that trending variables enter the Taylor Condition in deviation-from-balanced-growth-path (*BGP*) form. The Taylor Condition's term in expected future inflation, for example, thus emulates the deviation-from-target form in which this variable typically enters a conventional rule. Secondly, the Benk et al. model allows the velocity of money to vary by granting the representative consumer a choice between money and intratemporal credit as competing means of facilitating consumption purchases. As shown in Chapter-I, generalising the standard, constant velocity cash-in-advance model in this manner is crucial to obtaining an inflation coefficient in excess of unity as a

theoretical proposition. Without this, the coefficient on inflation is constant at one, as is the case for a cash-in-advance model which does not feature the endogenous money-credit choice, and the Taylor principle cannot be replicated. The Taylor Condition is, however, capable of generating an inflation coefficient of one as a special case at the Friedman (1969) optimum nominal interest rate ($\bar{R}=0$). In this scenario, the credit alternative to money is not chosen by the representative consumer because money carries no opportunity cost. However, as shown in Chapter-III, the Taylor Condition's inflation coefficient is not permitted to fall below one.

In the context of a conventional rule, the more-than-proportional relationship between the nominal interest rate and expected future inflation found in the full Taylor Condition would be interpreted to show that the rule satisfies the (rule-of-thumb) Taylor principle, whereby policymakers adjust the nominal interest rate more than proportionally in response to nascent inflationary pressures. Rules which incorporate this property are often interpreted to be virtuous ('desirable') rules which prevent nominal explosions in a backward-looking model, or preclude multiple equilibria in a forward-looking model, and are found to be associated with stable economic outcomes empirically (e.g. Clarida et al., 2000). Conversely, rules which violate the Taylor principle potentially admit nominal explosions or multiple equilibria theoretically and have been linked to unstable economic outcomes empirically. The Taylor Condition therefore corresponds only to the former, virtuous, type of rule.

5.1.2 The Taylor Condition and the Fisher Relation

We also derived a 'long-run' counterpart to the Taylor Condition which featured terms in expected future inflation and expected future consumption growth only (equation 1.37 of Chapter-I). The coefficient on inflation was found to take a magnitude of unity and the coefficient on consumption growth was simply the coefficient of relative risk aversion. Both of these predictions are consistent with the analytical form of Arnwine and Yigit's (2008) 'augmented Fisher relation', which they argue better reflects Fisher's original theory because the term in

consumption growth allows the real component of the Fisher relation to vary procyclically with (expected) fluctuations in income.

The connection between the implicit rule and the Euler equation is particularly clear for this long-run form because it effectively represents a linearized version of the consumption Euler equation for 'standard preferences', as evaluated empirically by Canzoneri et al. (2007). This is also apparent from the fact that an implicit rule of this type can be obtained from a constant velocity cash-in-advance model, although one would have to employ a dubious timing assumption in order to replicate the forward-looking timing convention usually found in the Fisher relation (see equations 1.24 and 1.26 of Chapter-I and the related discussion). The Taylor Condition does not need to adopt this counter-intuitive assumption in order to obtain a forward-looking Fisher relation, as explained below.

5.1.3 Chapter-by-Chapter Summary

In Chapter-I we began by exploring the rationale for monetary policy rules with reference to the 'time inconsistency problem' and the 'rational expectations revolution' in macroeconomics, both of which imply that central bankers should not be granted unfettered discretion in the conduct of monetary policy. Although in principle, alternative arrangements for monetary policy are capable of imposing an appropriate constraint on policymakers' actions, the contemporary literature tends to favour the interest rate rule as a means for doing so. Expressing the rule in terms of the nominal interest rate is intuitively attractive because it is consistent with the way in which monetary policymakers appear to communicate in practice (Romer, 2000; Mehrling, 2006). Interest rate rules were also shown to play a prominent role in the New Keynesian (NK) framework for monetary policy analysis. A rule of this type is typically added to the NKIS equation and the NK Phillips Curve in order to 'close' the model. The analytical requirements for a unique equilibrium outcome suggest that a useful rule-of-thumb is that the coefficient on inflation must exceed one in order to deliver a determinate equilibrium outcome and this result sits favourably with the empirical evidence described above.

We subsequently documented how the rise to prominence of the interest rate rule has been accompanied by a decline in the importance of monetary variables as a component of monetary policy analysis. From a theoretical perspective, there is a direct link between these two observations. The three-equation model is often taken to constitute a complete representation of the economy (e.g. Woodford, 2008) because it forms a self-contained system which, technically, can be solved without reference to any other variables, including money.¹ Although it is more difficult to establish a direct link, this diminished role for money in theory is also consistent with the way in which it has been marginalised in practice at the central banks of many of the world's advanced economies over the past two decades or so (e.g. Bernanke, 2006). One practical argument for this diminished role is that the demand for money is too unstable to be modelled accurately. However, others have shown that a stable relationship can be obtained so long as the money demand function is 'correctly' specified and so long as appropriate empirical proxies are used to represent the opportunity cost of money (e.g. Lucas, 1988a; McGrattan, 1998; Ball, 2001, 2012; Gillman and Otto, 2007). There also exists an abundance of evidence regarding the link between money growth and inflation at low frequencies (e.g. McCandless and Weber, 1995; Monnet and Weber, 2001; Haug and Dewald, 2012). As such, many have questioned the notion that monetary policy analysis can be conducted without reference to monetary variables and even prominent policymakers have expressed their concerns about such an approach (e.g. King, 2002; Bullard, 2009).

Chapter-I proceeded to introduce the notion of an 'implicit interest rate rule'. The Taylor Condition described above is an example of an implicit interest rate rule but similar expressions can be derived from alternative analytical frameworks. We primarily focused on implicit rules derived from models in which the central bank uses the money supply as the instrument of monetary policy. Such expressions were derived from the reduced form model of Sørensen and Whitta-Jacobsen (2005), a modified NK model extended to include money (Minford, 2008) and the constant velocity cash-in-advance model of Schabert (2003).

¹ In the 'textbook' three equation model there are three equations (the NKIS, the NKPC and the interest rate rule) and three endogenous variables (the output gap, the rate of inflation and the nominal interest rate).

However, we argued that each of these money-based frameworks suffers from various shortcomings which limits the generality of the implicit rules obtained. Firstly, the 'textbook' reduced form derivation of Sørensen and Whitta-Jacobsen is susceptible to the Lucas (1976) critique of policy evaluation. 'Modern Macro' generally begins from structural, micro-founded relationships relating to preferences and technology (e.g. Gillman, 2011) as opposed to starting from aggregate, reduced form relationships. Secondly, the NK model with money (Minford, 2008) still incorporates the (assumed) price rigidities that are central to the monetary transmission mechanism in that model. We wished to obtain an implicit interest rate rule from a framework with flexible prices in order to generalise the link between money growth and interest rate rules. We showed how other studies have attempted to provide a similar generalisation but how the implicit rules derived from these alternative models also suffer from certain shortcomings.

Fève and Auray (2002), for example, obtained an implicit interest rate rule from a constant velocity, flexible price cash-in-advance model in which the central bank follows a money growth rule but found that it lacked a real term to stand alongside the term in inflation. While it is perfectly possible to specify a conventional interest rate rule without a real variable, most rules incorporate such a term so that monetary policy 'leans against the wind' of business cycle fluctuations (Taylor and Williams, 2010, p.10). Salyer and Van Gaasbeck (2007) evaluated the 'interest rate rule' implicit in the limited participation model. Their expression features a real term but it carries the 'wrong' sign from the perspective of a conventional rule. Schabert (2003) overcame both of these shortcomings using a constant (unit) velocity cash-in-advance model. This implicit rule can be interpreted as a standard consumption Euler equation rewritten in terms of the nominal interest rate and, as such, it features a coefficient of one on the term in inflation. This runs contrary to a 'desirable' interest rate rule which includes an inflation coefficient in excess of one in order to comply with the Taylor principle. Furthermore, in order to replicate the class of forward-looking interest rate rule typically integrated into the NK framework, one would need to adopt a cash-in-advance model which employs a dubious assumption about the timing with which

goods and financial markets open (Carlstrom and Fuerst's, 2001, 'CWID timing'). The Taylor Condition derived from the Benk et al. (2008, 2010) framework is a forward-looking expression obtained from a cash-in-advance model which uses an appropriate timing convention, incorporates real terms alongside inflation and, in general, reflects the more-than-proportional relationship between the nominal interest rate and inflation stipulated by the Taylor principle.

In the remainder of the thesis we focused on Euler-equation-based implicit rules. Chapter-II compared the contemporaneous equilibrium relationship derived from the constant velocity cash-in-advance model under Carlstrom and Fuerst's (2001) favoured 'CIA timing' to a contemporaneous interest rate rule of the Taylor (1993) form. Because neither expression involves forward-looking terms, they could be analysed using the simple calibration techniques employed by Taylor (1993), Kozicki (1999) and Orphanides (2001). Specifically, we used quarterly U.S. time series data for the period 1960q1-2011q1 in order to obtain a predicted nominal interest rate series from both the Taylor Rule and the Implicit Rule and compared these to the observed nominal interest rate. Generally speaking, both expressions provided a reasonable fit to the data during Taylor's (1993) short sample period (1987-1992) but larger discrepancies between rule-generated and observed nominal interest rates were produced outside of this period. Furthermore, the nominal interest rate series generated by each expression showed a propensity to either over- or under-state the observed nominal interest rate during broadly similar historical periods. This is not particularly surprising given the similarities between the two expressions but the interpretation of the discrepancy series differs for each.

For the Taylor Rule, discrepancies between the rule-generated and observed rates of interest were interpreted as 'policy mistakes' in a manner consistent with Taylor's (1999) 'historical approach'. For the Implicit Rule, we instead interpreted such discrepancies as departures from the long-run Fisher relation. This latter interpretation raises the issue of the timing structure of the Implicit Rule. Under Carlstrom and Fuerst's (2001) 'CIA timing', the Implicit Rule featured a contemporaneous inflation term on the right hand side rather than the forward-

looking term that one typically finds in the ‘textbook’ Fisher relation. Accordingly, we turned to the forward-looking expression – equation (1.24) of Chapter-I, which corresponds to the ‘long-run Taylor Condition’ described above. We demonstrated that the discrepancy series obtained from this forward-looking expression is correlated with inflation misperceptions, as calculated from survey data. Specifically, this implicit rule tends to overstate the observed nominal interest rate when private agents underestimate the rate of inflation and *vice versa*. This offers an alternative explanation of the discrepancy series in terms of misguided inflation forecasts.

Chapter-III presented a more detailed description of the Benk et al. (2008, 2010) model along with a full derivation of the Taylor Condition. We subsequently simulated the model in order to generate 1000, 100 period samples of artificial data and used the full Taylor Condition along with several misspecified variants in order to construct a set of estimating equations. This exercise is similar to the one conducted by Fève and Auray (2002) and Salyer and Van Gaasbeck (2007) in the context of their cash-in-advance and ‘limited participation’ models respectively. In order to obtain a set of coefficient estimates, the simulated data was first passed through one of three statistical filters to account for the deviation-from-*BGP* form of the Taylor Condition. The filters applied in Chapter-III, and particularly the Hodrick-Prescott and 3-8 band pass filter, are consistent with the types of filter used to extract ‘business cycles’ (i.e. high frequency fluctuations) from the data (e.g. Christiano and Fitzgerald, 2003). Coefficient estimates were obtained using ordinary least squares, two stage least squares and generalised method of moments (GMM) estimators. On balance, the GMM procedure was shown to produce the most ‘precise’ set of estimates. Table 5.1 summarises the estimated inflation coefficients obtained from this procedure:

[Table 5.1 here]

The coefficient estimates obtained provide support for the theoretical prediction for the inflation coefficient in the Taylor Condition. Section 3.4 of Chapter-III showed that the predicted value for the inflation coefficient is 2.125. As Table 5.1

demonstrates, this compares to estimates of 2.299, 2.423 and 2.306 for simulated data filtered using Hodrick-Prescott, 3-8 band pass and 2-15 band pass filters respectively. However, this result was found to break-down when the 'correct' estimating equation is arbitrarily restricted in one of several ways. As Table 5.1 shows, arbitrarily omitting the forward nominal interest rate term from the full Taylor Condition ($\beta_5=0$) induced a substantial decline in the magnitude of the inflation coefficient to 0.621, 0.682 and 0.964 under the three filters respectively. As such, the mean estimate falls decisively below one for two out of the three filters and therefore produces inadmissible estimates according to the underlying model (see Proposition 2 of Chapter-III for a list of parameter restrictions). Arbitrarily replacing the term in consumption growth with a term in output growth, on the other hand, caused the magnitude of the inflation coefficient to increase substantially to 5.274 under the 2-15 filter and restricting the estimating equation to comply with a 'standard Taylor rule' yielded an inflation coefficient of 0.894, which again violates the theoretical restriction implied by the underlying model. As with any of the implicit interest rate rules reviewed in Chapter-I, the magnitude of the coefficient on inflation cannot be interpreted to reflect policymakers' interest rate response to inflation. Instead, shifts in the estimated coefficients arise because of misspecification bias induced by an incorrectly specified empirical model.

Chapter-IV firstly extended the results obtained in Chapter-III to apply to statistical filters which retained more of the low frequency fluctuations in the simulated data, i.e. periodicities that the 'business cycle' filters applied previously would have consigned to the trend component. Secondly, it investigated the circumstances under which the one-for-one relation between the nominal interest rate and inflation prescribed by the Fisher relation can be recovered from model-simulated data. The full Taylor Condition and various restricted forms were also assessed against the same sample of U.S. time series data (1960q1-2011q) considered in Chapter-II. Although many other studies have provided separate evidence in favour of a short-run Taylor principle (e.g. Taylor, 1999; Clarida et al., 2000) and a long-run Fisher relation for actual data (e.g. Mishkin, 1992), confirming that both of these results can be obtained from the simulated data

would demonstrate that the Benk et al. framework incorporates both the short-run Taylor principle (via the full Taylor Condition) and the long-run Fisher relation (via the 'long-run Taylor Condition'). There is some doubt as to whether models which incorporate the short-term Taylor principle can also account for long-run relationships (e.g. Nelson, 2008a) and models which account for long-run relationships often explain short-run fluctuations as an atheoretical reduced form process. In conducting this analysis, we adhered to the econometric techniques typically employed within the respective Taylor rule and Fisher relation literatures. As such, we treated actual data in unfiltered form, despite the concerns expressed by Siklos and Wohar (2005) and Österholm (2005) about the informal way in which the empirical literature treats the issue of whether the data are stationary or not, and adopted rational expectations as a maintained assumption, despite the correlation between Implicit Rule discrepancies and inflation misperceptions established in Section 2.3.1. For the Fisher relation, we considered an error correction model of the type often applied in the Fisher relation literature (e.g. Arnwine and Yigit, 2008). This model casts the Fisher relation as a long-run equilibrium relationship and uses a reduced form process to describe short-run departures from this long-run state.

For model-simulated data, we used the band pass filter to extract three different frequency components. Unsurprisingly, estimates obtained from the 'high-frequency component' of 2-8 periods ('years') were similar to the 'business cycle' estimates presented in Chapter-III (see Table 5.1). The contribution of Section 4.4.2 was to show that the 'Taylor principle' result extends to a band pass filter which retains lower frequency fluctuations in addition to high frequency fluctuations.² We referred to this extended frequency as a 'medium-term cycle' and initially assumed that it comprised of cycles of 2-20 periods, though if one 'period' is interpreted as one year this is shorter than Comin and Gertler's (2006) original 2-200 quarter 'medium-term cycle'. We showed that the unrestricted estimating equation generates a mean inflation coefficient of 2.068 with 1000 statistically significant estimates at this extended frequency. Furthermore,

² Filtered data which retains the low frequency fluctuations alone ('medium-frequency component') tended to generate autocorrelated residuals when the estimating procedure was applied hence coefficient estimates at this frequency are not summarised here.

misspecifying the ‘true’ estimating equation to include an output growth term instead of a consumption growth term again generates an upward shift in the magnitude of the inflation coefficient. As previously, this upward shift should not be interpreted to indicate that monetary policymakers now take a more aggressive stance against inflation.

Section 4.4 estimated a ‘standard Taylor rule’ for model-simulated data. The ‘non-dynamic’ form ($\beta_5=0$) featured terms in expected future inflation and expected future output growth. The estimates obtained differed according to the frequency range considered. A near-zero estimated inflation coefficient was generated at the high frequency component (0.021, see Table 5.1). On the other hand, a mean estimate of 1.269 was generated at the ‘medium-term cycle’. Accordingly, from an interest rate rule perspective one might conclude that the Taylor principle is satisfied over the medium-term cycle, just as the empirical literature has often concluded upon generating estimates of a similar magnitude from actual data (e.g. Mankiw, 2001; Clarida et al., 2000), but that it was violated at higher frequencies. However, these estimates are again derived from a misspecified empirical model and so do not carry the conventional interpretation.

The unrestricted Taylor Condition was subsequently evaluated against U.S. time series data for a ‘full sample’ period (1960q1-2011q1), for a ‘pre-Volcker’ subsample (1960q1-1979q2) and for several different post-Volcker subsamples (1979q3-1996q1, 1979q3-2000q3 and 1979q3-2011q1). Lagged dependent variable terms were added to the empirical specification in order to relieve the error term of serial correlation; the interest rate rule literature typically interprets such terms to reflect ‘interest rate smoothing’ but this interpretation does not apply to the Taylor Condition. Table 5.2 summarises the estimates obtained from actual data.

[Table 5.2 here]

The key result is that while the transition from ‘pre-’ to ‘post-Volcker’ subsamples does involve the pronounced upward shift in the estimated inflation coefficient

often reported in the empirical literature (e.g. Clarida et al., 2000), the pre-Volcker estimate exceeds unity and hence the Taylor principle is satisfied even for this subsample. There is no comparable transition from pre-Volcker violation of the Taylor principle to post-Volcker compliance. Clarida et al. (2000), for example, report a pre-Volcker (1960q1-1979q2) estimate of 0.83 and a ‘Volcker-Greenspan’ (1979q3-1996q4) estimate of 2.15 for the inflation coefficient for their conventional interest rate rule.³ This compares to corresponding estimates of 1.170 and 1.973 for the unrestricted Taylor condition, which suggests that omitting terms such as the velocity of money might be responsible for biasing the inflation coefficient downwards and could lead to the appearance that the Taylor principle is violated for the pre-Volcker era (we return to this point below).

Having illustrated the circumstances under which the rule-of-thumb Taylor principle result is obtained, Section 4.5 demonstrated the conditions under which the simulated and actual data conforms to the Fisher relation. Firstly, we extended the upper periodicity of the band pass filter used to define the ‘medium-term cycle’ from the 20 periods (‘years’) used in Section 4.4.2. As reported in Table 5.1, the inflation coefficient obtained from the ‘full Taylor Condition’ converges towards its Fisher relation implied magnitude of unity as the upper periodicity of the filter is extended. At Comin and Gertler’s (2006) upper periodicity of 50 years (200 quarters), the estimated inflation coefficient is 1.097 and as such is consistent with the Fisher relation. This result suggests that it would be more appropriate to view the Fisher relation as a low frequency (‘long-run’) equilibrium relationship for the simulated data. This is also apparent from the fact that the number of statistically significant estimates obtained for some of the ‘non-standard’ Fisher relation terms, and in particular the terms in productive time growth and the forward interest rate term, decline substantially under the 2-50 year filter just as the ‘long-run Taylor Condition’ would suggest.

³ Clarida et al.’s (2000) rule allows for ‘interest rate smoothing’ via lagged dependent variable terms. Table 5.2 presents their estimates (Clarida et al., 2000, Table II) but as reported in Section 4.4.3 of Chapter-IV, our econometric procedure was able to closely replicate their results, producing estimates of 0.80 and 2.17 for their ‘pre-Volcker’ and ‘Volcker-Greenspan’ subsamples respectively.

In light of these findings, we proceeded to consider several restricted versions of the full estimating equation. The first specification omitted the forward interest rate term ($\beta_5=0$) and the second included terms in inflation and consumption growth only ($\beta_3=\beta_4=\beta_5=0$). Reverting back to the 2-20 ‘medium-term cycle’, both restrictions produced a mean inflation coefficient consistent with the one-for-one Fisher relation – 1.025 for the former restriction and 0.931 for the latter (see Table 5.1). The former restriction ($\beta_5=0$) is entirely arbitrary, however, although it does usefully illustrate the importance of the forward interest rate term for retrieving an appropriately-sized estimate for the inflation coefficient of the Taylor Condition. The latter restriction ($\beta_3=\beta_4=\beta_5=0$), on the other hand, has a clearer theoretical motivation grounded in the ‘long-run Taylor Condition’. However, one troubling feature of the results under this restriction is that the estimated residuals exhibited signs of serial correlation (see Table 4.8).

We subsequently applied these two restricted forms to our sample of U.S. time series data (Tables 4.9 and 4.10). For the specification which omits the forward interest rate term, the estimated inflation coefficient traverses unity between pre- and post-Volcker subsamples in a manner consistent with the conventional ‘interest rate rule account’ of the historical record. The ‘pre-Volcker’ inflation coefficient of 0.892 is similar in magnitude to Clarida et al.’s (2000, Table II) pre-Volcker estimate of 0.83 and the ‘CGG post-Volcker’ estimate of 1.969 is similar to Clarida et al.’s estimate of 2.15 for this same sample period (the ‘Taylor post-Volcker’ and ‘extended post-Volcker’ subsamples yield similar estimates of 1.906 and 2.189, respectively). Comparing these to the estimates obtained from the unrestricted Taylor Condition described above, it is apparent that omitting the forward interest rate term biases the estimated inflation coefficient downwards. However, in the context of the Taylor Condition it would again be inappropriate to apply an interest rate rule interpretation to these estimates. We also evaluated the ‘long-run Taylor Condition’ against actual data. Over the full sample the estimated inflation coefficient is approximately one (1.073), which would be consistent with the Fisher relation. However, as with model-simulated data, the estimated residuals from this regression exhibit signs of serial correlation over the full sample period.

The estimates obtained as the filter used to extract the 'medium-term cycle' was extended and the serially correlated residuals obtained from the restricted form consistent with the 'long-run Taylor Condition' motivated consideration of an error correction model to evaluate the Fisher relation. We constructed an error correction model which set the 'augmented Fisher relation' as a long-run equilibrium condition and modelled short-run departures from this equilibrium as a reduced form process involving lagged dependent and independent variable terms. Several pre-requisites must be satisfied before the error correction model can be applied. Beginning with actual U.S. data, the statistical tests presented in Table 4.11 suggested that two of the variables which enter the long-run equilibrium relationship – the nominal interest rate and the rate of inflation – are $I(1)$ over the full sample period. In contrast, the remaining term – the consumption growth rate – appeared to be stationary. These findings resonate with Siklos and Wohar's (2005) and Österholm's (2005) criticism of the empirical literature. For the purposes of our error correction model, we required cointegration between these two non-stationary variables in order to proceed. Table 4.12 reported the results obtained from 'cointegrating regressions' between the two non-stationary series and found the estimated residuals to be stationary, thus suggesting that these variables are cointegrated over the 1960q1-2011q1 sample period. As such, the error correction model can be legitimately applied. Table 4.13 showed that the estimated inflation coefficient obtained is robust to the choice of OLS or GMM estimators and robust to whether the effective federal funds rate or the 3 month Treasury bill rate is used as the empirical proxy for the nominal interest rate. Table 5.2 just presents the GMM estimate generated when the 3 month Treasury bill rate was used – this estimate is 1.210.

At first sight, this appears to be too large to conform to the Fisher relation. However, the nominal interest rate used to produce this estimate was not adjusted to account for the rate of taxation applied to capital (nominal government bond) income in the U.S. It has long been known that failing to account for this form of taxation potentially biases the estimated inflation coefficient upwards (e.g. Crowder and Hoffman, 1996). To account for this tax effect, we used the methodology of Padovano and Galli (2001) to calculate an

appropriate adjustment to apply to the nominal interest rate series. Upon confirming that the appropriate pre-requisites are also satisfied for tax-adjusted data, Table 4.15 presented a new set of estimates. The choice of estimator was again found to be unimportant to the resulting coefficient estimate but the choice of empirical proxy for the nominal interest rate was found to affect the outcome. The GMM estimate obtained when the 3 month Treasury bill rate is used to represent the nominal interest rate is 1.041 (Table 5.2) but a larger estimate (1.161 for GMM) was obtained under the effective federal funds rate. Nevertheless, the 3 month Treasury bill rate provides support for the Fisher relation, as many other studies have found for actual time series data (see Section 4.1.1 for a brief review).

Finally, the same error correction methods were applied to data simulated from the Benk et al. (2010) model. In this case it is not immediately obvious that an error correction framework should be used because Table 4.3 suggested that the majority of the simulated series are stationary. However, it is not necessarily the case that error correction methods may only be applied to non-stationary series (e.g. De Boef and Keele, 2008) and this framework is also potentially useful for ridding the estimated residuals of the serial correlation identified in Table 4.8. The mean estimate for the inflation coefficient is again similar across OLS and GMM estimators, standing at 0.928 and 1.033 respectively, but the OLS estimator produces a residual series which is afflicted with serial correlation. We are therefore inclined to favour the GMM estimate and report this in Table 5.1.

5.2 Final Remarks and Future Research Agenda

In this thesis we have analysed a structural model which assigns a central role to money and demonstrated that this theoretical framework can offer a unified account of both short- and long-run accounts of the relationship between the nominal interest rate and inflation.

To do so, we first established a link between conventional interest rate rules and money supply rules. The fact that an 'interest rate rule' can be derived from a structural model in which the central bank actually follows a money growth rule

can be viewed in two ways. On the one hand, it can be interpreted to reveal the 'correspondence' between these two policy regimes. In this sense, our analytical result can be taken to be somewhat complimentary to the conventional rule because it demonstrates that a 'desirable' interest rate rule is linked to a well-regulated money supply. Indeed, others have discussed the connection between these two, ostensibly distinct, policy regimes (e.g. Taylor, 1999; Gerberding et al., 2007; Nelson, 2008b). On the other hand, and in a less flattering light, this result adds further doubt as to whether empirical studies can legitimately claim to retrieve the central bank's 'reaction function' and its associated 'reaction coefficients' from aggregate data. The Taylor Condition incorporates certain variables which do not generally feature in a conventional interest rate rule, such as the velocity of money. This raises the possibility that estimated inflation coefficients which fall below one for a conventional rule might simply result from misspecification bias rather than pointing towards a period of inept policymaking. The fact that the underlying Benk et al. model does not incorporate the nominal rigidities which are essential to the logic of an interest rate rule in the context of a broader framework only serves to compound this intrigue.

The future research agenda derived from this work might include the consideration of alternative monetary policy regimes beyond the constant money growth rule. For example, the money supply growth rate could be allowed to feedback on the state of the economy (e.g. McCallum, 1988) just as the nominal interest rate does in a conventional rule, or the analysis might be extended to an open economy formulation which allows terms in the exchange rate to feature in the implicit rule, as others have considered for conventional rules (e.g. Ball, 1999; Cecchetti et al., 2000). Finally, a full 'policy model' could be constructed to rival the three equation NK model and thus extend the comparison between the two frameworks beyond the single-equation-level analysis conducted in this thesis. More ambitiously still, the assumption of rational expectations might be modified in order to incorporate the type of inflation misperceptions documented in Chapter-II – that is, the propensity for economic agents to systematically underestimate inflation when it is high and overestimate it when it is low.

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FIGURES AND TABLES

Figure 2.1: Inflation, the Output Gap and the Output Growth Rate

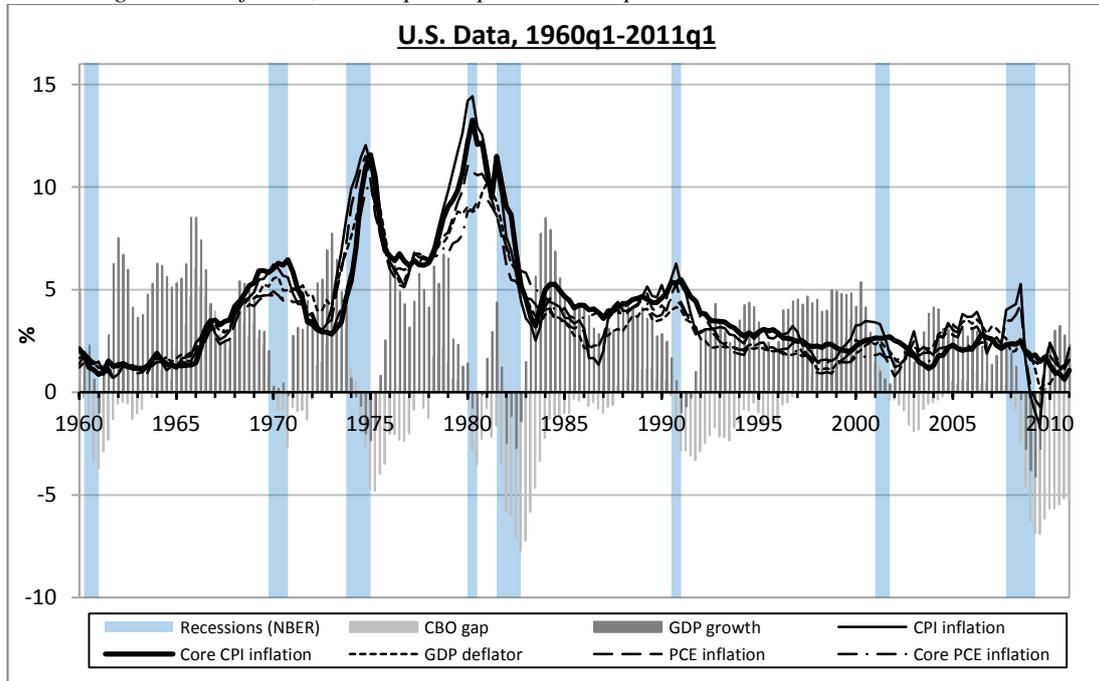


Figure 2.2: Taylor and Implicit Rules over the Full Sample Period

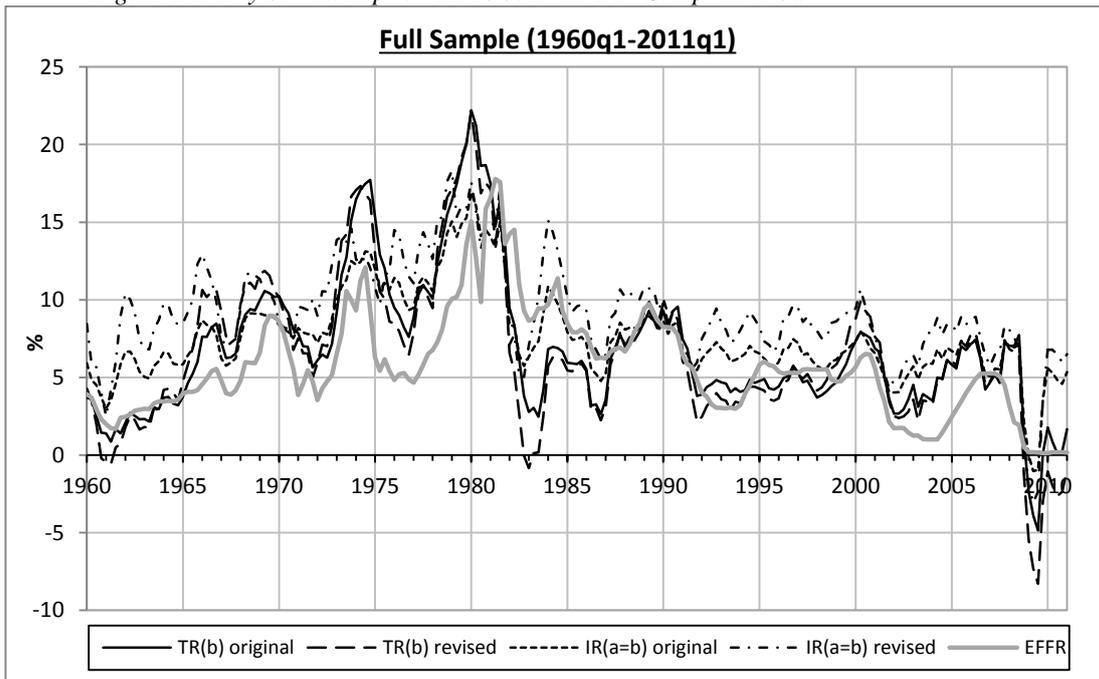


Figure 2.3: Taylor and Implicit Rule Discrepancy Series

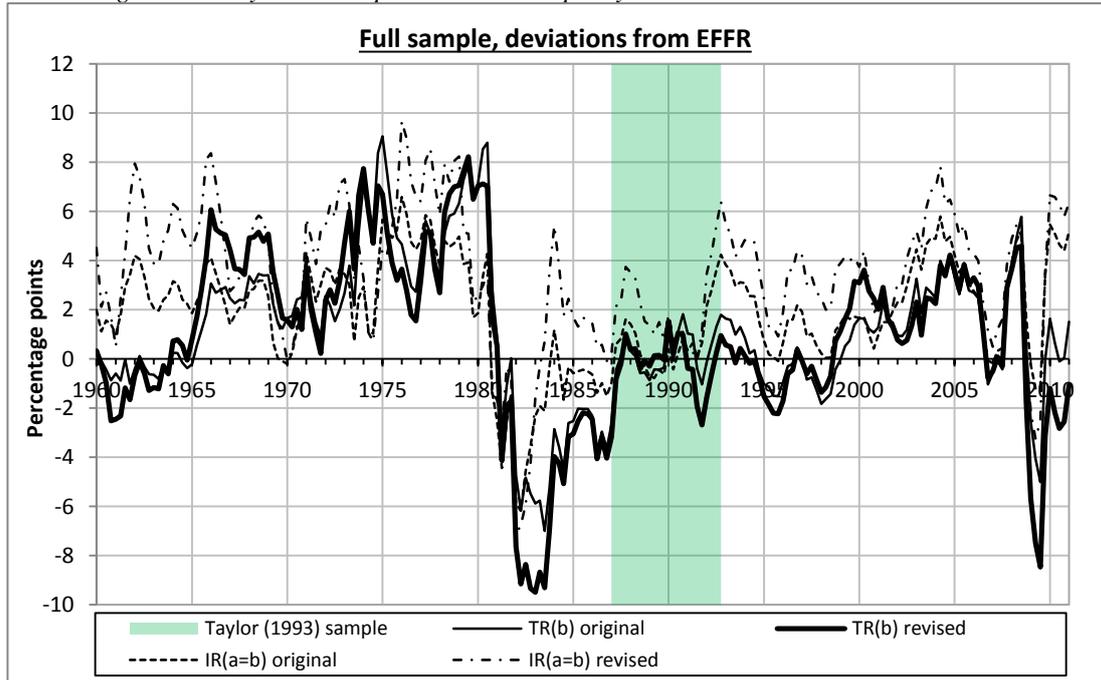


Figure 2.4: Taylor Rule vs. Implicit Rule Counterpart

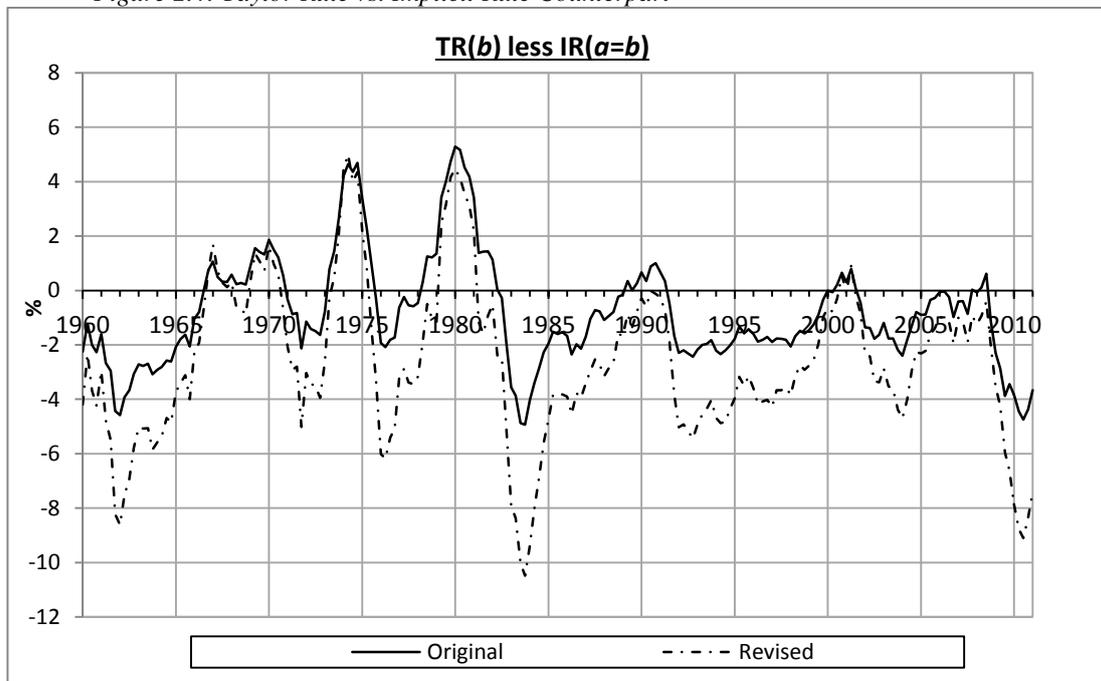


Figure 2.5: 'Original' Divergence Series and Components of Inequality (2.4)

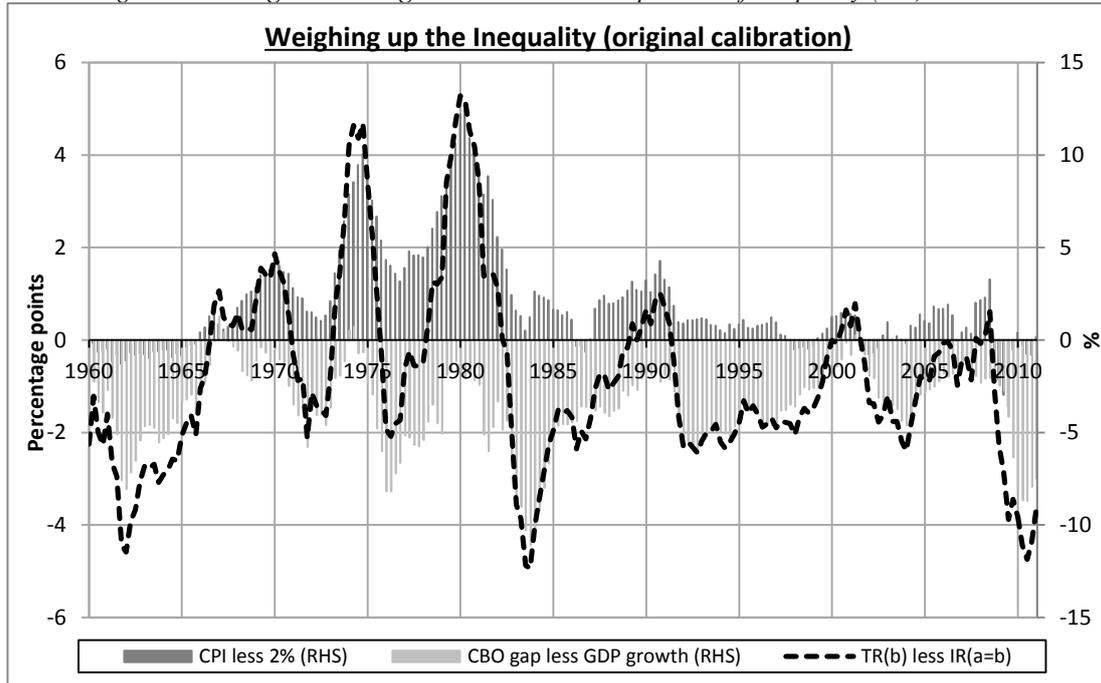


Figure 2.6: Differences between the Real Terms of the Taylor/Implicit Rule

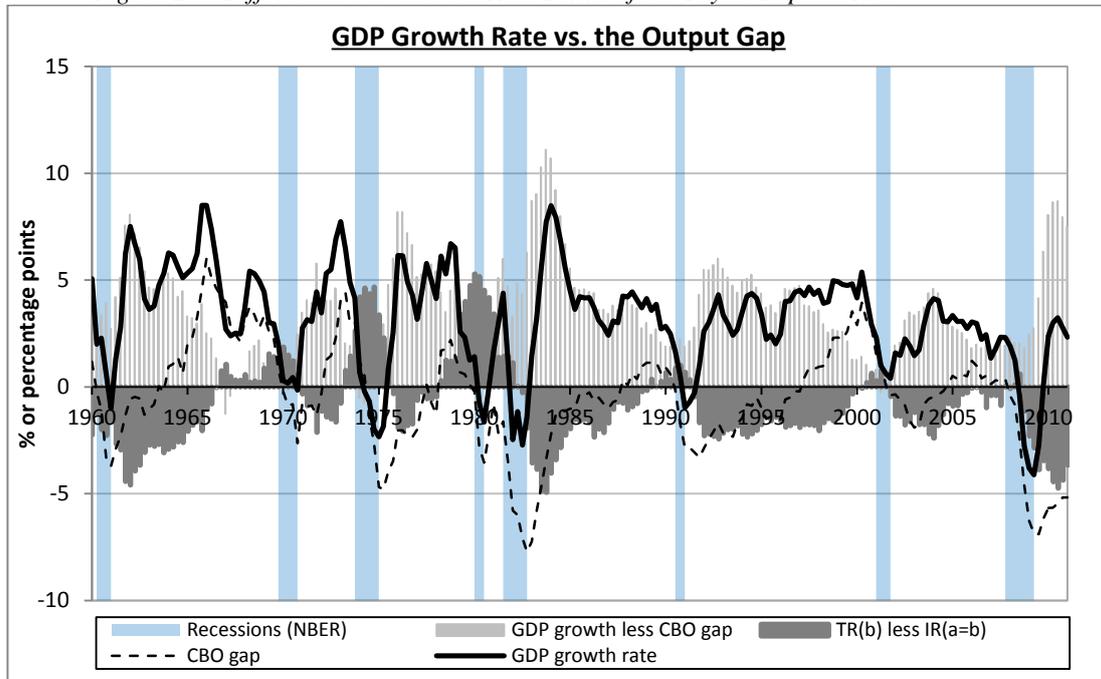


Figure 2.7: Discrepancy Series by 'Policy Era'

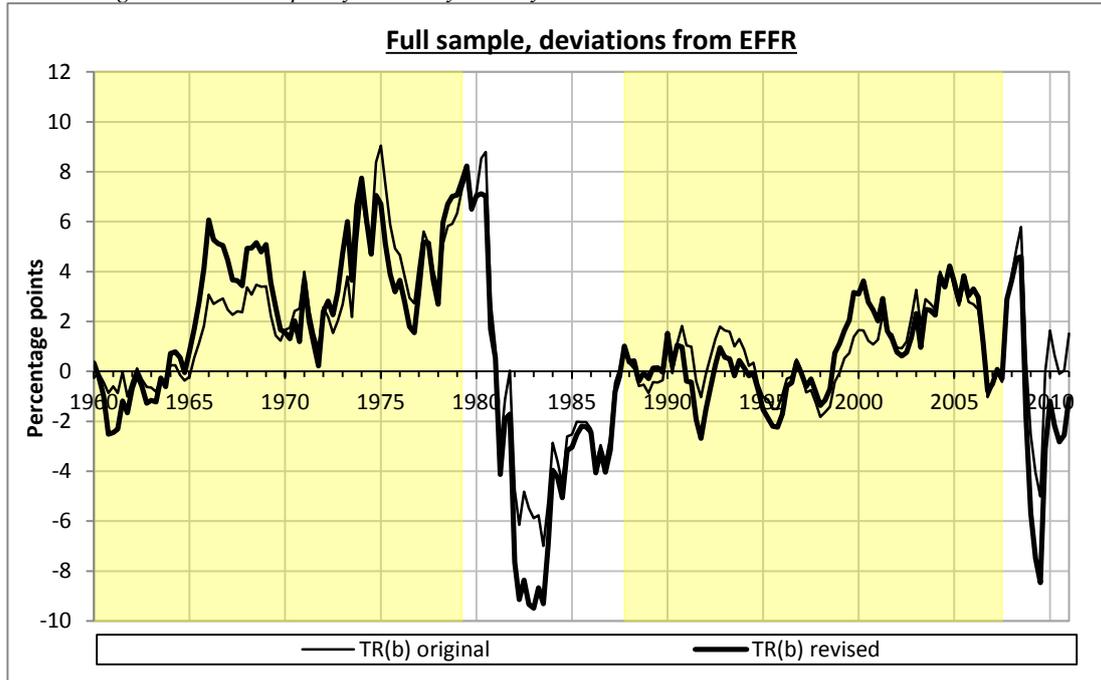


Figure 2.8: The Pre-Volcker Era

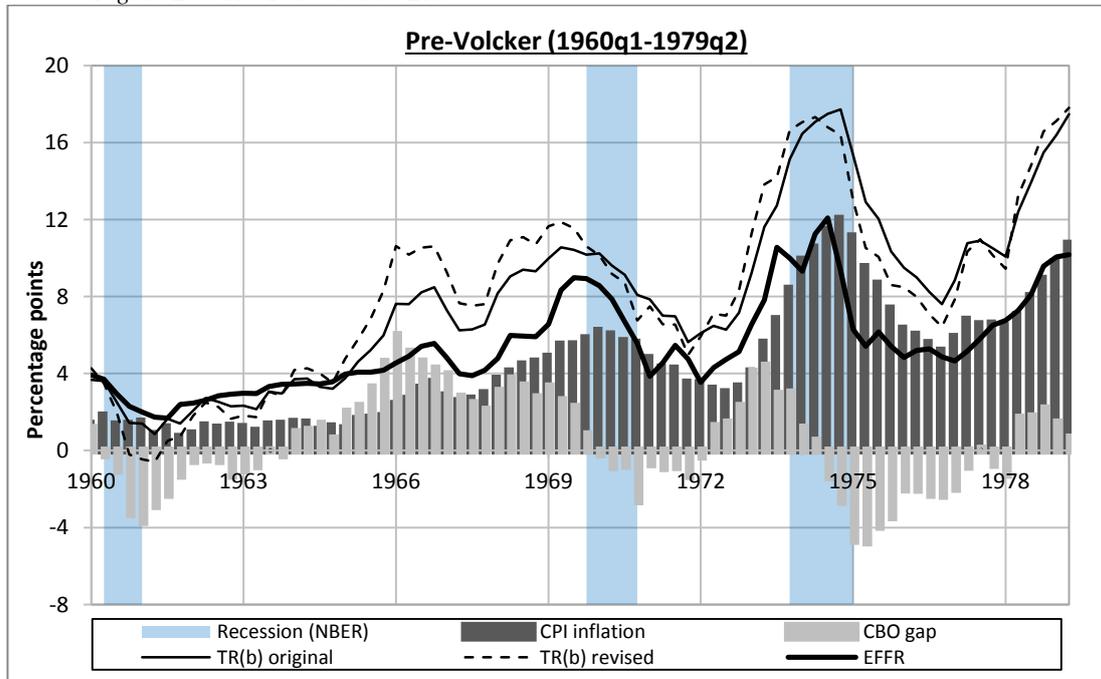


Figure 2.9: The Volcker Disinflation Era

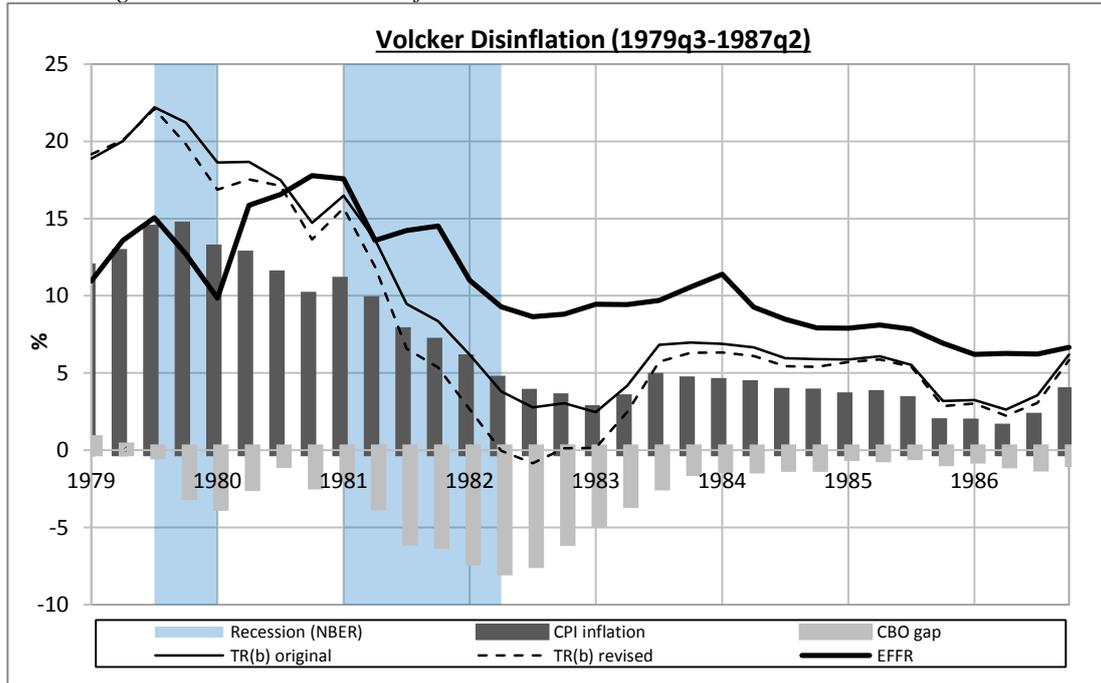


Figure 2.10: The Greenspan-Bernanke Era

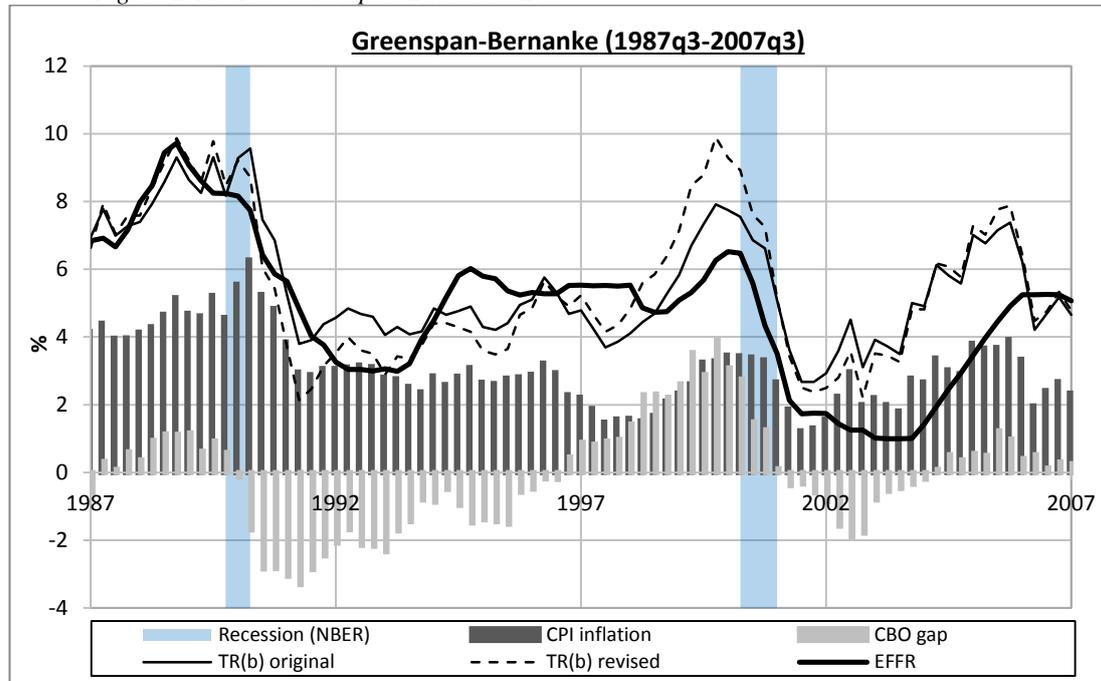


Figure 2.11: Crisis Period

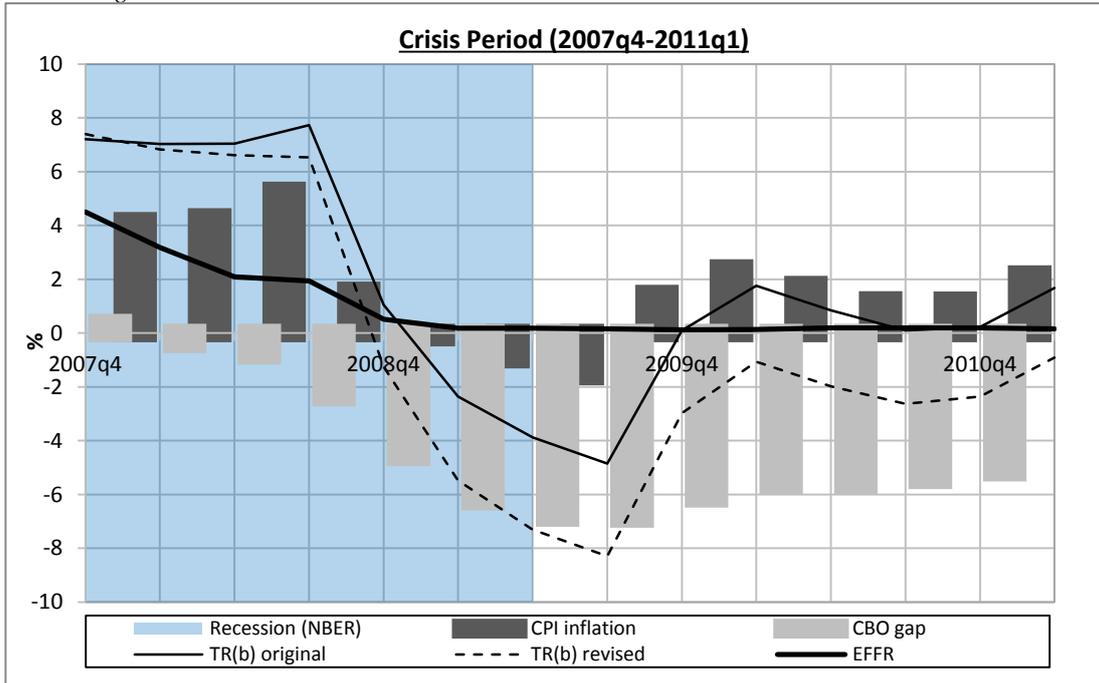


Figure 2.12: ZLB frontiers

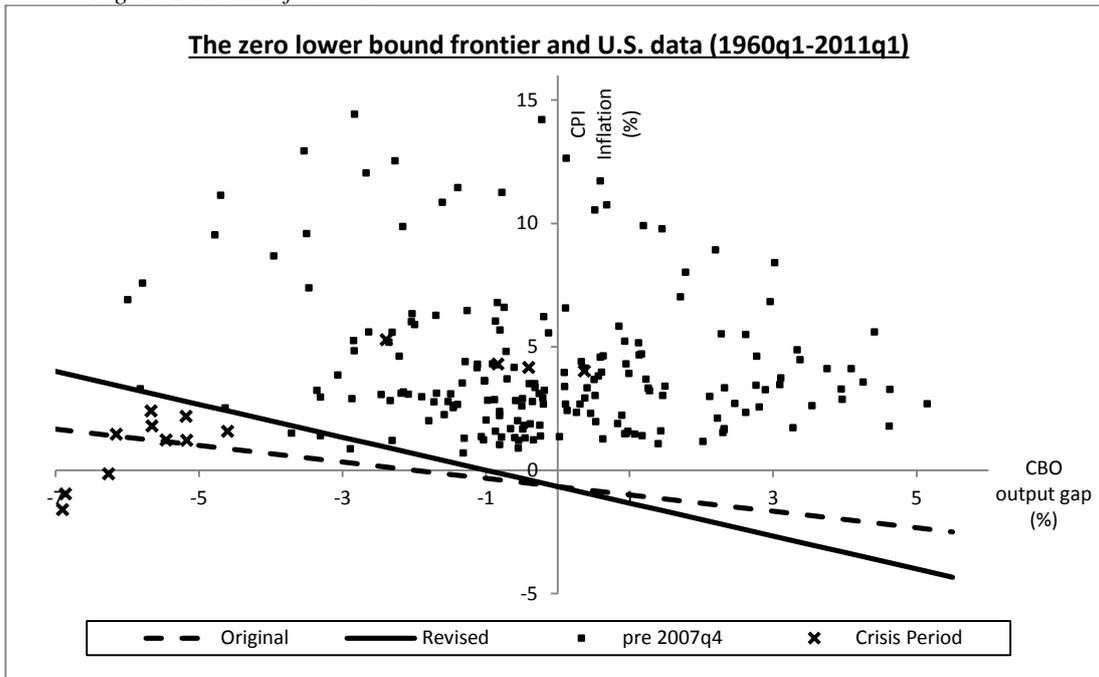


Figure 2.13: The ('augmented') Fisher Relation (1960q1-2011q1)

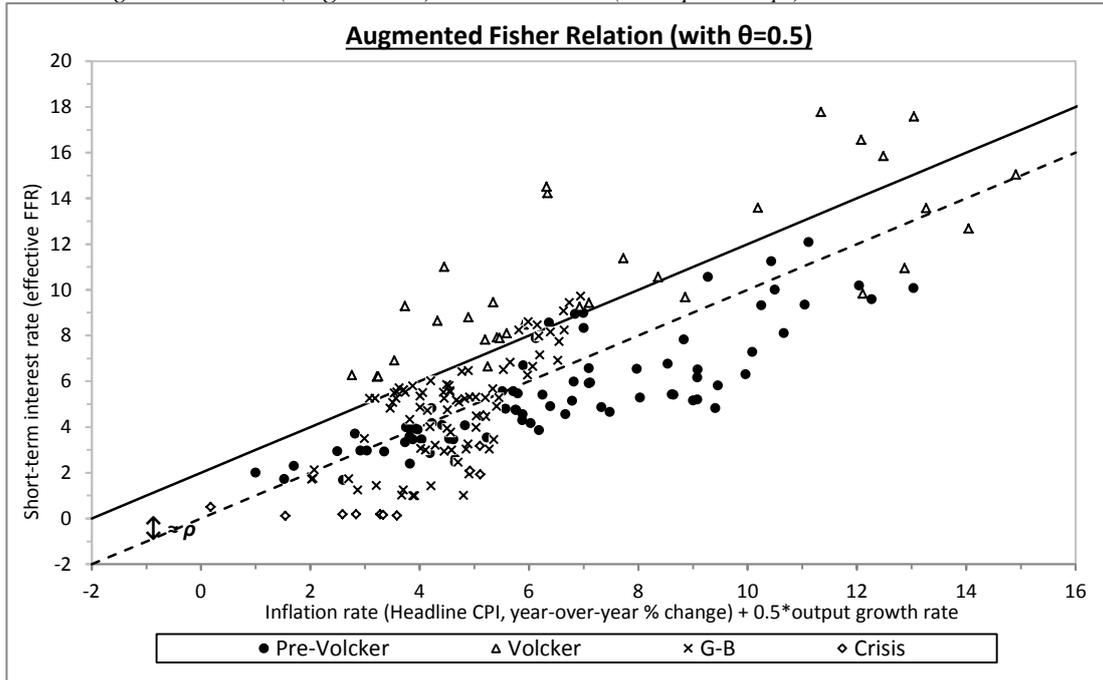


Figure 2.14: Canzoneri et al. (2007) Analysis for the Implicit Rule (2.2)

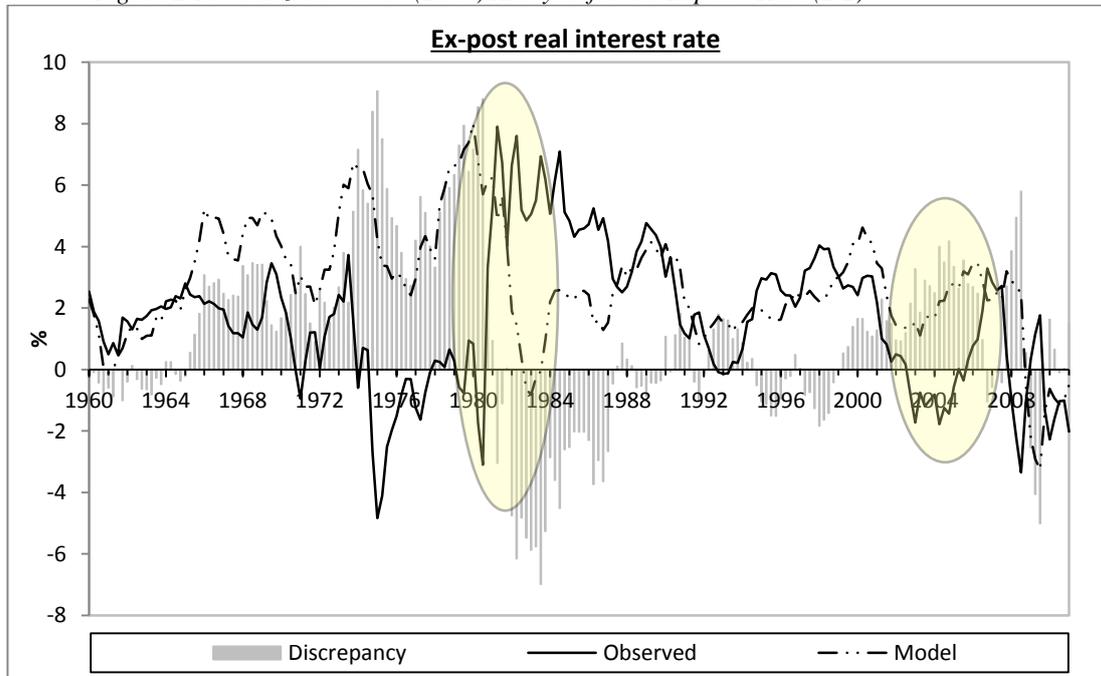


Figure 2.15: Figure 2.14 Expressed in terms of the Nominal Interest Rate

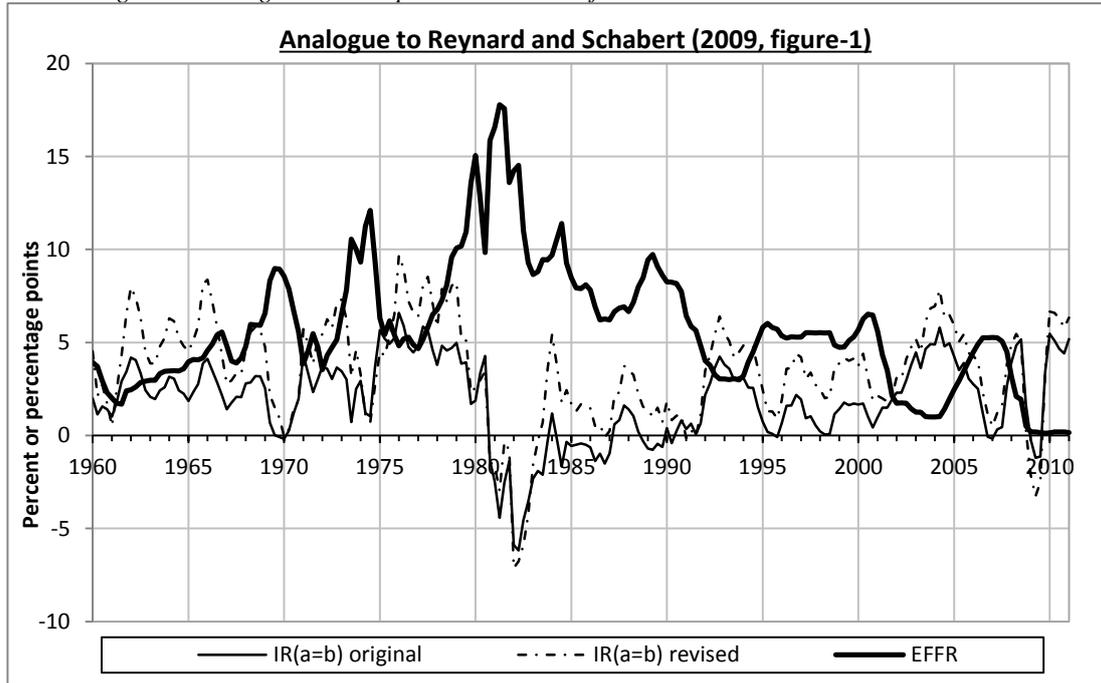


Figure 2.16: Inflation Misperceptions and Discrepancy Series for the 'Long-Run Taylor Condition'

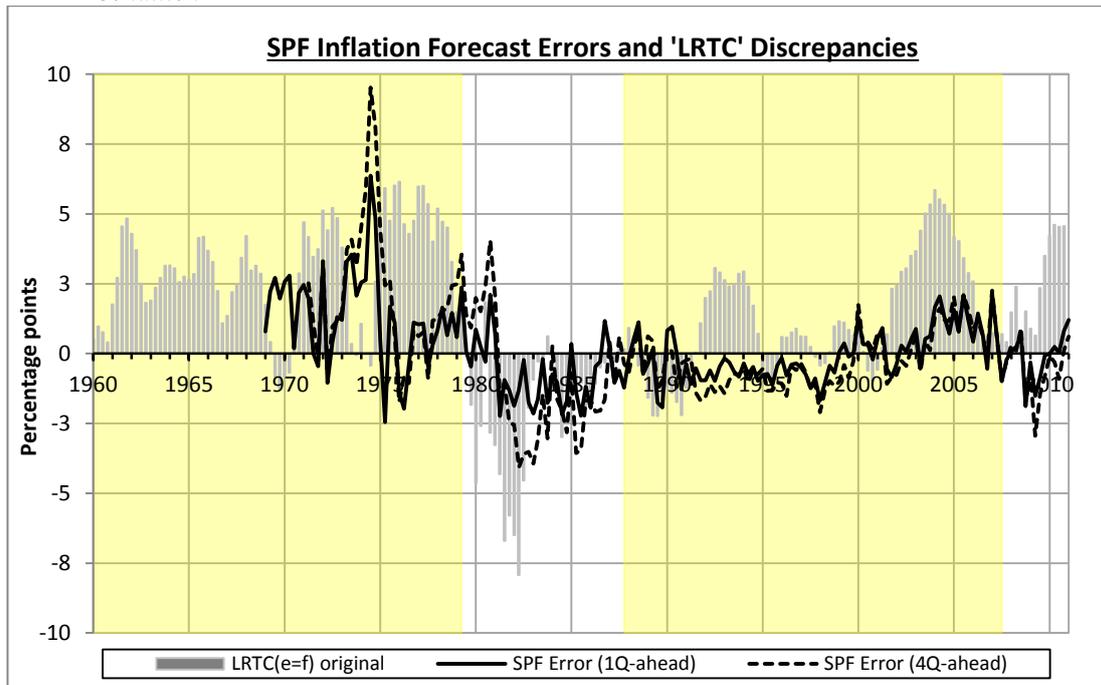


Table 2.1: Numerical Calibration of Equations (2.1) and (2.2)

	'Original Taylor Rule'	'Revised Taylor Rule'	'Original Implicit Rule'	'Revised Implicit Rule'
$\bar{\pi}^*$	2	2	2	2
ρ	<i>n/a</i>	<i>n/a</i>	2	2
θ	<i>n/a</i>	<i>n/a</i>	0.5	1.0
\bar{r}^*	2	2	<i>n/a</i>	<i>n/a</i>
$(1+\beta_\pi)$	1.5	1.5	<i>n/a</i>	<i>n/a</i>
β_v	0.5	1.0	<i>n/a</i>	<i>n/a</i>

NOTES:

- The 'original' Taylor Rule follows Taylor's (1993) calibration and the 'revised' Taylor Rule follows Orphanides' (2003c) modified calibration.
- The 'original' implicit rule mimics the coefficient of 0.5 on the real term and the 'revised' implicit rule follows the Benk et al. (2010), log-utility calibration.

Table 2.2: Empirical Specifications

Specification label	Inflation	Potential output
Implicit Rule (<i>a=b</i>)	Headline CPI	<i>n/a</i>
Implicit Rule (<i>c=d</i>)	Core CPI	<i>n/a</i>
Implicit Rule (<i>e=f</i>)	GDP deflator	<i>n/a</i>
Implicit Rule (<i>g=h</i>)	Headline PCE	<i>n/a</i>
Implicit Rule (<i>i=j</i>)	Core PCE	<i>n/a</i>
Taylor Rule (<i>a</i>)	Headline CPI	Log-linear trend
Taylor Rule (<i>b</i>)	Headline CPI	CBO estimates
Taylor Rule (<i>c</i>)	Core CPI	Log-linear trend
Taylor Rule (<i>d</i>)	Core CPI	CBO estimates
Taylor Rule (<i>e</i>)	GDP deflator	Log-linear trend
Taylor Rule (<i>f</i>)	GDP deflator	CBO estimates
Taylor Rule (<i>g</i>)	Headline PCE	Log-linear trend
Taylor Rule (<i>h</i>)	Headline PCE	CBO estimates
Taylor Rule (<i>i</i>)	Core PCE	Log-linear trend
Taylor Rule (<i>j</i>)	Core PCE	CBO estimates

NOTES:

- The Implicit Rule uses the real GDP growth rate rather than an output gap term hence there are twice as many Taylor Rule specifications as there are Implicit Rule specifications.

Table 2.3: Summary Statistics

	Mean discrepancy (percentage points)	Standard deviation of discrepancy	Mean absolute discrepancy (percentage points)	Maximum discrepancy (percentage points)	Minimum discrepancy (percentage points)	Correlation coefficient
'Original'	<i>Taylor, Full</i>	<i>Taylor, Full</i>	<i>Taylor, Full</i>	<i>Taylor, Full</i>	<i>Taylor, Full</i>	<i>Taylor, Full</i>
TR (a)	0.97, 1.17	0.94, 3.57	1.14, 2.98	2.64, 10.43	-1.59, -6.75	0.89, 0.77
TR (b)	0.14, 1.09	1.02, 2.94	0.79, 2.36	1.82, 9.05	-2.66, -6.99	0.86, 0.75
TR (c)	1.30, 1.09	0.78, 3.07	1.33, 2.51	2.62, 11.09	-0.38, -5.08	0.94, 0.80
TR (d)	0.46, 1.02	0.96, 2.34	0.85, 1.81	2.32, 9.71	-1.36, -5.93	0.92, 0.81
TR (e)	-0.34, 0.49	0.47, 3.14	0.46, 2.52	0.69, 10.35	-1.16, -6.03	0.98, 0.74
TR (f)	-1.18, 0.42	0.65, 2.64	1.21, 2.10	0.38, 8.98	-2.13, -7.05	0.97, 0.73
TR (g)	0.44, 0.51	0.66, 3.11	0.66, 2.52	1.58, 9.24	-0.66, -7.27	0.94, 0.77
TR (h)	-0.40, 0.44	0.77, 2.58	0.70, 1.97	1.28, 7.87	-1.60, -8.29	0.92, 0.75
TR (i)	0.63, 0.41	0.82, 2.71	0.84, 2.16	1.88, 8.90	-0.80, -5.68	0.92, 0.78
TR (j)	-0.20, 0.34	0.95, 2.16	0.77, 1.62	1.56, 7.52	1.75, -6.70	0.91, 0.79
IR (a=b)	0.73, 1.90	1.36, 2.25	1.08, 2.43	4.24, 6.59	-0.97, -6.18	0.72, 0.76
IR (c=d)	0.95, 1.84	1.58, 2.08	1.31, 2.30	4.58, 6.89	-1.40, -4.83	0.65, 0.80
IR (e=f)	-0.15, 1.45	1.44, 2.42	1.16, 2.28	3.29, 6.60	-1.87, -6.78	0.72, 0.71
IR (g=h)	0.37, 1.46	1.46, 2.33	1.09, 2.20	3.89, 6.27	-1.33, -7.61	0.67, 0.73
IR (i=j)	0.50, 1.39	1.68, 2.33	1.33, 2.18	4.08, 6.58	-1.61, -6.55	0.50, 0.74
'Revised'	<i>Taylor, Full</i>	<i>Taylor, Full</i>	<i>Taylor, Full</i>	<i>Taylor, Full</i>	<i>Taylor, Full</i>	<i>Taylor, Full</i>
TR (a)	1.45, 0.99	1.30, 5.00	1.76, 4.12	3.40, 12.00	-1.54, -11.93	0.93, 0.74
TR (b)	-0.23, 0.83	1.15, 3.55	0.82, 2.80	1.53, 8.23	-3.16, -9.49	0.90, 0.70
TR (c)	1.78, 0.91	0.69, 4.50	1.78, 3.71	3.03, 10.12	0.58, -10.47	0.95, 0.76
TR (d)	0.10, 0.76	0.65, 2.86	0.55, 2.21	1.47, 7.36	-0.83, -8.25	0.94, 0.76
TR (e)	0.13, 0.31	0.81, 4.54	0.69, 3.68	1.55, 9.38	-1.31, -9.98	0.96, 0.70
TR (f)	-1.54, 0.16	0.62, 3.25	1.54, 2.63	-0.46, 6.63	-2.59, -10.05	0.96, 0.65
TR (g)	0.92, 0.33	1.11, 4.53	1.26, 3.67	2.58, 9.00	-1.74, -10.58	0.93, 0.72
TR (h)	-0.76, 0.18	0.92, 3.19	0.87, 2.47	0.46, 6.46	-2.89, -11.28	0.92, 0.68
TR (i)	1.11, 0.23	1.01, 4.12	1.29, 3.32	3.01, 8.68	-0.79, -9.83	0.91, 0.73
TR (j)	-0.57, 0.08	0.89, 2.71	0.84, 2.06	0.94, 5.36	-2.07, -9.70	0.90, 0.72
IR (a=b)	2.06, 3.47	1.72, 2.82	2.07, 3.87	6.39, 9.67	-0.14, -7.12	0.55, 0.65
IR (c=d)	2.28, 3.42	1.87, 2.65	2.28, 3.74	6.74, 9.97	0.10, -5.66	0.40, 0.67
IR (e=f)	1.18, 3.02	1.81, 3.01	1.59, 3.57	5.45, 9.68	-1.38, -7.68	0.47, 0.56
IR (g=h)	1.70, 3.03	1.88, 2.94	1.88, 3.56	6.05, 9.35	-1.01, -8.47	0.47, 0.59
IR (i=j)	1.83, 2.96	2.07, 2.94	2.07, 3.55	6.24, 9.66	-1.12, -7.60	0.34, 0.57

NOTES:

- The 'Full' sample is 1960q1-2011q1 and consists of 205 quarterly periods.
- The 'Taylor' subsample is 1987q1-1992q4 and consists of 24 quarterly periods.
- TR denotes Taylor Rule; IR denotes Implicit Rule. Tables 2.1 and 2.2 provide the calibration and empirical proxies used.

Table 3.1: Parameters

<i>Preferences</i>		
θ	1.000	Relative risk aversion parameter
ψ	1.840	Leisure weight
β	0.960	Discount factor
<i>Goods Production</i>		
α	0.640	Labour share in goods production
δ_k	0.031	Depreciation rate of goods sector
A_G	1.000	Goods productivity parameter
<i>Human Capital Production</i>		
ε	0.830	Labour share in human capital production
δ_h	0.025	Depreciation rate of human capital sector
A_H	0.210	Human capital productivity parameter
<i>Banking Sector</i>		
γ	0.110	Labour share in credit production
A_F	1.100	Banking productivity parameter
<i>Government</i>		
Θ^*	0.050	Money growth rate
<i>Shock processes</i>		
<i>i) Autocorrelation coeffs.</i>		
φ_z	0.840	Production productivity
φ_u	0.740	Money growth rate
φ_v	0.730	Banking productivity
<i>ii) Std. dev. of innovations</i>		
$\sigma_{\varepsilon z}$	0.770	Production productivity
$\sigma_{\varepsilon u}$	0.500	Money growth rate
$\sigma_{\varepsilon v}$	1.160	Banking productivity

Table 3.2: Target Values

\bar{g}	0.0240	Avg. Annual output growth rate
$\bar{\pi}$	0.0260	Avg. annual inflation rate
\bar{R}	0.0944	Nominal interest rate
l_G	0.2480	Labour used in goods sector
l_H	0.2000	Labour used in human capital sector
l_F	0.0018	Labour used in banking sector
i/y	0.2380	Investment-output ratio in goods sector
m/c	0.3800	Share of money transactions
x	0.5500	Leisure time
$1-x$	0.4500	Productive time

Table 3.3: Full Taylor Condition (HP)

HP filtered data, $\lambda=6.25$	Unrestricted			Restricted ($\beta_5=0$)		
	OLS	2SLS	GMM	OLS	2SLS	GMM
β_0	0.000 [0]	0.000 [0]	0.000 [17]	0.000 [0]	0.000 [0]	0.000 [8]
Standard error	0.000	0.000	0.000	0.000	0.000	0.000
Adj. mean	-	-	0.000	-	-	0.000
$E_t \bar{\pi}_{t+1}$	2.019 [1000]	2.309 [691]	2.299 [1000]	0.315 [830]	0.757 [397]	0.621 [925]
Standard error	0.248	1.488	0.268	0.126	0.856	0.265
Adj. mean	2.019	1.800	2.299	0.293	0.475	0.614
$E_t \bar{g}_{c,t+1}$	0.251 [1000]	0.336 [959]	0.293 [1000]	0.172 [1000]	0.313 [989]	0.231 [1000]
Standard error	0.024	0.096	0.020	0.020	0.048	0.025
Adj. mean	0.251	0.324	0.293	0.172	0.311	0.231
$E_t \bar{g}_{l,t+1}$	-0.243 [890]	-0.536 [774]	-0.374 [997]	-0.281 [864]	-0.530 [774]	-0.427 [996]
Standard error	0.094	0.321	0.079	0.100	0.231	0.111
Adj. mean	-0.236	-0.448	-0.374	-0.265	-0.453	-0.427
$E_t \bar{g}_{v,t+1}$	-0.137 [990]	-0.267 [800]	-0.212 [1000]	-0.098 [889]	-0.317 [888]	-0.190 [992]
Standard error	0.031	0.228	0.033	0.036	0.109	0.056
Adj. mean	-0.137	-0.229	-0.212	-0.093	-0.293	-0.190
$E_t \bar{R}_{t+1}$	-1.819 [1000]	-2.338 [646]	-2.005 [1000]	N/A	N/A	N/A
Standard error	0.221	2.282	0.277			
Adj. mean	-1.819	-1.692	-2.005			
Mean:						
R-squared	0.789	<0	0.796	0.544	<0	0.482
Adj. R-squared	0.778	<0	0.785	0.525	<0	0.459
Pr(F-statistic)	0.000 (1000)	0.015 (974)	N/A	0.000 (1000)	0.003 (992)	N/A
Pr(J-statistic)	N/A	N/A	0.258 {1000}	N/A	0.159 {482}	0.269 {1000}
D-W	1.474 <151>	2.243 <1000>	2.194 <970>	1.732 <419>	2.145 <999>	2.047 <882>
Adj. sample size	1000×99	1000×98	1000×96	1000×99	1000×98	1000×96

NOTES:

- Coefficient estimates have been generated using the three procedures described in the text.
- The sample size is depleted due to dynamic terms in the estimating equation and/or lagged terms in the instrument set.
- ‘Standard error’ measures the variation in the coefficient estimates.
- ‘Adjusted mean’ assigns a value of zero to non-statistically-significant coefficient estimates (at the 5% level of significance).
- F-statistic: the null hypothesis is of no joint significance of the independent variables (not available under GMM).
- J-statistic: the null hypothesis that the instrument set is ‘valid’ (only available if there are over-identifying restrictions).
- Durbin-Watson (D-W) statistic: tests the null hypothesis that successive residuals are serially uncorrelated against an AR(1) alternative.
- [] reports the number of statistically significant coefficient estimates, () the number of F-statistic rejections, { } the number of J-statistic *non*-rejections and < > the number of times the D-W statistic exceeds its upper critical value (all at the 5% level of significance).

Table 3.4: Full Taylor Condition (3-8)

BP filtered data, 3-8 window	Unrestricted			Restricted ($\beta_5=0$)		
	OLS	2SLS	GMM	OLS	2SLS	GMM
β_0	0.000 [0]	0.000 [0]	0.000 [3]	0.000 [0]	0.000 [0]	0.000 [1]
Standard error	0.000	0.000	0.000	0.000	0.000	0.000
Adj. mean	-	-	0.000	-	-	0.000
$E_t \bar{\pi}_{t+1}$	2.166 [998]	2.484 [724]	2.423 [1000]	0.633 [969]	2.417 [965]	0.682 [974]
Standard error	0.391	32.906	0.298	0.195	1.125	0.222
Adj. mean	2.166	2.141	2.423	0.628	2.291	0.679
$E_t \bar{g}_{c,t+1}$	0.283 [1000]	0.304 [623]	0.314 [1000]	0.155 [1000]	0.175 [834]	0.168 [1000]
Standard error	0.043	7.324	0.027	0.029	0.074	0.030
Adj. mean	0.283	0.231	0.314	0.155	0.160	0.168
$E_t \bar{g}_{l,t+1}$	-0.237 [827]	-0.573 [430]	-0.312 [982]	-0.222 [685]	-0.595 [666]	-0.268 [870]
Standard error	0.131	10.199	0.099	0.133	0.361	0.135
Adj. mean	-0.229	-0.193	-0.312	-0.195	-0.455	-0.259
$E_t \bar{g}_{v,t+1}$	-0.152 [982]	-0.453 [351]	-0.174 [998]	-0.174 [976]	-0.604 [973]	-0.194 [984]
Standard error	0.043	15.068	0.039	0.052	0.252	0.057
Adj. mean	-0.151	-0.128	-0.174	-0.173	-0.578	-0.193
$E_t \bar{R}_{t+1}$	-2.026 [994]	-1.532 [424]	-2.289 [1000]	N/A	N/A	N/A
Standard error	0.435	116.012	0.339			
Adj. mean	-2.024	-1.211	-2.289			
Mean:						
R-squared	0.789	<0	0.842	0.576	<0	0.590
Adj. R-squared	0.778	<0	0.833	0.558	<0	0.572
Pr(F-statistic)	0.000 (1000)	0.077 (874)	N/A	0.000 (1000)	0.005 (981)	N/A
Pr(J-statistic)	N/A	N/A	0.213 {1000}	N/A	0.344 {848}	0.249 {1000}
D-W	1.568 <54>	1.653 <330>	1.517 <49>	1.728 <333>	1.728 <378>	1.715 <306>
Adj. sample size	1000×99	1000×98	1000×96	1000×99	1000×98	1000×96

NOTES:

- Coefficient estimates have been generated using the three procedures described in the text.
- The sample size is depleted due to dynamic terms in the estimating equation and/or lagged terms in the instrument set.
- ‘Standard error’ measures the variation in the coefficient estimates.
- ‘Adjusted mean’ assigns a value of zero to non-statistically-significant coefficient estimates (at the 5% level of significance).
- F-statistic: the null hypothesis is of no joint significance of the independent variables (not available under GMM).
- J-statistic: the null hypothesis that the instrument set is ‘valid’ (only available if there are over-identifying restrictions).
- Durbin-Watson (D-W) statistic: tests the null hypothesis that successive residuals are serially uncorrelated against an AR(1) alternative.
- [] reports the number of statistically significant coefficient estimates, () the number of F-statistic rejections, { } the number of J-statistic *non*-rejections and < > the number of times the D-W statistic exceeds its upper critical value (all at the 5% level of significance).

Table 3.5: Full Taylor Condition (2-15)

BP filtered data, 2-15 window	Unrestricted			Restricted ($\beta_5=0$)		
	OLS	2SLS	GMM	OLS	2SLS	GMM
β_0	0.000 [0]	0.000 [0]	0.000 [22]	0.000 [0]	0.000 [0]	0.000 [21]
Standard error	0.000	0.001	0.000	0.000	0.000	0.000
Adj. mean	-	-	0.000	-	-	0.000
$E_t \bar{\pi}_{t+1}$	2.179 [1000]	3.816 [580]	2.306 [1000]	0.614 [999]	1.127 [763]	0.964 [999]
Standard error	0.195	51.040	0.272	0.108	0.640	0.169
Adj. mean	2.179	1.402	2.306	0.614	0.936	0.963
$E_t \bar{g}_{c,t+1}$	0.277 [1000]	0.570 [730]	0.302 [1000]	0.170 [1000]	0.262 [851]	0.207 [1000]
Standard error	0.016	5.546	0.025	0.017	0.103	0.026
Adj. mean	0.277	0.265	0.302	0.170	0.230	0.207
$E_t \bar{g}_{l,t+1}$	-0.295 [997]	-0.737 [526]	-0.359 [999]	-0.210 [732]	-0.263 [405]	-0.277 [935]
Standard error	0.067	8.208	0.085	0.088	0.203	0.111
Adj. mean	-0.294	-0.242	-0.359	-0.182	-0.152	-0.272
$E_t \bar{g}_{v,t+1}$	-0.196 [1000]	-0.347 [807]	-0.269 [1000]	-0.158 [998]	-0.307 [944]	-0.236 [1000]
Standard error	0.024	0.271	0.031	0.032	0.077	0.042
Adj. mean	-0.196	-0.273	-0.269	-0.158	-0.292	-0.236
$E_t \bar{r}_{t+1}$	-1.761 [1000]	-5.586 [335]	-1.729 [1000]	N/A	N/A	N/A
Standard error	0.201	114.905	0.322			
Adj. mean	-1.761	-0.712	-1.729			
Mean:						
R-squared	0.830	<0	0.782	0.625	<0	0.522
Adj. R-squared	0.821	<0	0.770	0.609	<0	0.501
Pr(F-statistic)	0.000 (1000)	0.051 (907)	N/A	0.000 (1000)	0.003 (985)	N/A
Pr(J-statistic)	N/A	N/A	0.315 {1000}	N/A	0.298 {757}	0.298 {1000}
D-W	1.558 <141>	2.059 <972>	2.040 <881>	1.954 <864>	2.052 <998>	2.205 <977>
Adj. sample size	1000×99	1000×98	1000×96	1000×99	1000×98	1000×96

NOTES:

- Coefficient estimates have been generated using the three procedures described in the text.
- The sample size is depleted due to dynamic terms in the estimating equation and/or lagged terms in the instrument set.
- ‘Standard error’ measures the variation in the coefficient estimates.
- ‘Adjusted mean’ assigns a value of zero to non-statistically-significant coefficient estimates (at the 5% level of significance).
- F-statistic: the null hypothesis is of no joint significance of the independent variables (not available under GMM).
- J-statistic: the null hypothesis that the instrument set is ‘valid’ (only available if there are over-identifying restrictions).
- Durbin-Watson (D-W) statistic: tests the null hypothesis that successive residuals are serially uncorrelated against an AR(1) alternative.
- [] reports the number of statistically significant coefficient estimates, () the number of F-statistic rejections, { } the number of J-statistic *non*-rejections and < > the number of times the D-W statistic exceeds its upper critical value (all at the 5% level of significance).

Table 3.6: Output Growth instead of Consumption Growth (2-15)

BP filtered data, 2-15 window	Unrestricted			Restricted ($\beta_5=0$)		
	OLS	2SLS	GMM	OLS	2SLS	GMM
β_0	0.000 [0]	0.001 [0]	0.000 [16]	0.000 [0]	0.000 [0]	0.000 [5]
Standard error	0.000	0.031	0.000	0.000	0.000	0.000
Adj. mean	-	-	0.000	-	-	0.000
$E_t \bar{\pi}_{t+1}$	4.219 [971]	-25.003 [189]	5.274 [961]	0.541 [941]	2.338 [882]	1.101 [990]
Standard error	1.715	1290.303	2.582	0.170	1.151	0.264
Adj. mean	4.185	2.522	5.235	0.532	2.010	1.100
$E_t \bar{g}_{y,t+1}$	0.303 [967]	-2.019 [206]	0.406 [940]	0.038 [563]	0.211 [262]	0.082 [956]
Standard error	0.125	122.643	0.204	0.020	0.304	0.029
Adj. mean	0.300	0.244	0.402	0.029	0.077	0.081
$E_t \bar{g}_{l,t+1}$	-2.098 [959]	14.698 [211]	-2.815 [954]	-0.284 [424]	-1.462 [353]	-0.610 [941]
Standard error	0.892	825.197	1.417	0.189	1.740	0.232
Adj. mean	-2.073	-1.672	-2.790	-0.189	-0.655	-0.598
$E_t \bar{g}_{v,t+1}$	-0.118 [884]	0.069 [310]	-0.191 [970]	-0.095 [733]	-0.246 [587]	-0.158 [923]
Standard error	0.042	16.979	0.064	0.043	0.164	0.061
Adj. mean	-0.113	-0.117	-0.190	-0.084	-0.161	-0.156
$E_t \bar{R}_{t+1}$	-3.878 [907]	29.503 [128]	-4.498 [849]	N/A	N/A	N/A
Standard error	1.812	1437.910	2.802			
Adj. mean	-3.767	-1.757	-4.372			
Mean:						
R-squared	0.361	<0	0.127	0.246	<0	<0
Adj. R-squared	0.327	<0	0.079	0.214	<0	<0
Pr(F-statistic)	0.001 (995)	0.379 (411)	N/A	0.020 (924)	0.055 (829)	N/A
Pr(J-statistic)	N/A	N/A	0.226 {1000}	N/A	0.260 {682}	0.264 {1000}
D-W	1.882 <699>	1.982 <868>	2.342 <945>	2.295 <1000>	2.145 <997>	2.728 <999>
Adj. sample size	1000×99	1000×98	1000×96	1000×99	1000×98	1000×96

NOTES:

- Coefficient estimates have been generated using the three procedures described in the text.
- The sample size is depleted due to dynamic terms in the estimating equation and/or lagged terms in the instrument set.
- ‘Standard error’ measures the variation in the coefficient estimates.
- ‘Adjusted mean’ assigns a value of zero to non-statistically-significant coefficient estimates (at the 5% level of significance).
- F-statistic: the null hypothesis is of no joint significance of the independent variables (not available under GMM).
- J-statistic: the null hypothesis that the instrument set is ‘valid’ (only available if there are over-identifying restrictions).
- Durbin-Watson (D-W) statistic: tests the null hypothesis that successive residuals are serially uncorrelated against an AR(1) alternative.
- [] reports the number of statistically significant coefficient estimates, () the number of F-statistic rejections, { } the number of J-statistic *non*-rejections and < > the number of times the D-W statistic exceeds its upper critical value (all at the 5% level of significance).

Table 3.7: A Taylor Rule (2-15)

BP filtered data, 2-15 window	Unrestricted			Restricted ($\beta_5=0$)		
	OLS	2SLS	GMM	OLS	2SLS	GMM
β_0	0.000 [0]	0.000 [0]	0.000 [8]	0.000 [0]	0.000 [0]	0.000 [12]
Standard error	0.000	0.006	0.000	0.000	0.000	0.000
Adj. mean	-	-	0.000	-	-	0.000
$E_t \bar{\pi}_{t+1}$	0.310 [239]	0.671 [22]	0.132 [344]	0.326 [926]	1.472 [416]	0.894 [981]
Standard error	0.448	162.564	0.955	0.099	3.431	0.315
Adj. mean	0.185	0.017	0.092	0.317	0.826	0.892
$E_t \bar{g}_{y,t+1}$	0.020 [277]	-0.185 [40]	0.019 [237]	0.021 [408]	0.035 [163]	0.031 [460]
Standard error	0.017	16.569	0.027	0.012	0.582	0.027
Adj. mean	0.011	0.012	0.012	0.013	0.041	0.024
$E_t \bar{R}_{t+1}$	0.008 [147]	4.225 [27]	0.918 [524]	N/A	N/A	N/A
Standard error	0.475	88.304	1.002			
Adj. mean	0.012	0.104	0.788			
Mean:						
R-squared	0.169	<0	<0	0.153	<0	<0
Adj. R-squared	0.142	<0	<0	0.136	<0	<0
Pr(F-statistic)	0.029 (887)	0.527 (162)	N/A	0.024 (891)	0.149 (599)	N/A
Pr(J-statistic)	N/A	N/A	0.050 {339}	N/A	0.352 {679}	0.058 {440}
D-W	1.828 <850>	2.012 <974>	2.236 <991>	1.817 <783>	2.047 <996>	2.186 <990>
Adj. sample size	1000×99	1000×98	1000×96	1000×99	1000×98	1000×96

NOTES:

- Coefficient estimates have been generated using the three procedures described in the text.
- The sample size is depleted due to dynamic terms in the estimating equation and/or lagged terms in the instrument set.
- ‘Standard error’ measures the variation in the coefficient estimates.
- ‘Adjusted mean’ assigns a value of zero to non-statistically-significant coefficient estimates (at the 5% level of significance).
- F-statistic: the null hypothesis is of no joint significance of the independent variables (not available under GMM).
- J-statistic: the null hypothesis that the instrument set is ‘valid’ (only available if there are over-identifying restrictions).
- Durbin-Watson (D-W) statistic: tests the null hypothesis that successive residuals are serially uncorrelated against an AR(1) alternative.
- [] reports the number of statistically significant coefficient estimates, () the number of F-statistic rejections, { } the number of J-statistic *non*-rejections and < > the number of times the D-W statistic exceeds its upper critical value (all at the 5% level of significance).

Table 3.8: Full Taylor Condition (Unfiltered Data)

Unfiltered data	Unrestricted			Restricted ($\beta_5=0$)		
	OLS	2SLS	GMM	OLS	2SLS	GMM
β_0	0.000 [409]	0.000 [27]	0.000 [260]	0.000 [389]	0.000 [165]	0.000 [429]
Standard error	0.000	0.004	0.000	0.000	0.001	0.000
Adj. mean	0.000	0.000	0.000	0.000	0.000	0.000
$E_t \bar{\pi}_{t+1}$	0.837 [1000]	-0.263 [107]	0.515 [804]	0.702 [1000]	0.784 [905]	0.782 [1000]
Standard error	0.262	24.570	0.270	0.069	0.367	0.101
Adj. mean	0.837	0.101	0.478	0.702	0.729	0.782
$E_t \bar{g}_{c,t+1}$	0.177 [1000]	0.096 [143]	0.178 [925]	0.164 [1000]	0.282 [779]	0.235 [1000]
Standard error	0.028	3.133	0.059	0.015	0.241	0.032
Adj. mean	0.177	0.038	0.173	0.164	0.210	0.235
$E_t \bar{g}_{i,t+1}$	-0.031 [124]	0.069 [19]	0.078 [328]	-0.017 [83]	0.143 [93]	0.087 [407]
Standard error	0.082	2.670	0.109	0.074	0.329	0.113
Adj. mean	-0.016	0.005	0.056	-0.006	0.028	0.069
$E_t \bar{g}_{v,t+1}$	-0.169 [1000]	-0.099 [185]	-0.167 [936]	-0.167 [1000]	-0.285 [860]	-0.199 [1000]
Standard error	0.026	4.460	0.056	0.025	0.151	0.044
Adj. mean	-0.169	-0.050	-0.163	-0.167	-0.239	-0.199
$E_t \bar{R}_{t+1}$	-0.170 [360]	1.430 [11]	0.438 [543]	N/A	N/A	N/A
Standard error	0.308	30.153	0.402			
Adj. mean	-0.138	0.012	0.365			
Mean:						
R-squared	0.786	<0	0.641	0.775	<0	0.692
Adj. R-squared	0.774	<0	0.621	0.766	<0	0.678
Pr(F-statistic)	0.000 (1000)	0.098 (844)	N/A	0.000 (1000)	0.005 (989)	N/A
Pr(J-statistic)	N/A	N/A	0.494 {1000}	N/A	0.515 {956}	0.430 {1000}
D-W	1.653 <281>	1.937 <843>	1.973 <902>	1.803 <607>	1.993 <977>	1.863 <719>
Adj. sample size	1000×99	1000×98	1000×96	1000×99	1000×98	1000×96

NOTES:

- Coefficient estimates have been generated using the three procedures described in the text.
- The sample size is depleted due to dynamic terms in the estimating equation and/or lagged terms in the instrument set.
- ‘Standard error’ measures the variation in the coefficient estimates.
- ‘Adjusted mean’ assigns a value of zero to non-statistically-significant coefficient estimates (at the 5% level of significance).
- F-statistic: the null hypothesis is of no joint significance of the independent variables (not available under GMM).
- J-statistic: the null hypothesis that the instrument set is ‘valid’ (only available if there are over-identifying restrictions).
- Durbin-Watson (D-W) statistic: tests the null hypothesis that successive residuals are serially uncorrelated against an AR(1) alternative.
- [] reports the number of statistically significant coefficient estimates, () the number of F-statistic rejections, { } the number of J-statistic *non*-rejections and < > the number of times the D-W statistic exceeds its upper critical value (all at the 5% level of significance).

Table 4.1: Parameters

<i>Preferences</i>		
θ	1.000	Relative risk aversion parameter
ψ	1.840	Leisure weight
β	0.960	Discount factor
<i>Goods Production</i>		
α	0.640	Labour share in goods production
δ_k	0.031	Depreciation rate of goods sector
A_G	1.000	Goods productivity parameter
<i>Human Capital Production</i>		
ε	0.830	Labour share in human capital production
δ_h	0.025	Depreciation rate of human capital sector
A_H	0.210	Human capital productivity parameter
<i>Banking Sector</i>		
γ	0.110	Labour share in credit production
A_F	1.100	Banking productivity parameter
<i>Government</i>		
Θ^*	0.050	Money growth rate
<i>Shock processes</i>		
<i>i) Autocorrelation coeffs.</i>		
φ_z	0.840	Production productivity
φ_u	0.740	Money growth rate
φ_v	0.730	Banking productivity
<i>ii) Std. dev. of innovations</i>		
$\sigma_{\varepsilon z}$	0.770	Production productivity
$\sigma_{\varepsilon u}$	0.500	Money growth rate
$\sigma_{\varepsilon v}$	1.160	Banking productivity

Table 4.2: Target Values

\bar{g}	0.0240	Avg. Annual output growth rate
$\bar{\pi}$	0.0260	Avg. annual inflation rate
\bar{R}	0.0944	Nominal interest rate
l_G	0.2480	Labour used in goods sector
l_H	0.2000	Labour used in human capital sector
l_F	0.0018	Labour used in banking sector
i/y	0.2380	Investment-output ratio in goods sector
m/c	0.3800	Share of money transactions
x	0.5500	Leisure time
$1-x$	0.4500	Productive time

Table 4.3: Unit Root and Stationarity Tests for Simulated Data

Unfiltered data	ADF(i)	ADF(ii)	ADF(iii)	KPSS(i)	KPSS(ii)
Nominal interest rate (\bar{R})	-3.787*** {0.809} [975]	-3.960** {0.870} [925]	-4.149** {1.080} [841]	0.249 [876]	0.099 [863]
Inflation rate ($\bar{\pi}$)	-3.363** {0.893} [957]	-3.586** {0.942} [827]	-3.837* {1.108} [695]	0.285 [822]	0.108 [808]
Real consumption growth rate (\bar{g}_c)	-5.995*** {1.313} [993]	-6.142*** {1.321} [968]	-6.373** {1.289} [913]	0.148 [983]	0.082 [948]
Productive time growth rate (\bar{g}_l)	-4.916*** {1.236} [999]	-4.948*** {1.282} [963]	-5.064** {1.338} [883]	0.148 [978]	0.082 [948]
Consumption velocity growth rate (\bar{g}_{vc})	-6.983*** {2.481} [999]	-6.943*** {2.633} [997]	-6.892*** {2.842} [987]	0.114 [987]	0.080 [925]
Real output growth rate (\bar{g}_y)	-8.824*** {0.923} [990]	-8.934*** {0.947} [988]	-8.929*** {1.088} [981]	0.161 [969]	0.079 [947]
Leisure time growth rate (\bar{g}_x)	-4.916*** {1.236} [999]	-4.948*** {1.282} [963]	-5.064** {1.338} [883]	0.148 [978]	0.082 [948]

NOTES:

- The Augmented Dickey-Fuller (ADF) test is conducted under the null hypothesis that the series in question is integrated of order one. ADF(i) includes neither a constant nor a trend; ADF(ii) includes a constant but no trend; ADF(iii) includes both a constant and a trend. The lag length is selected using the Akaike Information Criterion (as in Österholm, 2005, and Siklos and Wohar, 2005) and the maximum lag length is selected according to the Schwert (1989) criterion. The table reports the mean test statistic over the 1000 simulated sample periods along with the mean number of lags included in the test (in braces) and the number of null hypothesis rejections at the 5% level of significance (in square brackets).
- The Kwiatkowski, Phillips, Schmidt and Shin (1992) test is conducted under the null hypothesis that the series in question is stationary. KPSS(i) includes a constant but no trend; KPSS(ii) includes both a constant and a trend. The test is performed using a Bartlett kernel, the bandwidth for which is set according to the Newey-West automatic bandwidth selection method (as in Österholm, 2005). The table reports the mean test statistic over 1000 simulated sample periods along with the number of null hypothesis *non*-rejections (in square brackets). The asymptotic critical values obtained from Kwiatkowski et al. (1992) are 0.739 (1% significance), 0.463 (5% significance) and 0.347 (10% significance) for KPSS(i) and 0.216 (1% significance), 0.146 (5% significance) and 0.119 (10% significance) for KPSS(ii).
- *** denotes that the null hypothesis is rejected on average at the 1% level of significance, ** denotes rejection at the 5% level, and * denotes rejection at the 10% level.

Table 4.4: Full Taylor Condition for Model-Simulated Data

Unrestricted model	Correctly specified			Misspecified (g_v instead of g_c)		
	High-freq. component (2-8 yrs.)	Medium-freq. component (8-20 yrs.)	Medium-term cycle (2-20 yrs.)	High-freq. component (2-8 yrs.)	Medium-freq. component (8-20 yrs.)	Medium-term cycle (2-20 yrs.)
β_0	0.000 [4]	0.000 [32]	0.000 [24]	0.000 [2]	0.000 [41]	0.000 [12]
Standard error	0.000	0.000	0.000	0.000	0.000	0.000
Adj. mean	0.000	0.000	0.000	0.000	0.000	0.000
$E_t \bar{\pi}_{t+1}$	2.221 [1000]	0.208 [596]	2.068 [1000]	9.409 [995]	-0.097 [595]	3.229 [823]
Standard error	0.296	0.667	0.295	3.320	0.716	2.026
Adj. mean	2.221	0.191	2.068	9.399	-0.093	3.079
$E_t \bar{g}_{c,t+1}$ or $E_t \bar{g}_{v,t+1}$	0.279 [1000]	-0.035 [639]	0.293 [1000]	0.685 [999]	-0.049 [704]	0.264 [779]
Standard error	0.021	0.132	0.031	0.231	0.072	0.174
Adj. mean	0.279	-0.035	0.293	0.685	-0.047	0.249
$E_t \bar{g}_{l,t+1}$	-0.340 [996]	-0.114 [775]	-0.301 [991]	-4.890 [995]	0.138 [601]	-1.770 [809]
Standard error	0.090	0.116	0.093	1.719	0.359	1.150
Adj. mean	-0.340	-0.110	-0.300	-4.887	0.129	-1.685
$E_t \bar{g}_{v,t+1}$	-0.180 [1000]	-0.231 [1000]	-0.276 [1000]	-0.091 [699]	-0.233 [1000]	-0.187 [979]
Standard error	0.035	0.037	0.033	0.083	0.034	0.057
Adj. mean	-0.180	-0.231	-0.276	-0.087	-0.233	-0.186
$E_t \bar{R}_{t+1}$	-1.999 [1000]	0.972 [828]	-1.395 [987]	-9.780 [995]	1.259 [890]	-2.123 [562]
Standard error	0.275	0.866	0.376	3.300	0.768	2.209
Adj. mean	-1.999	0.953	-1.389	-9.771	1.247	-1.894
Mean:						
R-squared	0.826	0.962	0.764	0.384	0.963	0.019
Adj. R-squared	0.816	0.960	0.751	0.349	0.961	<0
Pr(J-statistic)	0.214 {1000}	0.195 {1000}	0.391 {1000}	0.214 {1000}	0.196 {1000}	0.302 {1000}
D-W	2.082 <887>	0.324 <0>	2.015 <860>	1.460 <149>	0.324 <0>	2.468 <997>
Pr(Q-statistic)	0.405 (852)	0.000 (0)	0.486 (940)	0.146 (384)	0.000 (0)	0.091 (302)
Adj. sample size	1000×96	1000×96	1000×96	1000×96	1000×96	1000×96

NOTES:

- Coefficient estimates have been generated using the GMM procedure described in the text.
- The sample size is reduced to 1000×96 periods due to lagged terms in the instrument set.
- The band pass filter employed is an asymmetric Christiano and Fitzgerald (2003) filter with no detrending.
- ‘Standard error’ measures the variation in the coefficient estimates.
- ‘Adjusted mean’ assigns a value of zero to non-statistically-significant coefficient estimates (at the 5% level of significance).
- J-statistic: the null hypothesis that the instrument set is ‘valid’.
- Durbin-Watson (D-W) statistic: tests the null hypothesis that successive residuals are serially uncorrelated against an AR(1) alternative.
- Pr(Q) is the P-value associated with the Q-statistic for the first lag of a ten lag test. The null hypothesis is that there is no autocorrelation in the estimated residual series.
- [] reports the number of statistically significant coefficient estimates, { } the number of J-statistic non-rejections, <> the number of times the D-W statistic exceeds its upper critical value and () the number of Q-statistic non-rejections (all at the 5% level of significance).

Table 4.5: Full Taylor Condition for U.S. Data, 1960q1-2011q1

Full specification	Pre-Volcker (1960q1-1979q2)	CGG post-Volcker (1979q3-1996q4)	Taylor post-Volcker (1979q3-2000q3)	Extended post-Volcker (1979q3-2011q1)	Full sample (1960q1-2011q1)
β_0	5.125*	-2.630***	-1.932**	-1.684	0.146
Standard error	(2.285)	(1.234)	(1.070)	(1.570)	(1.938)
$E_t \bar{\pi}_{t+1}$	1.170**	1.973***	1.955***	1.747***	0.919**
Standard error	(0.333)	(0.154)	(0.136)	(0.254)	(0.272)
$E_t \bar{g}_{c,t+1}$	0.619	0.730***	0.596***	0.576	0.537
Standard error	(0.663)	(0.220)	(0.180)	(0.345)	(0.415)
$E_t \bar{g}_{l,t+1}$	1.353	1.199**	1.361***	1.568	2.871
Standard error	(1.622)	(0.487)	(0.488)	(1.012)	(1.018)
$E_t \bar{g}_{v,t+1}$	-2.329***	0.163**	0.145***	0.025	-0.091
Standard error	(1.341)	(0.057)	(0.045)	(0.091)	(0.125)
$E_t \bar{R}_{t+1}$	0.617***	1.272***	1.279***	1.121***	1.114***
Standard error	(0.051)	(0.082)	(0.081)	(0.029)	(0.023)
\bar{R}_{t-1}	0.440***	N/A	N/A	N/A	N/A
Standard error	(0.062)				
\bar{R}_{t-2}	N/A	N/A	N/A	N/A	N/A
Standard error					
Mean:					
R-squared	0.959	0.878	0.887	0.936	0.919
Adj. R-squared	0.955	0.868	0.880	0.933	0.917
Pr(J-statistic)	0.766	0.846	0.889	0.946	0.861
D-W	N/A	2.139	2.145	1.854	1.634
Critical D-W	[N/A]	[1.464-1.768]	[1.525-1.774]	[1.628-1.792]	[1.718-1.820]
Pr(Q-statistic)	0.421	0.473	0.419	0.598	0.010
Adj. sample size	74	70	85	126	200

NOTES:

- Coefficient estimates have been generated using the GMM procedure described in the text.
- Sample sizes are depleted by the lagged terms in the instrument set.
- The reported coefficient estimates for the variables which enter the estimating equation (4.11) are “long-run” estimates, i.e. indirect estimates which remove the influence of the dynamic adjustment process (see Mehra, 1999, p.41, for example). The reported coefficients for the lagged dependent variable terms are direct estimates.
- The figures in parenthesis represent standard errors calculated using the delta method for the “long-run” estimates (e.g. Mihailov, 2006) or simply the conventional standard error for the lagged dependent variable terms.
- Superscript asterisks denote the statistical significance of the underlying direct estimates (*=10%, **=5%, ***=1%).
- J-statistic: the null hypothesis that the instrument set is ‘valid’.
- Durbin-Watson (D-W) statistic: tests the null hypothesis that successive residuals are serially uncorrelated against an AR(1) alternative (not available when lagged dependent variable terms are included in the estimating equation). The 5% critical region is provided in square brackets.
- Pr(Q) is the P-value associated with the Q-statistic for the first lag of a ten lag test. The null hypothesis is that there is no autocorrelation in the estimated residual series.

Table 4.6: A Standard Taylor Rule for Model-Simulated Data

'Taylor rule' ($\beta_3 = \beta_4 = 0$)	'Dynamic' ($\beta_5 \neq 0$)			'Non-dynamic' ($\beta_5 = 0$)		
	High-freq. component (2-8 yrs.)	Medium-freq. component (8-20 yrs.)	Medium-term cycle (2-20 yrs.)	High-freq. component (2-8 yrs.)	Medium-freq. component (8-20 yrs.)	Medium-term cycle (2-20 yrs.)
β_0	0.000 [1]	0.000 [17]	0.000 [8]	0.000 [0]	0.000 [33]	0.000 [11]
Standard error	0.000	0.000	0.000	0.000	0.000	0.000
Adj. mean	0.000	0.000	0.000	-	0.000	0.000
$E_t \bar{\pi}_{t+1}$	0.564 [445]	0.042 [494]	0.047 [280]	0.021 [425]	0.739 [1000]	1.269 [982]
Standard error	0.967	0.451	0.897	0.233	0.112	0.401
Adj. mean	0.490	0.040	0.033	0.018	0.739	1.265
$E_t \bar{y}_{t+1}$	0.027 [489]	0.002 [537]	0.017 [153]	0.026 [515]	0.047 [736]	0.037 [321]
Standard error	0.023	0.047	0.039	0.026	0.035	0.077
Adj. mean	0.021	0.002	0.010	0.021	0.045	0.032
$E_t \bar{r}_{t+1}$	-0.623 [476]	0.820 [873]	1.340 [700]	N/A	N/A	N/A
Standard error	1.011	0.481	0.929			
Adj. mean	-0.549	0.802	1.212			
Mean:						
R-squared	0.029	0.772	<0	<0	0.689	<0
Adj. R-squared	-0.002	0.765	<0	<0	0.682	<0
Pr(J-statistic)	0.027 {69}	0.047 {313}	0.132 {782}	0.011 {4}	0.024 {101}	0.113 {490}
D-W	1.972 <975>	0.311 <0>	2.124 <990>	2.067 <983>	0.296 <0>	2.031 <969>
Pr(Q-statistic)	0.672 (994)	0.000 (0)	0.456 (878)	0.537 (970)	0.000 (0)	0.504 (945)
Adj. sample size	1000×96	1000×96	1000×96	1000×96	1000×96	1000×96

NOTES:

- Coefficient estimates have been generated using the GMM procedure described in the text.
- The sample size is reduced to 1000×96 periods due to lagged terms in the instrument set.
- The band pass filter employed is an asymmetric Christiano and Fitzgerald (2003) filter with no detrending.
- 'Standard error' measures the variation in the coefficient estimates.
- 'Adjusted mean' assigns a value of zero to non-statistically-significant coefficient estimates (at the 5% level of significance).
- J-statistic: the null hypothesis that the instrument set is 'valid'.
- Durbin-Watson (D-W) statistic: tests the null hypothesis that successive residuals are serially uncorrelated against an AR(1) alternative.
- Pr(Q) is the P-value associated with the Q-statistic for the first lag of a ten lag test. The null hypothesis is that there is no autocorrelation in the estimated residual series.
- [] reports the number of statistically significant coefficient estimates, { } the number of J-statistic non-rejections, < > the number of times the D-W statistic exceeds its upper critical value and () the number of Q-statistic non-rejections (all at the 5% level of significance).

Table 4.7: Full Taylor Condition for Alternative Filter Specifications

Correctly Specified Model, Medium-Term Cycle					
Filter window:	2-15 yrs.	2-20 yrs.	2-25 yrs.	2-50 yrs.	2-75 yrs.
β_0	0.000 [22]	0.000 [24]	0.000 [30]	0.000 [31]	0.000 [44]
Standard error	0.000	0.000	0.000	0.000	0.000
Adj. mean	0.000	0.000	0.000	0.000	0.000
$E_t \bar{\pi}_{t+1}$	2.306 [1000]	2.068 [1000]	1.840 [1000]	1.097 [977]	0.813 [940]
Standard error	0.272	0.295	0.316	0.327	0.305
Adj. mean	2.306	2.068	1.840	1.089	0.798
$E_t \bar{g}_{c,t+1}$	0.302 [1000]	0.293 [1000]	0.280 [1000]	0.232 [995]	0.205 [975]
Standard error	0.025	0.031	0.036	0.048	0.053
Adj. mean	0.302	0.293	0.280	0.231	0.203
$E_t \bar{g}_{l,t+1}$	-0.359 [999]	-0.301 [991]	-0.241 [921]	-0.053 [334]	0.014 [246]
Standard error	0.085	0.093	0.098	0.112	0.108
Adj. mean	-0.359	-0.300	-0.235	-0.043	0.010
$E_t \bar{g}_{v,t+1}$	-0.269 [1000]	-0.276 [1000]	-0.270 [1000]	-0.230 [998]	-0.199 [983]
Standard error	0.031	0.033	0.035	0.046	0.052
Adj. mean	-0.269	-0.276	-0.270	-0.230	-0.198
$E_t \bar{R}_{t+1}$	-1.729 [1000]	-1.395 [987]	-1.114 [951]	-0.244 [367]	0.087 [293]
Standard error	0.322	0.376	0.421	0.454	0.428
Adj. mean	-1.729	-1.389	-1.100	-0.207	0.055
Mean:					
R-squared	0.782	0.764	0.750	0.687	0.664
Adj. R-squared	0.770	0.751	0.736	0.670	0.645
Pr(J-statistic)	0.315 {1000}	0.391 {1000}	0.436 {1000}	0.533 {1000}	0.526 {1000}
D-W	2.040 <881>	2.015 <860>	1.999 <874>	1.984 <872>	1.980 <892>
Pr(Q-statistic)	0.458 (913)	0.486 (940)	0.500 (949)	0.542 (962)	0.571 (970)
Adj. sample size	1000×96	1000×96	1000×96	1000×96	1000×96

NOTES:

- Coefficient estimates have been generated using the GMM procedure described in the text.
- The sample size is reduced to 1000×96 periods due to lagged terms in the instrument set.
- The band pass filter employed is an asymmetric Christiano and Fitzgerald (2003) filter with no detrending.
- ‘Standard error’ measures the variation in the coefficient estimates.
- ‘Adjusted mean’ assigns a value of zero to non-statistically-significant coefficient estimates (at the 5% level of significance).
- J-statistic: the null hypothesis that the instrument set is ‘valid’.
- Durbin-Watson (D-W) statistic: tests the null hypothesis that successive residuals are serially uncorrelated against an AR(1) alternative.
- Pr(Q) is the P-value associated with the Q-statistic for the first lag of a ten lag test. The null hypothesis is that there is no autocorrelation in the estimated residual series.
- [] reports the number of statistically significant coefficient estimates, { } the number of J-statistic *non*-rejections, < > the number of times the D-W statistic exceeds its upper critical value and () the number of Q-statistic *non*-rejections (all at the 5% level of significance).

Table 4.8: Restricted Taylor Conditions for Model-Simulated Data

	Restricted ($\beta_5=0$)			Restricted ($\beta_3=\beta_4=\beta_5=0$)		
	High-freq. component (2-8 yrs.)	Medium-freq. component (8-20 yrs.)	Medium-term cycle (2-20 yrs.)	High-freq. component (2-8 yrs.)	Medium-freq. component (8-20 yrs.)	Medium-term cycle (2-20 yrs.)
β_0	0.000 [2]	0.000 [58]	0.000 [20]	0.000 [0]	0.000 [23]	0.000 [16]
Standard error	0.000	0.000	0.000	0.000	0.000	0.000
Adj. mean	0.000	0.000	0.000	-	0.000	0.000
$E_t\bar{\pi}_{t+1}$	0.392 [778]	0.949 [1000]	1.025 [1000]	-0.037 [301]	0.668 [1000]	0.931 [937]
Standard error	0.230	0.080	0.154	0.143	0.099	0.393
Adj. mean	0.370	0.949	1.025	-0.026	0.668	0.916
$E_t\bar{g}_{c,t+1}$	0.221 [1000]	0.107 [996]	0.214 [1000]	0.180 [1000]	0.098 [812]	0.135 [812]
Standard error	0.028	0.031	0.031	0.022	0.064	0.065
Adj. mean	0.221	0.107	0.214	0.180	0.095	0.128
$E_t\bar{g}_{l,t+1}$	-0.421 [990]	-0.084 [681]	-0.202 [764]	N/A	N/A	N/A
Standard error	0.129	0.114	0.115			
Adj. mean	-0.420	-0.080	-0.186			
$E_t\bar{g}_{v,t+1}$	-0.152 [948]	-0.246 [1000]	-0.254 [1000]	N/A	N/A	N/A
Standard error	0.059	0.036	0.041			
Adj. mean	-0.150	-0.246	-0.254			
Mean:						
R-squared	0.527	0.952	0.529	0.411	0.728	<0
Adj. R-squared	0.506	0.950	0.509	0.398	0.722	<0
Pr(J-statistic)	0.149 {997}	0.150 {992}	0.325 {1000}	0.018 {38}	0.024 {91}	0.071 {373}
D-W	1.904 <752>	0.306 <0>	2.152 <984>	1.784 <647>	0.303 <0>	1.692 <492>
Pr(Q-statistic)	0.475 (937)	0.000 (0)	0.401 (877)	0.375 (858)	0.000 (0)	0.284 (726)
Adj. sample size	1000×96	1000×96	1000×96	1000×96	1000×96	1000×96

NOTES:

- Coefficient estimates have been generated using the GMM procedure described in the text.
- The sample size is reduced to 1000×96 periods due to lagged terms in the instrument set.
- The band pass filter employed is an asymmetric Christiano and Fitzgerald (2003) filter with no detrending.
- ‘Standard error’ measures the variation in the coefficient estimates.
- ‘Adjusted mean’ assigns a value of zero to non-statistically-significant coefficient estimates (at the 5% level of significance).
- J-statistic: the null hypothesis that the instrument set is ‘valid’.
- Durbin-Watson (D-W) statistic: tests the null hypothesis that successive residuals are serially uncorrelated against an AR(1) alternative.
- Pr(Q) is the P-value associated with the Q-statistic for the first lag of a ten lag test. The null hypothesis is that there is no autocorrelation in the estimated residual series.
- [] reports the number of statistically significant coefficient estimates, { } the number of J-statistic non-rejections, <> the number of times the D-W statistic exceeds its upper critical value and () the number of Q-statistic non-rejections (all at the 5% level of significance).

Table 4.9: A Restricted Taylor Condition for U.S. Data, 1960q1-2011q1

<i>Restricted</i> ($\beta_5=0$)	Pre-Volcker (1960q1- 1979q2)	CGG post- Volcker (1979q3- 1996q4)	Taylor post- Volcker (1979q3- 2000q3)	Extended post- Volcker (1979q3- 2011q1)	Full sample (1960q1- 2011q1)
β_0	1.843	-0.713	-0.540	-2.152	2.936
Standard error	(2.924)	(0.649)	(0.735)	(1.558)	(2.079)
$E_t \bar{\pi}_{t+1}$	0.892*	1.969***	1.906***	2.189***	0.857**
Standard error	(0.282)	(0.109)	(0.108)	(0.211)	(0.331)
$E_t \bar{g}_{c,t+1}$	0.721	0.166	0.228	0.235	-0.352
Standard error	(0.752)	(0.142)	(0.135)	(0.374)	(0.445)
$E_t \bar{g}_{l,t+1}$	3.241***	1.556***	1.685***	2.794***	4.870***
Standard error	(1.927)	(0.446)	(0.442)	(0.800)	(1.221)
$E_t \bar{g}_{v,t+1}$	-1.123**	0.178***	0.185***	0.194**	0.148
Standard error	(0.828)	(0.047)	(0.047)	(0.081)	(0.121)
\bar{R}_{t-1}	1.240***	0.677***	0.688***	0.877***	0.916***
Standard error	(0.076)	(0.032)	(0.035)	(0.019)	(0.016)
\bar{R}_{t-2}	-0.343***	N/A	N/A	N/A	N/A
Standard error	(0.063)				
Mean:					
R-squared	0.909	0.929	0.935	0.953	0.939
Adj. R-squared	0.901	0.923	0.931	0.951	0.937
Pr(J-statistic)	0.694	0.738	0.653	0.775	0.126
D-W	N/A	N/A	N/A	N/A	N/A
Critical D-W	[N/A]	[N/A]	[N/A]	[N/A]	[N/A]
Pr(Q-statistic)	0.455	0.469	0.312	0.654	0.126
Adj. sample size	74	70	85	126	200

NOTES:

- Coefficient estimates have been generated using the GMM procedure described in the text.
- Sample sizes are depleted by the lagged terms in the instrument set.
- The reported coefficient estimates for the variables which enter the estimating equation (4.11) are “long-run” estimates, i.e. indirect estimates which remove the influence of the dynamic adjustment process (see Mehra, 1999, p.41, for example). The reported coefficients for the lagged dependent variable terms are direct estimates.
- The figures in parenthesis represent standard errors calculated using the delta method for the “long-run” estimates (e.g. Mihailov, 2006) or simply the conventional standard error for the lagged dependent variable terms.
- Superscript asterisks denote the statistical significance of the underlying direct estimates (*=10%, **=5%, ***=1%).
- J-statistic: the null hypothesis that the instrument set is ‘valid’.
- Durbin-Watson (D-W) statistic: tests the null hypothesis that successive residuals are serially uncorrelated against an AR(1) alternative (not available when lagged dependent variable terms are included in the estimating equation). The 5% critical region is provided in square brackets.
- Pr(Q) is the P-value associated with the Q-statistic for the first lag of a ten lag test. The null hypothesis is that there is no autocorrelation in the estimated residual series.

Table 4.10: A 'Long-Run Taylor Condition' for U.S. Data, 1960q1-2011q1

<i>Restricted</i> ($\beta_3 = \beta_4 = \beta_5 = 0$)	Pre-Volcker (1960q1- 1979q2)	CGG post- Volcker (1979q3- 1996q4)	Taylor post- Volcker (1979q3- 2000q3)	Extended post- Volcker (1979q3- 2011q1)	Full sample (1960q1- 2011q1)
β_0	-1.415	-2.262	-2.200	-5.595***	-4.757**
Standard error	(2.665)	(1.971)	(1.928)	(1.980)	(2.772)
$E_t \bar{\pi}_{t+1}$	1.048***	2.121***	2.097***	2.482***	1.073*
Standard error	(0.187)	(0.281)	(0.272)	(0.333)	(0.387)
$E_t \bar{g}_{c,t+1}$	0.650*	0.798**	0.844***	1.178***	1.899***
Standard error	(0.492)	(0.353)	(0.331)	(0.364)	(0.741)
\bar{R}_{t-1}	1.368***	0.745***	0.745***	0.884***	1.376***
Standard error	(0.084)	(0.055)	(0.055)	(0.027)	(0.091)
\bar{R}_{t-2}	-0.530***	N/A	N/A	N/A	-0.438***
Standard error	(0.075)				(0.089)
Mean:					
R-squared	0.898	0.914	0.920	0.949	0.927
Adj. R-squared	0.892	0.911	0.917	0.947	0.926
Pr(J-statistic)	0.595	0.606	0.531	0.335	0.691
D-W	N/A	N/A	N/A	N/A	N/A
Critical D-W	[N/A]	[N/A]	[N/A]	[N/A]	[N/A]
Pr(Q-statistic)	0.482	0.821	0.887	0.749	0.052
Adj. sample size	74	70	85	126	200

NOTES:

- Coefficient estimates have been generated using the GMM procedure described in the text.
- Sample sizes are depleted by the lagged terms in the instrument set.
- The reported coefficient estimates for the variables which enter the estimating equation (4.11) are “long-run” estimates, i.e. indirect estimates which remove the influence of the dynamic adjustment process (see Mehra, 1999, p.41, for example). The reported coefficients for the lagged dependent variable terms are direct estimates.
- The figures in parenthesis represent standard errors calculated using the delta method for the “long-run” estimates (e.g. Mihailov, 2006) or simply the conventional standard error for the lagged dependent variable terms.
- Superscript asterisks denote the statistical significance of the underlying direct estimates (*=10%, **=5%, ***=1%).
- J-statistic: the null hypothesis that the instrument set is ‘valid’.
- Durbin-Watson (D-W) statistic: tests the null hypothesis that successive residuals are serially uncorrelated against an AR(1) alternative (not available when lagged dependent variable terms are included in the estimating equation). The 5% critical region is provided in square brackets.
- Pr(Q) is the P-value associated with the Q-statistic for the first lag of a ten lag test. The null hypothesis is that there is no autocorrelation in the estimated residual series.

Table 4.11: Unit Root and Stationarity Tests for U.S. Data, 1960q1-2011q1

<i>Unfiltered data</i>	ADF(i)	ADF(ii)	ADF(iii)	KPSS(i)	KPSS(ii)
First unit root					
Effective federal funds rate (<i>EFFR</i>)	-1.054 (0.263) {7}	-1.959 (0.305) {7}	-2.352 (0.404) {7}	0.456*	0.318***
3-month Treasury bill rate (<i>3m</i>)	-0.949 (0.305) {7}	-1.691 (0.434) {7}	-2.133 (0.524) {7}	0.477**	0.328***
Inflation, GDP deflator ($\bar{\pi}$)	-0.789 (0.373) {9}	-1.752 (0.404) {9}	-2.258 (0.454) {9}	0.467**	0.253***
Real consumption growth rate, PCE (\bar{g}_c)	-1.117 (0.240) {12}	-2.581* (0.099) {13}	-3.291* (0.071) {13}	0.352*	0.061
Tax adjusted effective federal funds rate (<i>EFFRTAX</i>)	-1.058 (0.261) {7}	-1.904 (0.330) {7}	-2.271 (0.447) {7}	0.445*	0.317***
Tax adjusted 3-month Treasury bill rate (<i>3mTAX</i>)	-0.775 (0.379) {13}	-1.612 (0.475) {7}	-2.029 (0.582) {7}	0.465**	0.326***
Second unit root					
<i>d</i> (<i>EFFR</i>)	-6.222*** (0.000) {6}	-6.209*** (0.000) {6}	-6.309*** (0.000) {6}	0.094	0.024
<i>d</i> (<i>3m</i>)	-4.836*** (0.000) {14}	-4.831*** (0.000) {14}	-5.105*** (0.000) {14}	0.108	0.026
<i>d</i> ($\bar{\pi}$)	-5.218*** (0.000) {8}	-5.204*** (0.000) {8}	-6.472*** (0.000) {7}	0.121	0.055
<i>d</i> (\bar{g}_c)	-6.963*** (0.000) {11}	-6.960*** (0.000) {11}	-6.956*** (0.000) {11}	0.017	0.017
<i>d</i> (<i>EFFRTAX</i>)	-6.232*** (0.000) {6}	-6.219*** (0.000) {6}	-6.318*** (0.000) {6}	0.097	0.027
<i>d</i> (<i>3mTAX</i>)	-4.706*** (0.000) {14}	-4.699*** (0.000) {14}	-4.958*** (0.000) {14}	0.114	0.028

NOTES:

- The Augmented Dickey-Fuller (ADF) test is conducted under the null hypothesis that the series in question is integrated of order one. ADF(i) includes neither a constant nor a trend; ADF(ii) includes a constant but no trend; ADF(iii) includes both a constant and a trend. The lag length is selected using the Akaike Information Criterion (as in Österholm, 2005, and Siklos and Wohar, 2005) and the maximum lag is selected according to the Schwert (1989) criterion. The table reports the value taken by the test statistic along with the corresponding MacKinnon (1996) one-sided P-values (in round brackets) and the number of lags included in the test (in braces).
- The Kwiatkowski, Phillips, Schmidt and Shin (1992) test is conducted under the null hypothesis that the series in question is stationary. KPSS(i) includes a constant but no trend; KPSS(ii) includes both a constant and a trend. The test is performed using a Bartlett kernel, the bandwidth for which is set according to the Newey-West automatic bandwidth selection method (as in Österholm, 2005). The asymptotic critical values obtained from Kwiatkowski et al. (1992) are 0.739 (1% significance), 0.463 (5% significance) and 0.347 (10% significance) for KPSS(i) and 0.216 (1% significance), 0.146 (5% significance) and 0.119 (10% significance) for KPSS(ii).
- *** denotes that the null hypothesis is rejected at the 1% level of significance, ** denotes rejection at the 5% level, and * denotes rejection at the 10% level.

Table 4.12: Cointegrating Regressions for U.S. Data, 1960q1-2011q1

Variable 1 (V_1)	Variable 2 (V_2)	Stage 1 slope coefficient (a_1)	ADF (applied to ζ_t)	KPSS (applied to ζ_t)
Effective federal funds rate	Inflation, GDP deflator	1.053*** (0.000)	-1.928* (0.052) {7}	0.222
Inflation, GDP deflator	Effective federal funds rate	0.502*** (0.000)	-2.072** (0.037) {9}	0.249
3-month Treasury bill rate	Inflation, GDP deflator	0.868*** (0.000)	-1.635* (0.096) {7}	0.243
Inflation, GDP deflator	3-month Treasury bill rate	0.579*** (0.000)	-2.025** (0.041) {9}	0.238
Tax adjusted effective federal funds rate	Inflation, GDP deflator	0.927*** (0.000)	-1.898* (0.055) {7}	0.216
Inflation, GDP deflator	Tax adjusted effective federal funds rate	0.587*** (0.000)	-2.130** (0.032) {9}	0.250
Tax adjusted 3-month Treasury bill rate	Inflation, GDP deflator	0.769*** (0.000)	-2.001** (0.044) {9}	0.220
Inflation, GDP deflator	Tax adjusted 3-month Treasury bill rate	0.678*** (0.000)	-2.083** (0.036) {9}	0.238

NOTES:

- The first stage regression is, $V_{1,t} = a_0 + a_1 V_{2,t} + \zeta_t$ and the third column reports the estimate for a_1 and its corresponding P-value.
- The Augmented Dickey-Fuller (ADF) test is conducted under the null hypothesis that the series in question is integrated of order one. Following Mehra (1991, Table 2), the test includes neither a constant nor a trend. The lag length is selected using the Akaike Information Criterion (as in Österholm, 2005, and Siklos and Wohar, 2005) and the maximum lag length is selected according to the Schwert (1989) criterion. The table reports the value taken by the test statistic along with the corresponding MacKinnon (1996) one-sided P-values (in round brackets) and the number of lags selected (in braces).
- The Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test is conducted under the null hypothesis that the series in question is stationary. The test excludes a trend for comparison with the ADF test (but a constant must be included at least). The test is performed using a Bartlett kernel, the bandwidth for which is set according to the Newey-West automatic bandwidth selection method (as in Österholm, 2005). The asymptotic critical values obtained from Kwiatkowski-Phillips-Schmidt-Shin (1992) are 0.739 (1% significance), 0.463 (5% significance) and 0.347 (10% significance).
- *** denotes rejection of the null hypothesis at the 1% level of significance, ** denotes rejection at the 5% level, and * denotes rejection at the 10% level.

Table 4.13: An ECM for U.S. Data, 1960q1-2011q1

Unadjusted data	EFFR		3 month Treasury bill rate	
	OLS	GMM	OLS	GMM
ρ_0	-4.381 (2.579)	-3.403 (2.735)	-3.477 (2.335)	-2.922 (3.073)
ρ_1	1.374 (0.308)	1.272 (0.581)	1.206 (0.290)	1.210 (0.606)
ρ_2	1.498 (0.544)	1.307 (0.455)	1.253 (0.475)	1.040 (0.501)
χ_0	-0.406** (0.187)	-0.260 (0.176)	-0.277* (0.149)	-0.183 (0.149)
$\chi_{1,0} (\Delta\bar{\pi}_t)$	0.548*** (0.191)	0.489 (0.672)	0.514*** (0.152)	0.609 (0.443)
$\chi_{1,1} (\Delta\bar{\pi}_{t-1})$	0.115 (0.207)	0.174 (0.281)	-0.091 (0.166)	-0.121 (0.230)
$\chi_{1,2} (\Delta\bar{\pi}_{t-2})$	-0.190 (0.187)	-0.075 (0.213)	0.065 (0.149)	0.130 (0.183)
$\chi_{2,0} (\Delta\bar{g}_{c,t})$	0.184** (0.071)	-0.035 (0.139)	0.149*** (0.057)	-0.068 (0.132)
$\chi_{2,1} (\Delta\bar{g}_{c,t-1})$	0.017 (0.071)	N/A	0.043 (0.057)	0.065 (0.045)
$\chi_{2,2} (\Delta\bar{g}_{c,t-2})$	-0.171** (0.073)	N/A	-0.105* (0.059)	N/A
$\chi_{3,1} (\Delta\bar{R}_{t-1})$	0.182** (0.072)	0.298** (0.139)	0.161** (0.072)	0.257** (0.106)
$\chi_{3,2} (\Delta\bar{R}_{t-2})$	N/A	-0.208* (0.116)	N/A	-0.280** (0.132)
$\chi_4 (\bar{\pi}_{t-1})$	0.127*** (0.041)	0.097** (0.043)	0.096*** (0.032)	0.076** (0.030)
$\chi_5 (\bar{g}_{c,t-1})$	0.139*** (0.037)	0.100*** (0.026)	0.100*** (0.030)	0.065** (0.031)
$\chi_6 (\bar{R}_{t-1})$	-0.093*** (0.028)	-0.077*** (0.019)	-0.080*** (0.026)	-0.063** (0.027)
R-squared	0.237	0.207	0.231	0.215
Adj. R-squared	0.197	0.169	0.191	0.173
Pr(Q-statistic)	0.556	0.166	0.501	0.535
Pr(J-statistic)	N/A	0.626	N/A	0.558
$[\tau_1, \tau_2, \tau_3]$	[2, 2, 1]	[2, 0, 2]	[2, 2, 1]	[2, 1, 2]
Adj. sample size	202	200	202	200

NOTES:

- Structural (ρ) coefficients are calculated as functions of the estimated χ coefficients, as described in the text. Accordingly, standard errors for the former are calculated using the delta method while conventional standard errors are reported for the latter.
- The sample size is depleted by the dynamic terms in the estimating equation and/or lagged terms in the instrument set.
- The lag lengths are selected by searching over 27 different specifications which allow τ_1 , τ_2 and τ_3 to vary between 0 and 2. The specification presented in the table minimises the Akaike Information Criterion for the OLS estimator and is selected in order to relieve the estimated residuals of serial correlation for the GMM estimator.
- Pr(Q) is the P-value associated with the Q-statistic for the first lag of a ten lag test. The null hypothesis is that there is no autocorrelation in the estimated residual series.
- J-statistic: the null hypothesis that the instrument set is 'valid'.
- *** denotes rejection of the null hypothesis at the 1% level of significance, ** denotes rejection at the 5% level, and * denotes rejection at the 10% level.

Table 4.14: Estimated Marginal Tax Rates for U.S. Data, 1960-2011 (Annual Frequency)

Unfiltered data, OLS	Effective marginal tax rate	Padovano and Galli's (2001) estimate	Calculated revenue- to-GDP (decade averages)	OMB revenue-to- GDP (decade averages)
1960-1969	0.227*** [0.907]	0.285	0.214	0.179
1970-1979	0.162** [0.778]	0.200	0.200	0.179
1980-1989	0.138*** [0.755]	0.192	0.191	0.183
1990-1999	0.251*** [0.976]	<i>Not available</i>	0.187	0.185
2000-2011	0.014 [0.003]	<i>Not available</i>	0.171	0.173

NOTES:

- The estimating equation is: $TAXREV_t = b_1 + b_2RGDP_t + residual_t$, and is evaluated using OLS.
- Tax revenue includes federal level receipts only and data is obtained from Office of Management and Budget (OMB) Historical Table 1.3; real GDP is series GDPC1 in the Federal Reserve Economic Data (FRED) database. Both series are measured at an annual frequency and are expressed in 2005 dollars.
- The estimate for the 'effective marginal tax rate' is the coefficient b_2 above; corresponding R-squared statistics are reported in square brackets.
- Padovano and Galli's (2001) estimated is the sum of the coefficient on real GDP and a coefficient capturing the marginal effect of tax reform.
- The penultimate column uses the data described above to calculate the revenue-to-GDP ratio, the final column takes the figures directly from OMB Historical Table 1.3.
- *** denotes rejection of the null hypothesis at the 1% level of significance, ** denotes rejection at the 5% level, and * denotes rejection at the 10% level.

Table 4.15: An ECM for Tax-Adjusted U.S. Data, 1960q1-2011q1

Tax adjusted data	EFFR		3 month Treasury bill rate	
	OLS	GMM	OLS	GMM
ρ_0	-4.022 (2.237)	-3.150 (2.292)	-3.228 (2.011)	-2.470 (2.327)
ρ_1	1.212 (0.268)	1.161 (0.493)	1.070 (0.251)	1.041 (0.489)
ρ_2	1.265 (0.470)	1.062 (0.386)	1.052 (0.407)	0.820 (0.397)
χ_0	-0.368** (0.159)	-0.247 (0.150)	-0.256** (0.127)	-0.165 (0.122)
$\chi_{1,0} (\Delta\bar{\pi}_t)$	0.481*** (0.163)	0.480 (0.580)	0.450*** (0.130)	0.524 (0.376)
$\chi_{1,1} (\Delta\bar{\pi}_{t-1})$	0.071 (0.177)	0.115 (0.246)	-0.099 (0.143)	-0.124 (0.196)
$\chi_{1,2} (\Delta\bar{\pi}_{t-2})$	-0.128 (0.160)	-0.039 (0.186)	0.085 (0.128)	0.137 (0.161)
$\chi_{2,0} (\Delta\bar{g}_{c,t})$	0.155** (0.061)	-0.032 (0.120)	0.126** (0.048)	-0.057 (0.111)
$\chi_{2,1} (\Delta\bar{g}_{c,t-1})$	0.021 (0.061)	N/A	0.040 (0.049)	0.054 (0.038)
$\chi_{2,2} (\Delta\bar{g}_{c,t-2})$	-0.146** (0.063)	N/A	-0.087* (0.050)	N/A
$\chi_{3,1} (\Delta\bar{R}_{t-1})$	0.169** (0.072)	0.267** (0.134)	0.145** (0.072)	0.229** (0.105)
$\chi_{3,2} (\Delta\bar{R}_{t-2})$	N/A	-0.219* (0.115)	N/A	-0.257** (0.130)
$\chi_4 (\bar{\pi}_{t-1})$	0.111*** (0.035)	0.091** (0.038)	0.085*** (0.028)	0.070** (0.027)
$\chi_5 (\bar{g}_{c,t-1})$	0.116*** (0.031)	0.083*** (0.023)	0.083*** (0.025)	0.055** (0.027)
$\chi_6 (\bar{R}_{t-1})$	-0.091*** (0.028)	-0.078*** (0.020)	-0.079*** (0.026)	-0.067** (0.027)
R-squared	0.232	0.205	0.229	0.212
Adj. R-squared	0.191	0.168	0.189	0.170
Pr(Q-statistic)	0.597	0.230	0.562	0.606
Pr(J-statistic)	N/A	0.632	N/A	0.574
$[\tau_1, \tau_2, \tau_3]$	[2, 2, 1]	[2, 0, 2]	[2, 2, 1]	[2, 1, 2]
Adj. sample size	202	200	202	200

NOTES:

- Structural (ρ) coefficients are calculated as functions of the estimated χ coefficients, as described in the text. Accordingly, standard errors for the former are calculated using the delta method while conventional standard errors are reported for the latter.
- The sample size is depleted by the dynamic terms in the estimating equation and/or lagged terms in the instrument set.
- The lag lengths are selected by searching over 27 different specifications which allow τ_1 , τ_2 and τ_3 to vary between 0 and 2. The specification presented in the table minimises the Akaike Information Criterion for the OLS estimator and is selected in order to relieve the estimated residuals of serial correlation for the GMM estimator.
- Pr(Q) is the P-value associated with the Q-statistic for the first lag of a ten lag test. The null hypothesis is that there is no autocorrelation in the estimated residual series.
- J-statistic: the null hypothesis that the instrument set is 'valid'.
- *** denotes rejection of the null hypothesis at the 1% level of significance, ** denotes rejection at the 5% level, and * denotes rejection at the 10% level.

Table 4.16: Cointegrating Regressions for U.S. Data, 1960q1-2011q1

Variable 1 (V_1)	Variable 2 (V_2)	Stage 1 slope coefficient (a_1)	ADF (applied to ζ_t)	KPSS (applied to ζ_t)
Nominal interest rate (\bar{R})	Inflation rate ($\bar{\pi}$)	0.540 [1000] (0.000)	-5.945 (0.002) {1.163} [993]	0.263 [848]
Inflation rate ($\bar{\pi}$)	Nominal interest rate (\bar{R})	0.767 [1000] (0.000)	-4.741 (0.007) {1.770} [963]	0.349 [745]

NOTES:

- The first stage regression is, $V_{1,t} = a_0 + a_1 V_{2,t} + \zeta_t$ and the third column reports the estimate for a_1 , its corresponding P-value in round brackets and the number of statistically significant estimates at the 5% level of significance (in square brackets).
- The Augmented Dickey-Fuller (ADF) test is conducted under the null hypothesis that the series in question is integrated of order one. Following Mehra (1991, Table 2), the test includes neither a constant nor a trend. The lag length is selected using the Akaike Information Criterion (as in Österholm, 2005, and Siklos and Wohar, 2005) and the maximum lag length is selected according to the Schwert (1989) criterion. The table reports the value taken by the test statistic along with the corresponding mean MacKinnon (1996) one-sided P-values (in round brackets), the mean number of lags included in the test (in braces) and the number of null hypothesis rejections at the 5% level of significance (in square brackets).
- The Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test is conducted under the null hypothesis that the series in question is stationary. The test excludes a trend for comparison with the ADF test (but a constant must be included at least). The test is performed using a Bartlett kernel, the bandwidth for which is set according to the Newey-West automatic bandwidth selection method (as in Österholm, 2005). The table reports the mean test statistic over 1000 simulated sample periods along with the number of null hypothesis *non*-rejections (in square brackets). The asymptotic critical values obtained from Kwiatkowski-Phillips-Schmidt-Shin (1992) are 0.739 (1% significance), 0.463 (5% significance) and 0.347 (10% significance).

Table 4.17: An ECM for Model-Simulated Data

Unfiltered Data	OLS	GMM
ρ_0	0.000	0.000
ρ_1	0.928	1.033
ρ_2	0.040	0.447
χ_0	0.000 (0.000) [443]	0.000 (0.000) [213]
$\chi_{1,0} (\Delta\bar{\pi}_t)$	-0.002 (0.016) [55]	-0.028 (0.227) [86]
$\chi_{1,1} (\Delta\bar{\pi}_{t-1})$	0.748 (0.045) [1000]	0.158 (0.226) [270]
$\chi_{1,2} (\Delta\bar{\pi}_{t-2})$	N/A	-0.048 (0.135) [98]
$\chi_{2,0} (\Delta\bar{g}_{c,t})$	0.015 (0.006) [690]	0.138 (0.064) [728]
$\chi_{2,1} (\Delta\bar{g}_{c,t-1})$	0.086 (0.008) [1000]	0.014 (0.023) [201]
$\chi_{2,2} (\Delta\bar{g}_{c,t-2})$	0.031 (0.004) [1000]	N/A
$\chi_{3,1} (\Delta\bar{R}_{t-1})$	-0.367 (0.029) [1000]	-0.018 (0.189) [111]
$\chi_{3,2} (\Delta\bar{R}_{t-2})$	N/A	N/A
$\chi_4 (\bar{\pi}_{t-1})$	0.176 (0.035) [916]	0.377 (0.113) [892]
$\chi_5 (\bar{g}_{c,t-1})$	0.038 (0.010) [770]	0.145 (0.038) [940]
$\chi_6 (\bar{R}_{t-1})$	-0.184 (0.050) [753]	-0.532 (0.176) [848]
Mean:		
R-squared	0.983	0.806
Adj. R-squared	0.981	0.785
Pr(Q-statistic)	0.001 [0]	0.661 [966]
Pr(J-statistic)	N/A	0.462 [933]
$[\tau_1, \tau_2, \tau_3]$	[1, 2, 1]	[2, 1, 1]
Adj. sample size	1000×97	1000×96

NOTES:

- Structural (ρ) coefficients are calculated as functions of the estimated χ coefficients, as described in the text. The table presents mean coefficient estimates along with a measure of the variation in the coefficient estimates (round brackets) and the number of statistically significant estimates at the 5% level of significance (square brackets).
- The sample size is depleted by the dynamic terms in the estimating equation and/or lagged terms in the instrument set.
- The lag lengths are selected by searching over 27 different specifications which allow τ_1 , τ_2 and τ_3 to vary between 0 and 2. The specification presented in the table minimises the Akaike Information Criterion for the OLS estimator and is selected in order to relieve the estimated residuals of serial correlation for the GMM estimator.
- Pr(Q) is the P-value associated with the Q-statistic for the first lag of a ten lag test. The null hypothesis is that there is no autocorrelation in the estimated residual series. The number of null hypothesis *non-rejections* is reported in square brackets.
- J-statistic: the null hypothesis that the instrument set is 'valid'.

Table 5.1: Summary of Inflation Coefficient, Model-Simulated Data, GMM estimates only

	Full Taylor Condition	Taylor Condition with $\beta_5=0$	Taylor Condition with g_v instead of g_c	Standard 'Taylor Rule'	'Augmented Fisher Relation'
HP filter	2.299 [1000] (3.3)	0.621 [925] (3.3)	-	-	-
3-8 BP filter	2.423 [1000] (3.4)	0.682 [974] (3.4)	-	-	-
2-15 BP filter	2.306 [1000] (3.5, 4.7)	0.964 [999] (3.5)	5.274 [961] (3.6)	0.894 [981] (3.7)	-
2-8 BP filter	2.221 [1000] (4.4)	0.392 [778] (4.8)	9.409 [995] (4.4)	0.021 [425] (4.6)	-0.037 [301] (4.8)
2-20 BP filter	2.068 [1000] (4.4, 4.7)	1.025 [1000] (4.8)	3.229 [823] (4.4)	1.269 [982] (4.6)	0.931 [937] (4.8)
2-25 BP filter	1.840 [1000] (4.7)	-	-	-	-
2-50 BP filter	1.097 [977] (4.7)	-	-	-	-
2-75 BP filter	0.812 [940] (4.7)	-	-	-	-
ECM	-	-	-	-	1.033 (4.17)

NOTES:

- The table reports the unadjusted mean inflation coefficient estimate for 1000 simulated samples.
- The number of statistically significant coefficient estimates at the 95% level of significance is reported in square brackets.
- 'Full Taylor Condition' is implemented by equations (3.31) and (4.11).
- 'Standard Taylor Rule' refers to the non-dynamic form, i.e. (3.33) and (4.12) with $\beta_5=0$.
- 'Augmented Fisher Relation' is implemented by equation (4.14).
- ECM is the error correction model described in Section 4.5.5 of Chapter-IV.
- 'HP' is the Hodrick-Prescott filter (with a smoothing parameter of 6.25) and 'BP' is a Christiano-Fitzgerald asymmetric band pass filter.
- The number in brackets states the table number in which each estimate can be found.

Table 5.2: Summary of Inflation Coefficient, U.S. Time Series Data, 1960q1-2011q1

	Full Taylor Condition	Taylor Condition with $\beta_5=0$	Standard 'Taylor Rule'	'Augmented Fisher Relation'
<i>Conventional GMM Estimations</i>				
Pre-Volcker (1960q1-1979q2)	1.170** (4.5)	0.892* (4.9)	0.83 CGG	1.048*** (4.10)
CGG post-Volcker (1979q3-1996q4)	1.973*** (4.5)	1.969** (4.9)	2.15 CGG	2.121*** (4.10)
Taylor post-Volcker (1979q3-2000q3)	1.955*** (4.5)	1.906*** (4.9)	-	2.097*** (4.10)
Extended post-Volcker (1979q3-2011q1)	1.747*** (4.5)	2.189*** (4.9)	-	2.482*** (4.10)
Full sample (1960q1-2011q1)	0.919** (4.5)	0.857** (4.9)	-	1.073* (4.10)
<i>ECM (3m T-bill rate and GMM estimates only)</i>				
Full sample, unadjusted data	-	-	-	1.210 (4.13)
Full sample, tax adjusted data	-	-	-	1.041 (4.15)

NOTES:

- The table reports the point estimate obtained from U.S. time series data, as described in Chapter-IV.
- CGG denotes that these estimates come directly from Clarida et al. (2000, Table II).
- ECM is the error correction model described in Section 4.5.3 of Chapter-IV; details regarding the tax adjustment can be found in Section 4.5.4.
- Superscript asterisks denote the statistical significance of the underlying direct estimates (*=10%, **=5%, ***=1%).
- The number in brackets states the table number in which each estimate can be found.