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THE TAYLOR RULE AND ITS IMPLICATIONS

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THE TAYLOR RULE AND ITS IMPLICATIONS

VOLUME I

by

Katkate Bunnag

A DISSERTATION

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ABSTRACT

THE TAYLOR RULE AND ITS IMPLICATIONS

By

Katkate Bunnag

The Taylor rule is an instrument rule implementing a nominal short-term interest rate in response to inflation and the output gap. The rule is based on the Taylor Principle that a central bank should raise (reduce) the policy rate more than one-to-one, relative to an increase (decrease) in inflation. Nonetheless, the rule has never been committed to by any central bank.

In Chapter 1, I explore the main aspects of the Taylor rule, beginning with an overview of monetary policy and where the Taylor rule fits into the monetary policy framework. I also discuss empirical studies, the rule's limitations and implications on discretionary policymaking. In addition, I survey the empirical work on the US as well as other developed economies. Most studies from other countries show that the Taylor rule in most cases explains their monetary policy conduct well.

Moreover, I discuss problems inherent to the Taylor rule in practice, for example, the real-time data – the data available at the time that the policy is made – versus the final or revised data can result in the different conclusion being drawn, the zero bound constraint on a nominal interest rate since a nominal interest rate cannot be negative and finally the assumption of a constant natural real interest rate which contradicts economic theory suggesting that it can vary across time.

Lastly, it may be the case that the successful monetary policy does not depend on the policy rule, as seen during the Greenspan chairmanship of the Federal Reserve. In this period, he implemented a risk management strategy, which can be considered as a discretionary policy.

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In Chapter 2, I examine one of many restrictions, i.e. the zero bound constraint on the nominal interest rate. Based on a simple backward-looking model used by Rudebusch and Svensson (1999), Chapter 2 shows that the rule continues to perform well if the constraint binds but the recession is not too severe. The major effect of the zero bound constraint is that the distributions of inflation and the output gap deviate from the unconstrained ones, while the effect on inflation is more pronounced. The risk of hitting the zero bound and falling into the deflationary trap is less the higher the inflation target and the less aggressive the rules than with a lower inflation target and more aggressive rules.

Finally, Chapter 3 examines another problem with the Taylor rule, the constant natural real interest rate. When the original Taylor rule was introduced in 1993, the natural real interest rate (NRR) was assumed constant at 2%. However, in the longer-term, the NRR should vary with real factors and structural changes of an economy. This chapter examines the effect of replacing the constant NRR by the time-varying one in the Taylor rule. I first present three pieces of evidence showing that the time-varying NRR is the correct interest measure to use. Then, I show that the time-varying NRR has more predictive power on the output gap and inflation than a constant one, as illustrated by simple and partial correlations. With the historical approach, the Taylor rule with the time-varying natural real interest rate tracks the actual federal funds rate more closely than that with a constant one, even the during the period of changing in the Federal Reserve's operating procedure. This is because the rule with time-varying NRR embraces changes in economic structure. Lastly, the constant natural real interest rate is dominated by the time-varying one both in real-time and latest available data, as shown in the stochastic simulations.

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INTRODUCTION

In monetary economics, a policy rule can be generally defined as a contingency plan that describes a central bank's behavior in changing the instruments of monetary policy, in response to changing economic environment, in order to accomplish macroeconomic objectives, e.g. price/inflation stability and full employment.

A policy rule has a long history. One of the most influential policy rules since the 1960s is the Friedman (1968) %k rule, which is specified as a constant money growth rate based on the Quantity Theory of Money equation (MV = PY). This was explicitly a long-run rule. Since then, policy rules have been developed to respond more to cyclical behaviors of an economy. The early policy rules followed the belief that responses to cyclical shocks destabilize the economy since we could not predict the economy well. When the econometric tools improved, economic forecasting became more efficient. Therefore, leaning against the wind by responding more aggressively to the change in economic environment could be stabilizing.

In the 1990s, one of the most widely recognized policy rules was the Taylor rule. It is an instrument rule, consistent with the Taylor Principle that a central bank should raise (reduce) the policy rate more than one-to-one, relative to an increase (decrease) in inflation.

Nonetheless, very few studies, e.g. McCallum (2000), Orphanides (2003) among others, compares and contrasts the Taylor rule to other policy rules in a general framework both historically and empirically. A literature review focusing on the Taylor rule, broadly defined, is still lacking.

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The dissertation starts with the overview of the Taylor rule in Chapter 1. It discusses the advantages and disadvantages of different monetary policy approaches, how they are related and work. Then, I focus the discussion on monetary policy rules versus discretionary in the context of time-consistency.

Emphasizing policy rules, I review some of the well-known controversies, i.e. targeting rules versus instrument rules. The latter also embraces the Taylor rule which is the main focus of this research.

This chapter aims at reviewing the literature on the Taylor rule both empirically and historically and at putting the rule into the perspective of a general monetary policy framework. This aspect enhances the comprehensibility and comparability of the Taylor rule to competing approaches.

The issues in Chapter 1 also include the empirical works on the central banks' policy reaction functions, some practical problems and limitations of the rule, the difference between robust and optimal policy rules in the context of the Taylor rule, and more importantly, its implications and finally what are missing from the rules.

Moreover, this chapter tackles some of the restrictions of the Taylor rule recently addressed, including the real-time data versus the revised data, the uncertainty in the measures of each variable, a binding zero bound constraint on the nominal interest rate and the time-varying natural real interest rate, compared to the constant employed in the rule. These restrictions were not concerns at the time the rule was introduced by John B. Taylor in 1993.

The limitations of the Taylor rule become more pronounced by numerous factors, for example, the change in economic environment at the end of the millennium and more developed econometric tools causing the estimation of unobservable variables to be more feasible.

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In Chapter 2, I study one of the limitations of the Taylor rule, namely, the zero bound constraint on the nominal interest rate. Since the nominal interest rate cannot be below zero, the Taylor rule must be modified in order to take the constraint into account. Most of the literature focuses on alternative policies whenever the zero bound constraint is binding. On the contrary, I pursue the question of whether the Taylor rule would be resuscitate the economy whenever the rule calls for a zero interest rate in lieu of a negative nominal interest rate.

In Chapter 3, I address the issue of the time-varying NRR. Since its introduction in 1993, the Taylor rule has employed a constant real interest rate (NRR) as a proxy for the natural real interest rate which represents the stance of monetary policy, contradicting the economic theory that the NRR should vary across time. I examine the difference between the nominal interest rate prescribed by the Taylor rule with time-varying NRR versus the rule with the constant NRR. I compare across the measures of the NRR in a model specification similar to that used in the second chapter with the slight modifications that both the Taylor rule and the aggregate demand function implement the time-varying NRR, instead of the constant NRR.

The purpose of this chapter is to examine whether the time-varying NRR can decrease the variability of inflation and the output gap, the components of the welfare loss function, and how well the Taylor rule with different measures of the NRR can track the actual data, and whether the time-varying NRR possesses higher predictive power than the constant NRR.

Chapter 3 substantiates the need for more extensive research in seeking for an appropriate and reliable measure of the time-varying natural real interest rate to represent the neutral monetary policy stance as a component of the Taylor rule.

CHAPTER 1

MONETARY POLICY RULES: SURVEY OF THE TAYLOR RULE

1.Introduction

Since 1993, one of the most widely addressed issues in monetary economics is the discussion about an interest rate rule called the "Taylor rule". From then on, research in monetary policy analysis has changed from focusing on monetary aggregates to emphasizing a short-term interest rate as a policy instrument, although many studies, e.g. Meltzer (1998), McCallum (2000b) and among others, still support monetary aggregates as the preferred policy instrument, especially during very high or very low inflation.

The Taylor rule gained more popularity in the 1990s because of the simplicity of the rule in response to only two macroeconomic variables, inflation and output, which are related to the main policy objectives of most central banks. By observing and backcasting the behavior of central banks, particularly the Federal Reserve of the US, the rule specification is derived as a good fit to actual policies followed.

Despite the large literature focusing on different aspects of the Taylor rule, there have been only a few comprehensive literature reviews of the Taylor rule and the literature it spawned, e.g. Orphanides (2003a) and Hamalainen (2004). However, the former does not include empirical studies on the Taylor rule. Basically, he describes the Federal Reserve's behavior in a narrative approach of how monetary policy in the US was conducted historically and does not present empirical evidence on the policy reaction function.

Hamalainen (2004) reviews most of the issues regarding the Taylor rule. However, he focuses on empirical studies in the US only. Implementation of the

Taylor rule in other countries, particularly industrialized countries that share some commonalities of economic structure with the US, would be a good exercise. If the Taylor rule can also describe the behaviors of other central banks well, it would be more useful to consider it as a general monetary policy framework applicable to other countries as well as the US.

The purpose of this chapter is not to pin down whether the Taylor rule is a must for the conduct of monetary policy rather than a monetary policy framework since no central bank has ever used the Taylor rule to conduct monetary policy. Instead, the present chapter only intends to describe and review most of the development of the Taylor rule since its introduction in 1993 by presenting the results of some empirical studies both in the US and other industrialized countries.

In the first section of this chapter, an overview of how monetary policy is conducted and where the Taylor rule fits in monetary policy analysis is discussed. Then, I compare two streams of research on policy rules including targeting rule, e.g. an inflation targeting regime, and instrument rules, e.g. the Taylor rule. The issue as to which policy rule, if any, serves as the best policy is still undecided. In fact, there is no unanimity among economists even on which structural model describes the underlying economy best.

In section two, I introduce the original Taylor rule and explain its background including the Taylor Principle. Then, it is followed by the empirical studies estimating a policy reaction function in the third section. Not only does the third section describe the behavior of the central bank in the US, but also those of other industrialized countries. Since the Taylor rule could describe the Fed's behavior well, it would be interesting to ask whether it could also explain the behavior of other central banks or not. The reviews of the answer to this question will be covered in the third section.

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In the fourth section, I explore the problems of the practical application of the Taylor rule, including the drawbacks of the assumptions on the rule; namely, the equilibrium real interest rate and the inflation target, the data used in calculating the rule-based nominal interest rate and the limitation on the policy instrument per se, i.e. the zero bound constraint. This section also partly incorporates some proposed remedies of these problems. In the fifth section, I compare the Taylor rule to optimal policy. Because the approach to obtain a simple policy rule, such as the Taylor rule, and the framework to develop an optimal policy rule are different, it is insightful to compare these approaches and see whether a simple framework such as the Taylor rule is an optimal rule or not.

Finally, the implications as well as the factors not encompassed in the Taylor rule are discussed. Section 6 also describes some arguments as to why the Taylor rule should not be used in conducting policy per se but rather as a guideline for monetary policy.

1.1. Macroeconomic goals

It is widely accepted that the ultimate objective of monetary policy is to improve the economic welfare of the people, which includes the achievement of maximum sustainable economic growth and of price stability. In the US, the central bank – Federal Reserve – is mandated by law to maintain such goals [1]. The requirement to achieve these two goals is sometimes called a dual mandate. In addition, there are other subordinate economic goals, namely, maintaining trade

[1] The first one is the 1977 amendment to the Federal Reserve Act, requiring the Fed to promote effectively the goals of maximum employment, stable prices, and moderate long-term interest rates. The other is the Humphrey-Hawkins Act of 1978 that decrees the Fed to promote "full employment and production, ... and reasonable price stability," among other things. In the long-run, central banks define targets for either output growth or inflation. However, they attempt to stabilize the economy in the short-run by countering business cycles or the deviations from targets.

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balance, the stability in financial markets, promoting capital investment, etc. But they are not as important as price stability and maximum sustainable output growth.

Recently, many countries have embraced price stability or low inflation as the sole objective of monetary policy. These countries include New Zealand[2], the United Kingdom, Canada, Sweden, New Zealand, Finland, Australia and Spain. Okina (1997) describes three main reasons. Firstly, these countries experienced high and persistent inflation in the past. Secondly, they believe that money is neutral with respect to real activity and only affects the price level in the long run. Thus, inflation should be only objective to focus on. Lastly, it is argued from the political economy viewpoint that targeting inflation can mitigate the inflationary bias problem[3]. Inflation targeting policies will be discussed in depth in Section 1.3.1.

It is noteworthy that the term "price stability" does not mean literally zero inflation. There are three main reasons why central banks should not adopt zero inflation as their main economic objective in practice as supported by Bernanke and Mishkin (1997); (1) much recent research shows that official CPI inflation tends to overstate the true rate of inflation due the failure to offset the biases in the fixed-weight consumer index; (2) according to Akerlof, Dickens and Perry (1996), if nominal wages are rigid downward, relative to general price levels, reductions in real wages must be through inflation. Zero inflation deters this reduction and reduces real-wage flexibility, as a consequence, it decreases allocative efficiency in the labor market. In addition, Bernanke and Mishkin investigate this issue by simulations and

[2] New Zealand pioneered in adopting the inflation targeting policy in 1990.

[3] The inflation bias stems from the exploitation of the short-run tradeoff between inflation and output. Since creating a temporary inflation or an inflation surprise leads to higher output temporarily, those policymakers staying in office for a short period of time can gain reputation by expanding the output even temporarily. Therefore, the inflation tends to be higher than the optimal level (Barro and Gordon (1983)).

find that zero inflation even raises the natural rate of employment; (3) lastly, with zero inflation, there is a chance that the economy would fall into a deflationary trap.

In order to accomplish the objectives of price stability and maximum sustainable output growth, central banks must follow some path which is called "monetary policy". Monetary policy can be defined as a group of procedures that central banks are capable of operating in order to achieve its mandatory goals.

Unfortunately, according to the Phillips curve, there is a tradeoff between price stability and full employment or maximum sustainable output growth. The latter are equivalent but on opposite sides of the same coin based on Okun's law (1962). Therefore, monetary policy cannot achieve the two ultimate goals at the same time, if the Phillips curve is stationary.

Nonetheless, this tradeoff is doubtful. If agents have rational expectations, there is no tradeoff between unemployment and inflation in the long-run and higher inflation does not tend to decrease the sustainable economic growth rate – a position supported by empirical work, e.g. Barro (1995)[4].

Based on cross country evidence, Taylor (1996) argues that lower rates of inflation tend to correspond to higher long-term economic growth rate and vice versa. Empirically, a low and steady inflation rate improves cyclical stability in the United States. This was seen when the high and volatile inflation rate was ended in the early 1980s as a result of more credible and systematic contractionary monetary policy[5].

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[4] Barro (1995) finds that a rise in average inflation by 10% annually reduces the growth rate of real per capital GDP by 0.2-0.3 % and the ratio of investment to GDP by 0.4-0.6%, annually. This equals to a decrease of 4-7% of the level of real GDP after 30 years, given that a permanent one-time increase in inflation of 10%.

[5] Monetary policy after the early 1980s was tighter than earlier, especially after Chairman Volcker was in the office. The studies, e.g. Judd and Rudebusch (1998), Kozicki (1999) and Romer and Romer (2002) show that the Federal Reserve was more aggressive to fight against inflation during that time illustrated by the high coefficient on inflation in the estimated policy reaction function. This issue will be discussed in Section 3.2.1.

However, there is no consensus about the short-run tradeoff between inflation and output. Early econometric models with rational expectation, e.g. Sargent (1976) and the real business cycle theorists, implied there was no short-run tradeoff, given that prices are perfectly flexible. On the contrary, when prices and wages are rigid or adjust gradually, there is a short-run tradeoff between inflation and output. This can be explained intuitively as follows; when the central bank changes its nominal interest rate target, the real interest rate is changed and then affects real output, while the price level does not adjust instantly. This causes monetary policy to be effective in the short-run. This tradeoff between output and the inflation rate change will not be true when price and inflation rate fully adjust instantly.

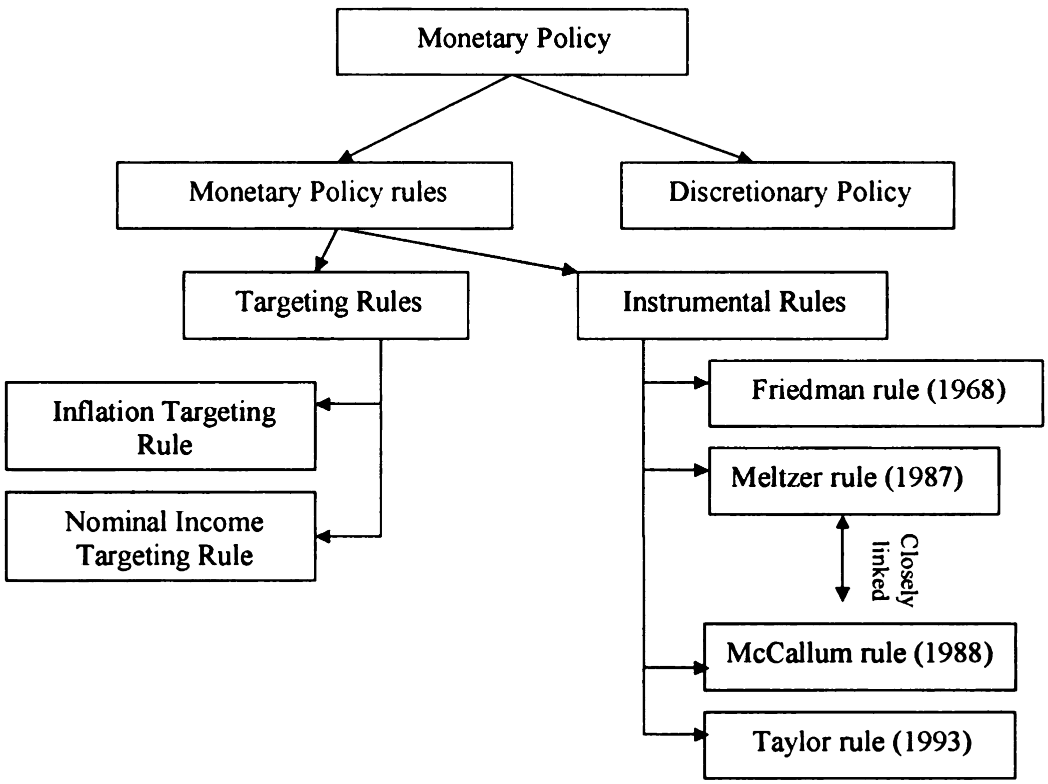

Figure 1.1: The breakdown of monetary policy

Due to the non-existence of a long-run tradeoff between inflation and output or unemployment rate, monetary policy cannot raise the output growth rate or lower the unemployment rate above the natural rate or Non-Accelerating Inflation Rate of Unemployment (NAIRU) in the long-run. In other words, monetary policy is neutral. Therefore, the best strategy for monetary policy in the long-run is to set a low inflation target, but not to set a target for output growth since there is no cost of disinflation in the long-run.

With the presence of wage and price rigidities, a tradeoff between inflation and output exists and can be the best described by their fluctuations or variability rather than their levels over time (Taylor (1993)). The variability in both variables[6] is basically incorporated into a social welfare loss function. In addition, the variability represents the unpredictability of inflation and output gap. The intuitive explanation for focusing on the variability of inflation and output, rather than their levels, is described nicely in Taylor (1997).

1.2. Rules versus discretionary policy

One of the most controversial issues in monetary policy is whether policy should be governed by rules or by the discretion of policymakers. According to many speeches and testimonial statements to the public by Fed chairmen and staff, it can be inferred that the Federal Reserve is reluctant to adopt an explicit policy rule to conduct monetary policy since they believe that policy rules do not allow for judgmental adjustments (McCallum (2004)). Thus, many central bankers, including Alan Greenspan (2004), oppose the adoption of a monetary policy rule.

In contrast, many academicians such as Kydland and Prescott (1977) and Barro and Gordon (1983) and recently Woodford (1999b) argue in favor of rules, due to the gains from policy rules in the long-run.

[6] However, the variability of the output gap rather than the output level is taken into account in most literature. The output gap is defined as a difference between actual output and its potential level or trend.

Even though the issue in rules versus discretion has been addressed since the late 1970s, there is still no solid conclusion on which one is the best policy, especially, when we are exploring the conduct of monetary policy during the Greenspan era. Hence, explaining the difference between rules and discretion will be useful in understanding not only discretionary policy per se, but also the policy rules when we discuss about the implications and the drawbacks of the policy rules, specifically the Taylor rule.

Basically, monetary policy procedures can be divided into two categories, namely, discretionary policies and monetary policy rules. A discretionary policy is a policy set by the central bank specifically in each period of time in response to shocks to the economy. There is no commitment to any formal formulation for a period of time. It depends on the policymakers' judgments whether to tighten or ease policy stances at each period.

On the other hand, a monetary policy rule can be defined as "nothing more than a contingency plan that describes as precisely as possible the circumstances in which a central bank changes the instruments of monetary policy[7]". Central banks follow monetary policy rules by implementing a policy instrument to reach their objectives. A policy instrument is characterized as a variable that central banks can control that relates closely to economic goals.

Taylor (1997) and Friedman (2000) point out the advantages of policy rules over discretionary policies as follows;

1) The most well-known problem of discretionary policy, leading to its sub-optimality relative to a policy rule, is the "inflation bias" – Barro and Gordon (1983). Due to the short-run tradeoff between inflation or the inflation rate change and the

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[7] Taylor (2000)

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output gap and the central bank's intention to offset some distortions e.g. taxes and economic regulations, created by the government, policymakers may stimulate output to decrease unemployment by increasing inflation as a surprise. Once the central bank creates the inflation surprise, the public perceives this increase and expects it continue. Thus, a larger surprise is necessary to create successive inflation surprises. At this point, bringing down inflation would be costly as it would depress output and raise unemployment enormously.

Without a commitment to a formal policy rule, policymakers, thus, tend to choose a sub-optimal monetary policy – Kydland and Prescott (1977) – due to the temptation to exploit the short-run gain from inflation surprises. The reason for the sub-optimality of a policy with inflation surprises is that the level of output and unemployment, corresponding to such a high inflation level, can be, in fact, achieved by a lower average inflation rate, if the central banks choose not to create an inflation surprise.

2) If people are forward-looking, they consider the future as well as current policy actions to evaluate the effects of policy. Given a forward-looking public, policy rules can anchor their expectations about future policy actions and mitigate the uncertainty problems in consumption and investment by means of enhancing the transparency of the conduct of monetary policy. Thus, social welfare subsequently rises.

In fact, the Federal Reserve has recently attempted to affect market expectations by using statements rather than taking actions. If the Fed fails to adhere to policy rules or commitments set forth and rational private agents form their expectations based on current monetary policy conduct, efforts to affect market expectations by the Fed are unlikely to be successful.

3) Policy rules can reduce uncertainty about policy actions and they can reduce risk premia in financial markets. Since returns in long-term financial markets are based largely on two components, namely, current and expected short-term returns and risk premia, policy rules can not only reduce the latter but also establish a more precise forecast of the expected short-term returns.

Nonetheless, there are some disadvantages of policy rules. The main issue is inflexibility of policy rules in conducting monetary policy. Since the economic environment changes over time, it is maintained that central banks have to use their judgment in revising their monetary policy conduct from time to time, in particular, when large shocks such as oil or productivity shock hits the economy. Based on this rationale, the central bankers argue against policy rules since they do not allow necessary discretion for any changes.

However, this point is tackled by McCallum (2004) that it might be due to the *misconception* of most central banks since they are inclined to perceive policy rules as constant or non-activist rules, e.g. Friedman's constant money growth rule (Friedman's %k rule)[8]. If the central banks take activist rules or rules with contingency plans into account and respond to changes in the economic environment, this disadvantage would disappear.

Taylor (2000)[9] also emphasizes that monetary policy rules are not the mechanical rule - to put in some numbers and calculate the values from the rule and then follow it exactly without considering the appropriateness. In fact, he reminds us many times about the concept of policy rules that it is not an ironclad rule which cannot be changed in Taylor (1993), for example,

> *Moreover, in my view, a policy rule need not be a mechanical formula .... A policy rule can be implemented and*

[8] See Section 1.4 for more details in the Friedman's rule

[9] In fact, Taylor (1993) has emphasized this point since he introduced his famous "Taylor rule".

operated more informally by policymakers ... but who also recognizes that operating the rule requires judgment and cannot be done by computer... ..... (p. 4).

McCallum (2004) also adds that the central banks can revise their policy operation from time to time but it must be in systematic way and with the "timeless manner[10]", i.e. in the sense that the revisions should not be based on just the conditions currently prevailing but all the information about the future, including public expectations. Or else, the adjustments would cause the policy rules to not be credible since the people would expect continuous deviations from the rules and the policy rules would be dominated by discretionary policies eventually.

1.3. Targeting rules versus Instrument rules

There are two basic types of rules: instrument rules and targeting rules. The former specifies period-by-period settings of a controllable instrument, including interest rates and monetary aggregates, which central banks can influence directly. These rules include the McCallum rule (1988), the Taylor rule (1993) and exchange rate rules (McCallum and Nelson (2000a)). In addition, Bernanke (2004) pointed out that an instrument rule can be viewed as a simple feedback rule linking the central bank's policy instrument to a set of macroeconomic variables that either is directly observable or estimated from current information.

On the other hand, targeting rules specify a policy target, e.g. inflation or nominal income, which central banks cannot control directly but can influence through monetary policy. Bernanke (2004) labels a targeting rule as a "forecast-based policy" since it stems from the forecast of macroeconomic variables. The most well-known one is "inflation targeting rule" supported by Svensson (1997, 1999 and 2004).

[10]This is akin to the concept of "Timeless Perspective" in Woodford (1999b).

Bernanke and Mishkin (1997) argue that targeting rules such as an inflation targeting rule should not be considered as a rule at all. Instead, they should be characterized as "constrained discretion". The reasons are that targeting rules do not provide simple, mechanical operating guides to the central bank and they embody some discretionary aspect, since they allow some judgmental adjustments from time to time. The flexibility of the rule to be adjusted from time to time is one of the strengths of a targeting rule, compared to an instrument rule – Svensson (2004).

Put simply, a targeting rule is a policy rule expressing a relationship between a target variable, e.g. inflation, nominal income or aggregate price level and macroeconomic indicators without specifying the path to achieve such a target. The emphasis is on the target variable which central banks have to announce or release the target values, e.g. by releasing the formal reports, for transparency and credibility of the policy rule not on the rule itself. In contrast, an instrument rule sets an instrument, either nominal interest rate or monetary aggregates in response to the deviations of macroeconomic indicators from their targets.

Taylor (2000) proposes an interesting analogy of a targeting rule and an instrument rule to sailing a boat. While a targeting rule is compared to the destination for a sailboat, an instrument rule is how to sail the boat to get to the destination, which requires many things, for example, the angle of attack, the sail trim, the contingency for wind change and so forth.

There are some advantages and disadvantages of the two classes of policy rules. Some of them are discussed below.

1.3.1. A targeting rule

According to Svensson (1997), a targeting rule is basically obtained from an optimal control exercise to specify an optimal level, i.e. a target. The key ingredient in attaining a targeting rule is an operational objective[11] loss function. Svensson (2002a) also categorizes targeting rules into two types, namely, a general targeting rule and a specific targeting rule. The former specifies an operational objective for monetary policy, i.e. an operational loss function[12]. Committing to a general targeting rule is equivalent to committing to minimizing a loss function.

A specific targeting rule, on the other hand, is a commitment to set an instrument, e.g. a short-term interest rate, to achieve the target variables, corresponding to the optimal decision based on the minimization of the loss function. Committing to a specific targeting rule is to set an instrument variable (by any means necessary) to achieve the target variables.

Therefore, an advantage of targeting rules is that it is flexible for central banks to use any operating procedure as long as they reach the target. However, the main disadvantage is that the targeting rules are based entirely on the models and objective function (typically, the welfare loss function, composed of the variability of inflation and the output gap, is implemented) used by the central bank but there is no agreement among the economists on the best model to describe an economy.

As long as we do not restrict the policy rules to just optimal instrument rules, simple instrument rules such as the Taylor rule or Henderson and McKibbin rule, do not change along the model specifications. In other words, they do not rely on the specification of the model underlying the economy. However, the robustness of the simple instrument rules will be discussed in Section 4.2.2.

Targeting rules can be divided into four main types, depending on their targets. These include:

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[11] The operational objectives in Svensson (2003)' sense is the objectives specified in terms of variables or numbers in the conventional welfare loss function , i.e. inflation and the output gap, rather than statements, e.g. price stability or maximum sustainable output growth.

[12] Nonetheless, Svensson (2004) accepts that the term "general targeting rule" might be less appropriate than "targeting regimes" defined by Walsh (2003).

1) An inflation targeting rule: Since it is unanimously agreed among macroeconomists that in the long run, monetary policy cannot expand output above or reduce unemployment rate below their natural rates, adopting price stability as a primary policy objective seems sensible.

To achieve this goal, the implementation of an inflation targeting rule by announcing an explicit inflation target would be straightforward. Also, the inflation targeting policy would enhance the effectiveness as well as the credibility of monetary policy since it is explicit that the central banks seriously intend to commit to a certain level of inflation.

Moreover, an advantage of implementing an inflation targeting rule is that inflation is a simple concept to understand for the public, relative to other indicators including nominal GDP or monetary aggregates[13].

In addition, only some data on inflation are released more often than other indicators, in particular nominal GDP, and it is not revised as often as nominal income. The revision of the data is another crucial problem in designing monetary policy since the difference between the final data and real-time data leads to difference in the results of policy design.

On the other hand, a major disadvantage of inflation targeting rule is that it makes the price level follow a random walk, since it does not offset the deviations of price level from trend. In turn, the price stability achieved by inflation targeting regime in the long-run may not be as strong as the one attained by targeting the price level directly in terms of variability in the price level.

For instance, suppose that the inflation target is 2%. In the initial period, the price level is 100 and then it grows at 2% for two following years. In the next period,

[13] Nevertheless, I do not claim that inflation is very easy to understand per se since there are a number of ways to calculate price indices which it is beyond the focal point of the present chapter.

it will be 102 while the following year's price level is 104.4. Based on inflation targeting regime, inflation is stable and the economy is in good condition since inflation is still on the target of 2%, whereas, the price level drifts away from the original level infinitely.

The countries explicitly implementing an inflation targeting regime include Australia (1993)[14], Canada (February 1991), Finland (February 1993), Korea (1998), Israel (December 1991), New Zealand (March 1990), Spain (January 1995), Sweden (January 1993), Thailand (May 2000), and the United Kingdom (October 1992).

Inflation targeting policy is discussed nicely in Svensson (1997) and Bernanke et al. (1998).

2) price-level targeting rule: Instead of targeting inflation, some researchers, e.g. Svensson (1999), considers the alternative of targeting the general price-level. The nature of price-level targeting is to offset the last period change in the aggregate price level if it deviates from the desired target. Suppose that in the last period, the price level is higher (lower) than the target, the central banks should attempt to lower (raise) the price in this period. However, this results in a higher variability in output as well as in price level.

On the other hand, inflation targeting treats a change in price level as bygone, as long as the inflation is on the target. Hence, in an inflation targeting regime, the price level may increase much more than that in the price-level targeting regime in the long-run, even though central banks maintain the constant inflation target.

Price level targeting can be traced back to Wicksell (1965). Wicksell introduced a policy rule or norm which sets a discount rate in response to deviations of the price level from the target. The central bank should raise its discount rate when

[14] Parentheses are the dates in which those countries began to adopt inflation targeting regime.

the price level is rising, lower it when the price level is falling and keep it constant when the price level does not change.

One of the advantages of price-level targeting is that it is self-stabilizing. Deflation (inflation) in this period guarantees inflation (deflation) in the next period, provided that the price-level targeting regime is credible to the public. In order to maintain the price target, the price index in the next period must offset the movement of the price index in the current period. Nonetheless, the price movements also causes inflation (a change in price index) to be more volatile in the short-run, even though it is predictable.

According to Svensson (1999), the short-term inflation volatility in the price-level targeting policy is lower than that of the inflation targeting regime in a sticky price model with some output persistence. This is because the variance of inflation is proportional to the variance of the output gap *level* in the decision rule of inflation targeting, of which the feedback for inflation on the output gap, comparing to the decision rule in price-level targeting, of which the feedback for the price level on the output gap. Therefore, inflation is a linear function of the *first difference* of the output gap not the *size* of the output gap in the price-level targeting regime. In turn, the variance of inflation is proportional to the variance of the *first difference* of the output gap, which is smaller than the *level* of the output gap due to output persistence.

Noticeably, the problem of "time inconsistency", defined as the policy a central bank chooses optimally in one period which is not optimal in the next period, would be mitigated by the price-level targeting policy, since the public would expect the lower price index in the next period to offset the potential exploitation of the short-term gain from output expansion by an inflation surprise. Therefore, the central bank cannot exploit the short-term gain from inflation surprises. The time-inconsistency problem disappears.

The main disadvantage of price level targeting is that every shock hitting the economy must be offset, even though it is **permanent**. As a consequence, price level targeting regime induces unnecessary variability to the price level. An increase in the variability of price level may even raise the variability in real output if the price level is sticky, which possibly outweighs the welfare gain from price stability in the long-run aforementioned, compared to the inflation targeting regime.

The price-level targeting regime is also suggested by Svensson (2003) in his fool-proof way to escape from the liquidity trap. Berg and Jonung (1999) discussed the case in Sweden as the first and only case ever to implement this targeting regime after it left the gold-standard system in 1931-32.

3) Money-growth targeting: This type of targeting rule targets an intermediate variable namely, monetary aggregates. The reason for this is that it is closer to the central bank in terms of controllability than targeting the final goal, i.e. inflation targeting. However, there are a number of definitions of monetary aggregates or money supply: monetary base (M0)[15], narrow defined money supply (M1) and broad money supply (M2). It is still a matter of disagreement which monetary aggregate should be targeted. For instance, M0 is quite controllable by central banks but it excludes some liabilities in a banking system which may have an important effect on inflation.

A simple way to explain the effect of the money growth targeting rule is through the Quantity Theory of Money (MV=PY, where M is money supply, V is velocity, P is price level and Y is real output). Central banks implement this rule by

[15] A monetary base (M0) – monetary base or reserve money – is composed of domestic currency and banks' deposits at the central bank, while M1 is composed of domestic currency in circulation and demand deposits held at banks. Finally, M2 – broad money – is M1 combined with time deposits.

setting the desired final target for future price, output level and expected velocity. Then, the money supply needed to support the desired price level and output can be inferred.

An advantage of targeting a monetary aggregate is that central banks are believed to be able to easily control the monetary aggregate, in particular, the monetary base (M0), more than other variables since it is on the central banks' balance sheet. Therefore, monetary aggregates should be easily controllable – McCallum (1988).

Judd and Motley (1992) argue that the rule using a monetary base as the policy instrument can induce more dynamic stability in a variety of models given the uncertainties in the economic structure, compared to an interest rate rule, based on the simulation results. The former rule controls the aggregate price level more effectively and induces less volatility in real GDP than the latter, which implements an interest rate as the policy instrument, in the long run. In addition, they suggest the growth rather than level of nominal GDP (or M2) as the intermediate target.

Another problem is that targeting an intermediate variable, i.e. money growth, is that it is more difficult to understand than other variables including the goal variables such as the inflation rate or nominal GDP. A change in the monetary aggregates may not convey any useful messages to the public in making a decision in their consumption and investment, compared to a change in inflation or a change in nominal GDP.

Lastly, the problem of implementing a monetary aggregate as a targeting variable concerns velocity. From the Quantity Theory of Money, predictable base velocity is a requirement to calculate the money supply accurately. One of the countries successful in implementing a monetary aggregate target was Germany since its base velocity has been stable for the past 20 years. The Bundesbank announced a monetary target every year before Germany joined the European Monetary Union and all monetary policy has been conducted by the European Central Bank since 1998, conforming to the monetary aggregate targeting regime (M3). By targeting the monetary aggregate, the Bundesbank gained a very high reputation for controlling the inflation rate.

4) A nominal GDP targeting rule: Apart from targeting inflation, another ultimate goal that can be targeted is nominal GDP. This policy is supported by a number of researchers including Hall and Mankiw (1993), McCallum (1999), McCallum and Nelson (1999). They justify that targeting nominal income or GDP yields more stable output than targeting inflation.

The reasons to support a nominal income targeting rule are

1) Monetary policy cannot determine inflation and/or the real output level separately, thus, targeting nominal income/GDP would be similar to targeting both inflation and real output at the same time.

2) Nominal output can serve as a long-run nominal anchor for monetary policy. In most models, except the fully flexible price and rational expectations model where money is neutral even in the short-run, monetary policy can affect real output only in the short-run, targeting nominal output, composed of both real output and inflation, would help stabilize the economy by countering economic fluctuations, specifically in output.

3) Based on the stylized facts[16], monetary policy impacts the economic activity more quickly than on inflation. Therefore, a nominal income targeting regime would counteract the shocks more quickly than other regimes.

[16] As illustrated in Section 3.6 in Chapter 3, based on the empirical partial correlations, the real interest rate (gap) has an impact on the output gap or real activity with shorter lags than it has on inflation.

4) Given the difficulty in predicting and controlling inflation, policies which stabilize nominal GDP growth may be more likely to produce good economic outcomes. This result is presented by Cecchetti (1995).

However, there are some who are skeptical about adopting a nominal income targeting rule. These include:

1) Ball (1997) and Svensson (1997) argue that with a backward-looking model where monetary policy affects output with a shorter lag than inflation, nominal output targeting leads to instability of the system, i.e. infinite variances in inflation and output.

However, McCallum (1999) contends that Ball (1997) and Svensson (1997) used the models with the realization of past inflation, not the expectations of future inflation. By contrast, McCallum (1999) finds that monetary policy does not lead to instability if the economy is well-characterized by forward-looking rational expectation models[17].

In addition, Dennis (2001) shows that the nominal GDP targeting could still induce the stability of the economy even with a slight degree of forward-looking in the Phillips curve. Ball's (1997) and Svensson's (1997) are just a special case where the degree of forward-looking in the inflation adjustment function equals zero.

2) Rudebusch (2002) shows that a policy rule targeting nominal income performs poorly in his New Keynesian structural model, comprising two main equations, namely, aggregate supply or expectations augmented Phillips curve and aggregate demand.

Moreover, Blinder (1995) and Monetary Policy Committee of Bank of England (1999) find some evidence substantiating this argument. Other studies implementing the backward-looking models, e.g. Svensson (1996), Ball (1997) and Rudebusch and Svensson (1999) also describe the shorter lags monetary policy on the output gap than inflation.

[17] He implements the model with an extreme case with a degree of forward-looking in aggregate supply of unity, compared to Ball (1997) and Svensson (1997) where they employ an accelerationist Phillips curve in which the degree of forward-looking is nil.

1.3.2. An instrument rule

Instrument rules are the policy rules, relating a policy instrument to policy targets in a specific way, e.g. the linear relationship in response to the output gap and inflation as such in the Taylor rule, compared to a targeting rule which may not even include a policy instrument in the rule, and not specify how to adjust the policy instrument to reach those targets.

Instrument rules can be derived from two possible methods. One is to backcast the economic data directly, e.g. the Taylor rule. These can be classified as simple instrument rules which do not rely on any specific macroeconomic model. Another method is to derive from the optimization of the central bank's loss function subject to a specific model and the policy rule specification.

Despite that instrument rules can fit the empirical data in many countries well as will be shown in Section 3, especially the Taylor rule, it is not necessary that the central banks in those countries follow any rules at all. Thus far, none of the central banks around the world announced outright that they followed a specific instrument rule.

Svensson (2004) provides some interesting interpretations of instrument rules by dividing them into two types, namely, an explicit instrument rule and an implicit instrument rule. The former is an instrument rule in which the instrument variable is related to pre-determined variables. This corresponds to a simple instrument rule introduced by McCallum (1988) and Taylor (1993a). On the other hand, the latter conforms to an equilibrium condition where several variables are simultaneously determined. Basically, it can be derived from the first order conditions of the central bank's optimization problem and from writing the instrument variables in terms of macroeconomic indicators.

The advantages of an instrument rule can be described as follows;

1) Since an instrument rule sets a policy instrument to respond to just a small number of macroeconomic variables, it is easy for the public to understand and to use to form expectations of the way monetary policy will evolve in the future. As a consequence, bonds and other financial assets are priced more efficiently because financial assets' prices are determined partly by future monetary policy stance.

2) Due to the explicit and simple setting of an instrument rule, it is easy to verify by the public, thus, credibility is easily gained (if the central banks commits to the rule). With very credible monetary policy, the central bank may not have to take any actions to influence the economy to reach its economic goals or take less action than without the commitment.

3) Based on the simulation results obtained by a number of researchers including McCallum (1988), Taylor (1999a), Orphanides and Williams (2002) and Levin and Williams (2003), an instrument rule approach can often result in a robust policy – good results in wide classes of model specifications. In other words, it is model-independent. The only information that a simple instrument rule needs is normally the current observable or estimated values of the macroeconomic indicators. This is one of the important properties of monetary policy because there is, by far, no consensus on which model best describes the economy.

Since the strong arguments in favor of targeting rules by Svensson (1997, 1999, 2003), whether a central bank should implement a targeting rule or an instrument rule is very contentious in monetary policy analysis, especially with the working papers by McCallum and Nelson (2004) and Svensson (2003, 2004). The arguments from these papers include:

1) A simple instrument rule may not be optimal in some circumstances since it tends to neglect other important variables, such as foreign output, the real exchange rate, terms of trade and the foreign interest rate. McCallum and Nelson (2004) argue that these variables can be included either implicitly or explicitly in an instrument rule. Because a policy rule, such as the Taylor rule, represents just one class of instrument rules, it is not necessary to encompass every variable.

Yet, in some model specifications such as McCallum and Nelson (1999) and McCallum (2003), foreign variables are taken into account implicitly by means of re-interpreting the parameters representing CPI inflation, output and the real interest rate to capture the open economy effects. Another example is Ball (1999) who incorporates the effect of real exchange rate in two channels; namely, incorporating directly to aggregate demand and supply and embedding it to the general price index.

2) A commitment to an instrument rule does not allow any judgmental adjustments to be used – Svensson (2004). However, McCallum and Nelson (2004) strongly object to this argument since there exist a number of ways to adjust an instrument rule. The rules are not necessarily followed mechanically or without any systematic adjustment. This issue has also been emphasized several times in Taylor (1993a, 1997, 2000) and others.

3) Once-and-for-all commitment to an instrument rule does not allow any improvement after some new information concerning the transmission mechanism, variability of shocks or the sources of shocks arrives. However, this argument is groundless when the concept of a "timeless perspective" – Woodford (1999b) – comes into the policy design. The timeless perspective policy is to commit to the policy which is chosen optimally in the last period for the current period.

4) Thus far, there is no central bank announcing and committing itself to an explicit instrument rule. Unlike targeting rules, in particular an inflation targeting rule, most central banks have their own inflation target or even output growth target (even though, in the long-run, there is no use in announcing a specific output growth target since monetary policy is neutral and cannot affect the long-term output growth). An explicit target is a necessary condition for targeting rules in Svensson (1997) sense since it is required to designate the operational objective function.

Regarding this issue, McCallum and Nelson (2004) question the validity of the claim based on the ground that the objective function, i.e. the loss function, to be minimized requires some weight of central banks' preferences on either inflation or output that it is still unknown. In addition, they question what is the best model describing the economy and being used in the optimization problem.

5) Svensson comments that the goodness of fit to the quarterly data that an estimated policy reaction function, e.g. in the US, could explain is just 66% of the variance of changes in the federal funds rate. However, McCallum and Nelson (2004) contend that, since the empirical study which Svensson's argument based on - Judd and Rudebusch (1998) – specifies the policy reaction function by relating a *change* in the federal funds rate to the policy targets as well as policy inertia, Svensson's argument is grounded on the *change* in the federal funds rate not the *level*. With only 33% of unexplained variance of the change instrument rate, it is relatively high in terms of the regression on the difference variable.

6) Finally, McCallum and Nelson (2004) illustrate that, in some models, e.g. Bullard and Mitra's (2002), Clarida, Gali and Gertler's (1999) and one-period-ahead model used by Svensson (1997), the increase in the variability of a short-term interest rate in an instrument rule, specifically, the federal funds rate of the US, is lower than

that of a targeting rule when the policy rule is more aggressive in response to inflation. Therefore, a targeting rule may not be very robust because it underperforms in some models.

1.4. Monetary base versus short-term interest rate

In this section, I focus on instrument rules. Even though many economists advocate targeting rules as an appropriate policy to use to achieve the objectives as discussed earlier, the proponents of instrument rules have also gained much attention in monetary policy analysis.

Policy instruments can be divided into two categories, namely, monetary aggregates and short-term interest rates. The monetary aggregates are, for example, the monetary base, bank reserves, M2, or other definitions of money. The second category of policy instruments, i.e. short-term interest rates, is of interest to economists since one of the most influential papers, Taylor (1993a), introduced an interest rate rule incorporating a feedback loop to some economic indicators.

Instrument rules came to prominence in the late 1980s when Meltzer (1987) and McCallum (1988) emphasized the importance of monetary aggregates in a rule-based setting. The choice of the instrument was not problematic initially since interest rates were not recognized as policy instruments due to their unpredictability and uncontrollability (McCallum (1988)) even Taylor (1979, 1993b) exploited monetary aggregates in his early work regarding policy rules. Since the introduction of the Taylor rule (1993a), short-term interest rates have become preferred policy instrument in monetary policy design for both policymakers and monetary policy analysts.

Even though the Friedman rule is argued to be a type of targeting rule rather than an instrument rule – Svensson (1997), it is worthwhile to discuss the Friedman rule as an instrument rule because of the following reasons. First, it employs monetary aggregates as the policy instrument, similar to the instrument rules proposed by Meltzer (1987) and McCallum (1988). Second, the rule emphasizes how the constant money growth rate would affect the policy targets rather than defining optimal levels of policy targets like inflation or nominal income targeting rule. And lastly, it is the rule, from which many instrument rules, including Meltzer (1987) and McCallum (1988), are developed.

1.4.1. The instrument choice problem

Basically, the problem of the choice of policy instruments emerges due to the dilemma that central banks can control only one instrument and must allow the other to be determined by the money market represented by LM curve in the traditional IS-LM framework, while the IS curve represents equilibrium in the goods market. The IS-LM curves jointly determine the demand-side of the economy represented by an aggregate demand curve.

Where does monetary policy fit in this framework? Considering the money market in Figure 1.2, M^S is a money supply function. It is vertical since it is exogenously determined by a central bank. M^D is the money demand function, which is determined by income, and an interest rate. r^* and M^* are an equilibrium interest rate and equilibrium monetary aggregate, respectively.

A central bank can conduct monetary policy by influencing either monetary aggregates or an interest rate, while allowing the other to be determined by the money market. If the central bank uses the monetary aggregate as the policy instrument such as M^1 by reducing monetary aggregate, then it has to allow the interest rate to be adjusted to r^1, conforming to the equilibrium in the money market.

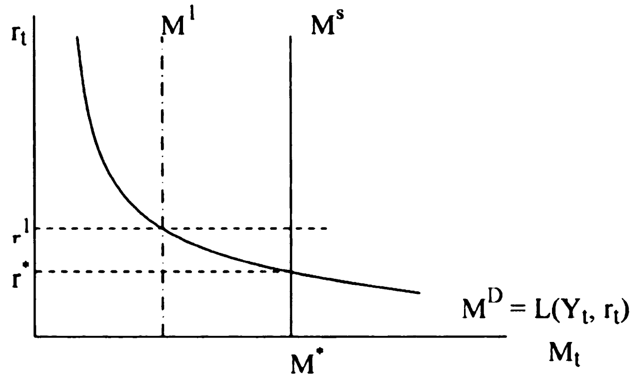

Figure 1.2: Money market equilibrium

On the other hand, if the central bank targets the interest rate, corresponding to the interest rate at r^1, it has to supply as much money as necessary in order to support the pegged interest rate level, i.e. the supply of money must be reduced to M^1. In other words, the central bank allows the monetary aggregates to adjust endogenously, corresponding to the demand for money required by the desired interest rate level. In that case, the money market equilibrium schedule or LM curve is horizontal at the level of the interest rate desired by the central bank.

1.4.1.1. Poole's analysis

One of the classic analyses of the instrument choice problem in monetary policy analysis is Poole's analysis (1970). He handles the problem of instrument choices by considering where shocks enter the economy, that is whether they stem from the goods or money market, based on a simple IS-LM model. Noticeably, he focuses on the stabilization of output which is a short-run policy objective of the central banks, while he does not consider price stability which is a long-run objective of central banks.

According to Poole's basic results, the steeper LM curve (smaller elasticity of demand for money in response to the interest rate) and/or the flatter the slope of the IS curve[18] (higher elasticity of output in response to a change in an interest rate) and/or the higher the variance coming from money demand function results in the preference of an interest rate operating procedure rather than monetary aggregate operating procedure and vice versa.

When the variability mainly originates in the financial sector (e.g. money demand shocks) and the money demand function is unstable or difficult to predict, implementing an interest rate rule would be preferred since it would stabilize output directly and the money demand function, which is unstable in this case, is irrelevant. On the contrary, if the main source of short-run instability stems from non-monetary shocks, using monetary aggregates as the policy instrument would yield a more desirable result – lower output variability.

Nonetheless, Friedman (2000) points out that the instrument choice problem between monetary aggregates and interest rates emerges due to the uncertainty of the effects of the operating procedures upon the aggregate demand (goods markets) or financial markets. If there is no such uncertainty, it does not make any difference whether monetary aggregates or the interest rate is chosen as the policy instrument, based on Poole's analysis.

It is noteworthy that the Poole's analysis does not include other sources of variability such as the effects of inflation, expectations, or aggregate supply disturbances. These factors are also important in the economy. Therefore, more sophisticated approaches for policy analysis are needed.

[18] The slope of the IS-curve is $\Delta r/\Delta y$ while the elasticity of the output on the interest rate is $\Delta y/\Delta r$ (in the logarithms). Hence, the steeper is the slope of the IS-curve, the smaller is the elasticity. In addition, the slope of the LM-curve relates to the elasticity of demand for money on an interest rate via the money demand equation. Considering Figure 1.2, higher output shifts up the money demand function, resulting in higher interest rate to equilibrate supply and demand for money. Hence, the smaller is the elasticity of demand for money on the interest rate (high $\Delta M/\Delta r$), the steeper LM-curve is.

1.4.1.2. The modern approach of the analysis of instrument choice problem

In the late 1970s, the problem concerning the choice of the instrument has been discussed in the framework of indeterminacy of the nominal variables initiated by Sargent and Wallace (1975) in their early studies of rational expectation models. They argued that, given an interest rate rule and the structural model in which all private agents form their expectations rationally and free from money illusion, the general price level in the economy would be indeterminate. Nonetheless, McCallum (1981, 1986) shows the opposite results. He argues that all nominal variables are determinate, given that the policy rule utilized in the model contains some nominal variables. Some rationales for this are provided in McCallum (1999).

Furthermore, McCallum (1986) proposed an important distinction between the "nominal indeterminacy" and "solution multiplicity (or non-uniqueness)". The nominal indeterminacy is a situation where a model cannot specify time paths for nominal variables while the time paths of real variables are well-specified. In other words, the nominal variables lack a nominal anchor to pin down their values.

On the contrary, the solution multiplicity or non-uniqueness is a situation where there exist solutions and time paths of nominal variables including price and the stock of money but there are too many or an infinite number of them. In this case, the time paths of nominal variables are well-specified. The adoption of an interest rate rule leads to the second problem, i.e. the non-uniqueness of solutions, rather than the problem of indeterminacy of nominal variables.

One of the main objections to using monetary aggregates in the US as the policy instrument is that a large fraction of the monetary aggregates are held by foreign countries, Jefferson (1997) shows that the use of only the monetary base held domestically can change the relationship between nominal GDP and the monetary base for the period 1984-1995.

Another problem of using monetary aggregates is that this operating procedure induces larger variability into short-term interest rates than do policy rules with interest rates. As a result, it causes uncertainty in the financial markets. In turn, financial assets would be priced less precisely.

More importantly, the public is familiar with a short-term interest rate rather than a monetary aggregate. Consumers and investors use a short-term interest rate in deciding their consumption and investment plans. Even though the public can determine short-term interest rates from the money demand function, in many cases, demand for money is unstable.

McCallum (1999) also points out the reasons why central banks, specifically the Federal Reserve, prefer to use a short-term interest rate to the monetary base as the policy instrument. These include the instability of the monetary aggregate if the central banks try to control them exogenously and the role of the central banks as a lender-of-last-resort to prevent financial crises.

The first reason can be shown by a simple regression, which relates the monetary base to a short-term interest rate and its lag. Consider Equation (1.1);

Equation (1.1) .... $b_t = \alpha_0 + \alpha_1 R_t + \alpha_2 R_{t-1} + \eta_t, \qquad \alpha_1 < 0$

Where b_t is a monetary base

R_t is a nominal short-term interest rate

Then, when the central banks control monetary base exogenously, Equation (1.1) becomes Equation (1.2);

Equation (1.2) .... $R_t = \beta_0 + \beta_1 R_{t-1} + \beta_2 \eta_t + \beta_3,$

Where $\beta_1 = (-\alpha_2/\alpha_1)$ and $\beta_3 = (-1/\alpha_1)$, if $\alpha_2 < 0$, then there will be oscillations around R_t and if $| \alpha_2 | > | \alpha_1|$, then the system will be explosive. Thus, the central banks might be reluctant to adopt the monetary base as the policy instrument[19].

Regarding the second reason as McCallum (1999) points out, a central bank can lend out as a last resort whenever the economy is in crisis. However, they do that with some policy inertia, i.e. attempt to intervene without inducing too much volatility into the economy. The only way to incorporate policy inertia into the rule is to use a short-term interest rate as the policy instrument with some degree of interest rate smoothing.

Finally, a crucial issue in implementing monetary aggregates as the policy instrument is the stability of the money demand relationship, i.e. the stability of base velocity and short-term interest rate relationship since the demand for money partly determines the equilibrium in the money market, in turn, determining the aggregate demand schedule. Therefore, the stability of money demand relationship is important. Much research substantiates the stability of the money demand relationship in the US, e.g. Meltzer (1998) and Anderson and Rasche (2001). However, the stability of money demand is still a controversial issue in many countries. For example, during the period in which the zero bound constraint was binding in Japan, the relationship between the monetary base and interest rates tended to fail – Coenen and Wieland (2003).

1.4.2. Types of the instrument rules

In this section, some examples of instrument rules are reviewed. Mainly, the instrument rules implement either an interest rate or monetary aggregate, which can be considered as traditional instrument rules. On the other hand, another group of

[19] However, McCallum (1999) argues that it is not true that $| \alpha_2 | > | \alpha_1 |$ in reality – McCallum (1985). In that case, R_{t-1} may be even irrelevant to the function.

instrument rules implement other instruments including exchange rate or Monetary Condition Index (MCI). I will turn to them in the next section.

1.4.2.1. Friedman %k rule[20]

In the Program for Monetary Stability written by Friedman (1959), he recommended a basic rule by setting the stock of money to grow at a constant rate without any changes to respond to economic cycles. Also, Friedman defines the stock of money in broader terms (M2 rather than M1) than had the Federal Reserve by adding time deposits in commercial banks into it.

In addition, he specifies the appropriate growth of the stock of money, conforming to a stable long-run level of final product prices, of slightly over 4% per year. This figure is contributed by 3% of growth in output while another 1% of the growth rate stems from a secular decrease in velocity. However, he mentioned that this range was not as important as the adoption of a constant growth rate of stock of money which would not incur too much fluctuation in general prices. Therefore, Friedman's constant money growth rule is referred as Friedman' %k rule. Generally, %k is arbitrary, which can be any values corresponding to the future growth rate of output in the long-run.

Finally, he adds that the treatment of intra-year movements is unnecessary. The seasonal movement of the stock of money is quasi-deliberate by the Federal Reserve since one of the subordinate objectives of central banks is to reduce the variability of interest rates to maintain the stability in financial markets, which, in turn, imposes greater variability in the stock of money. The variability of the stock of

[20] Notwithstanding, Svensson (2004) argues that Friedman's %k rule is, in fact, a targeting rule since it refers to a broad monetary aggregate, such as M3, growth of k percent. A central bank adopts this operating procedure by setting a target for a broad monetary aggregate growth, based on the forecast of the future growth of the broad monetary aggregates then change the instruments such as interest rate or monetary base to hit that target. Svensson (2004) additionally explains that the central bank cannot control a broad monetary aggregate which is determined by demand and supply in the reserve market, thus, it is an intermediate target, not an instrument. As a consequence, the Friedman's %k rule is a targeting rule not an instrument rule.

money is caused by the nature of operating monetary policy, thus, it is not necessary to offset this variability.

Moreover, Friedman casts some doubts that leaning against the wind – the main strategy of most central banks nowadays – would be a better strategy to achieve economic goals because we do not know with certainty what winds would blow. In other words, the data available in the current period when the policy is being made are the previous period data due to lags necessary to collect the data before they are released and it is difficult to forecast or predict economic shocks or events in advance. This becomes one of the ideas in Meltzer (1987).

The difficulty in forecasting changes in economic environment discourages central banks to lean against the wind or to respond to changes in economic environment. Since the introduction of the Friedman's constant money growth rule, the development of more sophisticated macroeconometric techniques helps us forecast economic environments better than before. Thus, the leaning against the wind strategy is in favor more than ever, compared to the 1960s, as will be seen in more recent policy rules, e.g. the McCallum rule or the Taylor rule.

1.4.2.2. Meltzer's suggestion (1987)

Meltzer (1987) addresses an issue in the uncertainty due to forecast error in policy design. This uncertainty can raise variability of both output growth and inflation, as a result it reduces social welfare. He proposes an adaptive rule which does not depend on forecasts of economic indicators. In comparison with fixed policy rules, in particular the Friedman's %k rule, which does not adjust to permanent changes of economic indicators, Meltzer's adaptive rule gradually adjusts to any new information entering the policymakers' information set. However, it does not absorb information concerning cyclical behavior.

The rule proposed by Meltzer (1987) is based fundamentally on the Quantity Theory of Money, in growth terms. The rule requires a central bank to set the annual growth rate of the monetary base equal to a moving three-year average of nominal output minus a moving three-year average of the growth rate of base velocity. The three-year period is intended to average out cyclical behavior as well as to learn to separate between permanent and transitory shocks. With this rule, permanent shocks will be taken into account to adjust the monetary base (through the change in base velocity), while there is no adjustment for transitory shocks.

Furthermore, Meltzer (1998) suggests that if central banks' focus on policy in the medium- to long-term, they should consider policy rules with a monetary base as the policy instrument. In spite of the argument on the instability of money demand function, he argues that the money demand function is, in fact, stable in the medium- to long-term rather than in the short-term, based on the illustrations of regressions of base velocity on long-term interest rate and one-period lag of base velocity.

1.4.2.3. McCallum rule (1988)

The McCallum rule has been developed to respond to a change in economic environment by implementing the monetary base as the policy instrument similar to Meltzer's (1987) proposition. However, the response to cyclical behavior of the economy is dropped in the Friedman rule due to the argument by Friedman as mentioned above. McCallum (1988) created an adaptive or feedback policy rule by extending the Meltzer's rule. With this rule, he also introduces the response to the cyclical behaviors into the rule. In other words, the McCallum rule combines two main components of output over time, namely, cyclical behavior and permanent shifts in its growth rate. Also, the McCallum rule can be thought of as a rule nesting both

Friedman's %k rule and Meltzer rule of the average monetary base to maintain the long-term average growth of nominal output, as shown below.

The McCallum rule uses the monetary base to keep nominal aggregate demand growing smoothly at a non-inflationary rate. McCallum (1988) supports the use of the monetary base on the grounds that the Federal Reserve can observe the monetary base, composed of currency outstanding and banks' deposits at the Fed, directly as frequently as it desires. Therefore, if there are deviations from the rule-prescribed targets, the Fed can respond very quickly. Also, McCallum (1988) gives the reason why a monetary base should be used as the policy instrument rather than a short-term interest rate since there still lacked empirical evidence to indicate the relationship[21] between an interest rate and the output at that time.

McCallum (1999) show that the monetary base policy rule performs better in terms of lower root mean squared errors – the measure of how the prediction of the model is closed to the data – of the inflation and the output gap by conducting historical counterfactual simulation of two policy rules implementing either monetary aggregates (he has used a monetary base in his study) and a short-term interest rate for the US economy based on an unconstrained Vector Autorregressions (VAR) with four lags.

Taylor (1999) explains that the emphasis on money growth during the change in the operating procedure during 1979-1982 played the key role in the Volcker Disinflation period during that time since lower money growth to curb inflation resulted in a large increase in interest rate, though he supported using an interest rate

[21] It is noteworthy that by the time McCallum (1988) introduced his rule, John B. Taylor (1993a) has not yet come out with his famous Taylor rule. However, a policy rule implementing an interest rate was earlier introduced by Judd and Motley (1992) to relate the interest rate to nominal output rather than the output gap as such in the Taylor rule. Nonetheless, it has not been recognized as much as the Taylor rule.

as a policy instrument since the beginning of the 1990s. He also adds that the role of money growth targets faded due to the desire not to destabilize financial markets.

The McCallum rule can be described as follows;

Equation (1.3) ……….. $\Delta b_t = \Delta x^* - \Delta v_t + \lambda(\Delta x^* - \Delta x_t)$, $0 < \lambda < 1$

where Δb_t is the growth rate of the monetary base

Δx^* is the long-run nominal output growth

Δv_t is the growth in base velocity defined by the difference between the growth of nominal output growth and the growth of monetary base

Δx_t is the nominal output growth.

Basically, the McCallum rule is comprised of three terms, the first term represents the long-term nominal GNP growth which was originally suggested to be 3% per year[22]; the second term is the average growth rate of base velocity over the previous four years; the last term is the deviation of the nominal GNP growth rate from the target as a feedback part of the rule.

For the coefficient on the deviation of nominal GDP growth from the target (λ), McCallum (1988) suggests that it should be sufficiently large to respond to the deviations of the nominal GDP growth from the target but not too large to induce dynamic instability. He recommended the coefficient on this feedback term of 0.25% based on the simulation based on the atheoretical VAR model. On the other hand, based on the structural model such as the Keynesian type model or Real Business Cycle model, the coefficient associated with the target deviation part rises to 0.5%, which is consistent with McCallum (2002).

[22] However, in the McCallum (2002), the target is adjusted to reflect the current economic circumstance to 5%, which composed of 3% of average long-run real GDP growth and 2% of inflation target. Noticeably, he used GDP in McCallum (2002) rather than GNP but the difference between the growth of nominal GDP and GNP from 1960 to the present is less than 1% on average. Therefore, they might be interchangeable in this case.

Based on Equation (1.3), it can be shown that the McCallum rule nests both the Friedman's %k rule and the Meltzer rule. When $\lambda = 0$, the target deviation part disappears and the policy rule collapses to the Meltzer rule which prescribes an average growth rate of the monetary base.

If $\lambda = 0$ and base velocity is constant ($\Delta v_t = 0$), then the central bank should maintain the growth rate of monetary base at the same rate as the growth rate of nominal output. This is consistent with the Friedman's constant money growth rule.

Even though the Federal Reserve does not adopt a monetary aggregates targeting regime as an operating procedure, the implied monetary base based on the McCallum rule is also reported in Monetary Trends, published by the Federal Reserve Bank of St. Louis, as an additional indicator to track the policy, apart from the target federal funds rate.

1.4.2.4. Taylor rule (1993a)

One of the most influential policy rules in monetary policy analysis is the Taylor rule. It is based on John B. Taylor's seminal paper in 1993. In addition, the policy rule embodies the Taylor Principle by setting a short-term interest rate in response to the deviations of macroeconomic indicators from their targets, including average inflation for the whole year and the output gap. It will be the central issue in this present paper due to its attractiveness in terms of simplicity, transparency and fitting well with the empirical data in many countries. This issue will be discussed in depth in Section 2.

1.4.3. Other non-traditional instrument rules

Many problems are inherent in policy rules with traditional instruments. These include uncertainty in measurement of intermediate targets or trend, the unknown natural rates used as benchmarks to calculate the gaps and more importantly limitations in the instrument's nature such as the zero bound constraint on the nominal interest rate. For these reasons, alternative policy instruments have been suggested. Examples are an exchange rate rule (McCallum (2003)) and a policy rule based on the Monetary Condition Index (Ball (1999)).

1.4.3.1. Exchange rate rule

In the late 1990s, Japan experienced the zero bound constraint problem on the nominal interest rate. Many researchers attempted to come up with alternative policies to handle this problem since nominal interest rates cannot fall lower than zero percent as may be required by the rule when a severe recession emerges and nominal short-term interest rates are at low levels. McCallum (2003) proposed a policy rule implementing an exchange rate instead of a short-term interest rate as the policy instrument. Among many critics of using an exchange rate as a policy instrument due to the inability of the central bank to control this instrument, McCallum argues that this policy rule can be used effectively during the period when the short-term interest rate hits the zero bound.

Regarding the problem of controlling the instrument, he points out that central banks can affect the foreign exchange rate easily when they intend to devalue the domestic currency since the central banks have unlimited ability to print domestic money and use it to purchase foreign assets. The policy rule he proposed is as follows;

Equation (1.4) ………………… $\Delta s_t = \mu_0 + \mu_1(\Delta p^*_t - \Delta p_t) + \mu_2(y^*_t - y_t), \quad \mu_1, \mu_2 > 0$

Where Δs_t is the rate of depreciation of an exchange rate

Δp_t is the inflation rate

Δp^*_t is an inflation rate target, which McCallum (2003) recommends to be 2% in Japan's case

y^*_t is potential output or an output target

y_t is the output level, therefore, $(y^*_t - y_t)$ is the output gap

The rule states that whenever inflation or output is below its target level, the central bank should attempt to depreciate their currency and vice versa. However, the rule may be difficult to implement for two main reasons. First, the foreign exchange market is huge, compared to short-term domestic assets, it would be much more difficult even for a central bank to influence prices in such a gigantic market, in line with this rule.

Second, depreciation of the domestic currency means appreciation of foreign currencies. This scenario might not be welcome by the trading partners because their exports would be more expensive while their imports (particularly from the country with the domestic currency depreciating) would be cheaper. As a result, the trade balances and output of trading partners may deteriorate.

Nevertheless, the first problem is immaterial in small countries where their currencies are thinly traded. Moreover, a solution to this problem for small economies is the coordination among the central banks to simultaneously intervene in the foreign exchange market. However, this issue is beyond the scope of this research.

For the second issue, Krugman (1998) and Svensson (2003) argue that the trading partners will, in fact, benefit enormously in the long-run. This is because when the domestic economy is out of the recession, the imports from the trading partners will expand. Thus, allowing the currency to depreciate (appreciate in the trading partners' view) should be more gain rather than loss for both domestic and foreign economies in the long-run.

1.4.3.2. Monetary Conditions Index (Ball (1999))

Ball (1999) extends the simple closed-economy model in Svensson (1997) and Ball (1997)[23], by adding the real exchange rate to incorporate the open-economy into aggregate demand and supply and appending the interest rate parity into the model. The exchange rate affects the economy via two means; one is through output in the aggregate demand function. The other is through the change in the real exchange rate augmented into the inflation adjustment function owing to the direct pass through of the import prices on domestic inflation. Then, he derives an optimal policy rule based on the assumption of a linear policy rule and a quadratic loss function.

Ball's optimal policy rule is different from that of the closed economy model in two ways. Firstly, the instrument implemented by the policy rule is a weighted average between the real exchange rate and real interest rate, i.e. Monetary Conditions Index (MCI), instead of only a short-term interest rate in the optimal Taylor-type rules in his closed-economy model. Secondly, a long-run inflation target, composed of an inflation target as well as an adjustment of the real exchange rate in the last period, is used, instead of the current inflation rate.

Ball (1999) illustrates that the conventional policy rules, in particular, the Taylor rule and inflation targeting rule, can be less efficient than with his optimal policy rule with the MCI as the policy instrument and targeting long-run inflation in terms of reducing fluctuation to both inflation and the output gap.

This is because the instrument rules, including the Taylor-type rules, are designed specifically for closed-economy model, thus, they do not perform well in

[23] In the closed-economy version of Ball (1997), an optimal instrument rule is determined by an aggregate demand function linking the output gap to its lag and a lag of real interest rate, aggregate supply or the Phillips curve relating the current inflation to its lag and a lag of output gap and a policy rule implementing an interest rate as the policy instrument. According to this model, the policy instrument (an interest rate) can affect inflation solely through output channel in the aggregate demand function. A change in a real interest rate affects the output with one lag and the change in output successively affects the inflation with another lag. Thus, inflation is affected by real interest rate with totally 2 lags.

reducing the variability of inflation and output in his open-economy model due to the neglect of effects of the exchange rate passing through both aggregate demand and supply.

Furthermore, the targeting rules, specifically an inflation targeting rule, can induce larger fluctuation in output and the exchange rate in Ball's open-economy model, despite that inflation can reach its target after one period. The direct effect of monetary policy on inflation is a result of the change in the real exchange rate[24]. However, a change in inflation is traded off by a change in the output gap in the next period, which in turn, requires some adjustments of the real exchange rate later on. Thus, in the small open economies, the targeting rules may add to fluctuations both in the output gap in aggregate demand and in the real exchange rate.

On the contrary, the fluctuation in output and the exchange rate disappears when the long-run inflation target replaces the current inflation rate in the Phillips curve and the policy rule and the MCI is used as the policy instrument. When inflation deviates from its target, the central bank can adjust the MCI in response to the long-run inflation only through the output channel, similar to the closed-economy case. Therefore, the problem of exchange rate and output gap fluctuation aforementioned does not occur.

However, the most important limitation of this model is that it is applied to a small open economy. Ball (1999) focuses on New Zealand which can be considered as a small open economy in the sense that it cannot affect the world prices of any products. For the large open economies such as the US, the model may not be appropriate.

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[24] The real exchange rate can be linked to the real interest rate through the interest parity condition.

2. The original Taylor rule

The Taylor rule, introduced by John B. Taylor in 1993, is a simple feedback rule responding to both inflation and output gaps with the weights on each goal specified in the rule. Numerous research works examine this rule since it is believed that the Taylor rule can describe the Federal Reserve's behavior in operating monetary policy well, especially in the late 1980s. The rule implements a short-term interest rate, i.e. the federal funds rate[25] in the original Taylor rule, as the policy instrument.

In the Taylor rule, the weight in response to inflation is greater than one-to-one, as a result of the **Taylor Principle**. Basically, the principle states that a change in the *nominal* interest rate should respond more than one-to-one to a change in inflation. Otherwise, the real interest rate[26] decreases rather than increases when the inflation rises, leading to ineffectiveness of monetary policy in curbing inflation. This basic idea can be traced back to Wicksell's (1965) "cumulative process" that an increase in expected inflation, leads to a lower perceived real interest rate, which stimulates demand. It, then, generates higher inflation again, increasing expected inflation further, and driving inflation higher in a self-fulfilling spiral[27]. However, this analysis implicitly assumes an exogenous target path for the nominal interest rate. The feedback from inflation and the output gap prescribed by the Taylor-type rules can hinder the occurrence of this process by prescribing the higher nominal interest rate to prevent the movement of the inflation rate toward a self-fulfilling deflationary spiral.

[25] The federal funds rate is a short-term interest rate representing the rate of lending-borrowing among commercial banks and financial institutions in the US

[26] The real interest rate, reckoned by the public in determining consumption and investment plan since it represents the opportunity cost of deferring consumption or investment into the future, is composed of a nominal interest rate and inflation. Central banks can control a nominal interest rate more closely than they do on inflation.

[27] Bullard and Mitra (2000) consider this idea in terms of "expectational stability", based on a stability analysis under adaptive learning dynamics – Evans and Honkapohja (1999).

The Taylor rule can be divided into two parts. The first part is composed of the natural real interest rate and an inflation target. An equilibrium real interest rate depends on the economic structure which is beyond the control of the central bank. The second component of the constant is an inflation target which can be set by the central bank.

The second part, the target deviation part, represents the adjustment to output and inflation deviations According to the rule, the inflation deviation is measured by the deviation of inflation from its target, while the output deviation is assessed by the output gap – the difference between the actual level of output in real terms and potential output or output at full employment (at fully flexible prices).

The deviations of inflation and actual output from the targets incorporate both long-run and short-run goals. The inflation gap adjustment incorporates the central bank's long-run inflation goal. In contrast, the output gap adjustment factor incorporates the short-run goal of counteracting economic cycles. In addition, the output gap adjustment factor can be interpreted as a measure of future inflation pressure. Thus, the interest rate rise prescribed by the policy rule means preemptive action against future inflation.

The original Taylor rule can be written algebraically as follows;

Equation (2.1) .... $i_t = r^* + \pi_t + \gamma(\pi_t - \pi^*) + \varphi x_t$

where i_t is the federal funds rate or other short-term interest rate, e.g. the 3-month Treasury bill rate,

r^* is the natural real interest rate which is assumed to be 2% in the original Taylor rule in 1993

π_t is an average inflation rate over the contemporaneous and prior three quarters (GDP deflator),

π^* is target inflation rate which is assumed to be 2% in the original Taylor rule in 1993

x_t is output gap, i.e. the difference between the actual real GDP and the potential output, which was measured by a log linear trend of real GDP over 1984:Q1 to 1992:Q3. However, research now being conducted uses the potential output estimated by Congressional Budget Office.

The original Taylor rule assigns the weights in response to a deviation of inflation from the target (γ) as well as to the output gap (φ) to be each 0.5. With these weights, the original Taylor rule describes the Fed's behavior during 1987 – 1992 nicely. Given that the natural real interest rate and the inflation target are assumed to be 2%. In reality, the natural real interest rate should, however, vary along with the state of economy. Therefore, the constant natural real interest rate assumption should not hold across the time.

For other periods, a number of monetary economists explored the policy reaction function[28] by estimating the parameters, according to different Fed chairmen on the grounds that the preference for fighting against inflation was different for different chairmen.

Also, the disinflation period in the beginning of 1980s as well as the change in the Federal Reserve's monetary policy operation procedure during 1979-1982[29] can be accounted for by testing for the structural breaks in those periods. The empirical results are discussed after the introduction of the degree of interest rate smoothing

[28]The original Taylor rule is calibrated with the specific weights to inflation and output gap, however, these parameters fit the Fed's behavior well during 1987-1992. On the other hand, the parameters in policy reaction function are estimated based on the Taylor-type rule, implementing a short-term interest rate as a policy instrument in response to inflation and output gap.

[29] During that period, it is widely believed that the Federal Reserve targeted the non-borrowed reserves rather than the federal funds rate. Goodfriend (1991) argued that the Fed still had the interest rate target in mind even though they focused on the non-borrowed reserves. However, Bernanke and Mihov (1998) finds the evidence to support the claim that during the Fed chose the non-borrowed reserves as the operating instrument of monetary policy over the 1979 - 1982 period, the short-term interest rate is implemented as the policy instrument for the rest of time.

which is one of the important empirical issues in the estimation of policy reaction functions.

3. Empirical results

This section includes the estimation results of Fed policy reaction functions conforming to the Taylor-type rules. The Taylor type rule differs from the original Taylor rule in terms of the parameters. In the original Taylor rule, the parameters were chosen rather than estimated to fit the Fed's behavior as mentioned in Section 2. With the short period of time under consideration, 1987 – 1992, it is doubtful whether these parameters fit for other periods and whether the policy rule can be a good proxy for the monetary policy rule that the central banks, in particular the Federal Reserve in the US, operate. Since Taylor (1993a) introduced the rule, much empirical work including Judd and Rudebusch (1998), Kozicki (1999), Taylor (1999b) and Clarida, Gali and Gertler (2000) (henceforth CGG) has been published.

This empirical work mostly succeeded in estimating the policy reaction functions, conforming to the original Taylor rule. However, the goodness of fit improves largely when these researchers append an additional interest rate smoothing term to the original Taylor rule. It helps the original Taylor rule describe most central banks' behavior. It is based on an empirical finding rather than on theoretical grounds. Nevertheless, there are some theoretical grounds to substantiate the addition of interest rate smoothing into the original Taylor.

3.1. Interest rate smoothing

According to various empirical works, e.g. Rudebusch (2001b, 2002 and 2005a), Sack (1998, 2000), Williams (1999), Lansing (2002), CGG (2000) and

Woodford (2003) the Federal Reserve and other central banks tend to smooth the changes in the short-term interest rate they control as their policy instrument. This behavior is called "interest rate smoothing". However, its real causes are still controversial. Five rationales behind this behavior are summarized as follows;

1) Williams (1999) suggests that frequent reversals are likely to be perceived by the public as central bank policy mistakes, thus maintaining momentum in interest rate smoothing may show the central bank's intentions and willingnesses to pursue a certain direction of the interest rate.
2) Sack (2000) attributes the Fed's behavior to parameter uncertainty which leads the Fed to adjust the funds rate less aggressively than that would be optimal in the absence of parameter uncertainty.
3) Rudebusch (2002) points out that a large coefficient on the lag of interest rate is a result of the omission of correlated or persistent variables from the policy reaction function. However, some studies, e.g. English et al (2003) and Castelnuovo (2003) proposed empirical evidence that the interest rate smoothing implemented by the central bank still plays a key role in the policy reaction function, albeit the presence of serially correlation in the residuals.
4) Lansing (2002) explains that interest rate smoothing may stem from the estimation of the policy reaction function with the final data, instead of using the real-time data normally employed by the policymakers at the time of making the deicions. As a result, the final data creates the illusion, though it is non-exists, by picking up the serially correlated real-time measurement errors not accounted into the standard estimation procedures.
5) Woodford (2003) proposed that central banks can convincingly show their commitment to a particular monetary policy by adjusting the short-term

interest rate gradually but continuously. Suppose that the public is convinced that the Fed operates a(n) easy (tight) monetary policy, the nominal interest rate determined in the market may fall (rise) without any further easing (tightening) by the Fed.

Interest rate smoothing can be incorporated into the policy rule in different forms. Each form leads to different magnitudes of interest rate movements. The simplest form is used by Taylor (1999), which is also called a generalized Taylor rule;

Equation (3.1) .... $i_t = \rho i_{t-1} + \gamma\pi_t + \varphi x_t + c$

where the notation corresponds to that of Equation (1) and c represents a constant.

On the other hand, CGG (2000) employ a partial-adjustment form of the Taylor rule. Also, they modify the rule by adding forward-looking behavior by the monetary authority. They estimate the policy reaction function as follows:

Equation (3.2) .... $i^*_t = i^T + \varphi(E[\pi_{t,k}|\Omega_t[- \pi^*] + \beta E[x_{t,q} \mid \Omega_t]$

Where i^*_t is the target nominal interest rate;

i^T is the desired interest rate when inflation and output are at their target values (i.e. the policy rule at neutral stance), composed of the equilibrium real interest rate (r^*) and target inflation (π^*);

$\pi_{t,k}$ is a change in the price between periods t and t+k;

$x_{t,q}$ is a measure of the average output gap between periods t and t+q;

Ω_t is the information set available at the time the interest rate is set.

And interest rate smoothing is added through a partial-adjustment process of

Equation (3.3) ....$i_t = \rho(L)i_{t-1} + (1 - \rho)i^*_t$; $\rho(L) = \rho_1 + \rho_2 L + \ldots\ldots + \rho_n L^{n-1}$; $\rho_1 \equiv \rho(1)$

Substituting the interest rate recommended by the rule in Equation (3.2) into Equation (3.3) and expanding the terms gives us

Equation (3.4) .... $i_t = (1 - \rho)[r^* - (\varphi - 1)\pi^* + \varphi\pi_{t,k} + \beta x_{t,q}] + \rho(L)i_{t-1} + \varepsilon_t$

Finally, Judd and Rudebusch (1998) append the degree of interest rate smoothing by incorporating an error-correction approach to the original Taylor rule. Starting from the policy reaction function, they add the first lag of output gap to it as follows

Equation (3.5) .... $i^*_t = r^* + \pi_t + \alpha(\pi_t - \pi^*) + \beta_1 x_t + \beta_2 x_{t-1}$

where i^*_t is denoted as the rule-prescribed rate.

Noticeably, Equation (3.5) is a general specification allowing for the possibility that the Fed responds to a variety of variables proposed as reasonable monetary policy targets, including inflation alone ($\beta_1 = \beta_2 = 0$, as in Meltzer (1987)), nominal GDP growth ($\alpha = \beta_1 = -\beta_2$, as in McCallum (1988)), inflation and real GDP growth with different weights ($\alpha \neq \beta_1 = -\beta_2$), as well as inflation and the GDP gap in level form (as in Taylor (1993a)). In addition, the short-term interest rate's adjustment process is given by;

Equation (3.6) .... $\Delta i_t = \gamma(i^*_{t-1} - i_{t-1}) + \rho\Delta i_{t-1}$

That is, the change in the funds rate at time t partially corrects the "error" between last period's setting and the current recommended level (the first term), as well as maintaining some of the "momentum" from last period's funds rate change (the second term).

Expanding all terms as follows;

Equation (3.7) .... $\Delta i_t = \gamma\xi - \gamma i_{t-1} + \gamma(1 + \alpha)\pi_t + \gamma\beta_1 x_t + \gamma\beta_2 x_{t-1} + \rho\Delta i_{t-1}$

Where $\xi = r^* - \alpha\pi^*$.

Equation (3.7) also embeds the test for serially correlated residuals versus interest rate smoothing with the null hypothesis that $\rho = 1$, representing the serial correlation in the residuals, as supported by Rudebusch (2002), while rejecting the null supports the interest rate smoothing conducted by the central bank.

These three forms of the interest rate smoothing can be interpreted differently.

1) The first one in Taylor (1999a) (Equation (3.1)) is modified by adding a lag of a short-term interest rate, in an attempt to increase the goodness of fit, i.e. reducing the unexplained variance in the short-term interest rate which cannot be explained by inflation and output gap (exogenous variables). In Equation (3.1), an autoregressive term is, thus, added into the original Taylor rule to explain more of the short-term interest rate's variance.

2) The second type of modification recommended by CGG (2000) (Equation (3.2), (3.3), and (3.4)) is to restrict the influence of the structural part (the response to inflation and output gap) by adjusting it in proportion to the lagged interest rate. If ρ is large, the effect of the structural part is small, compared to the last period interest rate and vice versa.

3) The last case (Equation (3.5), (3.6), and (3.7)) used by Judd and Rudebusch (1998) separates the adjustment of the interest rate into the "error" and the "momentum". The coefficient γ measures the correction to the "error" in the interest rate setting while the coefficient ρ measures the "momentum" from last period's interest rate change, compared to the second type of modification, which does not include the momentum part and the first-lag of output is dropped.

3.2. Estimation results in the US

3.2.1. Early estimation of the Taylor rule

I will begin with the estimation originally conducted by John B. Taylor. Taylor (1999b) estimated the policy rule with his original form (Equation (2.1)) but divided the sample into two sub-samples. The first one is International Gold Standard Era (the earliest period recognized as a monetary policy rule) and the Bretton Woods (the fixed exchange rate era). However, during the International Gold Standard Era, the coefficients estimated in the interest rate rule are not significant and very small in value. Also, the R^2's are quite small. Therefore, I will neglect that period.

Table 1.1: Bretton Woods and Post-Bretton Woods Era[30]

Coefficent	(1960:1 – 1979:4)	1987:1-1997:3	1954:1-1997:3
Constant	2.045 (6.34)	1.174 (2.35)	1.721 (5.15)
π	0.813 (12.9)	1.533 (9.71)	1.101 (15.1)
y	0.252 (4.93)	0.765 (8.22)	0.329 (3.16)
R^2	0.70	0.83	0.58

Note: The policy instrument is the federal funds rate for the years 1954-1997. The variable π is measured by the average inflation rate over four quarters, and the variable x is measured by the percentage deviation of real output from a trend. Numbers in parentheses are the t-statistic.

The comparison between during Bretton Woods Era and Post- Bretton Woods in Table 1.1 shows that the coefficients in the latter period conform to the original Taylor rule, even though the coefficient associated with the output gap is slightly higher than 0.5 set by Taylor (1993a).

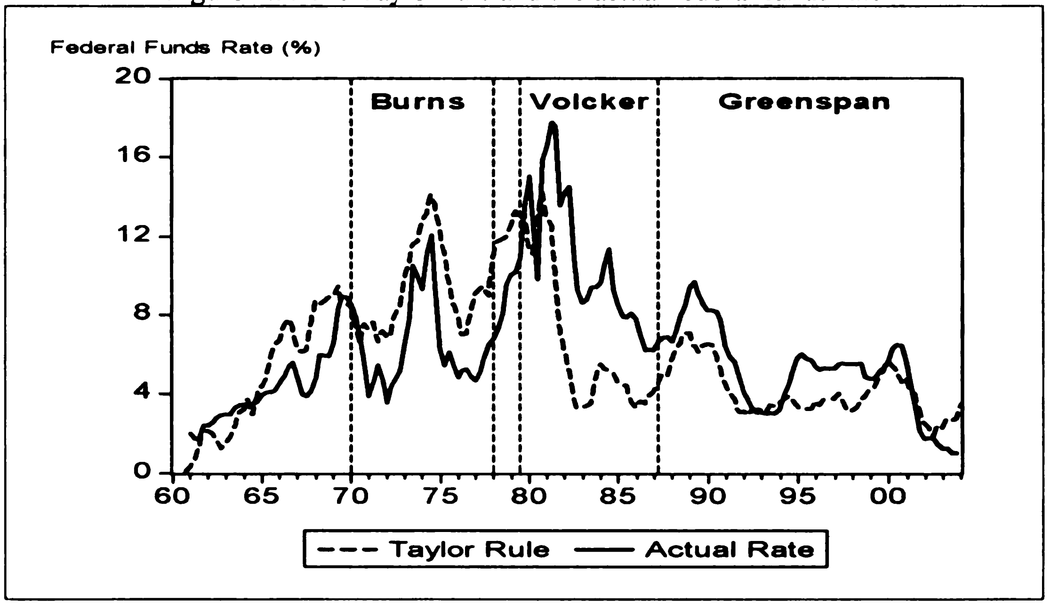
The key point is to consider whether the Taylor Principle holds; that is, the coefficient in response to inflation is greater than unity, which is called "stability threshold" in Taylor (1999b). If it is greater than one, the *nominal* interest rate is

[30] In fact, the fixed exchange rate of Bretton Woods ended around the first quarter of 1973, after Smithsonian Agreement allowed monies of all industrial countries to float.

raised (reduced) so that the *real* interest rate increases (decreases) whenever the inflation is higher (lower). As a consequence, inflation will be lower (higher) and output will contract (expand). In such a case, the monetary policy rule stabilizes the economy and vice versa.

Judd and Rudebusch (1998) estimated a policy reaction function incorporating interest rate smoothing. They estimated the coefficients of the policy rule across Fed chairmen. They divided the time interval into three sub-samples including the terms of Authur Burns (1970.Q1 – 1978.Q1), Paul Volcker (1979.Q3 – 1987.Q2) and Alan Greenspan (1987.Q3 – present), while neglecting Chairman Miller (1978.Q2 – 1979.Q2) due to his very brief tenure.

Figure 1.3: The Taylor rule and the actual federal funds rate



From the descriptive figures shown above, the federal funds rate during Burns' tenure, was consistently lower than the rule's recommended rate. This result conforms to the continuous increase in inflation during this period. During the Volcker period, when the Fed significantly reduced inflation, the funds rate was consistently higher than the rule-prescribed target rate, indicating that the Fed was more aggressive in lowering inflation than the rule would have been.

Judd and Rudebusch (1998) estimated the reaction function and allowed for interest rate smoothing by estimating the Taylor type rule in the context of an error correction model. Their model follows Equation (3.5) – (3.7).

Table 1.2: Regression results for each period

Equation (3.5)..........$i^*_t = r^* + \pi_t + \alpha(\pi_t - \pi^*) + \beta_1 x_t + \beta_2 x_{t-1}$

Equation (3.6)..................$\Delta i_t = \gamma(i^*_t - i_{t-1}) + \rho \Delta i_{t-1}$

Type	ξ	γ	α	β_1	β_2	ρ	R^2	SEE	Q
Burns Period (1970:Q1 – 1978:Q1)									
A	1.68 (1.43)	0.56 (4.34)	-0.15 (-0.80)	0.16 (0.45)	0.72 (2.59)	0.25 (1.67)	0.53	0.84	15.92 (0.04)
B	0.71* (2.68)	0.58 (4.78)	-	-	0.89 (5.85)	0.26 (1.76)	0.52	0.84	14.81 (0.06)
Volcker Period (1979:Q3 – 1987:Q2)									
A	2.04 (0.87)	0.36 (2.25)	0.69 (1.32)	2.40 (1.35)	-2.04 (-1.42)	-0.08 (-0.44)	0.47	1.33	10.95 (0.22)
B	2.42 (1.56)	0.44 (3.64)	0.46 (1.79)	1.53** (1.92)	-1.53** (-1.92)	-	0.48	1.31	9.43 (0.31)
Greenspan Period (1987:Q3 – 1997:Q4)									
A	1.21 (1.79)	0.27 (4.87)	0.57 (2.72)	1.10 (2.83)	-0.12 (-0.31)	0.43 (3.94)	0.67	0.27	20.32 (0.03)
B	1.31 (2.26)	0.28 (5.27)	0.54 (2.96)	0.99 (7.46)		0.42 (4.00)	0.67	0.27	20.78 (0.02)

Note: *A is the basic regression, while B is to drop the insignificant variables off.*

* *denotes $\xi = r^*$ due to $\alpha = 0$.*

** *denotes the insignificance of the test of $\beta_1 + \beta_2 = 0$*

During Burns' period, the coefficient in response to the deviation of inflation from its target is not significantly different from zero at the conventional level of 5%, compared to the rest of the periods shown above. However, this insignificance does not mean that the *nominal* interest rate does not respond to the inflation at all[31]. From Equation (3.7), the *nominal* interest rate still responds to the inflation but with one-to-one correspondence which is sufficient to maintain the level of *real* interest rate unchanged in response to inflation. Thus, Table 1.2 suggests that the *real* fed funds rate was not adjusted on the basis of changes in inflation (α is insignificant) and monetary policy during the Burns' period was not counter-cyclical against inflation,

[31] Recall that Equation (3.5) nests the original Taylor rule when $\beta_2 = 0$ and $\alpha = \beta_1 = 0.5$.

indicating that the Taylor Principle was not followed in this period. It could partly explain increasing inflation during the Burns period in Figure 1.3.

During the Volcker era, Table 1.2 shows the opposite result of the Burns' period. The coefficient in response to inflation indicates a value significantly greater than unity. This can be interpreted as the aggressiveness of Chairman Volcker in fighting inflation. Also, the estimates suggest gradual adjustment of the funds rate towards the rule. Even though it is greater than that of Greenspan's period, it is lower than that of Burns.

Lastly, Greenspan's period from 1987:Q3 to present, confirms the aggressiveness in fighting inflation. The estimate in the response to the deviation of inflation from the target (α) is close to the parameter used by Taylor of 0.5. In terms of output gaps, the policy reaction function responds one-to-one to the output gap which is slightly more aggressive than that suggested by the original Taylor rule. Regarding the degree of adjustment to the rule, the funds rate typically adjusts enough to eliminate 28 percent of the difference between the lagged actual and rule-recommended funds rate each quarter (recall that Judd and Rudebusch (1998) estimate using quarterly data). Thus, the degree of interest rate smoothing is higher in Greenspan's period.

3.2.2. Forward-looking policy rule

In the previous sub-section, the estimates are based on the current and lagged variables in the policy reaction function. In reality, central banks do not know actual data in real-time. Economic data are released with a lag. In the United States, real GDP data is first released one month after the end of the quarter and revised one month later[32]. The third or final revision is roughly three months after the end of that quarter. To tackle the information lag problem, there are two approaches; estimating forward-looking or forecast-based policy rules or estimating backward-looking or lagged variable rules such as the work done by Kozicki (1999). The latter approach is equivalent to using the revised data of the last period.

CGG (2000) implement the General Method of Moments (GMM) to estimate a policy reaction function. The model specification corresponds to Equations (3.2), (3.3) and (3.4) which incorporates the degree of interest rate smoothing through partial adjustment of the current interest rate from the previous period interest rate. The variables, including inflation and the output gap, are in expectational terms conditioned on the information set at the current period. They implicitly assume that the central bank sets short-term interest rates in response to the forecast values of economic indicators as proxies of the contemporaneous variables. In addition, the optimal weighting matrix employed in their GMM technique also accounts for possible serial correlation in the error terms.

The data are quarterly time series starting from 1960:1 to 1996:4. They used the average Federal Funds rate in the first-month of each quarter, expressed as an annual rate as the proxy for a short-term interest rate. The baseline inflation measures a (annualized) rate of change of the GDP deflator between two subsequent quarters. The baseline "output gap" measure is the series constructed by the difference between actual output and potential output of the Congressional Budget Office. The instrument set includes lags of the federal funds rate, inflation, and the output gap, as well as the same number of lags of commodity price inflation, M2 growth, and the "spread" between the long-term bond rate and the three-month Treasury Bill rate.

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[32] This realization of time series corresponds to the "*operationality problem*" pointed by McCallum (1999) and McCallum and Nelson (2000b).

The whole sample is divided into two sub-samples. The first part labeled "Pre-Volcker" period (1960:1-1979:2) encompasses the tenures of William M. Martin, Arthur Burns, and G. William Miller as Federal Reserve chairmen. The second sub-sample labeled "Volcker-Greenspan" period (1979:3-1996:4) contains the terms of Paul Vocker and Alan Greenspan. These sub-periods roughly conform to the unstable and stable eras of monetary policy in recent macroeconomic history. The forecast horizon for the baseline estimate is one period ahead in both inflation and the output gap.

Table 1.3: Baseline estimates by CGG (2000)

Equation (3.4) .... $i_t = (1 - \rho)[r^* - (\varphi - 1)\pi^* + \varphi\pi_{t,k} + \beta x_{t,q}] + \rho(L)i_{t-1} + \varepsilon_t$

Time Periods	π^*	φ	β	ρ	J-test*
Pre-Volcker	4.24 (1.09)	0.83 (0.07)	0.27 (0.08)	0.68 (0.05)	0.834
Volcker-Greenspan	3.58 (0.50)	2.15 (0.40)	0.93 (0.42)	0.79 (0.04)	0.316

Note: Standard errors are reported in parentheses.
P-values are reported for J-test.
The set of instruments includes four lags of inflation: output gap, the federal funds rate, the short-long spread, and commodity price inflation.
The forecast horizons for inflation and output are k = 1 and q = 1, respectively.

Table 1.3 shows many interesting results. First of all, the null hypothesis of whether the model is over-identified is tested by the Hansen J-test is not rejected and all coefficients are significantly different from zero at the conventional level of confidence of 5%. Regarding the estimates, the coefficient associated with expected inflation is below unity during the Pre-Volcker period, whereas, it is above unity in the Volcker-Greenspan period. Likewise, the output gap coefficient is low in the Pre-Volcker period and very high in the latter period.

Furthermore, estimates of the interest rate smoothing parameter are high in all cases, suggesting considerable interest rate inertia. Thus, their estimate is consistent with conventional wisdom that the Federal Reserve smoothes interest rate movement.

In sum, the estimates of the policy reaction function are not different when they are estimated with either the forward-looking type in CGG (2000) or with contemporaneous variables as in Judd and Rudebusch (1998) in terms of the stability of the policy reaction function.

Instability and stability in monetary policy in the Pre-Volcker and Volcker-Greenspan period can also be illustrated by simulating the policy rule along with a simple macroeconomic model within the New Keynesian framework in the second part of CGG (2000).

With this method, they demonstrated that the estimated rule for the pre-Volcker period allowed greater macroeconomic instability than that of Volcker-Greenspan period since the pre-Volcker estimated policy reaction function allows for the possibility of bursts of inflation and output caused by self-fulfilling inflation expectations. This self-fulfilling expectation of inflation is also addressed in Chari, Christiano, and Eichenbaum (1998). They indicate that inflation in the 1970s – the so-called Great Inflation – may have been due mainly to self-fulfilling behavior of inflation. Their argument is, however, based on the multiplicity of equilibria in reputational models of monetary policy, compared to the study by CGG (2000), which is based simply on the implications of the estimated historical policy reaction function shown above. On the contrary, self-fulfilling fluctuations cannot occur under the estimated rule for the Volcker–Greenspan era since, within this regime, the Federal Reserve adjusts interest rates sufficiently to counter any change in expected inflation.

Interestingly, CGG (2000) also test for sub-sample stability, corresponding to the different chairmen. Starting from Chairman Martin in 1960 to the second quarter of 1979 before the Volcker's period, the coefficients in response to the inflation are obviously different across the chairmanships, while they are not in the coefficients associated with the output gap. The coefficient in the Burns and Miller period is larger than in the Martin era, indicating a possible aggressiveness in responding to the output gap in the Burns-Miller period. Thus, monetary policy during the Pre-Volcker period shows macroeconomic policy instability which could possibly have caused the Great Inflation in the 1970s.

Table 1.4: The estimation of policy reaction function with different chairmen by CGG (2000)

Equation (3.4) .... $i_t = (1 - \rho)[r^* - (\varphi - 1)\pi^* + \varphi\pi_{t,k} + \beta x_{t,q}] + \rho(L)i_{t-1} + \varepsilon_t$

Period	π^*	φ	β	ρ	J-test
Martin (60:1-69:4)					
(k = 1,q = 1)	5.16 (7.12)	0.86 (0.08)	0.14 (0.16)	0.77 (0.06)	0.524
(k = 4,q = 1)	7.15 (5.55)	0.92 (0.08)	0.06 (0.07)	0.72 (0.05)	0.719
Burns-Miller (70:1-78:1)					
(k = 1,q = 1)	5.16 (1.72)	0.86 (0.08)	0.78 (0.18)	0.69 (0.04)	0.524
(k = 4,q = 1)	7.15 (5.55)	0.92 (0.08)	1.24 (0.39)	0.80 (0.05)	0.719
Volcker (79:3-87:2)					
(k = 1,q = 1)	3.75 (0.28)	2.02 (0.23)	-0.02 (0.15)	0.63 (0.04)	0.612
(k = 4,q = 1)	2.45 (0.47)	2.38 (0.35)	0.68 (0.30)	0.74 (0.04)	0.804
Greenspan (87:3-96:4)					
(k = 1,q = 1)	3.75 (0.28)	2.02 (0.23)	0.99 (0.18)	0.63 (0.04)	0.612
(k = 4,q = 1)	2.45 (0.47)	2.38 (0.35)	0.68 (0.30)	0.91 (0.02)	0.804
Post-82					
(k = 1,q = 1)	3.43 (1.24)	1.58 (0.72)	0.14 (0.42)	0.91 (0.03)	0.416
(k = 4,q = 1)	3.16 (0.10)	3.13 (0.33)	0.09 (0.15)	0.82 (0.02)	0.894

Note: Standard errors are reported in parentheses.
P-values are reported for J-test.
The set of instruments includes two lags of inflation, output gap, the federal funds rate, the short-long spread, and commodity price inflation, as well as the same variables with a multiplicative sub-period dummy.

In the sub-sample robustness tests, they also examine the effects of removing the first three Volcker years based on the grounds that the Federal Reserve targeted non-borrowed reserves as the policy instrument rather than the federal funds rate[33]. Therefore, the Volcker-Greenspan period started from 1983:Q1, instead of 1979:Q3. Furthermore, there was a sharp one-shot disinflation episode which brought down inflation abruptly during that three year period. The result of this exclusion is that the coefficient associated with expected inflation (φ) is still above unity, similar to the estimation in this period without the exclusion. However, the coefficient measuring the sensitivity to the cyclical variable (β) is insignificantly different from zero at the conventional level.

The sub-sample estimations depending on chairmanship are reported in Table 1.4. In the same table, the target horizon of inflation and the output gap forecast are also presented. The first case corresponds to the target horizon of one quarter ahead which they used in Table 1.3 and the other is 4 quarters ahead.

Apart from the forward-looking type reaction function estimated by CGG (2000), another interesting paper is Romer and Romer (2002). They estimated a reaction function without a degree of interest rate smoothing and expanded the CGG (2000)'s dataset to start from the beginning of 1950s. Their model specification is somewhat simpler to that of CGG (2000) while still implementing the forward-looking type policy reaction function;

Equation (3.8) .... $i_t = \alpha + \beta E_t\pi_{t+1} + \gamma E_t(Y - Y^*)_{t+1}$

Where i_t is the federal funds rate

π_t is inflation

$Y\text{-}Y^*$ is the deviation of output from trend.

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[33] Bernanke and Mihov (1998) presented the evidence that over the 1979:10 – 1982 period, non-borrowed reserves was the operating instrument of monetary policy. For the rest of the time they showed that the Federal Reserve treated the Federal Funds rate as the instrument of monetary policy.

Romer and Romer (2002) use leads of variables to represent the expected values of inflation and output gaps. The contemporaneous and two lagged values of inflation and the contemporaneous deviation of output from trend plus a constant are used as the instrument for this instrumental variables method. The dataset from CITIBASE was divided into four sub-samples. The results are reported in Table 1.5.

Table 1.5: Estimated Forward-Looking Monetary Policy rule
by Romer and Romer (2000)

Sample	Inflation[a]	Output[b]	Constant
1952:1-1958:4	1.178 (0.876)	-0.040 (0.295)	-0.562 (1.874)
1964:1-1979:3	0.891 (0.090)	0.269 (0.112)	1.410 (0.517)
1979:4-1987:3	1.263 (0.187)	-0.056 (0.287)	4.614 (0.992)
1987:4-2000:4	1.390 (0.305)	0.672 (0.315)	2.311 (0.760)

Note: The standard errors are in parentheses.
[a] *is one quarter ahead.*
[b] *is the deviation of output from trend, one quarter ahead.*

The most important result is that the weight on expected inflation or the leads of inflation in the policy reaction function in the 1950s is close to that of the Volcker-Greenspan era and apparently different from that of the 1960s and 1970s. In the 1950s and during Volcker-Greenspan eras, the coefficients associated with expected inflation are unsurprisingly greater than unity, showing the stability of monetary policy.

Another crucial work supporting the forward-looking or forecast-based rule is Batini and Haldane (1999). They found that a moderate forecast horizon could improve the performance of policy rules since they encompass the lags caused by transmission mechanism of a policy towards the targets, all information useful for predicting future inflation and lower output variability without any direct response to the output gap. Moreover, they found that the appropriate forecast horizon is approximately three to six quarters. Shorter or longer horizons risk raising both output and inflation variability.

3.2.3. Robustness to different measures

After having explored all the regime changes depending on different chairmanships, another intricate issue in policy reaction function estimation is the measurement of the relevant variables including inflation and the output gap. Kozicki (1999) focuses on this issue. She estimated four different measures of inflation depending on the type of economic indicators and six measures of output gaps depending on their sources.

For inflation, Kozicki (1999) focused on CPI inflation, core CPI inflation, GDP price inflation and expected inflation. The former three are of the backward-looking type while the other is a forward-looking one similar to the one implemented by CGG (2000) and Romer and Romer (2002) which focus on the forecast-based policy rule.

On the other hand, she estimated different measures of the output gap depending on the sources of data and the approaches of potential output estimation. These include a government agency (the Congressional Budget Office, or CBO), two international institutions (the International Monetary Fund, and the Organization for Economic Cooperation and Development), and corporations that produce commercial forecasts (Standard and Poor's DRI). Also, she included two other measures based on the output trend constructed with standard econometric procedures. These measures are Taylor (1993) and Recursive[34]. The data range is the period of 1983 – 1997[35]. The

[34] The output gap based on Taylor (1993a) was constructed using a linear-trend estimate of potential output. The fitted value obtained in a regression of the natural logarithm of real GDP on a constant and linear time trend was used as the linear-trend estimate of potential output. The estimation period is 25 years. Last but not least, the recursive output gap was constructed using a recursive linear-trend estimate of potential output. Recursive linear-trend estimates of potential output were based on a series of regressions. The estimate of potential output for a given quarter was the fitted value obtained in a

estimated policy reaction function, similar to the original Taylor rule in Equation (2.1), is

Equation (3.9) .... $i_t = c + (1 + \alpha)\pi_{t-1} + \beta x_{t-1}$

The variables i_t, π_t and x_t represent a short-term interest rate, inflation and output gap, respectively. The constant term is reduced to only "c", which comprises $r^* - \alpha\pi^*$. The result of estimation is shown in Table 1.6.

Her estimation is based mainly on the backward-looking policy rule, in contrast to the original Taylor rule which uses contemporaneous inflation and the output gap over the previous four quarters. The lagged variables are used on the grounds that the central banks realize the economic indicators with some lags. Thus, it is another approach to handling the problem of information lags, apart from using the forecast based or forward-looking policy rules as in CGG (2000) and Romer and Romer (2002). Also, the use of lagged data is based on the implicit assumption that the lagged values are (sufficiently) good predictors of the current data which are not realized at the time of setting the short-term interest rate.

From the study by Kozicki (1999), three main results are found. Firstly, the recommendations from estimated rules do not fit historical policy very well. Goodness of fit of the estimated rule with the actual federal funds rate is measured by the mean absolute deviation between the actual federal funds rate and the fitted funds rate from the estimated policy rules. Most mean absolute deviations across the different measures of inflation and sources of output gaps are basically greater than unity, except the case using expected inflation as the inflation measure.

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regression of the natural logarithms of real GDP on a constant ad linear time trend, using data over the 25 years ending in that quarter.

[35] The dataset starts from the disinflation period which is the first three years in Volcker's era. This period is both including one-shot extreme disinflation period and the non-borrowed reserves targeting as a policy procedure period.

Table 1.6: Estimates of weights in the Taylor-type rules with the data ranging from 1983-1997 by Kozicki (1999)

Output Gap Measure	**Inflation Measure**	**Inflation weight (α)**	**Output weight (β)**	**Mean absolute Deviation**
CBO	*CPI Inflation*	0.01	-0.01	1.50
CBO	*Core CPI inflation*	0.48	0.14	1.30
CBO	*GDP Price inflation*	0.88	0.32	1.17
CBO	***Expected inflation***	**1.37**	**0.38**	**0.70**
OECD	*CPI Inflation*	0.01	-0.02	1.50
OECD	*Core CPI inflation*	0.42	0.12	1.33
OECD	*GDP Price inflation*	0.71	0.29	1.23
OECD	***Expected inflation***	**1.21**	**0.36**	**0.79**
IMF	*CPI Inflation*	-0.06	0.18	1.43
IMF	*Core CPI inflation*	0.36	0.22	1.29
IMF	*GDP Price inflation*	0.65	0.35	1.14
IMF	***Expected inflation***	**1.09**	**0.34**	**0.75**
DRI	*CPI Inflation*	-0.01	-0.10	1.49
DRI	*Core CPI inflation*	0.51	0.10	1.31
DRI	*GDP Price inflation*	0.94	0.28	1.20
DRI	***Expected inflation***	**1.55**	**0.39**	**0.68**
Taylor	*CPI Inflation*	-0.12	0.18	1.40
Taylor	*Core CPI inflation*	0.28	0.18	1.31
Taylor	*GDP Price inflation*	0.53	0.27	1.16
Taylor	*Expected inflation*	0.99	0.26	0.80
Recursive	*CPI Inflation*	0.03	-0.10	1.50
Recursive	*Core CPI inflation*	0.41	0.00	1.34
Recursive	*GDP Price inflation*	0.70	0.13	1.24
Recursive	***Expected inflation***	**1.31**	**0.24**	**0.81**

Note: Bold-face entries are significantly different from 0.5, the weight used by Taylor (1993).

Secondly, the estimated rules responding to expected inflation fit the historical federal funds rate well. This result substantiates the forecast-based policy rules in CGG (2000). In addition, it supports that the central bank makes policy decisions based on economic conditions expected in the future.

The last conclusion that can be drawn from Kozicki (1999) is that the weights in response to inflation and the output gap in the original Taylor rule are justified by historical data. From Table 1.6, the bold entries represent the values that are significantly different from 0.5 – the value designated by Taylor (1993a) in his original rule. However, the result is sensitive to the sample range. Kozicki (1999) also estimated the data spanning 1987-1997 which is solely Greenspan's tenure. More than half of the estimates are significantly different from 0.5. Noticeably, many inflation weights are negative values which do not make much sense. The results are shown in

Appendix A. One possible explanation of this result is the larger persistence of the interest rate.

Furthermore, Kozicki (1999) added interest rate smoothing behavior of central banks in her estimation. The results are not different from other researchers in estimating policy reaction functions with a degree of interest rate smoothing appended. She also obtained values ranging from 0.75 to 0.82, depending on the output gap measures. The expected inflation is used for the inflation measure due to its better fit with the historical data.

Nonetheless, these results may not be robust since Kozicki (1999) compares between the forward-looking type and the backward-looking type policy reaction function without incorporating the interest rate smoothing found in most empirical works. The only case encompassed is in when estimating the policy reaction function with the expected inflation, as above.

CGG (2000) also estimated two alternative measures of the output gap, including, the deviation of (log) GDP from a fitted quadratic function of time, and the deviation of the unemployment rate from a quadratic time trend, with the sign of unemployment series switched due to the negative relationship between the output gap and the unemployment. The justification for using the unemployment rate as a proxy for the output gap is that it is highly negatively correlated with output growth implied by Okun's law (1962). However, CGG (2000) considered an alternative measure of inflation to the GDP price deflator – the rate of change of the consumer price index (CPI). The result excerpted from CGG (2000) is reported in Appendix B.

Generally, most results are similar to their baseline estimates. However, the coefficients in response to the output gap during the Volcker-Greenspan period are not significant at the conventional level of 5% with any of the alternative measures of the output gap. Also, the estimate goes up to 1.49 in the Volcker-Greenspan period when using CPI as the inflation measure.

Judd and Rudebusch (1998) obtain a slightly different result, recalling that the model specification used in their work does not include forward-looking aspect or any expectation terms. Regarding inflation, the estimated regressions show little sensitivity to these alternative measures.

In terms of the output gap, Judd and Rudebusch (1998) implemented three estimates of potential GDP, namely, the potential output released by the Congressional Budget Office, a segmented linear trend with one break in 1973[36], and a quadratic trend. The GDP gap computed by the Congressional Budget Office has cross-correlations of 0.99 and 0.80 with the quadratic and linear trend gaps, respectively. An obvious divergence of these three series occurred in the 1990s, when the segmented linear trend showed output consistently below potential, while the other two measures showed a rising gap that became positive toward the end of the sample. Differences like these can have conspicuous effects on Fed policy concerns. The regression results for the reaction function using the linear trend unsurprisingly differ from those using the other gap measures. In fact, in the Greenspan period, the introduction of the linear trend actually changes the sign of the response to the inflation gap. The alternative measures of the gap have little effect on the results for the Burns or the Volcker periods.

3.3. Discussion

The central issues concerning the estimation of policy rules or the policy reaction function can be summarized as follows;

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[36] The linear trend was also employed by Taylor (1993a) but with the data ranging from 1984-1992, which did not account for the break in 1973 as such Judd and Rudebusch's estimation.

1. The sample spanning 1960-2004 can be differentiated into two main periods; namely, Pre-Volcker (1960-1979:2) and Volcker and Greenspan (1979:3-2004:1), depending on the stability of monetary policy.
2. It is conventionally believed that monetary policy during 1960s and 1970s did not stabilize the economy and could possibly be one of the causes of the Great Inflation in the 1970s while Romer and Romer (2002) showed that monetary policy in the 1950s also stabilized the economy.
3. Policy rules are stable if they have coefficients in response to inflation greater than unity; that is, if the Taylor Principle holds. The rise in real interest rate contracts the economy, resulting in lower inflation when the inflation rate increases. However, Woodford (2001) has formally proven the stability criterion of policy rules in light of the Taylor Principle, based on a "neo-Wicksellian" model.
4. The Taylor Principle can also be explained simply through the definition of the real interest rate.

$$i_t - \pi_t = r_t$$

Suppose that inflation (π_t) rises (falls), given the nominal interest (i_t) constant, the real interest rate (r_t) will falls. If a central bank needs to increase real interest rate to curb inflation, the only way to achieve such a goal is to raise the nominal interest rate more than the increase in inflation.

5. The estimated policy rules are sensitive to the measures of inflation and the output gap.
6. Empirically, central banks smooth their short-term interest rate used as a policy instrument.

7. The forward-looking or forecast-based rules dominate the backward-looking or contemporaneous rules, following Batini and Haldane (1998) and Kozicki (1999).
8. Additionally, Taylor (1999b) identified two episodes of the deviation of the actual federal funds rate from the rule-based values or what he calls "policy mistakes". The first one was addressed earlier - the Great Inflation at the end of 1960s and the 1970s and the other was the prior- recession period in the beginning of 1980s. It has been shown empirically that monetary policy in the 1960s and 1970s was possibly excessively easy leading to the economic instability and inflation. This was indicated by the coefficient associated with inflation being less than unity in the estimated policy reaction function. On the contrary, the prior-recession episode was possibly induced by the excessive monetary tightness of the early 1980s leading to the recession at that time. However, it is noteworthy that the second episode was addressed less often than the former possibly due to inflation being posed as the first priority threat to the economy.

Finally, I estimate a reaction function with contemporaneous variables and a degree of interest rate smoothing appended. My estimation is based on the dataset spanning 1960:Q1 – 2004:Q1. Also, I separated the whole sample into two sub-samples illustrating the instability and stability of the estimated policy rule. These sub-samples include Pre-Volcker (1960:Q1-1979:Q2) and Volcker-Greenspan (1979:Q3-2004:Q1). The model specification is described as follows;

Equation (3.10) .... $i^*_t = r^* - (\gamma - 1)\pi^* + \gamma(\pi_t - \pi^*) + \varphi x_t$

Where i^*_t is the effective federal funds rate;

π_t is inflation at time t (annualized quarterly change in GDP deflator);

x_t is the output gap, which is the difference between actual output and potential output estimated by the Congressional Budget Office;

r^* and π^T are the natural real interest rate and inflation target, respectively.

And interest rate smoothing is added through a partial-adjustment process of:

Equation (3.11) .... $i_t = \rho i_{t-1} + (1 - \rho)i^*_t$

Substituting the interest rate recommended by the rule in Equation (3.10) and expanding the terms as;

Equation (3.12) .... $i_t = (1 - \rho)[r^* - (\gamma - 1)\pi^* + \gamma\pi_{t-k} + \varphi x_{t-k}] + \rho i_{t-1} + \varepsilon_t$; $k = 0,1$

From Table 1.7 below, the estimation with a lag of the economic indicator corresponding to the rule specification of Kozicki (1999) yields a higher Adjusted R^2 than that of the estimation with the contemporaneous variables in the first and third row, while the result is opposite in the others. Noticeably, all except one of the constants are not significantly different from zero at the conventional level of 5%.

Table 1.7: The estimation of the Taylor type rule with interest rate smoothing

Sample	$\gamma/(1-\rho)^{**}$	$\varphi/(1-\rho)^*$	$c/(1-\rho)^*$	ρ	Adjusted R^2	DW
1960:1-2004:1						
Contemporaneous	**1.531**	**0.753**	1.428	**0.881**	0.868	2.335
One-lag	**1.477**	**0.945**	1.906	**0.873**	0.871	2.315
1960:1-1979:2						
Contemporaneous	**0.991**	**0.467**	1.527	**0.722**	0.906	1.499
One-lag	**0.854**	**0.611**	**2.346**	**0.721**	0.894	1.649
1979:3-2004:1						
Contemporaneous	**1.904**	0.429	1.331	**0.823**	0.856	2.566
One-lag	**2.038**	**0.582**	1.164	**0.778**	0.870	2.533
1982:4-2004:1						
Contemporaneous	3.228	**2.700**	-2.177	**0.967**	0.953	1.228
One-lag	2.763	**2.198**	-1.670	**0.970**	0.951	1.154

Note: Bold-face entries are significant at 5% level.

* *These coefficients can be interpreted as the long-run response because the denominator represents the autoregressive term and can be expanded in infinite moving average term*[37].

For the whole sample (1960:1-2004:1), the estimated coefficients are quite similar to the ones designated by Taylor (1993a) in the estimation using contemporaneous variables. However, the estimate of the weight on the output gap is

[37] Refer to Hamilton (1994)

double that of the original Taylor rule when estimating the policy reaction function with the one-lag variables.

Likewise, the estimated policy reaction function during the Pre-Volcker period has the coefficient in response to inflation less than unity in either estimating with one lag or contemporaneous variables.

Finally, the exclusion of 1979:3-1982:3, during which it is widely believed that the Federal Reserve operated monetary policy with a different procedure from targeting the federal funds rate, leads to much higher coefficients in response to inflation and output gap. However, the coefficient responding to inflation is not significant at 5%. An explanation could be the persistence of the interest rate. In this case, the current interest rate largely depends on last period's interest rate rather than the exogenous variables such as inflation and output gap, implying a very high degree of interest rate smoothing after 1983.

3.4. Evidence from other industrialized countries

As is well recognized, the Taylor rule empirically described the Fed's behavior during the end of 1980s to the beginning of the 1990s quite well. It is worthwhile to examine the estimated policy reaction functions in other industrialized countries, of which the size of their economies are about the size of the US economy and the monetary policy institutions share some commonalities with the Fed, whether it could also be explained by the Taylor-type rules. If they can, the implications applied to the US would also be applicable to those economies. I will begin describing the UK case, based on Nelson (2000) and Clarida, Gali and Gertler (1998) (henceforth CGG (1998)), then Japan and eventually, the European Union – which includes Germany of which the central bank was one of the most influential in the world economy before the European Central Bank (ECB) was established in 1998. Prior to 1998, the central banks in the European Union had independently conducted their monetary policy.

3.4.1. The policy reaction function in the UK

Nelson (2000) estimated the policy reaction function for the UK from 1972-1997. This period included many interesting events of the history of UK's monetary policy. In particular, some events paralleled those of the Federal Reserve in the US. For example, the British Pound was allowed to float in June 1972, compared to the US dollar after the Bretton-Wood era in 1973. After having allowed the pound to float, the British government implemented some non-monetary policy to curb the prices of particular products to fight inflation, instead of focusing on monetary policy[38].

In the mid-1970s to the mid-1980s, the Bank of England targeted the M3 monetary aggregate, compared with the period 1979–1982 of non-borrowed reserves targeting in the US. Then, exchange rate management was the main focus of the Bank of England in the late 1980s, culminating in the period of 1990 – 1992, when the UK became a member of the Exchange Rate Mechanism (ERM). After 1992, the UK departed from the ERM and adopted inflation targeting monetary policy. From May 1997, the Bank of England has received the fully operational independence in its monetary policy.

Nelson (2000) estimated England's monetary policy with both backward- and forward- looking policy reaction functions. He used quarterly and/or monthly datasets, depending on the number of observations in each regime. In some regimes, using a quarterly data leads to few observations that the estimates are unreliable. The

[38] This era was governed by the Labor party believing that they could implement expansionary monetary and fiscal policies to stimulate the output and employment, whereas inflation could suppressed through statutory wage and price control.

estimation methods included Ordinary Least Square (OLS) and Instrumental Variable method (IV).

In terms of the definition of the variables, he implemented the Treasury bill rate as a proxy for a short-term interest rate, the Retail Price Index for price and the output gap measured empirically by the residuals from 1971:Q3 – 1998:Q4 regression of real GDP on a linear and a quadratic trend. All variables except the interest rate are in logarithms.

Nelson (2000) argues that the estimation for the whole sample might be inappropriate based on low R^2 and Durbin-Watson. This is because the policy reaction function conforming to the Taylor type rule poorly captures the dynamic structure of the nominal interest rate. Even though both coefficients in response to inflation and the output gap are significantly different from zero based on the conventional t-test, their values are very small and can be inferred that this type of policy reaction function destabilizes the economy since the coefficient in response to inflation is less than unity.

Furthermore, estimation of the whole sample may not represent the policy reaction function when considering the Chow test – the test for structural break. The null hypothesis of no structural break in the second quarter 1979 can be rejected. However, it is worthwhile to show the result of the whole sample estimates[39] in Equation (3.13) for the comparison with CGG (1998).

Equation (3.13) .... $R_t = 0.0824 + 0.1922\Delta_4 p_{t-1} + 0.2725 x_{t-1}$

$$\qquad (0.0046) \quad (0.0442) \qquad (0.0877)$$

$R^2 = 0.226$, Standard error of estimate (SEE) = 0.0258, DW = 0.25

[39] The standard errors are in parentheses.

Having unsuccessfully estimated the policy reaction function using the whole sample, Nelson divided the data into 6 sub-samples. These can be described as follows;

- July 1972 – June 1976: the first month of British Pound floated to the month prior to adopting the monetary aggregate, specifically M3, as a policy instrument
- July 1976 – April 1979: the first month of monetary aggregate targeting procedure to the month prior to the elected Conservative government being elected
- May 1979 – February 1987: the first month of Margaret Thatcher government to the abandonment of M3 targeting in October 1985
- March 1987 – September 1990: informal linking of the British pound to the Deutsche mark
- October 1990 – September 1992: England joining the ERM, however, this period will be ignored in the estimation due to the fixed exchange rate regime
- October 1992 – April 1997: the Bank of England adopted inflation targeting as a monetary policy procedure

The estimation results are reported in Table 1.8. These are a part of all results obtained from either OLS or Instrumental Variable method, depending on the best goodness of fit. The long-run inflation response equals the sum of estimated coefficients in response to inflation divided by one minus the sum of degree of interest rate smoothing. Likewise, the long-run output gap response is computed in the same way as the long-run inflation response[40].

[40] The computation is similar to my estimation of the US reaction function in Table 1.7.

After 1992 the coefficients in response to inflation and the output gap are 1.27 and 0.47, respectively, analogous to those of the Taylor rule. However, Nelson (2000) pointed out that relatively restrictive monetary policies are not necessarily always characterized by a greater than one-to-one long-run response of the nominal interest rate to inflation. Instead, tightening monetary policy is sometimes implied by a policy shift by means of a sharp increase in the average level of the real interest rate, in case that the contractionary policy stems from other factors, not captured in the Taylor-type rules. For instance, the average ex post real interest rate tremendously increased by 750 basis points from the period of 1976-79 to 1979-84, while the coefficients in response to inflation was not consistent with the Taylor Principle.

Table 1.8: Summary of the policy reaction function estimates in the UK

Regime	**Long-run Inflation response**	**Long-run output gap response**	**Smoothing parameter**	**Ex post real interest rate**	**Method**
1972-76	0.138 (0.049)	0.591 (0.132)	0.260 (0.174)	-5.72	OLS
1976-79	0.620 (0.088)	0.00	0.620 (0.095)	-3.14	Instrumental Variable
1979-87	0.380 (0.058)	0.145 (0.122)	0.373 (0.156)	4.66	Instrumental Variable
1987-90*	0.00	0.454 (0.119)	0.522 (0.115)	5.76	Instrumental Variable
1992-97	1.267 (0.468)	0.470 (0.131)	0.288 (0.116)	2.99	Instrumental Variable

*Note: - * German short-term interest rate enters the UK's reaction function with a significant long-run coefficient of 1.11.*
- The standard errors are in parentheses.

Nelson (2000) explained that the Taylor rule approach[41] failed to describe the monetary policy during this period since the rule is assumed average real interest rate be a constant or in the range of 2-4%, comparing to the average (ex post) real interest

[41] In fact, Taylor (1993) did not define precisely which equilibrium real interest rate should be used. He assumed an arbitrary 2% as an equilibrium real rate, which was close to the assumed steady-state growth rate of 2.2% at that time – Taylor (1993), p. 202. And recall that the equilibrium real interest rate of 2% was chosen based on the data his sample (1987-1992), it can be time-varying as economic theory tells us. The assumption of a constant natural real interest rate becomes one of the major weaknesses of the Taylor rule to be discussed later in the present chapter and Chapter 3.

rate[42] during 1979-1984 which was approximately 4.66% in Table 1.8. With such an average real interest rate, the Taylor rule calls for the lower nominal interest rate than the ex post real interest rate.

In this case, the Taylor rule can explain only the monetary policy in response to inflation and the output gap but not the tightening monetary policy from other variables. Thus, monetary policy can be tightening, though it does not respond to or respond slightly to inflation and the output gap. For example, the tightening monetary policy serves other purposes of the government such as the stability of the exchange rate or fiscal budgets.

In light of Nelson's (2000) remark on the high average real interest rate during 1979-87, it is worth pointing out that the greater than unity condition in the Taylor-type rule is only to guarantee non-explosive self-fulfilling expectations of inflation not to guarantee tightening monetary policy. Raising nominal interest rate greater than one-to-one in response to inflation is just one of many ways to ensure the sufficiently contractionary policy.

Moreover, the change in the natural real interest rate in the UK can be another possible explanation. If there is a change in the natural real interest rate while the original Taylor rule does not incorporate this change, the Taylor rule will call for a lower real interest rate than an ex post rate. In this case, using the time-varying natural real interest rate may embrace some structural change and track the policy better than the constant one.

Furthermore, the interpretation of the policy reaction function in the UK, of which the monetary policy historically experienced both inter- and independence periods with that of other countries in Europe, in particularly, Germany, should be

[42] It is noteworthy that Nelson (2000) did not calculate the natural real interest rate from the estimated policy reaction function but he only averaged the ex post real interest rate in each sub-samples that he examined.

done with some caution. The estimation of the UK policy reaction function could be more complicated than that of the US. Some omitted variables such as the foreign monetary policy may be needed to explain this inter-dependence across countries.

Another interesting episode in the UK's monetary policy history was the period of 1987-90. Not only was the British Pound closely linked with the Deutsche Mark, but also UK monetary policy depended largely on German monetary policy. It can be observed from the policy reaction function with a significant short-term interest rate in Germany in the period of 1987-1990 – the period right before the EMS was fully in effect. Furthermore, the effect of German monetary policy was added to the policy rule estimation by CGG (1998).

Before Nelson (2000), CGG (1998) estimated policy reaction functions in the UK as well as other countries. They studied the group of countries called G3, including the US, Japan and Germany and E3, including the UK, France and Italy. E3 group is the main trading partner of G3, specifically Germany and the US.

The data they used were monthly, compared to quarterly data in Nelson (2000). CGG (1998)'s sample started from June of 1979 which was the first month that Margaret Thatcher became Prime Minister, until the end of the dataset in October of 1990 when the UK joined the ERM.

The gain from using a monthly dataset is that it has more observations. The more observations, the more consistent estimates we will obtain. However, there is a tradeoff between high and low frequency data. One of the disadvantages of using high frequency data is that the dataset contains more noise than that of the lower one. Thus, the interpretation of the estimation results from such high frequency data might be misleading sometimes because most variability in a dependent variable is largely explained by its lags. Apart from the noise, seasonality is more problematic in monthly data than in the quarterly data or annual data.

The specification of the policy reaction function is similar to Equation (3.1), (3.2) and (3.3) and the estimation method is GMM as in CGG (2000) for the US. However, one issue they added in the UK case is to augment the policy reaction function by either the German interest rate targeted by the Bundesbank or the real exchange rate, compared with the Deutsche Mark. It is convenient to expand all the terms and put them in Equation (3.14);

Equation (3.14) .... $i_t = (1 - \rho)\{\alpha + \varphi(E[\pi_{t+n}| \Omega_t]) + \beta(E[x_{t+n}| \Omega_t] + \xi E[z_t| \Omega_t])$

$+ \rho i_{t-1} + \varepsilon_t$

Where all notations are similar to Equation (3.4) except that z_t represents the variables capturing the external factors.

The result of the baseline model with exclusion of both the German interest rate and the real exchange rate ($z_t = 0$) shows the coefficient associated with inflation around one, while the constant is surprisingly high. They also pointed out that unreasonably high values of the constant might suggest misspecification of the model, similar to Nelson (2000). Also, they calculated a natural real rate of 5.72%, which was very high compared with the average natural real interest rate computed by the sample averages.

Table 1.9: Bank of England reaction functions

	Inflation response	**Output gap response**	**Degree of interest rate smoothing**	**Constant**	**German variables**
Baseline	0.98 (0.09)	0.19 (0.04)	0.92 (0.01)	5.76 (0.69)	-
Adding: short-term interest rate	0.48 (0.05)	0.28 (0.02)	0.87 (0.01)	4.89 (0.40)	0.60 (0.07)
Adding: Pound/DM rate	0.95 (0.12)	0.17 (0.07)	0.91 (0.01)	6.07 (0.95)	0.09 (0.03)

Note: The standard errors are in parentheses.

However, both German interest rate and real exchange rate relative to the Deutsche Mark are significant. The coefficient in response to inflation declines by a half along with the constant, even though the coefficient associated with the output gap goes up slightly. The effect of adding the German short-term interest rate is greater than that of adding the real exchange rate. It can confirm the influence of German monetary policy on British monetary policy. The estimates results in CGG (1998) are shown in Table 1.9.

From Table 1.9, it is noteworthy that CGG (1998) addressed the same issue as Nelson (2000) concerning the unreasonably high constant from the estimation. Even though the explanations of these two papers are different, they can be complimentary with each other. As mentioned earlier, Nelson (2000) pointed out that the upward shift in average real interest rate indicates more restrictive monetary policy on average, but not indicated through the responses of inflation and the output gap in a policy reaction function. Therefore, the specification of the policy reaction function, conforming to the Taylor-type rule may be insufficient to explain the Bank of England policy during that period.

On the other hand, CGG (1998) explain the reason for the high constant in the estimated policy reaction function that it is a result of too close a link between the UK and German monetary policy bound by the exchange rate commitment policy between two countries. Despite very low inflation in the UK in the 1980s, the Bank of England still had to maintain a high level of the average real interest in order to maintain a strong real exchange rate. Therefore, external factors could be one of the explanations for the policy shift in the UK, as pointed in the arguments on Nelson's explanation of the high ex post real interest rate, compared with the policy inferred from the Taylor rule.

In sum, monetary policy used in the US could not be applied to the UK before 1990, due to the dependence on the foreign economy, i.e. Germany. In light of focusing on the policy objective instead of the policy instrument like the Taylor rule through inflation targeting regime as the main policy procedure, the Taylor rule can well explain the behavior of the Bank of England after 1992.

Two additional issues worth pointing out in the estimation of policy reaction function of the UK are the estimation in the period of targeting the M3 monetary aggregate during the mid-1970s until the mid-1980s and the period before the operational independence of the Bank of England (pre-1997).

The policy reaction function in the period of targeting the monetary aggregate may have not represented the true behavior of the Bank of England at all since the function relates a short-term interest rate, which the Bank of England did not even target, to some economic indicators including inflation, the output gap and other factors, e.g. the monetary aggregate. Thus, the estimated policy reaction function following the Taylor rule in this period may be interpreted as a behavior of a short-term interest rate determined by the variables set forth, in lieu of the behavior that the Bank of England followed the Taylor rule or other interest rate rules.

Interestingly, the higher average (ex post) real interest rate in the UK corresponded to the period of targeting the M3 monetary aggregate. This also paralleled the experiment targeting non-borrowed reserves by the Fed during 1979-1982, in which the real federal funds rate hit an historical high in the US. Thus, targeting a monetary aggregate rather than targeting a short-term interest rate could be one of the factors responsible for the high average real interest rate.

Noting that the Bank of England just received fully operational independence in May 1997, it might have had to serve the Treasury Department to satisfy some fiscal purposes. Therefore, it might be misleading to estimate the policy reaction function of the Bank of England without taking this effect into account. Whether the estimated policy reaction function with a structural break when the Bank of England received the operational independence is different from the ones estimated earlier is still an open question.

3.4.2. The policy reaction function in Japan

For Japan, CGG (1998) estimated the reaction function similar to Equation (3.14) with external factors including lagged inflation, money growth represented by annualized rate of M2 over the last 3 months, the federal funds rate and the real exchange rate of Yen/US$. The sample starts from 1979:4 to 1994:12.

They found that the Bank of Japan was more aggressive in the response to inflation rather than output gap, noticing from the coefficient on inflation of higher than unity and significant coefficient on the output gap but with small value. The implied estimate of target inflation is approximately 2.03%, inferred from the sample average real rate of 3.32%.

Noticeably, lagged inflation is not significant at the conventional confidence level while the other coefficients remain unchanged. It implies that the Bank of Japan tends to be more forward-looking. Finally, neither the foreign short-term interest rate nor the real exchange rate is significant. Therefore, the baseline estimation, excluding all external factors, is sufficient to characterize the Japanese economy. CGG's (1998) results are reported in Table 1.10.

In the recent literature, Kuttner and Posen (2003) estimated the reaction function, allowing a second-order partial adjustment mechanism. They also showed that the different output gap measures cause non-robust results for Japan's case and there is still no generally agreed upon appropriate measure for potential output.

Therefore, they estimated the policy reaction function implementing different measures of output gaps, including recursive linear trend, Recursive HP filter, One-sided Kuttner-Posen model (2001), Full-sample HP filter and Quadratic trend (CGG (1998)).

Table 1.10: The estimation of policy reaction function by CGG (1998) during 1979:4-1994:12

External factors	φ	β	ρ	α	ξ
Baseline	2.04 (0.19)	0.08 (0.03)	0.93 (0.01)	1.21 (0.44)	-
Lagged Inflation	1.89 (0.27)	0.09 (0.04)	0.93 (0.01)	1.64 (0.38)	0.06 (0.16)
Money Growth	2.01 (0.16)	0.07 (0.03)	0.94 (0.01)	0.74 (0.47)	0.07 (0.03)
Fed Funds Rate	1.81 (0.18)	0.10 (0.03)	0.93 (0.01)	0.91 (0.40)	0.09 (0.03)
Real Yen/US$	1.92 (0.11)	0.03 (0.03)	0.91 (0.01)	1.67 (0.27)	0.09 (0.01)

Note: The standard errors are in parentheses.

The model specification is similar to CGG (1998) except that they also estimated backward-looking type of policy reaction function. The method of estimation for the backward-looking type is non-linear least squares, while the forward-looking type model is estimated with GMM. Their sample was from 1986:Q1 to 2001:Q1. The call money rate was used as a proxy for a short-term interest rate, while the CPI inflation[43] was implemented as a proxy for inflation. The policy rule that Kuttner and Posen estimated can be described as follows,

Equation (3.15)........ $i^*_t = c + \alpha(y_t - y^*_t) + \beta(\pi_t - \pi^*)$

Where i_t is a short-term interest rate

c is a constant, composed of an equilibrium real interest rate (r^*) and a desired inflation rate (π^*) and set to 1.0%

[43] The CPI inflation over the *preceding* four quarters is a proxy for the backward-looking inflation, while the CPI inflation over the *next* four quarters is a proxy for the forward-looking inflation.

π_t is inflation

y_t is actual output

y^*_t is potential output, therefore, $y_t - y^*_t$ is the output gap

For a second-order partial adjustment,

Equation (3.16)………..$i_t = (1 - \rho_1 - \rho_2)i^*_t + \rho_1 i_{t-1} + \rho_2 i_{t-2} + e_t$

Expanding all terms in Equation (3.15) and (3.16) gives us;

Equation (3.17) …… $i_t = (1 - \rho_1 - \rho_2)[c + \alpha(y_t - y^*_t) + \beta(\pi_t - \pi^*)] + \rho_1 i_{t-1} + \rho_2 i_{t-2} + e_t$

According to Table 1.11, with different measures of the output gap, the coefficients associated with inflation are small, specifically *less than unity* in the backward-looking model even though they are of the correct sign and significantly different from zero. This indicates that the estimated policy reaction function may be destabilizing. With two cases out of five, the coefficients on inflation are less than one. Therefore, it is still inconclusive whether the estimated coefficients are less than one and the Taylor Principle may or may not hold during this period (1986:Q1 – 2001:Q1) or not.

On the contrary, the forward-looking model estimation yields consistently large coefficients in response to inflation and conforms to the Taylor Principle of greater than one-for-one response to inflation.

In addition, the estimates for the coefficient on the output gap are small and insignificant. This finding can be interpreted as the strong reaction against inflation and a weak response to the output gap of Japanese monetary policy during 1986 through 2001. Nonetheless, these regression exercises might be misleading in some circumstances. An important problem of the Taylor-type rule is that it is constrained by the zero bound on the *nominal* interest rate, which is the case for Japan in the late 1990s. Some researchers including Kuttner and Posen (2003) suggested using a Tobit model[44] to estimate the reaction function as an alternative for the OLS estimated earlier.

Table 1.11: The estimation by Kuttner and Posen (2003)

Output gap	r^*	β	α	ρ_1	ρ_2
Backward-looking reaction function					
Recursive linear trend	2.36 (0.55)	1.12 (0.33)	0.58 (0.17)	1.15 (0.26)	-0.29 (0.21)
Recursive HP filter	1.18 (0.90)	1.64 (0.49)	0.79 (0.30)	1.26 (0.27)	-0.36 (0.22)
One-sided Kuttner-Posen model	1.88 (0.82)	0.72 (0.48)	1.60 (0.64)	1.25 (0.25)	-0.34 (0.21)
Full-sample HP filter	0.79 (0.65)	1.11 (0.59)	0.48 (0.47)	1.36 (0.28)	-0.43 (0.25)
Quadratic trend	0.87 (0.96)	0.60 (0.64)	0.57 (0.73)	1.38 (0.27)	-0.44 (0.25)
Forward-looking reaction function					
Recursive linear trend	2.14 (0.20)	2.52 (0.36)	-0.04 (0.21)	1.31 (0.34)	-0.45 (0.33)
Recursive HP filter	2.34 (0.35)	2.46 (0.32)	-0.10 (0.22)	1.27 (0.27)	-0.42 (0.26)
One-sided Kuttner-Posen model	2.10 (0.27)	1.91 (1.37)	0.51 (1.34)	1.26 (0.23)	-0.37 (0.22)
Full-sample HP filter	1.67 (1.26)	2.79 (0.46)	-0.35 (0.17)	1.27 (0.26)	-0.42 (0.26)
Quadratic trend	1.95 (0.31)	1.93 (0.59)	0.01 (0.12)	1.49 (0.36)	-0.59 (0.33)

Note: -The standard errors are in parentheses.
- The natural real interest rate (r^*) can be estimated by subtracting the desired inflation rate (π^*) of 1% from the estimated constants (c).

Comparing the result obtained by Kuttner and Posen with CGG (1998), the results estimated support the forward-looking type reaction function rather than the backward-looking type reaction function, which corresponds to some finding that the central banks should implement monetary policy with some forward-looking components due to the lags of its effects.

According to the estimation results with the forward-looking type in both CGG (1998) and Kuttner and Posen (2003), the weights on inflation are

[44] Tobit model is an econometric model, implementing regime switching with some known truncation values, compared with Markov-Switching model, of which the truncation values are unknown. The estimation method of this model leans on the maximum likelihood method.

approximately 2, which is higher than the original parameter set by Taylor (1993a), while the coefficients associated with the output gap are consistently insignificant in both papers.

Regarding the degree of interest rate smoothing, CGG (1998) employed a first-order partial adjustment, whereas Kuttner and Posen used a second-order partial adjustment. However, the long-term elasticity coefficients (one minus the summation of the degree of interest rate smoothing) in CGG and Kuttner and Posen are very close to 0.9, indicating high persistence in the short-term interest rate. Also, it resembles that of the US during Greenspan's tenure.

Even though time periods in both papers are different, they end up with similar results. While CGG used monthly data spanning 1979:4 – 1994:12, excluding the period of the call money rate approaching a zero rate in Japan, Kuttner and Posen use the data in the 1986:Q1 – 2001:Q1 period. For this reason, it could be implied that the period during which the nominal interest rate approached a zero bound may have not affected the reaction function estimation as much as expected as pointed out in Kuttner and Posen.

Another issue brought up by CGG concerns the effect of external factors, including the real exchange rate and foreign interest rate, specifically, on the US. In spite of very trivial values of no greater than 0.1, the estimates of these external factors are significantly different from zero while other estimated coefficients of other variables do not change at all. Therefore, the external factors can affect the policy reaction function but by very small amounts.

3.4.3. The policy reaction function in the European Union (EU)

CGG (1998) presented estimates of the policy reaction function in different countries as mentioned earlier. However, they did not estimate the EU as a whole due to the limitation of the data. By the time CGG (1998) published their paper, the ECB had been just established and their data ended in 1993. At that time, the stage two of the European Union – the transition stage concentrating on strengthening the cooperation of the central banks as well as monetary policy in the member countries before establishing the European Central Bank (ECB) in 1998 and the third stage of single currency in 1999 – had not even started. Instead, it was in the stage of a fixed exchange rate system, so-called European Monetary System (EMS)[45]. Thus, it is inevitable to account for EMS in the estimation due to the effect of the fixed exchange rate on policy rule and monetary policy implementation. Therefore, CGG (1998) estimated the reaction functions in individual countries; namely, Germany, France and Italy with monthly data and the forward-looking reaction function similar to Equation (3.14) rather than estimating the EU.

The sample for Germany is 1979:4-1993:12, while the samples for France and Italy are 1983:5-1989:12 and 1981:6-1989:12, respectively. All data are monthly. The sample for France is very short, compared to the other two. This problem might distort the estimates, especially with the GMM method[46]. As a consequence, the estimates from GMM with small sample size such as CGG (1998) might not yield consistent estimates.

For Germany the implied inflation target was 1.97% with a real interest rate of 3.76%. This was consistent with the official inflation target by the Bundesbank. For France and Italy, the targets were assumed to be 2%, paralleling to the Bundesbank. On the other hand, the long-run real interest rates in France and Italy inferred from the

[45] The European Monetary System required each member country to maintain the fixed exchange rate in the group. Therefore, the central banks in the member countries had to implement their own monetary policy to maintain the fixed exchange rate, compared with the fully developed European Union, in which the European Central Bank sets the monetary policy, not the central banks of the member countries.

[46] The drawback of the GMM is beyond the scope of the present chapter. This issue can be found in Greene (2002).

inflation target as well as the constant were 6.01% and 6.94%, respectively. Apparently, these rates were very high, compared to the average real interest rate in Germany which was amazingly consistent with the official inflation target by Bundesbank of 2%.

Considering the external factor (ξ), lagged inflation is insignificant in Germany. This finding implies that the Bundesbank tended to be forward-looking in implementing monetary policy. On the other hand, money growth represented by deviation of log money stock – M3 after 1988, Central Bank Money before that – is significant at a very high level of confidence. This substantiates the conventional view, e.g. Dornbusch (1997), that the Bundesbank targets a money aggregate, aforementioned in Section 1. For the rest of the variables, they have very small effects, in spite of their significance.

CGG (1998) found that France and Italy were influenced enormously by German monetary policy, even before the EMS was in effect. Thus, appending the German interest rate or real interest rate would reasonably help explain the central banks' behaviors in both France and Italy. The dependence on German monetary policy is illustrated by the significant and large coefficients associated with German short-term interest rate and real exchange rate, except the real exchange rate for Italy.

With the baseline estimation, the coefficient on inflation in France is significant and greater than unity. However, it is far below 1.5, the parameter set by the original Taylor rule. On the other hand, the coefficients in the Italian regressions are even worse, as they are all below unity and do not show stabilized policy rules in all cases.

From CGG (1998) in Table 3.12, the policy rules that are aggressive against inflation in some industrialized countries, in particular, the Taylor rule, could not be used to describe the individual economies in the EU well before the 1990s.

Table 1.12: The estimates for the EU by CGG (1998)

	φ	β	ρ	α	ξ	r^*
Germany (1979:4-1993:12)						
Baseline	1.31 (0.09)	0.25 (0.04)	0.91 (0.01)	3.14 (0.28)	-	3.76
Lagged Inflation	1.10 (0.20)	0.28 (0.04)	0.91 (0.01)	3.26 (0.71)	0.12 (0.14)	3.76
Money Supply	1.29 (0.08)	0.28 (0.03)	0.91 (0.01)	3.12 (0.29)	0.7 (0.07)	3.76
Fed Funds rate	1.23 (0.06)	0.25 (0.04)	0.91 (0.01)	2.71 (0.84)	0.07 (0.02)	3.76
Real DM/US$	1.37 (0.09)	0.35 (0.04)	0.91 (0.01)	-0.93 (0.82)	0.05 (0.01)	3.76
France (1983:5-1989:12)						
Baseline	1.13 0.07)	0.88 (0.10)	0.95 (0.01)	5.75 (0.28)	-	6.01
German DTD rate	0.59 (0.02)	-0.07 (0.03)	0.87 (0.01)	2.16 (0.23)	1.14 (0.05)	6.01
Real France/ECU	1.33 (0.06)	0.27 (0.04)	0.95 (0.01)	7.75 (0.10)	2.91 (0.23)	6.01
Italy (1981:6-1989:12)						
Baseline	0.90 (0.04)	0.22 (0.08)	0.95 (0.01)	7.14 (0.37)	-	6.94
German DTD rate	0.59 (0.04)	-0.03 (0.05)	0.93 (0.01)	6.03 (0.28)	0.59 (0.04)	6.94
Real Lira/ECU	0.91 (0.02)	0.10 (0.03)	0.94 (0.01)	7.17 (0.18)	-0.03 (0.04)	6.94

The tightening monetary policy in these countries, in particular Italy and France, was not a result of the aggressive response to domestic inflation as shown in Table 1.12, but the external force from the European Monetary System in an attempt to maintain the exchange rate at a fixed level and the influence of the Bundesbank upon the rest of the countries maintaining the high real interest rate in Germany before the unification in 1990. France instead followed Germany, which was very influential before the ECB was established.

Gerlach and Schnabel (1999) (GS) estimated the policy reaction function for the European Monetary Union (EMU)[47] and found that the Taylor rule could describe the behavior of the average interest rate in the EMU are in the 1990-1997 period well, with the exception of the exchange rate turmoil in 1992-1993. It is worth pointing out that the dataset in GS (1999) is more updated and overlapping with CGG (1998) just in the case of Germany. The difference in the sample periods could be the main reason why the results are the opposite of CGG (1998).

The data were quarterly and the output gap was interpolated from the annual/semiannual data constructed by OECD. The annual change in quarterly averages of each country's consumer price indices was used as a proxy for inflation, then aggregating all series for the EMU area by using fixed weights provided by OECD. The inflation target was set arbitrarily at 2%, while the natural real interest rate was estimated with the adjustment for the credibility of monetary policy, rather than estimating through the policy reaction function like the others, e.g. CGG (1998). The reason for adjustment is the low credibility of monetary policy in some countries; e.g., Italy.

GS (1999) estimated two sets of policy reaction functions with the sample of 1990:Q1 - 1998:Q4. One corresponds to the Taylor-type rule with contemporaneous variables and the dummy variable accounting for the exchange market turmoil during 1992:Q3-1993:Q3. The other is consistent with the reaction function implemented by CGG (1998) with forward-looking policy rule appended by the exogenous variables, including the federal funds rate, the growth rate of M3 as a proxy for monetary

[47] European Monetary Union (EMU) is used as the formal terminology, prior to the European Union (EU). The term, however, emphasizes only the monetary aspect, compared with the term EU which incorporates in all aspects of cooperation among the member countries, including politics, etc. Hanspeter (2004) discusses the chronological development of the European Union and its functions very insightfully.

aggregate growth and the real exchange rate in terms of the US dollar. The estimation results for the first set of reaction functions are reported in Table 1.13.

Table 1.13: The reaction function in the EMU area by Gerlach and Schnabel (1999)

Coefficient	Estimation without AR(1)	Estimation with AR(1)
Constant	2.40* (0.30)	2.65* (0.39)
Output gap	0.45* (0.06)	0.46* (0.12)
Inflation	1.58* (0.09)	1.51* (0.11)
Dummies		
1992:3	2.30* (0.36)	2.37* (0.35)
1992:4	3.24* (0.35)	3.28* (0.37)
1993:1	2.70* (0.37)	2.80* (0.40)
1993:3	1.63* (0.38)	1.73* (0.41)
Autocorrelation	-	0.32*** (0.19)
Q-stat	0.018	0.09
Wald test	0.641	0.977
Adjusted R^2	0.98	0.98

Note: Q-test and Wald test show the p-value in the entries.
** and *** show the significance of the coefficients at 1% and 10%, respectively.*

Due to the presence of first-order autocorrelation indicated by the Q-test, GS (1999) also presented the estimates of the reaction function, allowing the possibility of the AR(1) residuals. From Table 1.13, with the control of the exchange rate turmoil period, the estimated coefficients in response to inflation and the output gap are consistent with the original Taylor rule of 1.5 and 0.5, respectively. In addition, the Wald test confirms statistically insignificant difference between the estimated coefficients and the parameters calibrated by Taylor (1993) by not rejecting the null hypothesis of not significantly difference from each other.

In Table 1.13, the dummies for 1992-93 are significant with a high confidence level (99%). Thus, the exchange rate turmoil in that period may not matter in the policy reaction function estimation and may have caused the shifts in the natural real interest rate level inferred from the constant.

However, we should cautiously interpret these results as the dummies representing only the shifts in the constant, but do not allow for possible structural changes in the responses to inflation and the output gap. In addition, it is doubtful whether the degree of interest rate smoothing would have been an omitted variable in this estimated reaction function since it was widely accounted for by many studies, e.g. CGG (1998).

With the degree of interest rate smoothing, GS (1999) also estimate the forward-looking policy reaction function with GMM method similar to CGG (1998). Also, they estimate the augmented reaction function with the external factors, namely, lagged inflation at time t-4, M3 money growth in the EU, the federal funds rate and the year-on-year basis change in the real exchange rate between the euro and the US dollar. Their sample was 1990:1-1998:1, resembling to CGG (1998) except that they dropped the data during 1992:3-1993:3 due to the exchange rate turmoil.

From their results with the analogous specifications to CGG (1998) reported in Appendix C, only the federal funds rate was significant at 5% (but negative) among other external factors. The long-run elasticities on inflation and the output gap[48] were approximately 1.84 and 0.34, respectively. Owing to the insignificance of degree of interest rate smoothing, these elasticities could be imprecise and implied that they are not significantly different from 1.5 and 0.5 designated by Taylor (1993a).

With the higher coefficient on inflation and lower on the output gap when the forward-looking type reaction function was estimated, it may suggests that central

[48] The long-run elasticities can be calculated by dividing the estimates by the term of one minus the sum of all coefficients on lagged dependent variable.

banks react to the output gap because it contains information about future price pressures.

In comparison, Piergallini and Rodano (2004) estimated the reaction function by extending the sample period of GS (1999). They divided the sample into two sets. One is consistent with GS (1999) but slightly shorter – the 1992:1 – 1998:12 period. It is noteworthy that the sub-sample started from January 1992, which was the year of the ERM breakdown. However, Piergallini and Rodano (2004) started their sample slightly earlier than the actual breakdown date of the ERM in the third quarter of 1992. Another sub-sample started from 1999:1 to 2004:3, which started from the currency changeover date[49].

Piergallini and Rodano (2004) used monthly data, compared to quarterly data in GS (1999). They estimated the reaction function in the EU, which was the main focus of their study, along with three individual countries including Germany, France and Italy. The industrial production index was used as a proxy for output, while consumer price indices represented inflation. Finally, a three-month interbank lending rate was used as a proxy for the short-term interest rate. For the most problematic variable - potential output, they employed the Hodrick-Prescott filter to derive the trend in industrial production.

Regarding the constant, the inflation target was set to 2%, corresponding to the original Taylor rule and consistent with the definition of price stability adopted by the Eurosystem. Based on the constant, inflation target and the coefficient in response to inflation, the natural real interest rate can be inferred.

The methods of estimation were Ordinary Least Square (OLS) and Instrumental Variables. The latter was used to mitigate the endogeneity problem – a

[49] All countries in the EU started to use the common currency "Euro" according to the Maastricht Treaty in January 1999.

regressor correlates with the error term from the regression. If the endogeneity is problematic in the estimation, the estimates are inconsistent. The result is reported in Table 1.14.

Table 1.14: The estimation results obtained from Piergallini and Rodano (2004)

Countries	**Constant**	**Inflation**	**Output gap**
A. Sample period of 1992:1 - 1998:12			
OLS estimation			
Germany	4.82** (0.07)	1.16** (0.06)	0.68** (0.12)
France	6.95** (0.32)	1.96** (0.35)	0.87** (0.16)
Italy	6.34** (0.41)	1.52** (0.17)	0.23 (0.13)
Euro Area	5.64** (0.15)	1.92** (0.11)	1.16** (0.20)
IV estimation			
Germany	4.83** (0.07)	1.23** (0.07)	0.74** (0.12)
France	7.10** (0.39)	2.32** (0.44)	0.88** (0.17)
Italy	6.29** (0.40)	1.53** (0.19)	0.22 (0.15)
Euro Area	5.65** (0.15)	2.02** (0.12)	1.23** (0.21)
B. Sample period of 1999:1 2004:3			
Euro area			
OLS	3.44** (0.18)	0.64* (0.28)	0.12 (0.28)
IV	3.43** (0.18)	0.73* (0.32)	0.07 (0.31)

Note: - ** statistically significant at the 5% level.*
- *** statistically significant at the 1% level.*
- *Instrumented variables: $(\pi_t - \pi^*)$ and $(y_t - y^*)$*
- *Instruments, including lagged short-term interest rate, inflation and output gap*
- *The standard errors are in parentheses, calculated by using the Newey-West estimator adjusted for heteroskedasticity and autocorrelation.*

From Table 1.14, the estimation during January 1992 – December 1998 shows stabilizing policy rules in all three countries in panel A, no matter which estimation method being used. Considering the estimation for each individual country, monetary policy in France is more aggressive than the others, according to the very large coefficients, which double the value suggested by Taylor (1993a). In Italy, the coefficient on the output gap, however, is insignificant at any conventional level, representing possibly "strict" inflation targeting: this policy may have mirrored the intention of its central bank in improving the credibility of fighting inflation seriously before the transition to the EU is complete in all stages[50] including the common currency (EURO) in 1999. Lastly, the Bundesbank – German central bank – placed the weight on inflation slightly less than the other two but put more on the output gap than the value parameterized by Taylor (1993a). The heavy weight on the estimate reflects the aggressiveness in responding to the output gap, which is equivalent to placing more weight on the unemployment gap. As a whole, the estimated coefficients in the EU on both inflation and the output gap are higher than originally used by Taylor (1993a).

In Panel B in Table 1.14, the results estimated from January 1999 to March 2004 for the EU contradict the earlier period, the coefficient in response to inflation are significantly different from zero but smaller than unity and the ones associated with the output gap are not significantly different from zero. It can possibly be interpreted that after the single currency was enforced in 1999, the European Central Bank was less aggressive in the response to inflation as well as the output gap and the conduct of monetary policy by the ECB deviated considerably from the past when each individual member country had independently conducted its monetary policy.

Nevertheless, these estimates are based on the backward-looking type model, i.e. implementing the contemporaneous and lagged variables. Piergallini and Rodano (2004) argued that it may be worthwhile to apply the forward-looking policy reaction function implemented by CGG (1998) to the period of January 1999 to March 2004,

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[50] Refer to the chronological development of the European Union – Hanspeter (2004)

when the common currency has been enforced. This is because if the ECB responds to the output gap for the purpose of curbing future inflation more than the individual central bank did before the monetary changeover, the forward-looking policy reaction function will describe the ECB's behavior better than the backward-looking one. Moreover, the forward-looking rule allows a variety of information relevant to forecast inflation to be used as instruments for estimations, compared with the backward-looking one.

Table 1.15: The estimation of forward-looking reaction function
by Piergallini and Rodano
Estimated Equation : $i_t = c + \alpha(\pi_{t+h} - \pi^*) + \beta(y_t - y^*)$

h: Target Horizon (months)	**Constant**	**Inflation**	**Output gap**
3	3.43** (0.18)	1.09** (0.38)	0.00 (0.25)
6	3.47** (0.17)	1.38** (0.32)	0.16 (0.18)
9	3.48** (0.14)	1.79** (0.32)	0.38* 0.15)
12	3.59** (0.14)	1.61** (0.25)	0.58** (0.12)

Note: * *Statistically significant at the 5% level.*
** *Statistically significant at the 1% level.*
The standard errors are in parentheses.

The results are surprising since the coefficients obtained from the forward-looking type model without interest rate smoothing are consistent with the original Taylor rule when the target horizon – the horizon of expected inflation in CGG's (1998) reaction function – increases. This is opposite to the estimation results obtained from the backward-looking reaction function in Table 1.14. The estimates based on the 12-month horizon of expected inflation are the most consistent with the parameters calibrated by Taylor (1993) of 1.5 and 0.5 for the inflation and the output gap, respectively. These estimation results corroborate the study by CGG (1998) in favor of the forward-looking model. The complete estimation results of the forward-looking reaction function excerpted from Piergallini and Rodano are in Table 1.15. Since the EU has been established, the policy tended to be more forward-looking.

In sum, the reaction function in the EMU area is consistent with the Taylor rule after the collapse of the EMS in 1992 in the backward-looking type and in the forward-looking type policy reaction function after 1999. This claim was supported by CGG (1998), Gerlach and Schnabel (1999) and Piergallini and Rodano (2004). The backward-looking type reaction function does not yield consistent results with the Taylor rule, while the forward-looking type does. If this claim is robust, it can be inferred that the European Central Bank operates monetary policy based on future economic conditions and tends to follow a Taylor-type rule.

The consistency with the Taylor rule after 1999 can also be interpreted as the commitment in achieving price stability, mandated as the sole policy objective of the ECB. This objective was not pronounced earlier when the individual countries conducted their own monetary policy.

Having shown by the US as well as international evidence, the Taylor rule can well describe the central banks' behaviors to some extent. There are, however, many drawbacks in this rule. Some have been roughly discussed in earlier sections and some have not. In the next section, I will delve in many issues hitherto recognized by monetary economists.

4. Practical issues in the Taylor-type rules

Even though the Taylor-type rules could explain the Fed's behavior quite well in the past, they have many potential problems. These include the data used in estimation, whether they are real-time or lagged and unobservable variables, e.g. potential output used to calculate the output gap, average real interest rate and inflation targets. In addition, a zero bound on the nominal interest rate is another concern which has occurred recently in Japan and it spurred some fear of this happening in other industrialized countries due to nominal interest rates decreasing towards zero in many countries

4.1. Empirical issues related to Taylor-type rules robust analysis

As illustrated in the estimation results, differences in inflation as well as output gap measures could yield different estimation results. However, it is a quite controversial issue on which measure is the most appropriate for inflation and the output gap.

Judd and Rudebusch (1998) found that different measures of inflation and the output gap did not yield different results from the baseline estimates, conforming CGG (2000). In contrast, Kozicki (1999) reports different results when estimating the policy reaction function with different measures.

Even though there is no coherence in defining inflation measures in the Taylor-type policy rule, the most common inflation measures include the GDP price deflator which is released quarterly but with the revision lagged up to 3 months and consumer price index[51] which is released every month.

Comparing the results obtained from different measures of inflation and the output gap, the latter generated more serious problems in terms of the robustness to the different measures than the former. This is because the output gap is a difference between actual and potential output, which is unobservable, while the inflation is defined as the change in price level, which can be observed. Therefore, the

[51] Taylor (1993a) used the CPI in the original Taylor rule.

unobservable potential output causes more uncertainty in using the output gap, depending on the measures.

4.1.1. Uncertainty in the measures of the output gap

Recall that the output gap is the percentage difference between the levels of actual and potential real output, the latter represents basically a trend of real output which is not affected by the policy rule or any counter-cyclical measures. In other words, it represents output at the full-employment level under the assumption of flexible prices. Potential output can shift with changes in the level of unemployment compatible with full employment, called the "natural rate" of unemployment[52], and/or with the rate of labor productivity improvement equivalent to the natural growth rate of output[53]. It is also unobservable and needs to be estimated.

The output gap can be perceived as a measure of resource utilization. Theoretically, the larger the output gap – the further actual output lies above potential output – the more resources are stretched, and the stronger inflationary pressures. Therefore, the choice of variable used as a proxy for the output gap is very crucial in policy rule design since the presence of an output gap not only reflects the need for stabilizing output itself but also represents future inflation which calls for a preemptive action to prevent it.

The first proxy for potential output implemented by many researchers including Taylor (1993a) is a linear trend of real output[54]. However, the linearly as well as quadratic detrended output depends sensitively on the time period selected for fitting the trend.

[52]It is also called the "non-accelerating-inflation rate of unemployment (NAIRU)".
[53] This part is influenced directly by the technology change.
[54] Taylor (1993a) estimated the linear trend as a proxy for potential output by fitting a trend to the data linearly ranging from 1984-1992.

Another widely used measure is the potential output imputed by Congressional Budget Office (CBO). Unfortunately, many countries do not have official potential output series like the one announced by CBO, therefore, we have to rely on other detrending methods, including the linear or quadratic trends.

CGG (2000) proposed to substitute the output gap with the deviation of unemployment rate from a similar time trend, however, the term should be in the opposite sign due to the negative relationship of output growth and unemployment rate. This relationship is explained by the Okun's law. CGG (2000)'s results estimating a policy reaction function with this unemployment gap measure were not, however significantly different from the baseline estimation results with the output gap constructed by CBO.

The last measure employed by researchers, e.g. McCallum (2000b), is Hodrick-Prescott filtered series of real output. This is a smoothing method to obtain a smooth estimate of the long-term trend component of a series. The method was first utilized by Hodrick and Prescott (1997) to analyze postwar U.S. business cycles. Nevertheless, McCallum (2000b) points out that the disadvantage of this procedure is that it produces a trend tracking the time path of actual GDP so closely that it would underestimate the true output gap.

4.1.2. Equilibrium real interest rates and inflation targets as unobservable variables

This sub-section explores the constant part of policy rules, which represents an equilibrium real interest rate and an inflation target. From policy rules, the equilibrium real interest rate is equivalent to the natural rate of interest when output equals potential and the price level is stable. For example, from Equation (3.10) the constant is $r^* - (\gamma - 1)\pi^*$. Hence, when $x_t = 0$ and $\pi_t = 0$, the rule-based *nominal* interest rate is determined solely by the constant. However, there is an under-identification problem since both r^* and π^* are unknown, therefore, one of them cannot be identified separately.

Originally, Taylor (1993a) assumed an equilibrium real interest rate and inflation target of 2%. Even though it is reasonable in his dataset, it is not sensible to maintain that the real interest rate and inflation target are constant throughout time. Rather, they are time-varying as seen by averaging real interest rate across chairmanships. Table 1.16, obtained from Judd and Rudebusch (1998) illustrates this result.

Table 1.16: Interest rates and Inflation

	Long Sample	**Greenspan**	**Volcker**	**Burns**
Average real interest rate (%)	2.39	2.82	5.35	0.02
Percentage point change in inflation	0.38	-1.32	-5.81	1.23
Average inflation (%)	4.38	3.03	5.35	6.47
End-of-sample inflation (%)	1.77	1.77	3.07	6.69

Note: The change in inflation (in percentage points) is calculated as the difference in four-quarter inflation from the first quarter to the last quarter of the sample. End-of-sample inflation is average over the final four quarters of the sample. Inflation is measured as the four-quarter change in the GDP deflator, and the interest rate is the federal funds rate.

Even though the real interest rate is reasonably close to 2% in the long sample, it changes across the chairmen. If either the equilibrium real interest rate or inflation target is known, it is possible to compute the other. Judd and Rudebusch (1998) handled the problem of identifying the equilibrium real interest rate in the constant of the Taylor rule by relating an equilibrium real interest rate to an inflation target linearly.

Kozicki (1999) added that the estimation of policy reaction function is not robust to estimates of the equilibrium real interest rate. She showed that the equilibrium real interest rates are different across the sample periods and across the inflation measures.

The equilibrium real interest rate in Kozicki (1999) is calculated by differencing the average federal funds rate (nominal interest rate) and the average inflation rate with a long sample period since the equilibrium real interest rate is a long-run concept. Using a long sample period averages out the cyclical swings occurring along the business cycles. Nevertheless, there are some disadvantages including the loss of information concerning the changes of real interest rate over time (if there is any structural shift).

CGG (2000) estimated this constant by restricting the equilibrium real interest rate equivalent to the sample average across the chairmanship and estimating an inflation target along with other parameters.

Yet, the equilibrium real interest rate in the Taylor rule depends on the real factors, e.g. the productivity, population growth and the saving rate of the economy, rather than the regimes across chairmanship. Thus, one may dispute the validity of this assumption.

Thus, some literature including Bomfim (1997), Laubach and Williams (2001) and Neiss and Nelson (2003)[55] estimate it with macro-econometric models, in particular models defining the equilibrium real interest rate as a variable determined by the public's decision-making in consumption and investment. These models are based on either structural models such as New Keynesian type models or non-structural models, e.g. VAR-based model.

Furthermore, the peril of using different equilibrium real interest rate between the central bank and the actual rate has been strongly argued by Taylor (1994). This difference can result in the persistence of inflation above or below the inflation target. In fact, the result from Taylor (1994) cautiously reminds policymakers not to maintain

[55] While Neiss and Nelson (2003) estimated the equilibrium real interest rate for the UK, Basdevant et al (2004) estimate it for New Zealand with both non-structural methods, e.g. Hodrick-Prescott filter and semi-structural model, i.e. the state-space model by extracting the signal from IS equation.

the equilibrium real interest rate at a constant as such implemented in the original Taylor rule, but to vary it corresponding to the changing economic circumstances in order to get rid of the gap between the central bank's perceived rate and the actual equilibrium real interest rate in the economy.

4.2. Data and model uncertainty in the policy reaction function

Uncertainty in the policy reaction function can be separated into two aspects. The first one is the uncertainty due to the difference between the data utilized by policymakers in setting the policy instrument at a particular time and the ex post revised data or final data. The second one is due to model uncertainty. The most influential papers on the problem of real-time data versus revised or final data include Orphanides (1998, 2001), while model uncertainty issue was focused on by Levin et al (1999) and Estrella and Mishkin (1999).

4.2.1. Real-time versus revised data

One of the widely accepted practical problems in estimating a policy reaction function is the issue of real-time data used by central banks in setting a policy instrument versus the revised data which are normally used in the estimation of policy reaction functions. This issue was nicely documented in Orphanides (1998, 2001) and also acknowledged in McCallum and Nelson (1999) and McCallum (2000b). Central banks typically set a policy instrument based on the data available at that particular time or so-called real time data in Orphanides (2001). However, the data at that time are revised repeatedly after the initial release. This deviation of the dataset results in enormous differences in policy recommendations.

Orphanides tackled this problem in two steps; the determination of the policy rule by accounting for real-time data, compared to the revised final data by both estimating the policy reaction function and constructing an interest rate based on the parameters from the original Taylor rule with the real-time data. The second paper concerns the evaluation of monetary policy performance based on a model-based simulation approach.

Orphanides (2001) focused on the policy reaction function implementing real-time data, rather than the ex post revised data normally used for the estimation of policy reaction functions. He divided the study into two parts based on the real-time data obtained from the "Greenbook" gathered by the Federal Reserve staff. The first one was to calculate the Taylor rule-based interest rate from this set of data and to compare it with the original Taylor rule (1993a). This approach is comparable to the the historical approach employed by many macroeconomists, e.g. Stuart (1996), Taylor (1999b) and McCallum (2000b). In the second part of Orphanides (2001), he estimated the reaction function with the real-time data, similar to the literature, e.g. Judd and Rudebusch (1998), Kozicki (1999) and CGG (2000).

According to Orphanides (2001), the concern about the validity of the use of final data is justified. Based on the estimation with real-time data, it appears that the parameter in response to inflation is less than unity. In other words, the policy rule is destabilizing when the real-time data are used. The problem is even worse with the presence of interest rate smoothing.

One rationale behind this finding is that the data available to the Federal Reserve at that historical time may be subject to the measurement errors as the data are revised after the initial release. He explored this issue based on two hypotheses explaining the difference between real-time data and final data – i.e. the revisions – in Mankiw and Shapiro (1986)

Orphanides (2001) tested two hypotheses explaining the difference in real-time data versus the final data. The first hypothesis argued that the real-time estimates are, in fact, the true variables measured with error, whereas the second one contends that the revisions contain the useful information and account for "news". The latter also represents the rational forecasts of the true values.

A simple method to test these two hypotheses, suggested by Mankiw and Shapiro (1986) is to calculate the correlations between the revisions with the real-time and final data; if the revisions represent noise, the revisions should be correlated with the real-time values. On the contrary, if the revisions represent news, it is vice versa. The results show that the revisions correlate with real-time data more than the final data both in inflation and the output gap. In other words, the revisions contain noise rather than news. As a consequence, the revised final data used in the estimation could be biased.

Another likely explanation for the difference between the results obtained from real-time data and revised data is that the policy reaction function should be the forward-looking type rule rather than the backward-looking type[56]. As it is well-known that monetary policy operates with lags, effective monetary policy should be sufficiently forward-looking to catch up with the lags. Orphanides (2001) then estimated the forward-looking type reaction function and found that the coefficients in response to inflation and output gap are higher when the target horizon is longer. In addition, he finds that a four-quarter horizon forward-looking reaction function yields the results just slightly different from the original parameters set by Taylor (1993a).

On the other hand, Orphanides (1998) furthered the issue of noisy data in terms of policy performance. He implemented the simulation-based approach,

[56] That central banks should implement monetary policy by looking forward is also advocated by the international evidence in Section 3.4.

analogous to Taylor (1999a) and Williams (1999), to evaluate the efficiency of the policy reaction function when real-time data is employed.

Orphanides (1998) implemented a model similar to Ball (1997) and Svensson (1997) – a backward-looking type model, which is composed of two equations. These include an aggregate supply curve or an "accelerationist" Phillips curve relating inflation to the lags of inflation and the output gap. The other equation is an aggregate demand curve which relates the output gap to its lag and a lag of the deviation of real interest rate from the equilibrium real interest rate. The details of this type of model will be described in Section 5. An efficient policy rule can be obtained by minimizing a central bank's loss function embodying the variability in inflation and the output gap subject to a structural model and a policy rule.

The real-time data was obtained from the "Greenbook" similar to Orphanides (2001). Due to the limitation of the data availability to the public[57], the sample ranges from 1980 to 1992. The frequency of the data is semi-annual[58]. Noticeably, this period contains the extreme disinflation in the beginning of the 1980s.

On the other hand, without the noise, the policy rule estimated from the historical data has been far away from the efficient variability frontier representing a set of efficient policy rules with different central bank preferences on inflation stabilization in the loss function. In other words, there exists some room to improve the policy performance in the US economy. However, the frontier with noise is even further away from the one without noise and the policy rule estimated with the historical data. Therefore, the policy recommendation accounting for noise cannot even accomplish the efficient policy based on the historical data and it is infeasible to reach the optimal policy rules frontier. This can be illustrated in Figure 1.4.

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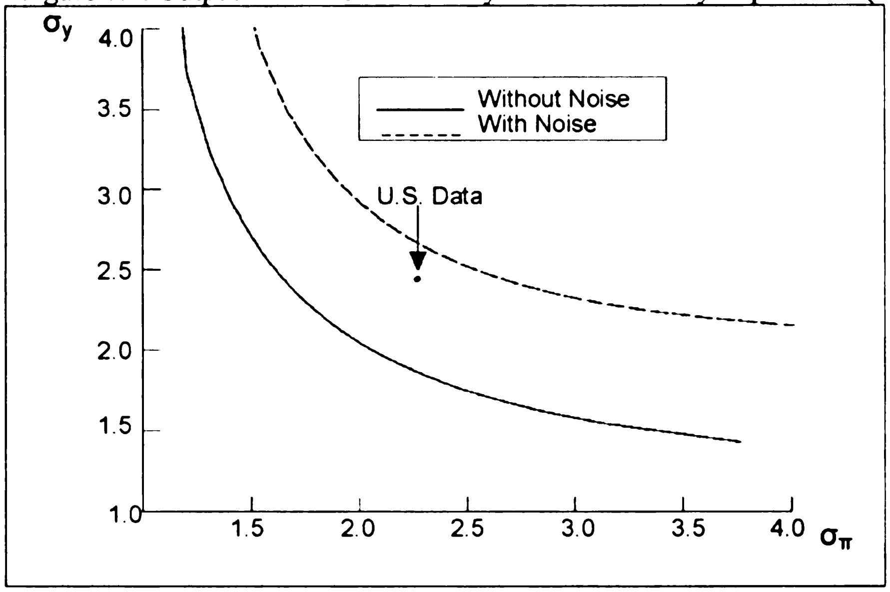
[57] The data used by the Federal Reserve in Greenbook is available to the public with the lag of 5 years.
[58] In Ball (1997), the model was not estimated but calibrated based on the sacrifice ratio of output gap and the inflation dynamic.

Figure 1.4: Output – Inflation variability frontier drawn by Orphanides (1998)



Note: The solid line shows the (infeasible) frontier constructed assuming no noise while the dashed line shows the actual variability with the noise accounted into.

Importantly, Orphanides (1998) found that noise causes the policymakers to consider less weight in response to inflation and the output gap in the policy rule than the one with no noise. It is because the policymakers are aware of the error inherent in their data when they set the policy instrument. As a consequence, they are reluctant to be too aggressive in responding to the economic condition.

An interesting application of the real-time uncertainty is addressed by Orphanides (2003c). He focused on an episode remarked on by Taylor (1999b) as a "policy mistake" in 1960s and 1970s. As pointed out earlier, this period accounted for the "Great Inflation" widely believed to be caused by the policy mistake during Arthur Burns' chairmanship. It was claimed that the Federal Reserve during that time implemented too easy monetary policy. In Orphanides (2003c), he proposed another explanation based on the concept of real-time data to analyze this counterfactually.

Figure 1.5: Simulated and actual inflation based on the Taylor rule by Orphanides (2003)

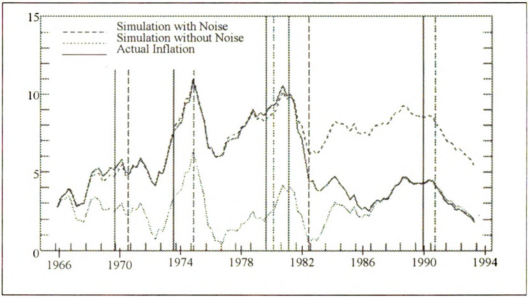
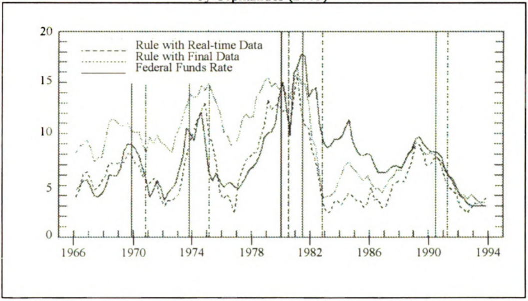


Figure 1.6: Simulated and actual interest rate based on the Taylor rule by Orphanides (2003)



According to the simulation based on the final or revised data, the interpretation from the result conforms to the conventional wisdom that a too mild policy rule was implemented during that time. However, he argued that the simulation accounting for noise in the data yielded the opposite result. Conversely, the Federal

Reserve must have conducted the policy consistent with the Taylor rule, leading to the accelerated Inflation from the late 1960s to the end of 1970s.

Furthermore, Orphanides adds that even though the output gap had already mismeasured considerably in 1965, it was still small relative to the figure in the early and mid 1970s. Nevertheless, the policy rule was tighter in the first half of the 1980s, causing inflation to slow down. These arguments are shown in Figure 1.5 and 1.6.

4.2.2. Model uncertainty

The model uncertainty problem was recognized by economists as early as the study by Brainard (1967) addressing the issue that policymakers make their decisions based on a single reference model and the true economy lies within a specified neighborhood of this model. In the same seminal paper, he investigated an optimal policy rule accounting for the model uncertainty.

Additionally, there are a number of aspects of the uncertainty categorized as relating to the model rather than the measurement of variables as such mentioned in Section 4.1.1. These include the uncertainty about the data-generating process of the exogenous disturbances addressed by Hansen and Sargent (2002), uncertainty about the estimated parameters by Giannoni (2001, 2002), the misspecification errors in the behavioral equations of the model by Onatski and Stock (2002) and Onatski and Williams (2002), whereas Svensson (1997) and Giannoni and Woodford (2003) argued that the optimal targeting rule for a given model has the sufficient characterization to be robust to other model specifications.

In this sub-section, the model uncertainty problem is caused by lack of knowledge about which model among a given set of alternatives provides the best description of the economy. One of the most popularly cited paper is Levin et al (1999). They simulated four forward-looking type models, including the Taylor multi-country model (1993b), the FRB-US model which is a large-econometric model currently used by the Federal Reserve, the Fuhrer-Moore (1995) model and the MSR model used by Orphanides and Wieland (1998). With these types of models, there exists marginal gain in using a complicated policy rule accounting for other variables to explain the economy apart from lagged interest rate, the output gap and inflation. In addition, simple rules are robust to model uncertainty.

They proposed a first-difference interest rate rule rather than a level-based interest rate rule. The first-difference interest rate rule is in fact equivalent to an interest rate rule with the degree of interest rate smoothing near unity. They explain the rationale behind this is that the persistence of the short-term interest rate leads to larger movement of a long-term interest rate, consequently, it stabilizes the economy more rapidly. This was rationalized by Goodfriend (1991) who recognized it as one of the possible causes for the interest rate smoothing behavior by most central banks found in the empirical work.

Levin et al (1999) also argue that interest rate smoothing can help reduce the variability in output in the second period. As a result, it can reduce the initial impact of aggregate demand shocks through the forward-looking nature of aggregate demand in most modern macroeconomic models. In addition, they claimed that complicated policy rules including optimal rules based on the optimization problem were dominated by the first-difference policy rule.

Another important study by Levin and Williams (2001) addressed the issue regarding the robustness of policy rules to model specification when non-nested models represent some controversial issues including expectations formation and inflation persistence. They considered three distinct macroeconomic models as follows. The first one is a pure forward-looking type model in both inflation adjustment and aggregate demand within New Keynesian framework. The second one is the backward-looking model utilized by Rudebusch and Svensson (1999) with inherent inflation persistence. The last one is the Fuhrer (2000) habit persistence model. This model assumes rational expectations and allows large intrinsic persistence of aggregate demand and inflation. Fuhrer's model is a hybrid model incorporating both forward- and backward-looking type models. To derive simple policy rules which are robust to all three models, they used the Bayesian averaging model and minimax methods. These methods are more popular in the recent literature studying model uncertainty.

They argue that focusing on specification errors or parameter uncertainty in the neighborhood of a specific reference model tremendously understates the true degree of model uncertainty. With the Bayesian and minimax methods by treating the model specification as unobservable, this problem will be mitigated.

The Bayesian approach is to assign some weights to the loss functions corresponding to each model specification and sum them up as an aggregate loss function, then minimizing it to obtain an optimal rule. For the minimax approach, Levin and Williams (2001) minimize the maximum of loss function among the macro models in the set. The first and second methods conform to Equation (4.1) and Equation (4.2), respectively.

Equation (4.1) .... $\Lambda^B = \omega_{NKB}\Lambda_{NKB} + \omega_{FHP}\Lambda_{FHP} + \omega_{RS}\Lambda_{RS}$

Equation (4.2) .... $\Lambda^M = \max\{\Lambda_{NKB}, \Lambda_{FHP}, \Lambda_{RS}\}$

where Λ represents a value of loss function;

NKB represents the New Keynesian forward-looking model;

FHP represents Fuhrer's habit persistence model containing both forward- and backward-looking elements;

RS represents the Rudebusch and Svensson's backward-looking model.

The results in Levin and Williams (2001) can be divided into two parts. First, they focus on the conventional optimization problem of a loss function constrained to each model specification. This results in policy rules with different degrees of interest rate smoothing. A "super-inertial" rule[59], i.e. the rule with a degree of interest rate smoothing greater than unity, is an optimal rule in the pure forward-looking model, while it causes instability in the backward-looking model, such as Rudebusch and Svensson (1999)[60]. From Fuhrer's (2000)'s model, an optimal policy rule contains a degree of interest rate smoothing near unity. On the other hand, the optimization of Rudebusch and Svensson's (1999) model yields an optimal policy rule with little or no interest rate smoothing. The difference in these optimal policy rules may be partly due to the expectation channel embodied in the forward-looking model, but not in the backward-looking model.

In the second part, they implemented the Bayesian model averaging and minimax approach. They find that it is always possible to find optimal policy rules that perform very well in a wide range of macro models or robust to model specifications as long as the policymakers have some preference on output gap in their loss function.

Brock, Durlauf and West (2004) emphasized that the policy analysis should not be done by conditioning on solely a specific model but rather should also reflect model uncertainty. They used the Bayesian model averaging methods similar to Levin and Williams (2001) by treating model specification as an unobservable, analogous to any other types of unknowns such as the equilibrium real interest rate or inflation

[59] This "super-inertial" rule was supported by Rotemberg and Woodford (1998) when they optimized their pure forward-looking model.

[60] The instability problem in the backward-looking model such as Rudebusch and Svensson (1999) is not surprising as it was reported in Rudebusch and Svensson (1999) along with the dynamic instability of the first-difference interest rate rule employed Levin et al. (1999).

target. Noticeably, the universe of model specifications in this study contains only Rudebusch and Svensson (1999)'s backward looking model and the hybrid model utilized by Rudebusch (2002). They did not consider the pure forward-looking model used by the modern monetary analysis including Rotemberg and Woodford (1998), unlike Levin and Williams (2001).

Brock et al (2004) supported that the Taylor rule has good robustness properties but the result may differ when incorporating interest rate smoothing. The Taylor rule may be less robust to the model specification, especially in the backward-looking model, relative to the optimal policy rules with interest rate smoothing. Nevertheless, the optimal policy rules always dominate the Taylor rule in the hybrid model which includes the forward-looking type model. This result is comparable to Levin and Williams (2001).

4.3. The zero bound on the interest rate

Recently, an important problem concerning the practical implementation of interest rate rules, such as the Taylor rule, has arisen. Since nominal interest rates cannot fall below zero, there is an implicit zero lower bound constraint in all interest rate rules. This constraint is likely to bind when the economy falls into recession and the short-term interest rate, which is employed as a policy instrument by many central banks, is reduced to near zero percent. As a consequence, interest rate rules will call for further reductions in short-term interest rates to stimulate the economy. However, since nominal interest rates cannot be negative, it is doubtful whether interest rate rules, e.g. the Taylor rule, will still be effective in resuscitating the economy in this case. Much literature regarding the zero bound constraint has been published since the late 1990s.

The zero bound constraint on the nominal interest rate is not a new issue in monetary economics. The origin can be traced back as early as the discussions of the "liquidity trap" following Keynes (1936) and Hicks (1937), even though they are not identical. This issue will be discussed in this section.

Before the end of 1990s, the concern about zero bound constraint problem faded from academic discussions. Nevertheless, a prominent study in this issue during the 1950s and 1960s was conducted by Brunner and Meltzer (1968).

In the late 1990s, the prolonged recession and nominal short-term interest rates near zero in Japan after the collapses of asset price bubbles triggered the *fear* of deflation and ineffectiveness of monetary policy in stimulating the economy. In particularly, an influential study by Krugman (1998) emphasized the issue of the zero bound constraint problem in Japan. Also, several studies matched the recession in Japan to the Great Depression in the US during the 1930s, including Sellon (2003), Orphanides (2002, 2003b). The studies argued that both events were constrained by the zero bound, which hindered interest rate rules to prescribe further reductions in the policy instrument – the nominal short-term interest rate – in order to expand output.

However, the main problem in the US and Japan during those periods, rather, stemmed from not only the zero bound constraint on nominal interest rates but also the weakened banking system that limited the effectiveness of monetary policy. Thus, solely focusing the zero bound constraint as the main problem in those periods might be somewhat misleading. As pointed out by Sellon (2003), one commonality between the Great Depression in the 1930s in the US and the collapse of the asset market in the 1990s in Japan was the weakness of the banking system. Nonetheless, the banking system problem is beyond the scope of the present chapter.

4.3.1. Some interpretations of the zero bound constraint

The term "the zero bound constraint on nominal interest rates" is often interpreted as the "liquidity trap" – the terminology coined by Keynes (1936) and Hicks (1937). In fact, the zero bound constraint is different from the "liquidity trap" in terms of the degree of ineffectiveness of monetary policy. Based on Buiter and Panigirtzoglou (1999, 2003), the liquidity trap is a circumstance in which all channels of monetary transmission are blocked, thus, monetary policy is completely ineffective. On the other hand, the zero bound constraint is a mild case of the liquidity trap since it shuts off only the interest rate channel, which is employed as a conventional transmission mechanism of conducting monetary policy.

Thus, the only case that the zero bound constraint is equivalent to the liquidity trap is if and only if the interest rate channel is the only monetary transmission channel, which is not true in modern monetary policy analysis[61]. Moreover, there exists some evidence that interest rate rules are still effective even when nominal interest rates hit the zero bound, since this is a temporary phenomenon and the economy can recover eventually[62]. Hence, a binding zero bound constraint could be an indicator of a liquidity trap but it does not imply the liquidity trap per se.

Even though it is widely known that nominal interest rates cannot be lower than zero percent, the question is whether the zero bound constraint means literally zero percent or could be any arbitrary value. The answer to this question is based on the substitutability between two assets including money or real balances and a short-term asset. This can be explained as follows.

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[61] It could be the case in the traditional IS-LM model which encompasses only one rate of interest. When the nominal interest rate hits the zero bound constraint, it shuts off the interest rate channel considered to be only one transmission mechanism in this model. Thus, the liquidity trap prevails.
[62] Many studies, e.g. Fuhrer and Madigan (1997), addressed this issue.

Figure 1.7: The call money rate and net borrowing during by NYSE during January 1929 – December 1939 excerpted from Hanes (2004)

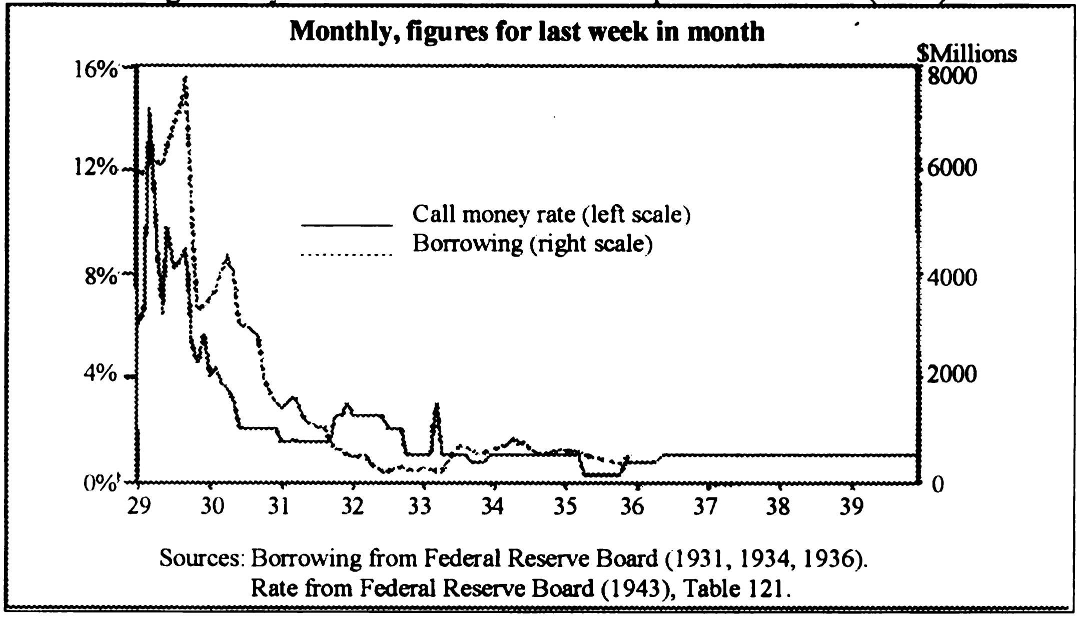
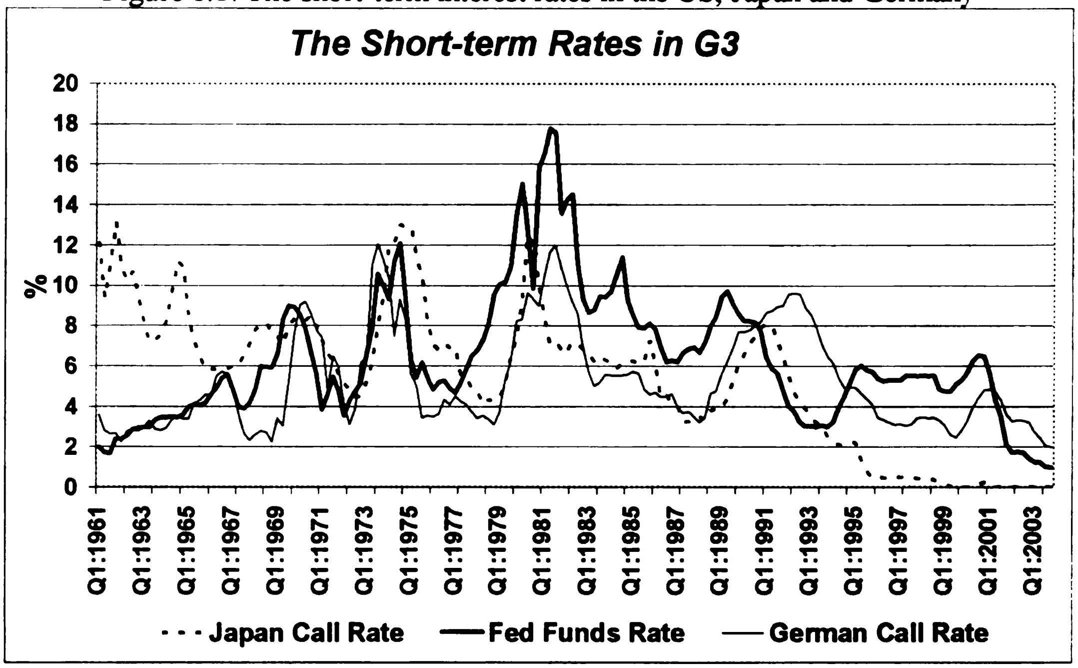


Figure 1.8: The short-term interest rates in the US, Japan and Germany



Suppose that there are two simple assets, real balances which pay a zero return and a short-term risk-free asset say a government bill which pays a positive return. Considering the case in which a nominal interest rate is bounded at zero and real balances can always be substituted for the short-term asset, neglecting all the transaction costs and other fees attached to real balances, the short-term asset cannot offer a return below zero. Otherwise, the public substitutes the risk-free asset which pays a negative return by real balances, which pay a zero return. In addition, the zero bound is literally zero in the "cash-in-advance" model studied by Cole and Kocherlakota (1998) when the marginal service becomes zero beyond some quantity of real money balances and assuming that there is no cost of carry, then the nominal interest rate could hit the zero bound but people feel indifferent between holding cash or bonds.

Nevertheless, if there is some cost in storing money such as costs of storing the real-balances in a vault or the cost of withdrawing cash from a bank, the short-term asset can offer a slightly negative return as long as it is still higher than the costs of carrying cash. In this case, the floor of the nominal interest rate can be slightly lower than zero.

Finally, it is also possible that real balances carry some services unavailable to other assets, such as the service of cash used for illegal economic transaction (Yates (2002)) or other non-pecuniary benefits (McCallum (2000a)). In addition, if there are some transaction costs, such as portfolio maintenance or brokerage fees attached to the short-term assets, these costs can lead to the unsustainable nominal interest rate floor at zero percent since the short-term assets must offer at least some positive return relative to their costs to attract the public to hold them.

However, if nominal short-term interest rates approach zero percent, it would cause the federal funds or other inter-bank markets to collapse. Therefore, the first and second rationales to support the zero percent or slightly negative floor of nominal interest rates might be groundless in these circumstances.

4.3.2. Mechanism of the zero bound constraint

Basically, a zero lower bound constrains interest rate rules to prescribe a zero rate whenever the rules call for a negative value. The question of how it happens has been addressed by two strains of the literature. One explains the mechanism of the zero bound constraint independently of the inflation target: a higher inflation target is not necessary to reduce the risk of hitting the zero bound. By contrast, the other strain points out that the higher the inflation target, the lower is the risk of hitting the zero bound in the economy.

The studies, addressing the mechanism of the zero bound constraint not depending on the inflation target, are Benhabib et al (1999, 2002) and Buiter and Panigirtzoglou (1999). These studies explain that the main factors contributing to the zero bound binding are policy rules that the central bank commits to and the expectation of the public concerning inflation.

According to interest rate rules, e.g. the Taylor rule requiring the slope or the coefficient in response to inflation be greater than unity, there exists an equilibrium at some positive inflation rate – a positive equilibrium. To attain this equilibrium, the current inflation must jump to the neighbourhood of the positive equilibrium, corresponding to π^*. In contast, Benhabib et al (2002) observed that with the zero bound constraint, another equilibrium emerges. This equilibrium is located in the negative inflation region, consistent with π^{**}. Because the positive equilibrium is a saddle point, any values in the neighborhood lower than the positive equilibrium, e.g. π_0, leads to the lower or negative equilibrium and the *nominal* interest rate is stuck at zero since the nominal interest rate cannot fall below zero percent even though the rule prescribes a negative interest rate. This is illustrated in Figure 1.9.

At π_0, inflation is lower than π^*. Only if the initial value is π^* will equilibrium inflation be π^*. In contrast, in a neighborhood around the deflationary equilibrium π^{**}, there are many equilibrium paths consistent with a perfect-foresight equilibrium. In this case, sunspot equilibria are possible, given this non-uniqueness or indeterminacy. For more details the model is explained nicely in Walsh (2003).

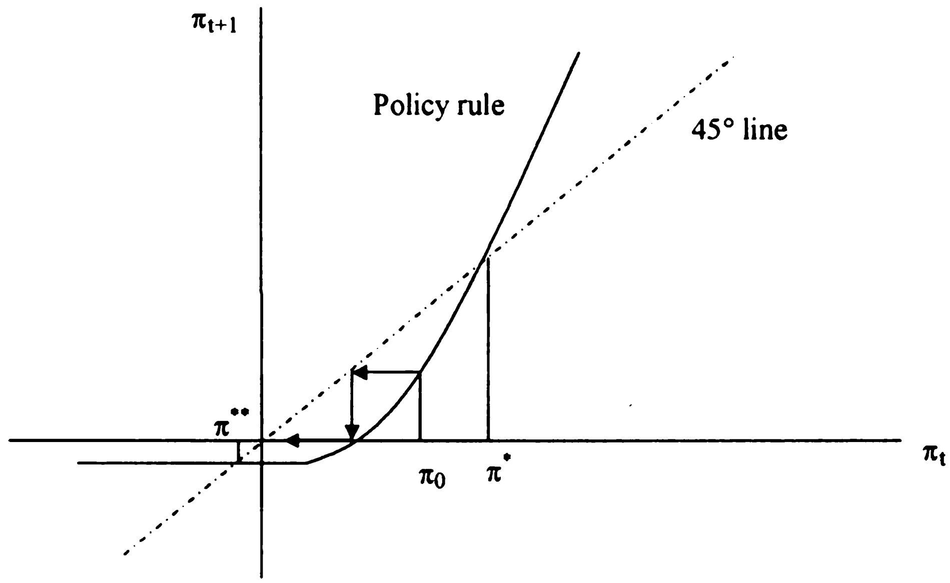


Figure 1.9: The Dynamics of the zero bound constraint

Another study of the mechanism leading to the zero bound constraint binding is examined by Reifschneider and Williams (2000). This mechanism depends on targeting inflation rates as well as average real interest rates. They started with a small backward-looking model similar to Ball (1997) and Svensson (1997), composed of an aggregate demand – IS curve, an aggregate supply – accelerationist Phillips curve, a policy rule – mainly the Taylor rule in the paper and the zero bound constraint – the condition calls for a zero rate whenever the Taylor rule calls for a negative nominal interest rate is prescribed a negative value by the Taylor rule.

Based on this model, two steady state equilibria can be derived; namely, high and low steady state equilibria. The lower one separates the region of instability and conditional stability in which any initial point will be constrained at zero interest rate for a period of time before converging towards the equilibrium. In other words, the low steady state equilibrium is a saddle point. A different initial value from the equilibrium leads to the divergence from the equilibrium or leads to a "deflationary spiral". Therefore, with the presence of lower equilibrium, the "liquidity trap" is a possible trajectory.

From this mechanism, it is worth pointing out that the multiple-equilibria occur as a result of the zero bound constraint. If there is no zero bound constraint, the slope of the aggregate demand function does not kink and change the sign, only one equilibrium at E_1 emerges[63]. The dynamic analysis is analyzed thoroughly in Reifschneider and Williams (2000) as well as Chapter 2 of this dissertation.

Therefore, the zero bound constraint leads the monetary policy design to be more complicated as it adds non-linearity (of the policy rule) into the model. Central banks have to take the risk of the zero bound constraint binding when setting policy rule, specifically when they target low inflation and consider the aggressive policy rule in response to inflation. If they set it too low, e.g. price stability level or zero inflation and/or assign very high coefficients in response to inflation, the central banks may encounter the zero bound constraint and may not be able to accomplish their macroeconomic goals because the policy rules with the zero bound constraint binding increase unconditional variance of inflation and the output gap, instead of lowering the variance of these two variables as of the fundamental purpose of policy rules.

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[63] Since Ball's (1997) and Svensson's (1997) model are linear in variables, the solution is in linear too. The discussion of this model will be elaborated in detail in Section 5.

4.3.3. A zero bound constraint on nominal interest rates in retrospect

From the historical perspectives, two economic events can be considered as the experience of the zero bound constraint problem. These include the Great Depression in the 1930s and the bursting of the asset price bubble in Japan at the end of the 1990s. Even though the zero bound constraint had a large effect on short-term financial markets in those periods, the central banks in both the US and Japan could still conduct monetary policy effectively but with procedures other than targeting short-run interest rates. Thus, it is hard to accept that both countries experienced a "liquidity trap" as claimed by many researchers.

In the US, the Great Depression era was exacerbated by two events of monetary policy implementation by the Federal Reserve. The first one corresponds to the initial period of the Great Depression in 1929-33. The widely believed cause of the Great Depression was the failure of the Federal Reserve to actively ease policy in response to an enormous decline of money supply at that time. The second event conforms to the return to recession during 1937-38 after the economy had slightly improved earlier. The cause of the recession in this period was blamed on doubling of the reserve requirement ratio by the Federal Reserve to fight against the inflationary pressure caused by the enormous gold reserve inflows.

However, Sellon (2003) pointed out that during the Great Depression the quantity of reserves via the discount window and open market operations were targeted by the Federal Reserve, rather than a short-term interest rate, which was instead employed as just a measure of the stance of monetary policy. Therefore, the Federal Reserve was not constrained by the zero bound on nominal interest rates.

Also, there is little evidence that the liquidity trap prevailed in the US economy during that time since the Federal Reserve successfully eased monetary policy by expanding the amount of reserves in the banking system and expanded its purchases of longer-term government securities after 1933. As a consequence, bank credit was expanded and the purchases of longer-term securities helped decrease longer-term interest rates.

Nonetheless, the excess reserves held by banks, also increased along with total reserves. It indicated some difficulty in targeting the quantity of the reserves in light of low interest rate environment and more importantly a weakened banking system.

After the collapse of the housing and stock market price bubbles in the late 1980s, Japan experienced a binding zero bound constraint. However, Japan's problem was more difficult to cope with than the US case due to the policy procedure of targeting interest rates directly and the policymakers' hesitation in adopting new policy procedures. However, the events in Japan and the US share some commonality in terms of weak banking systems which deterred the effectiveness of monetary policy.

In 1995, the Bank of Japan (BoJ) began to target an overnight interest rate, in light of extremely low short-term rate. After the overnight interest rate had been lowered in the wake of the Asian financial crisis, Japan encountered the zero bound constraint problem for the first time in February 1999, leading the BoJ to adopt the "Zero Interest Rate Policy" or ZIRP by maintaining the short-term interest rates at the target of 0%. However, after experiencing an improved economic outlook and concerns about the distortions of the zero lower bound on financial markets, the BoJ abandoned the ZIRP by raising the target short-term rate by 0.25% in August 2000. Thereafter, the economy returned to recession. In March 2001, the BoJ lowered the target rate to zero percent and they were, eventually, forced to alter the policy procedure radically, owing to deflationary pressure and a still more severe recession.

The new procedures include the "quantitative easing", which is a variant of reserve targeting procedure, combined with large purchases of long-term government securities. Along with these procedures, the BoJ also stated the exit strategy of the current policy procedures more explicitly, compared with the period of ZIRP during 1999-2000, in which the BoJ did not plan for the end of the ZIRP. This issue is important in terms of the credibility of the BoJ in implementing monetary policy because the public could be ensured that the BoJ would tighten monetary policy whenever the inflation would be perceived as a problem.

There is still some doubt about the effectiveness of the new procedures. After the collapse of the asset price bubbles, the banking system in Japan has been swamped with non-performing loans as a result of a number of failing and undercapitalized businesses and their debts. Furthermore, the circumstance was more distressed than that of the US. The BoJ was crippled by extremely low long-term interest rates, in contrast to the US case during the Great Depression in which it was still possible to reduce long-term interest rates.

For this reason, the quantitative easing might not help resuscitate the economy since overall bank credits did not expand much. This ineffectiveness may have been a result of banks' unwillingness as well as inability to expand credits. The evaluation of this policy is addressed thoroughly in Bernanke et al (2004).

In sum, the historic evidence shows that the zero bound constraint was more problematic in Japan during the 1990s rather than in the US in the 1930s due to the monetary policy procedures they were implementing. While the US adopted the reserve targeting procedure *before* and *after* short-term interest rates approached a zero rate, Japan chose the interest rate targeting procedure, in spite of extremely low short-term interest rates and altered to the reserve targeting when the zero bound was hit and the economy was still in severe recession.

4.3.4. The effects of the zero bound constraint on the monetary policy design

In this sub-section, the effects of a zero bound constraint are evaluated by simulation methods. The first thing needed is to construct a model based on either empirical or theoretical foundation grounds, and then attain the residuals corresponding to each structural equation in the model either by estimation or calibration. At this stage, the policy rule is put aside. Afterwards, a set of random shocks conforming to the distribution of the residuals obtained earlier are drawn and model is shocked. The calculation will be carried out iteratively until the end of the sample, along with the policy rules imposed at this stage. This is one simulation. The number of simulations can be carried out as many times as necessary. At the end, the unconditional variance and the probability of hitting the zero bound and the deflationary spirals can be inferred.

The literature employing this approach include Fuhrer and Madigan (1997), Orphanides and Wieland (1998) (OW), Reifschneider and Williams (2000) (RW) and Hunt and Laxton (2002) (HL). The thorough review is in Yates (2002) and Chapter 2 of this dissertation.

A simulation procedure mainly depends on four factors; namely, the distribution of shocks, an assumed equilibrium real interest rate, the policy rules implemented in the model and the structural models used in the simulations. The second factor was discussed earlier in Section 4.1.2, and the equilibrium real interest rates employed in OW (1998), RW (2000) and HL (2002) are all different. While the first study derives the equililibrium real interest rate from a model, the latter two implement simple averages of their whole samples.

The distribution of shocks is another important factor in the simulation-based exercises since the simulations are based on the shocks drawn from a certain distribution which is consistent with the distribution of the shocks inferred from the estimated model. Thus, the distribution of shocks determines the distribution of desired interest rate. When it is unknown, the uncertainty in drawing any inferences from the distribution of the desired interest rate occurs, leading to the possible non-robustness of the assessment of risk of nominal interest rates hitting the zero bound constraint.

Regarding the policy rules issue, I will narrow the scope to just the Taylor-type rules. These policy rules are mainly composed of the constant part – the real interest rate and inflation targets which cannot be separately determined and the feedback – the coefficients in response to inflation and the output gaps.

Even though more aggressive interest rate rules in response to inflation, such as Henderson and McKibbin (1993), can shrink the unconditional variances of inflation and output gap in the loss function, Reifschneider and Williams (2000) show that it is not the case when targeted inflation rates are lower, specifically lower than 2%. This is because the risk at hitting the zero bound constraint deters any further reductions of nominal interest rates whenever being called for by the rules.

The last factor is the structural models used in the simulations. In spite of the differences in the structural models employed in OW (1998), RW (2000) and HL (2002)[64], the results are close to each other. Their results can be summarized as follows.

[64] OW employed the small rational expectation model similar to Fuhrer and Madigan (1997), while RW used the FRB/US model – the large macroeconometric model currently used by the Federal Reserve. For HL, they employed MULTIMOD – used by IMF – to focus on Japan which experienced the zero bound constraint recently. In addition, MULTIMOD is a multi-country macroeconomic model allowing the interaction between the countries and regions, compared to the small rational expectation model

OW (1998) implemented three types of policy rules in their simulation. The baseline policy rule is an estimated Taylor-type rule, while the others include the original Taylor rule and the Henderson and McKibbin rule (HM). These rules follow a formulation similar to Equation (3.10) but with the lagged inflation and the output gaps instead of the contemporaneous variables as in Taylor (1993a). For convenience, it is re-written as follows

Equation (3.10) .... $i_t = r^* + \pi_{t-1} + \gamma(\pi_{t-1} - \pi^*) + \varphi x_{t-1}$

where i_t is the federal funds rate,

r^* is an equilibrium real interest rate which is assumed to be 1% estimated from the small rational expectation model they used, compared with 2% originally employed by Taylor (1993a)

π_t is an average inflation rate over the contemporaneous and prior three quarters (GDP deflator),

π^* is target inflation rate which is assumed to be 2% in the original Taylor rule in 1993

x_t is output gap, i.e. the difference between the actual real GDP and the potential output, which was measured by the potential output released by Congressional Budget Office.

The Taylor rule corresponds to the coefficients on inflation of 1.5 and the output gap of 0.5 while HM contains the coefficients in response to inflation and the output gaps of 2 equally. Therefore, the only difference in the HM rule from the Taylor rule is that the former is more aggressive in response to inflation and the output gap. Based on the study by Williams (1999) and Orphanides et al (1999), the

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which is a closed-economy model and the FRB/US model which focused mainly on the US while taking the foreign sector as given.

HM rule can lower the variability of inflation and the output gap by accepting greater variability in the short-term interest rate which is the policy instrument. But this finding based on the circumstance that the zero lower bound is not a concern.

RW (2000) also implemented the Taylor rule and the HM rule in their simulations. They set the equilibrium real interest rate as high as 2.5%, corresponding to the historical real interest rate the period of 1960-1998, compared to 1% by OW and 2.2% by HL. For HL, they implemented just the Taylor rule as the baseline policy rule and also modified the coefficients on inflation and the output gap to be more aggressive but different from the HM rule. Moreover, both RW and HL utilized the contemporaneous data of inflation and the output gaps rather than the lagged ones like OW.

All studies illustrated the dynamic responses of the variables by entering a negative shock to aggregate demand and the price adjustment function. In many cases, with a sufficiently large negative shock[65] coupled with a low inflation target, the Federal Reserve would want to simulate the economy by reducing the federal funds rate target, but this is infeasible when the zero bound constraint is binding. As a result, the federal funds rate is too high, relative to the policy rule excluding the zero bound constraint. The nominal interest rate stays at zero percent for awhile before the economy recovers adequately to call for some positive value due to the inflationary pressure.

Nevertheless, with a sufficiently high inflation target (2%), the distributions of interest rates are stationary and inflation and output have properties similar to those that obtain when the zero bound constraint does not bind. With inflation targets near

[65] A sufficiently large negative shock means the adverse shock which leads to the zero bound constraint to bind but not so large as to trigger a deflationary spiral and the nominal interest rate stuck at the zero bound forever.

zero, the asymmetric nature[66] of the constraint induces the policy to set the short-term interest rate with a significant bias. In other words, the stationary distributions of inflation are skewed to the left whenever the inflation target is lower than 2%, while the distributions of interest rates pile up around zero percent with low inflation targets.

The reason for this is that the constraint distorts the policy rule such that whenever it calls for a negative value the interest rate is instead set at zero, thus the policy rule is tighter, relative to the unconstrained policy rule. In other words, the policy is subject to a series of positive "shocks", according to RW (2000).

Comparing the policy rules with different degrees of aggressiveness in response to inflation and the output gaps such as the Taylor rule and the HM rule, the frequency with which the zero bound constraint binds and the distortion in the distribution of the nominal interest rate is much smaller in the less aggressive one, i.e. the Taylor rule. Apart from the higher frequency of hitting the zero bound constraint of the HM rule, OW (1998) shows that the HM rule causes the economy to spend more time in recession than the Taylor rule at the inflation target of 0%. In contrast, the HM rule leads to less persistent recessions than the Taylor rule when the zero bound constraint is not binding.

OW (1998) also shows the efficient frontiers, which represent the welfare loss due to the variability of inflation and the output gap, is higher or shifted to the northeast – the policy frontier with a binding zero bound constraint is less efficient than the unconstrained one in terms of higher inflation and the output gap variability, especially when the inflation target is lower.

[66] Recall that the zero bound constraint limits just the downside of the interest rate, it would be in effect only if the interest rate called for is infeasible due to non-negativity property of the nominal interest rate. On the other hand, increasing the interest rate is always possible as there is not limit for that. Therefore, the zero bound constraint causes asymmetry on the policy rule.

Finally, OW (1998) argue that the presence of the zero bound constraint can invalidate superneutrality of the monetary policy in the long-run, i.e. the long-run Phillips curve is not vertical. Consequently, welfare analysis regarding the optimal choice of inflation target should take the zero bound constraint into account since a more aggressive policy will not necessarily lower the variability in inflation and output gap when the zero bound constraint is binding and the inflation target approaches zero percent.

RW (2000) used the FRB/US model to simulate the effect of the zero bound constraint. It is a large-econometric model currently used by the Federal Reserve and requires large computational power, compared to the smaller forward-looking model used by OW (1998).

They illustrate that if the equilibrium real interest rate is high, either the inflation target can be set high or low because it does not affect the capability of central banks in setting a nominal interest rate. On the other hand, if the equilibrium real interest rate is low, the inflation target cannot be set too low as the capability of the central banks is limited in setting nominal interest rates especially, owing to the zero bound constraint.

HL (2001) also focus on the same issue as OW (1998) and RW (2000) but they address the issue particularly in Japan which experienced a binding zero bound constraint recently. With their multi-country model, they obtain results mostly similar to the earlier studies that with the inflation target below 2%, the zero bound constraint has a large effect on the policy rule implementation since it deters the monetary authority in setting a nominal short-term interest rate in response to inflation and the output gaps whenever the policy rule prescribes the nominal rate lower than zero percent.

Moreover, HL (2001) study uncertainty in potential output, considered as a large source of uncertainty in the simulation-based studies. They find that for a given target rate of inflation, the probability of hitting the zero bound constraint increases whenever the uncertainty in potential output is embodied. Additionally, the probability increases if the errors in potential output are persistent and correlated with the business cycle.

The problem of the binding zero bound constraint is aggravated when uncertainty in potential output is taken into account because policymakers hesitate to ease aggressively when deflationary shocks hit the economy since they are not certain whether potential output is correctly measured. As a result, more deflationary pressure would be built into the inflation expectations. The greater pressure requires a larger future reduction in short-term nominal interest rate to counteract inflation. At each point in time, the public anticipates this policymakers' underestimation of the magnitude of the output gap, consequently, it magnifies the extent of deflationary pressure in expectations.

In addition, HL (2001) divide the effects of increasing the aggressiveness of the policy rules in response to inflation and the output gaps on the frequency of hitting the zero bound constraint into two opposite effects; namely, that it increases the frequency of the zero bound constraint binding and that it can avoid hitting the zero bound constraint prior to taking effect. In the latter effect, the more aggressive rules normally prescribe a large reduction in nominal interest rate and can prevent the recession beforehand. However, in most cases the first effect dominates the second.

Finally, all studies recommend that setting a sufficiently high inflation target is an optimal strategy for preventing the zero bound constraint from binding.

4.3.5. The risk of hitting a zero bound constraint on policy design

Based on the simulations in the studies above, all agree that the zero bound constraint becomes a concern when the inflation target is below 2%, while the probability of hitting a zero bound constraint is marginal at an inflation target equal or higher than 2%. Furthermore, the relationship between the inflation target and the frequency of hitting the zero bound is non-linear. The chance of the zero bound constraint binding *exponentially* increases along with declining inflation targets.

Table 1 shows the results obtained from the studies on the probability of hitting a zero bound constraint. However, Yates (2002) re-simulated some models by setting the same equilibrium real interest rate as well as implementing the same policy rules including the Taylor rule[67] in order to compare across the models used in OW (1998), RW (2000) and HL (2002). From Table 1.17, the probability of hitting the zero bound constraint ranges from about 7-14% depending on which models used in the assessment.

Table 1.17: Estimates of risk of hitting the zero lower bound gathered by Yates (2002) (percent of time spent at a zero rate)

Model	0	0.5	1	1.5	2	2.5	3	3.5	4
Orphanides and Wieland (1998)	7	3	1	<1					
Reifschneider and Williams (2000)	14		9		5		1		<1
Hunts and Laxton (2002)	9	5	2		1				

Note: -For Orphanides and Wieland (1998), Yates employed 1.5% of interest rate, instead of original 1% and he imposed the original Taylor rule as the policy rule in the model.

- For Hunt and Laxton (2002), simulated the MULTIMOD model for Japan, which is the large cross-country econometric model used by the IMF. They assume a real rate of 2.2%, however, they note that these figures underestimate the risk of hitting the zero bound constraint.

In addition, the probability of falling into a deflationary spiral is trivial. HL (2001) reported that the economy is unlikely to fall into a deflationary spiral when

[67] Recall that the equilibrium real interest rate used in OW is as low as 1%, while it is set at 2% in HL (2001) and 2.5% in RW.

targeting inflation rates at 2%. Likewise, the chance of falling into a deflationary spiral increases along with the declines of inflation targets.

4.3.6. Alternative policies during the zero bound constraint binding

Even though the risk of the zero bound constraint binding is small at the higher inflation target and it increases significantly when the inflation target is lower, there is still a chance of it happening. When the zero bound constraint is inevitable, policymakers have to be prepared by having alternative policies which can work in this circumstance.

The alternative policies can be divided mainly into two strains: modification of the existing policy rules, i.e. modified Taylor rules, and use of different instruments or transmission mechanisms which do not depend on the interest rate channel. These alternative policies include quantitative reserve targeting policy, managing market expectations about future policy, large purchases of the long-term government or private assets, Gesell money or taxes on carrying money, exchange rate intervention and capital market stimulation.

The review of the alternative policies listed above is based mainly on the studies by Yates (2002) and Sellon (2003). Note that I will not delve into fiscal policy since the present chapter mostly addresses monetary policy. A good discussion about fiscal policy can be found in Buiter and Panigirtzoglou (1999) and Auerbach and Obstfeld (2004).

4.3.6.1. The modified Taylor rule and its variants

The literature studying to the first type of alternative policies include RW (2000) and HL (2001). They modified the policy rule by adjusting for the bias posed by the zero bound constraint discussed in Section 4.3.4. In RW (2000), they augment the Taylor rule with some adjustments in terms of a cumulative variable[68] of which the effects are intense immediately before and after the zero bound constraint binding. In particular, the adjusted policy rule allows policymakers to keep the short-term interest rate unusually low for a period of time and implement the original Taylor rule when the zero bound constraint is not a concern. This adjustment also offsets the upward bias of the interest rate prescribed by the zero bound constrained policy rules[69].

With the RW's (2000) adjusted rule, the central banks are able to compensate for their inability in operating through the interest rate rule when the zero bound constraint binds by affecting the expected short-term interest rate. By this method, the central bank commits to ease the policy stance in the future. Also, this adjusted policy rule may reduce the current level of the long-term interest rate even though the short-term interest rate is stuck at zero percent. The idea of exploiting the credibility of central bank in maintaining easy monetary policy to raise the expected inflation underlies Krugman's (1998) recommendation for the policy design in Japan.

HL proposed an alternative policy by suggesting the central bank intervene after the zero bound constraint binds for a period of time, while following the Taylor rule or other policy rules when the zero bound constraint is not the problem. Note that it is one type of the discretionary policy, whenever the zero bound constraint binds. The intervention can be implemented in one of the three ways; namely, an increase in government spending (fiscal policy), a credible commitment by the monetary authority to reverse the falling price level due to the deflationary pressure, i.e. price level targeting policy; and a sharp depreciation in the currency combined with a

[68] This cumulative variable is a result of accumulating the deviation of the unconstrained rule-based interest rate from the actual nominal interest rate in the last period.
[69] In other words, the policy rule always prescribe too high (higher than negative values) interest rate, when the zero bound constraint is binding.

credible commitment to a temporary price-level target, which is similar to the one suggested by Svensson (2003). In their simulation all the interventions are successful. Next the alternative policies operating through other transmission mechanisms apart from the interest rate channel will be discussed.

4.3.6.2. Quantitative reserves targeting

A simple solution to the zero bound constraint is that central banks may shift to target the amount of reserves provided to the banking system. The reserve targeting policy was earlier used by many central banks including the Federal Reserve during the experimentation on non-borrowed reserve targeting regime during 1979-1982, the Bank of Japan before 1995 and the Bundesbank prior to the establishment of the European Central Bank in 1998.

The strength of this policy is that a number of central banks have some experience in implementing it. Thus, the transition to this policy incurs a lower cost, in terms of welfare loss, than that of the transitions to other policies. As argued by McCallum (1988) and the monetary base supporters, the monetary base or reserves are on the central banks' balance sheets, consequently, they can monitor and control them easily. Besides, some central banks, such as the Federal Reserve, currently announce their monetary base target[70] along with the short-term interest rate target, therefore, the transition to the reserve targeting policy can be done without any delay.

Nevertheless, a main practical problem in this policy is the uncertainty about the money demand function, relating the reserves expansion to interest rates. Determining the amount of reserves needed to stimulate economic activity is more difficult. By contrast, interest rate rules do not require any information about money demand in determining economic activities, as long as the central bank can provide

[70] Recall that it does not mean that the central banks operate through the reserve targeting procedure. They can only use some rules such as the McCallum rule to calculate the target.

the reserves to maintain the interest rate target prescribed by the rules. Such a gain of the interest rate rule is a key reason why many central banks adopt an interest rate as the policy instrument.

Another drawback of this policy is that banks obviously have no incentive to lend their excess reserves in the inter-bank market when the zero bound constraint is binding. As a result, banks choose to hold these excess reserves rather than expanding their credits or purchasing any short-term securities which pay zero returns, which happened in Japan recently. In this circumstance, the banks can defer their excess reserves to invest in short-term securities after the zero bound constraint is not binding without fixing the funds with long-term instruments. Nevertheless, if the banks view the constraint as permanent, they will lend out their funds or purchase other risk-adjusted assets, including longer-term securities which still pay positive returns since the banks can earn some positive returns from the longer-term maturities rather than leaving the excess reserves idle. Thus, a requirement for this policy to work is that banks must believe the additional excess reserves injected into the banking system by the policymakers are long-lasting.

Finally, one may raise some doubt about whether it would be possible to encourage the banks to expand their credit to firms or consumers in light of the recession. During the economic slowdown, aggregate demand is weak. Even though the supply of reserves increases in the credit market, the demand for reserves may not sufficiently fulfill the supply and cause additional excess reserves to be left unexpanded.

4.3.6.3. Money Rain[71]

Another option of the central bank when it is constrained by the zero bound is to inject money into the economy in order to increase public wealth and stimulate consumption and aggregate demand directly without exchange for the debt instruments (unlike the reserve targeting). Money rain will lower actual real rates relative to their equilibrium and raise expected inflation, as a consequence, the aggregate demand expands.

Compared to the reserves targeting policy, money rains share some commonality with it in terms of injecting money into the economy. However, the difference is in the transmission mechanism that each policy works through. Reserve targeting works via the banking system while money rains works via the public.

Nevertheless, one may question the practicality of transferring money to the public since there lacks of the channel through which the central bank can transfer money to the public directly. In this case, some economists including Yates (2002) say that, in the modern financial economies, the money can be transferred easily into individuals' bank account directly since almost everybody has a bank account. Those, who do not have accounts at commercial banks, regularly have benefit accounts, in which government benefits such as unemployment benefits or the like are distributed. Thus, there should not be any problem if the central bank were to use the money rain to create the public wealth.

On the contrary, Clouse et al (2000) contend that the direct transfer by the central bank, in particular the Federal Reserve as mandated by the Federal Reserve Act, is infeasible in practice since the Act requires that any transfers to the public by the Federal Reserve must either be expenses or be transfers from the surplus funds for

[71] It is similar to Friedman's concept of the "helicopter drops".

the specific purpose, i.e. in the event of dissolution or liquidation of the Federal Reserve Bank, which is not the case for the money rain.

Another issue concerns whether some welfare loss increases or not since government interferes in the wealth distribution with this method. However, the policymakers can gather all wealth information about the public easily from the existing system in the financial institutions such as the amount of tax on wealth including capital gain, dividend, or interest, etc. Therefore, the policymakers can compare between the costs of gathering the information on the wealth distribution and the gain from the money rain.

Bryant (1999) and Goodfriend (2000) advocate the idea of monetized tax cuts – the governmental spending financed by the central bank's money rather than taxes. They argue that this method is more practical than the money rain. However, the monetized tax cuts may contradict to the independence of the central bank in conducting their own policies.

Another important issue is the magnitude of the wealth effect caused by the money rain since the money transfers which are not permanent and will be reversed at some point in the future have no wealth-stimulating effects on a private sector that faced no credit constraints - Goodfriend (2000).

4.3.6.4. Targeting longer-term interest rates

One of the traditional remedies for the zero bound constraint is to target longer-term interest rates. There are mainly three approaches to affecting long-term interest rates; namely, purchasing large amounts of longer-term securities to drive up the price and push down the yield, establishing a ceiling on the yield of these securities by promising to buy the long-term securities as long as the interest rates are higher than the ceiling, and twisting the term structure of interest rates by selling the short-term securities while simultaneously purchasing long-term securities. Many researchers support long-term market manipulation including Goodfriend (2000) and Orphanides (2003b).

The rationale behind targeting long-term interest rates is that long-term interest rates relate to real economic activity more closely than the short-term ones. Even though central banks can affect the long-term interest rates, central banks cannot target long-term rates directly owing to the lack of the information concerning the term structure of interest rate and the exact amount of the long-term assets to purchase to affect the long-term rates. Yet, central banks also need the information on which maturity that they have to operate in[72] to affect the whole structure of interest rates most effectively.

Moreover, central banks may be reluctant to purchase a large amount of long-term securities due to guaranteed large potential capital loss in the central bank' portfolio when the economy recovers. As a consequence, the credibility and independence of the central bank may deteriorate since it tends to sell its long-term securities held in the portfolio whenever the economy is about to recover, causing the prices to fall (the yields rise). As a result, it may slow the economic recovery. Nevertheless, the potential capital loss in the long-term portfolio can be mitigated by twisting the yield curve – purchasing the long-term securities and selling the short-term ones at the same time.

Purchases of longer-term securities can alternatively be viewed via the *portfolio balance channel.* The transmission mechanism essentially assumes that real balances, short-term securities and long-term securities are *imperfect* substitutes.

[72] Orphanides (2003b) proposed that the central bank can move from targeting the short-term interest rate, which is zero along a yield curve, to the adjacent longer-term securities which are still positive and pressure the longer term interest rates down until they approach the zero bound, then move again to the longer-term ones with positive returns.

Goodfriend (2000) argues that the central bank can increase the volume of "broad liquidity services" in any security through open market operations. The liquidity that the central bank injects into the economy will be used to re-balance the private sector's portfolios, given that they are initially optimal. Since the liquid assets including short-term assets, paying a zero return, are perfectly substituted by money and the long-term securities pay smaller returns after the absorption of the central bank in the liquidity injection, the private sector will rebalance its portfolio by buying other illiquid assets including consumer durables, physical capital and claims to intellectual and organizational capital. This attempt will bid up the prices of other illiquid assets. As a result, the yields on those assets decline. The idea can also be applied to other assets not just the long-term assets but other private assets or even foreign assets.

Historically, the Federal Reserve has relatively little experience in manipulating long-term securities markets. In the 1930s, the Federal Reserve attempted to lower the long-term interest rates by purchasing long-term securities and simultaneously selling short-term securities for the purpose of reducing long-term interest rate volatility. Moreover, in the 1960s during the Kennedy administration, the Federal Reserve twisted the yield curve to handle balance of payment and debt management problems. Noticeably, all the operations conducted by the Federal Reserve in the past were not intended to reduce the long-term interest rates, they were for other specific purposes. Thus, there was no historical evidence to support the effectiveness of targeting long-term interest rates.

In Japan, after the Zero Interest Rate Policy (ZIRP) was abandoned in the beginning of 2001, the Bank of Japan manipulated long-term government securities parallel to the quantitative easing. However, the long-term interest rates in Japan were extremely low and there was not much room to reduce them, unlike in the period of Great Depression in the US. Hence, the problem in Japan was more difficult than that of the US during the Great Depression since there were fewer options to handle the economic slowdown given the low interest rate environment.

4.3.6.5. Managing market expectations about future policy

According to the term structure of interest rates theory, a long-term interest rate is composed of two components: the expectation of future short-term interest rates and a term premium. The first component is based on the public's expectations on the central bank's current and future policy stances, given other factors. The central bank can also affect the long-term interest rates through a term premium by decreasing the uncertainty about its the future policy stance. Thus, the central bank can affect long-term interest rates by the expectation channel, rather than targeting long-term interest rates directly.

When the zero bound is *not* a concern, the central bank can signal its future policy stance by cutting or raising short-term interest rates continuously which would affect the expectation of the future short-term interest rate and subsequently long-term interest rates. This is not the case when the zero bound constraint is binding. Instead, the central bank can signal its policy stance by using statements promising to ease monetary policy as long as the economy is still in recession.

However, this type of promise or commitment reduces the flexibility of monetary policy. A solution is an open-ended statement, which is more flexible than a commitment to a specific policy stance. Thus, the tradeoff between open-ended statements and explicit commitments in terms of the flexibility of the policy should be taken into account by policymakers when making their decisions. Using statements to affect market expectations is a low cost policy since a central bank can affect the interest rates determined by the markets without any physical costs, i.e. purchasing or selling any assets.

Market expectations management is strongly supported by Krugman (1998) in his recommendations for Japan's monetary policy in the late 1990s. He proposed the announcement of an inflation target and gradually increasing the target later in order to drive down the ex ante real interest rate (the nominal interest rate minus expected inflation). Nevertheless, the success of this strategy is doubtful since no instrument or transmission mechanism can guarantee a rise in inflationary expectations during an economic recession. During the economic slowdown, inflationary expectations are superseded by deflationary expectations; therefore, Krugman's (1998) idea to raise inflationary expectations can be futile because of strong deflationary expectations. The Bank of Japan did not adopt Krugman's idea is due to the fear of losing their policy credibility (Okina (1999)). Moreover, Buiter and Panigirtzoglou (1999) argue that it is impossible to adopt such the policy at all because Krugman's idea is based fundamentally on the central bank's ability to increase expected inflation which is limited when the zero bound constraint is binding and the central bank has no instrument to raise expected inflation directly.

Among others, Svensson (1999b) and Smets (2000) advocate "price level targeting" rather than the inflation targeting regime, based on the grounds that undershooting of the price level target caused by deflation leads to inflationary expectations in the next period[73]. Nonetheless, the effectiveness of inflationary expectations depends on the confidence of the public in the central bank's ability to reflate the economy. Berg and Jonung (1999) illustrated that price-targeting policy

[73] Refer to Section 1.3.1.

was successful in Sweden in reviving the economy after it dropped out of the gold standard in 1931 which led to the enormous output decline.

4.3.6.6. Writing options on Treasury Securities

This policy is based entirely on Tinsley (1999). He exploits the disadvantage of targeting long-term interest rates that there is no commitment by central banks that they will target lower long-term interest rates by purchasing the long-term securities and there is no punishment for not following their decisions. In order to strengthen the perception of the public that the Federal Reserve is committing to maintain an easy policy stance in the future, the Federal Reserve may enter the markets for options on Treasury securities by writing an option with the strike price equal to the upper limit yield required by the Federal Reserve.

If the yield on the security on which the option is written is higher than the upper limit or the exercise price, the public can sell the Treasury bond to the Federal Reserve at the strike price by exercising the option. In this case, the Federal Reserve loses since the Federal Reserve must purchase the securities at higher price than the original price of the Treasury securities. In contrast, if the interest rate is lower than the limit, there is no gain or loss[74] for the Federal Reserve or the public as the option is not exercised. In other words, writing options is a strategy to show the assertiveness of the Federal Reserve in keeping the interest rate low or else they will be punished, unlike the conventional open market operations in which the Federal Reserve can cease purchasing Treasury securities at anytime.

Ordinarily, the effect of derivative issuance does not change the price but shrinks the bid-ask spread of the underlying assets – Hull (1997) and Mullin (1997) – since the prices of underlying assets depend on economic fundamentals which

[74] There is no gain or loss from unexercised options except the option premium that the holder must pay to the writer – the Federal Reserve.

determine the present value of expected earnings. However, it is not the case for options on Treasury securities. According to the term structure of interest rates, a long-term interest rate is composed of the expectation in the future short-term interest rates, and the expectation due to the uncertainty of the short-term interest rate policy in the term premium. When the options reduce the uncertainty inherent in these two components, the intrinsic price of the long-term bond would rise (as the yield will fall)[75]. In fact, this is partly analogous to the mechanism of managing the future policy stance in 4.3.6.5., which reduces the uncertainty in the term premium, resulting in lower long-term interest rates.

However, the problems with this policy are practical. These include the legal problem of whether the central bank has authority to issue derivatives or not. Also, it may work in the US because it has well-developed financial markets and a credible central bank. In less-developed financial markets, writing an option may be problematic since their central banks or governments may not have sufficient authority to conduct such a policy and the public may not have adequate knowledge on these sophisticated financial instruments. More importantly, the market for the underlying assets including Treasury securities or other short-term securities may not be so developed that their pricing is accurate, leading to inaccurate pricing of derivative instruments such as options. Finally, less developed financial markets may not even have a derivative market to facilitate the options trading.

4.3.6.7. Exchange rate channel

Two classes of policy exploiting the exchange rate channel include McCallum's (2003) exchange rate targeting policy and Svensson's (2003) foolproof

[75] The method of pricing an option on Treasury securities is described vividly in Tinsley (1999) and Clouse et al (2000).

way out the liquidity trap for Japan by using a one-off devaluation and defenses of an exchange rate peg until the economy is out of the liquidity trap.

McCallum and Nelson (1999) and McCallum (2003) proposed a moving exchange rate target as a function of current inflation and the output gap, similar to the Taylor rule but implementing an exchange rate as a policy instrument, instead of a short-term interest rate. Additionally, the rule is defined in terms of first-difference rather than levels and shown in Equation (4.3).

Equation (4.3) .... $s_t - s_{t-1} = v_0 - v_1(E_{t-1}\Delta p_t - \pi^*) - v_2 E_{t-1}(y_t - y^*_t) + \zeta_t \quad v_1 > 0; v_2 \geq 0$

Where s_t is the exchange rate in the domestic currency;

p_t is the price level;

π^* is the inflation target

y_t is the output level

y^*_t is potential output

Noticeably, McCallum (2003) employs the expectation in the last period of both inflation and the output gap. From this rule, the rate of depreciation of the foreign exchange rate falls if either the expected inflation or output in the previous period is higher than its target. The central bank operates through open market operations to maintain the exchange rate conforming to the values prescribed by the policy rule. In addition, the implicit assumption of this policy rule is that the short-term interest rate is fixed at zero percent or a positive value.

According to the simulation result in McCallum (2003) based on the open-economy model used by McCallum and Nelson (1999b) and the policy rule corresponding to Equation (4.3), the exchange rate rule can effectively reduce the variability of the target variables, relative to the Taylor-type rules.

An advantage of the exchange rate rule following McCallum's (2003) specification is that the Uncovered Interest Parity relationship (UIP) can be dropped out of the model. Basically, the UIP is an important link between short-term interest rates and exchange rates but it is not necessary in the model implementing the exchange rate as a policy instrument directly. The rationale behind it is similar to dropping the money demand function in the New Keynesian model when the central bank uses an interest rate rule. In that case, the money demand function is augmented only to determine the amount of reserves required to maintain the short-term interest rate at the target. Likewise, it is not necessary to know the magnitude of purchases of the currency in order to implement the exchange rate rule because the central bank can observe the foreign exchange price directly from the foreign exchange market and the central bank sets the exchange rate corresponding to the policy rule.

On the other hand, Svensson (2003) developed a so-called "foolproof" way out of the liquidity trap specifically for Japan. His idea is that a central bank first devalues a nominal exchange rate (or induces the *nominal* exchange rate to depreciate) at the current period and adopts a crawling peg for the nominal exchange rate following expected appreciation through the Uncovered Interest Rate Parity[76] in order to prevent the nominal interest rate from rising above zero, assuming that the domestic interest rate is zero and foreign interest rate is a positive number. To curb the expected appreciation in the future which would jeopardize the output expansion caused by the exchange rate devaluation or depreciation in the first period, the central bank should also announce an upward-slope price path target (rising price level targets) at the same time as it devalues (or cause the depreciation).

[76] A positive return in foreign (trading partners) countries requires an expected appreciation of the domestic currency. Therefore, the crawling peg is announced to follow this appreciation.

Svensson (2003) also pointed out that it is relatively easy to effectively devalue the nominal exchange rate rather than revalue due to the unlimited capability of the central banks to purchase foreign asssets and paying with domestic currency. On the contrary, to defend against the exchange rate depreciation is very difficult since the central banks have limited foreign reserves to sell for the domestic currency, e.g. Thailand during Asian financial crisis in 1997.

Nevertheless, the problem of foreign exchange intervention depends enormously on the response of trading partners. If the trading partner embraces the contractionary monetary policy for the economy, the currency in the trading partner's viewpoint will appreciate (depreciated domestic currency). However, if the trading partner also demands easy monetary policy, it will not comply with the appreciation of the currency and will attempt to devalue its currency against the domestic, which in turn, deters the depreciation of the domestic currency.

Even though the trading partner bears the costs of the currency appreciation due to the cheaper imports and more expensive exports, it will gain from exporting more to the home country of which the output is expanding in the long-run, when the domestic economy recovers. Krugman (1998) argues that the benefits overcome the costs for both home country and the trading partner, and the "Beggar-Thy-Neighbor" phenomenon does not happen.

In addition, another problem about foreign exchange intervention concerns the legal issue which was reviewed in McCallum (2003) for Japan's case. He concluded that intervention in the foreign exchange market in Japan for the purpose of monetary control is basically consistent with the Law that calls for the action of the Bank of Japan to achieve the sustainable development of the Japanese economy. Even though it is not stated explicitly in the Law regarding this foreign exchange intervention, the

Bank of Japan can seek the approval from the Ministry of Finance or amend the Law somewhat to authorize the Bank of Japan to intervene the market.

It is noteworthy that Svensson's (2003) idea also relies on the expectational channel to pull the economy out of the zero bound trap, in particular when the central bank must explicitly announce and commit to the rising pricing target. The less credible is the price targeting policy in the first place or the more backward-looking are expectations (the more expectations based on the history of the economy trapped at the zero bound), the weaker of the effects on expectational channels and it may require larger amount of exchange rate intervention.

Historical evidence on the use of this policy to handle the zero bound constraint is rare. One possible case is that of Switzerland in the late 1970s when a strong Swiss franc caused the economy to be on the edge of recession and the concern about deflation overclouded the economy; additionally the short-term interest rates approached zero. The Swiss National Bank used a tremendous amount of foreign exchange intervention in attempt to lower the exchange rate as well as stimulate economic activity. Even though the policy tended to be effective in the earlier year after recession hit the economy, it led to significant inflationary pressures later on.

4.3.6.8. A tax on money or Gesell money

Buiter and Panigirtzoglou (1999) and Goodfriend (2000) proposed a different approach in handling the zero bound constraint. They exploit fiscal policy by imposing a tax on money as well as on the reserves that banks have with the central bank. Normally, the banking reserves are taxed by the central bank since the reserves pay a zero interest rate, thus, it is implicitly taxed by inflation due to the lower purchasing power of money in real terms.

The tax on money or reserves is simply to lower the problematic interest rate floor at zero percent to be negative by imposing some costs– the tax. In retrospect, the tax was originated by Silvio Gesell (1863-1930), who attempted to stimulate the circulation of money. He proposed some tax on money to depreciate its value apart from inflation rate. The tax has been brought to economists' attention and been well known since Keynes (1936), who credited the idea of this kind of taxing to Gesell, but he contended that the tax would be impractical, on the grounds that money did not provide the unique liquidity services. Were it to be taxed, the other assets could replace money.

Nonetheless, the main practical problem of this policy is the technology to tax the money in circulation. It is, however, argued by Goodfriend (2000) that this cost is administrative and once and for all (excluding the maintenance fees for the technology imposed on the money or the reserves at the bank). After installation of the technology to impose a carry tax, it can be used to mitigate the zero lower bound constraint on nominal interest rate whenever the deflationary pressure threatens to push the economy into the liquidity trap.

Even though the Gesell tax is a brilliant idea to handle with the zero bound constraint, a provocative issue is that the probability of the zero bound constraint binding is very small. Imposing such a technology to levy a carry tax on money might not be worthwhile. If there exists an ad hoc alternative policy that would be triggered just at the time when the zero bound constraint becomes binding, would it not be a more attractive policy than this method? Imposing a tax on money or other necessary goods would be a contentious political issue and difficult to execute in practice. Besides, the re-distribution of wealth might be a concern, as some people are not in position to withstand a period of negative interest rates, e.g. the people relying on fixed-income.

4.3.6.9. Promoting the development of capital markets

Sellon (2003) proposed an additional policy to resuscitate the economy via the wealth effect. This policy is to promote the capital market. Normally, financial intermediation happens in two ways: through the banking system and through capital markets, including stock markets and long-term securities market.

If the zero bound constraint is a concern, the banking system is probably shut off. This problem is also substantiated by the historical events in both the Great Depression in the US and the collapse of asset price bubble in Japan that the banking system was so weak that the effectiveness of monetary policy was limited and numerous banks went bankrupt. Thus, capital markets can be an alternative transmission mechanism for the policy.

Evidently, the Bank of Japan has pursued this policy for a few years. They attempted to stimulate the growth of capital markets by relaxing some restrictions on the collateral used for the open market operations. Therefore, it increased the depth of financial markets as a channel to create the wealth to the private sector.

5. Optimal instrument rules

In this section, I will focus on a type of a policy rule called "an optimal rule", which is an outcome of the constrained intertemporal optimization problem of a central bank's loss function, introduced in Section 1. Furthermore, the circumstances in which the simple policy rules, e.g. the Taylor type rule, are optimal will be examined following Woodford (2001), Giannoni and Woodford (2002a, 2002b) and Walsh (2003).

An optimization problem basically requires two ingredients; one is a welfare loss function basically composed of the economic objectives that a central bank needs to achieve; and the other is a model capable of well describing the structure of the economy, for example, the New Keynesian model, the Neo-classical model, etc.

In the present chapter, I have discussed the simple instrument rules, including the Taylor type rule. They are not necessarily optimal. Fundamentally, these simple instrument rules are merely the policy rules under which a central bank adjusts its policy instrument, e.g. a short-term interest rate or the monetary base, in response to economic indicators to counteract the cyclical behavior of the economy in the short-run and accomplish price stability in the long-run. The economic model, which is used to derive an optimal rule, is irrelevant. The property of model independence of simple instrument rules is one of their main advantages, compared with other types of monetary policy rules.

The optimization problem in this section can be summarized by a simple framework by Tinbergen (1952) and Theil (1961). It is also described in detail in Blinder (1998). First, a known model of the macroeconomy can be described as follows:

Equation (5.1) .... $y = F(y,x,z) + e$

Or the reduced form is:

Equation (5.2) .... $y = G(x,z) + e$

Where y is the vector of endogenous variables in the model;

x is the vector of policy instruments, for this dissertation, it has a dimension of one;

z is the vector of non-policy exogenous variables;

e is the vector of stochastic disturbances.

Assume the macroeconomic model (represented by F(.)) is linear or is approximately linear around the steady state equilibrium. The policymaker's objective function is

Equation (5.3) .... $W = W(y)$,

which is assumed to be quadratic. This will be discussed in Section 5.1, while the model describing the economic environment, conforming to Equations (5.1) and (5.2) will be explored in Section 5.2.

If the policymaker maximizes the expected value of Equation (5.3), the outcome would be an linear optimal policy rule corresponding to Equation (5.4) as follows.

Equation (5.4) .... $x^* = H(z)$

where x^* is now an optimal value of the policy instrument.

5.1. Policy objective function

In the present chapter, monetary policy analysis is conducted based on the assumption that a central bank desires to minimize a quadratic loss function - a policy objective function - embracing the welfare loss incurred by inflation and output[77] fluctuations. These fluctuations are represented by the deviations of inflation and the output from its target and potential level, respectively, which are basically most central banks' policy objectives.

Generally, a policy objective function can be written as follows;

[77] In Barro and Gordon (1983), the policy objective function is formulated differently, based on the assumption that more output is better than less with constant marginal utility. Therefore, the deviation of output from its target enters the policy objective function linearly, compared with the quadratic form in the recent literature. It can be specified as follows;

$$U = \lambda(y - y_n) - 1/2\pi^2$$

Where y is actual output; y_n is the economy's natural rate of output; π is inflation rate, assuming that the inflation target is zero percent.

Equation (5.5) .... $\Lambda_t = E_t\Sigma^{\infty}{}_{i=0}\, \beta^i\, ((\pi_{t+i} - \pi^*)^2 + \lambda(y_{t+i} - y^*)^2)$

Where π_t is inflation rate

π^* is an inflation target which is typically normalized to 0%

y_t is output level

y^* is potential output or the nature rate of output

With the output gap entering into the policy objective function, there are two main definitions of potential output; one conforms to the Barro and Gordon (1983) definition, defining the output gap as output deviating from a trend, and the other is based on the New Keynesian framework defining the output gap as output deviating from the output at the fully-flexible price equilibrium.

The first definition depends on the natural rate of output. It is typically derived from the output trend either the linear trend or the non-linear trend such as that generated by the Hodrick-Prescott filter. However, the linear trend is simple and widely used in the empirical work including the Taylor rule (1993).

On the other hand, the definition of the output gap based on the New Keynesian approach can be used to derive a policy objective function similar to Equation (5.5), based on the general equilibrium conditions as illustrated by Woodford (2002b). He begins with a utility optimization problem of a representative household that consumes a composite of differentiated goods. Along with the assumption of the representative consumer suffering disutility from production and the monopolistic competition in the production of goods, the expected discounted utility function can be approximated around the steady-state equilibrium. As a result, the outcome depends mainly on two terms resembling the quadratic loss function assumed in other literature. One is the deviation of inflation from a target and the other is the deviation of output from the output level derived from fully-flexible price level, i.e. when the monopolistic competition is absent. The summary of the derivation of this policy objective function can be found in Woodford (2002b).

Thus, potential output in the New Keynesian framework is different from the Barro-Gordon one. The natural rate of output in Barro-Gordon varies with productivity shocks and consumer preferences are irrelevant, whereas the output at the fully-flexible price level also incorporates the influence of the preferences of a representative consumer.

5.1.1. The interest rate variability in the loss function

Even though the Federal Reserve is not mandated by law to incorporate interest rate volatility into its policy decision, the Fed is concerned about financial markets volatility in practice. This is because interest rate volatility is one of main factors affecting the prices of many financial assets. Thus, a conventional policy objective function similar to Equation (5.5) should be modified by appending the variability of a short-term interest rate.

Another intuitive reason for embedding the variability of the interest rate into the loss function is that whenever a central bank considers stabilizing inflation and output with more aggressive policy rules, it would trade this off against an increase short-term interest rate variability, as seen in Taylor (1999a), Levin et al (1999) and Levin and Williams (2003). The increased variability of interest rate would affect financial markets through many means, e.g. the precision in pricing financial assets.

In addition, appending the variability of a short-term interest rate onto the loss function is one way to include policy inertia, apart from entering the degree of interest rate smoothing into the policy rule directly – Section 3.1. As explained earlier, the concept of interest rate smoothing is motivated mostly by empirical work.

From the description above, a modified loss function to include the variability of interest rate is as follows[78].

Equation (5.6) .... $\Lambda_t = E_t\Sigma^{\infty}_{j=0}\, \beta^j\, (\lambda(x_{t+j} - x^*)^2 + (\pi_{t+j} - \pi^*)^2 + \nu(i_{t+j} - i_{t+j-1})^2)$

Where i_t is a short-term interest rate

$\lambda, \nu > 0$

Interestingly, Woodford (2001) incorporates the variability of interest rate in the loss function in his "Neo-Wicksellian" framework through the deviation of a nominal interest rate from its target, which is composed of the natural real interest rate and inflation target, instead of the change in the interest rate in the last period like other studies, e.g. Rudebusch (2002), Dennis (2003) and Favero and Rovelli (2003). He argues that in some cases, for instance the zero bound constraint on the nominal interest rate binding, it may be undesirable to completely stabilize inflation at a zero rate owing to distortions explained by Friedman (1969) and shown in Chapter 2 of this dissertation.

5.1.2. The estimation of the policy preference in the US

A number of studies estimate the policy objective function for the US, e.g. Dennis (2003) and Favero and Rovelli (2003). However, there still lacks of the empirical work on the policy objective function in other countries.

Dennis (2003) implements the Rudebusch and Svensson's (1999) model to estimate the structural model jointly with optimized outcome of the loss function,

[78] In fact, this specification is one of the three possibilities of appending the variability of an interest rate into a loss function. The other two include;

Svensson (2003): $\Lambda_t = Var[\pi_t\text{-}\pi^*] + \lambda Var[x_t\text{-}x^*] + \nu_i Var[E_{t-1}[i_t]\text{-}i_t]$

Woodford (1999): $\Lambda_t = Var[\pi_t\text{-}\pi^*] + \lambda Var[x_t\text{-}x^*] + \nu_i Var[i_t\text{-}r^*\text{-}\pi^*]$

The interpretation of these policy objective functions can be as follows. Svensson (2003) argues that the surprise in the policy rate should be appended to the loss function to represent the welfare loss caused by the financial instability, whereas Woodford (1999) suggest penalizing the deviations of the nominal interest rate from its target, corresponding to the Neo-Wicksellian concept. He also adds that the smaller interest rate fluctuations can reduce the chance of the zero bound constraint binding.

conforming to Equation (5.6) with x^* equaling zero. The model includes two lags of output gap and four lags of inflation with the restriction that the sum of all coefficients on lagged inflation is unity. With this method, an optimal policy rule corresponding to this model setup and the loss function is derived.

The sample is 1966:Q1 – 2000:Q2. He also allows the possibility of correlations across the equations in the model, thus, the Seemingly Unrelated Regression method (SUR) is used for the estimation. The sample is divided to two sub-samples including Pre-Volcker (1966:Q1 – 1979:Q3) and Volcker-Greenspan era (1982:Q1 – 2000:Q2), similar to the studies in the estimation of policy reaction function in Section 3.

The reason that the period of 1979:Q4-1981:Q4 is neglected is due to the change in operating procedure of the Federal Reserve from targeting a short-term interest rate to non-borrowed reserve targeting procedure. In this period, the short-term interest rate is very volatile, therefore, it is sensible to exclude this sample period. The results in Panel A of Table 1.18, corresponding to Dennis (2003), are quite interesting. The λ and ν, which are the policy preference in stabilizing the output gap and the interest rate, respectively, are not significant at the conventional level of 95% in Pre-Volcker period, while the opposite results are obtained in Volcker-Greenspan period.

In Volcker-Greenspan period, the weight on the variability of the output gap in the loss function is also insignificant. However, the coefficient on the output gap in the estimated optimal policy rule is significant (not report here). This may suggest that the Federal Reserve responds to the output gap, not because it is a policy stabilization goal but because it contains information about future inflation, which can be observed from the estimated policy reaction function.

Table 1.18: The estimates of policy preference parameters corresponding to Eqauation (5.7) ……. Loss = $E_t\Sigma^{\infty}_{j=0}\ \beta^j\ (\lambda(x_{t+j} - x^*)^2 + (\pi_{t+j} - \pi^*)^2 + \nu(i_{t+j} - i_{t+j-1})^2)$

Policy Preference Parameters				
	λ	ν	π^*	r^*
A. Dennis (2003)				
1966:Q1-1979:Q3	3.141 (8.229)	37.168 (57.847)	6.96	0.74
1982:Q1-2000:Q2	2.941 (5.685)	4.517 (1.749)	1.38	1.66
B. Favero and Rovelli (2003)				
1961:Q1-1979:Q2	0.00153 (0.0003)	0.0051 (0.0006)	5.795 (0.07)	1.92
1980:Q3-1998:Q3	0.00125 (0.0002)	0.0085 (0.0006)	2.628 (0.06)	3.71

Note: π^* *is inflation target*
r^* *is an equilibrium real interest rate*
Standard Errors are in parentheses

The weight on the variability of the interest rate in the policy objective function is significant in Volcker-Greenspan era. This result substantiates the claim that the Federal Reserve smoothes the interest rate.

On the other hand, Favero and Rovelli (2003) estimate two equations of the model implemented in Svensson (1997) jointly with the first order condition, which solves the intertemporal optimization problem faced by the Fed, given the loss function similar to Equation (5.6). They also restrict the discount factor (β) to be 0.975, compared with 0.99 in Dennis (2003)[79].

Furthermore, they estimate the model with the inclusion of the commodity price index in order to correct the "price puzzle" typically taking place in the VAR literature on the monetary transmission mechanism – Christiano, Eichenbaum and Evans (1998). However, they find that the estimation result for the aggregate supply function is slightly different with this inclusion.

[79] Dennis (2003) also conducts the sensitivity analysis of changing the discount factor in the estimates. Since it is not a focus of the present chapter, I do not report the results in here.

The sample size they use is somewhat different from Dennis (2003) since they employ 1961:Q1-1998:Q3. However, they divide the whole sample into two sub-samples due to the change in operating procedure in the late 1970s.

Even though the policy preference estimates in Favero and Rovelli (2003) are significant, they are very small values and barely different from zero, compared to Dennis (2003) where estimates on output are insignificantly different from zero. Söderlind, Söderström and Vredin (2004) argue that a small or zero policy preference on the output stabilization explains the small weight placed on output resulting in the low variability of inflation and high variability of output in the US data.

Comparing the estimate of the interest rate smoothing term in the policy objective function, it is significant in both periods in Favero and Rovelli (2003) while it is insignificant in Pre-Volcker in Dennis (2003). Noticeably, the estimated inflation and the real interest rate in Dennis (2003) and Favero and Rovelli (2003) are totally different except for the inflation target in the Pre-Volcker period.

In sum, the parameters estimated from Table 1.18 indicate the lower importance of output gap stabilization of the Federal Reserve since 1960, while the significant coefficient on interest rate smoothing in most cases confirms the Federal Reserve's behavior in smoothing its policy instrument, i.e. the federal funds rate.

5.2. Economic models

Having discussed the policy objective function, the second component of the optimization problem faced by a central bank in order to attain an optimal policy rule is a model describing the economy. The models can be categorized into two main groups; namely, theoretically-based and non-theoretical-based model. The former includes the Neo-Classical model and the New Keynesian model. The latter includes the Vector-Autoregression (VAR) model, based on the econometric methods, rather than any macroeconomic theory.

Nevertheless, the purpose of this section is not to describe all models in details but to introduce the models widely used in monetary policy analysis, specifically for the purpose of obtaining an optimal policy rule.

In addition, I discuss only on the models in which real output can be affected by a monetary disturbance and neglect the models with money neutrality. The reason is that monetary policy is the main issue, therefore, it would be tedious if monetary policy could affect only the price level but not the real economy.

5.2.1. Theoretically-based models

The theoretically-based models used in monetary policy analysis can be divided into two main classes. One is the Neo-classical model and the other is the New Keynesian framework. The former assumes the fully-flexible price adjustment while the latter typically encompasses a type of nominal rigidity and some imperfect competition.

5.2.1.1. Neo-classical framework

Basically, Neo-classical models are built jointly on the outcomes of the optimization problems of a representative consumer and firms in fully-flexible price environment. However, basic neo-classical models are intrinsically non-monetary frameworks. Therefore, they must be modified to incorporate money. Three approaches can be conducted. These include incorporating money into the utility function directly (Sidrauski (1967)), imposing some cost of transaction to motivate demand for money (Baumol (1952), Tobin (1956), Clower (1967) and Kiyotaki and Wright (1989), and treating money as one asset used to transfer resources inter-temporally (Samuelson (1958)).

However, most economists believe that the short-run effect of monetary policy is caused by sluggish wage and price adjustment which cannot be explained by the Neo-classical framework with fully-flexible prices. In other words, money in this framework is neutral. Therefore, some modifications are needed to match the short-run real effect of monetary policy on actual data. The first modification is to focus on misperceptions about aggregate economic conditions and the second focuses on the limited participation of agents in financial markets.

The former was formalized by Friedman (1968, 1977) to explain the existence of a short-run tradeoff between output and money with the long-run neutrality of money by introducing actual real wages – determined by firms' decisions in hiring – and perceived real wages – realized by the workers in deciding the amount of labor to supply. The principle is that if workers perceive an unexpected rise in the nominal wage as a rise in the real wage, they would supply more labor and production expands. Once they realize that it is just a misperception, the equilibrium at higher nominal wages and unchanged real wages would be re-established with the same level of employment as the beginning.

This concept can be generalized to other relative prices not just real wages. If agents misunderstand an increase in general price level (in all goods) as an increase in a relative price (one good), they will change their real activity, which in turn, affects the economy's real equilibrium. Once they realize this misperception, the equilibrium will be restored.

The limited participation model assumes that agents have some restrictions in some financial transactions and monetary injections are distributed unequally. In this class of model, a money disturbance can affect the real interest rate and real economy through *the liquidity effect*. With this effect, when a central bank injects some amount of money, it will lower a nominal interest rate[80]. The real equilibrium will be affected since the money injections are assumed to be unequally distributed among agents leading to unequal increases in real balances needed by all agents. Some agents will be left with higher real money holdings, others with lower real balances.

5.2.1.2. New Keynesian framework

Instead of imposing the Neo-classical model with some restrictions including imperfect information and agents' limited participation in financial markets, embedding nominal rigidities into the model directly is an alternative method to introduce the short-run effect of a monetary disturbance into the real economy. With nominal rigidities combined with the assumption of monopolistically competitive goods market condition faced by a representative consumer and firms, a class of general equilibrium model called *New Keynesian framework* emerges.

Generally, new Keynesian models can be collapsed to two main reduced form equations. These are an aggregate demand equation, depending on the optimization behavior of a representative consumer in consuming a composite of differentiated goods of which the individual prices are set by monopolistically competitive firms. The second equation is an aggregate supply or the new Keynesian Phillips Curve equation, derived from an inflation adjustment function of monopolistically competitive firms. The nominal rigidity enters the model via the inflation adjustment equation since it is assumed that only some firms can adjust their prices to correspond to the optimal levels in each period.

In the New Keynesian framework, an aggregate demand function is derived from a linear approximation of the representative household's first order condition

[80] This result is opposite of the results in Neo-classical models with fully-flexible price and no-friction in financial markets. According to such a model, if money growth is positively serially correlated, then money injections induce higher expected inflation which is a component of nominal interest rates. As a consequence, nominal interest rates may rise instead of falling.

relating marginal utility inter-temporally. This equation is generally called a representative consumer's Euler equation. The aggregate demand function in this case is

Equation (5.8) .... $x_t = E_t x_{t+1} - (1/\sigma)(i_t - E_t \pi_{t+1}) + u_t$

Where x_t is an output gap

i_t is a short-term interest rate

$E_t \pi_{t+1}$ is expected inflation

Obviously, if a central bank conducts monetary policy through an interest rate rule by setting a short-term interest rate as a feedback to some economic indicators such as inflation and the output gap, conforming to the Taylor rule, the aggregate demand function is determined without any assistance of the LM curve (money market equilibrium) since the interest rate affects output directly. This, in turn, is one of the main advantages of an interest rate rule, the Taylor rule, over a monetary aggregate rule, e.g. the McCallum rule, since central banks do not need any information on the money demand function.

The aggregate supply equation can be derived from either an inflation or price adjustment mechanism, which is assumed to be sluggish. The price rigidity[81] can arise from many sources; one of them is *menu costs* – some fixed costs in changing prices or wages. Firms cannot change the prices corresponding to the optimal conditions instantly when the economic environment changes since there exist some fixed costs in the process of changing their prices. These include printing new price tags or inventory write-offs or so forth. This class of models includes Akerlof and Yellen (1985) and Mankiw (1985)[82].

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[81] However, price rigidity or sluggishness is just a type of nominal rigidities apart from wage rigidity which brings in the effect of productivity shock upon output.

[82] The models incorporating menu costs are reviewed nicely in Chapter 6, Romer (2000).

Another reason why firms cannot set the price in every period is due to the contract set prior to the beginning of the period. The models explaining the price adjustment mechanism are, for example, Taylor (1980), Calvo (1983) and Fuhrer and Moore (1995). The distinction across the models depends on whether the price level or inflation is sticky.

The Calvo-type inflation adjustment function expresses more persistence in price than the Taylor type since in the Taylor rule all firms will adjust their prices to a one time change in the optimal price adjustment within two periods, while the Calvo-type takes longer time[83]. However, these two models do not necessarily contain inflation persistence. In contrast, the Fuhrer and Moore specification shows more sluggishness in price and the inflation stickiness, relative to Taylor and Calvo type.

Whether price-stickiness or inflation stickiness better describes the actual data is still an open question. Fuhrer and Moore (1995) argue that their specification fits the US data well while Roberts (1997) argue that the empirical data embody price stickiness rather than inflation stickiness.

Concerning the forward-looking aspect in the inflation adjustment function, Fuhrer (1997) argues that it may not be important, compared to the backward-looking one. Rudebusch (2002) estimates the aggregate supply similar to Fuhrer and Moore (1995) and finds that the coefficient on backward-looking aspect is 0.7, i.e. the coefficient on forward-looking aspect is 0.3.

In sum, the New Keynesian model can be summarized[84] by just two equations; an aggregate demand equation (expectational IS curve) and an aggregate supply equation (new Keynesian Phillips curve). With some degree of forward-looking, this

[83] Kiley (2002)
[84] Walsh (2003) derives an example of the new Keynesian models based on Calvo (1983)'s price adjustment function at length in Chapter 5.

type of model is also called the forward-looking type new Keynesian model, as described by Woodford (2001) and Walsh (2003).

Equation (5.9) ....$x_t = E_t x_{t+1} + \alpha_1(i_t - E_t\pi_{t+1}) + u_t$ $\quad ,\alpha_1 < 0$

Equation (5.10) .... $\pi_t = (1 - \phi)E_t\pi_{t+1} + \phi\pi_{t-1} + \kappa x_t + v_t$ $\quad ,0 < \phi < 1, \kappa > 0$

where π_t is an inflation rate;

x_t is an output gap;

i_t is a short-term interest rate;

u_t and v_t are demand shock and inflation or supply shock, respectively.

Another widely used model in the new Keynesian framework is a backward-looking model originally used by Rudebusch and Svensson (1999). It fits the data quite well compared with the forward-looking type. It has the new Keynesian structure since it is a general equilibrium model and contains a nominal rigidity. Likewise, the model is composed of two main equations; aggregate demand and aggregate supply.

Equation (5.11) .... $\pi_{t+1} = \alpha_1\pi_t + \alpha_2\pi_{t-1} + \alpha_3\pi_{t-2} + \alpha_4\pi_{t-3} + \alpha_5 x_t + \varepsilon_{t+1}$

Equation (5.12) .... $x_{t+1} = \beta_1 x_t + \beta_2 x_{t-1} + \beta_3(i^*_t - \pi^*_t) + \eta_{t+1}$

where π_t, x_t are defined similar to earlier but they are all demeaned before estimation, thus, there is no constant in these equations. i^*_t and π^*_t are averages of interest rate and annualized quarterly inflation of the previous four quarters, respectively.

Since there is some controversy on which theoretical model can explain the actual data best, a simple alternative approach would be to rely entirely on data and then derive an econometric model to describe the economy.

5.2.2. Atheoretical model

Atheoretical models do not depend on the macroeconomic theory but they allow the data to reveal economic behavior by using some econometric techniques to formulate an empirical model. The most widely known approach is the (unrestricted) Vector Autoregression approach (VAR). It was pioneered by Sims (1972, 1980) to estimate the impact of money on the economy. Christiano, Eichenbaum and Evans (1999) implement a VAR to study the impact of monetary policy actions on the economy. For a technical review of VARs, see Hamilton (1994).

The VAR can be described in one of these forms. *A structural form* is a system of equations explaining each endogenous variable in terms of other endogenous variables in the system both contemporaneously and with lags. Also, the endogenouos variable depends on its own lags. The errors corresponding to this form are, thus, structural shocks. In other words, in the structural form, we allow the feedback across the endogenous variables in the system. The structural form for a simple VAR(1) is shown in Equation (5.13) and (5.14) below.

Equation (5.13) .... $y_t = b_{10} - b_{12}z_t + \gamma_{11}y_{t-1} + \gamma_{12}z_{t-1} + \varepsilon_{yt}$

Equation (5.14) .... $z_t = b_{20} - b_{21}y_t + \gamma_{21}y_{t-1} + \gamma_{22}z_{t-1} + \varepsilon_{zt}$

Move all the endogenous variables to the left-hand-side and transform them into the matrix form,

Equation (5.15) .... $\begin{bmatrix} 1 & b_{1,2} \\ b_{2,1} & 1 \end{bmatrix} \begin{bmatrix} y_t \\ z_t \end{bmatrix} = \begin{bmatrix} b_{1,0} \\ b_{2,0} \end{bmatrix} + \begin{bmatrix} \gamma_{1,1} & \gamma_{1,2} \\ \gamma_{2,1} & \gamma_{2,2} \end{bmatrix} \begin{bmatrix} y_{t-1} \\ z_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{yt} \\ \varepsilon_{zt} \end{bmatrix}$

Equation (5.16) .... $B \quad X_t \quad = \quad \Gamma_0 \quad + \quad \Gamma_1 \quad X_{t-1} \quad + \quad \varepsilon_t$

Multiply Equation (5.16) with B^{-1}, a reduced form can be obtained,

Equation (5.17) .... $X_t \quad = \quad A_0 + A_1X_{t-1} + e_t$

Where $A_0 = B^{-1}\Gamma_0$, $A_1 = B^{-1}\Gamma_1$ and $e_t = B^{-1}\varepsilon_t$

The second form is called a reduced form, which is used for estimation and then converted to the structural form to retrieve the structural parameters as well as the structural shocks. Furthermore, from Equation (5.17), the error terms in the system, which are called *innovations* in the reduced form, are compositions of the structural shocks across the equations.

However, there is always the problem of under-identification in the estimation, i.e. the number of equations to compute the structural parameters are less than the unknowns. There are two approaches to correct this problem.

1) Use the type of recursive system approach proposed by Sims (1980) to eliminate some unknowns based on the assumption that some endogenous variables are actually exogenously determined outside the system. This approach is also called the Choleski Decomposition, identifying the system with ordering in a lower triangular fashion starting from the most exogenous variables and then the less ones.

2) A structural VAR is a compromise approach between an atheoretical model and a theoretical model. Even though the estimation is based on VAR approach, some structural restrictions based on macroeconomic theory are imposed on some unknowns sufficiently to identify the system in order to retrieve a structural form from an estimated reduced form.

The main advantage of the VAR model is that it is used to study the impact of shocks on the economy and how the economy responds directly, especially through the function called *impulse response function*. This function shows the responses of the endogenous variables to different types of shocks. Such shocks also affect other equations through the feedbacks of the endogenous variables.

5.3. Optimal policy rules versus the Taylor-type rules

Having discussed all components necessary to attain an optimal policy, it would be insightful to describe a general framework to solve for an optimal policy. First, consider a framework similar to Theil and Tinbergen mentioned in the introduction of this section, this framework encompasses any quadratic loss function as well as any linear (or approximately linear) structural model in monetary analysis. Afterwards, I will discuss how close the Taylor-type rules[85] are to optimal policy rules.

5.3.1. General framework for solving an optimal policy rule

Incorporating a structural model as a constraint in the optimization problem, we can generally write the state-space representation as follows;

Equation (5.18) .... $z_{t+1} = C + Az_t + Bx_t + u_{t+1}$

Where z_t is a vector of state variables

x_t is a vector of control variables or policy instruments, i.e. a nominal interest rate

Next consider an objective function in terms of the state and control variable vectors as

Equation (5.19) .... $\Lambda_t = E_t\Sigma^{\infty}_{j=0}\, \beta^j[(z_{t+j} - z^*)'W(z_{t+j} - z^*) + (x_{t+j} - x^*)'Q(x_{t+j} - x^*) + 2(z_{t+j} - z^*)'H(x_{t+j} - x^*) + 2(x_{t+j} - x^*)'G(z_{t+j} - z^*)]$

where W, Q, H and G are matrices containing the policy preference parameters and x^* and z^* are the targets for x_t and z_t, respectively. Introducing a matrix P for the target

[85] In this sub-section, I compare the whole class of the Taylor-type rules specified by the responses to the deviations of inflation and output from their targets rather than only the original Taylor rule which has quite specific coefficients on inflation and the output gap of 1.5 and 0.5, respectively. Therefore, the Taylor-type rules also embrace the Henderson and McKibbin rule, of which both coefficients in response to inflation and the output gap are 2.0 and the Taylor rule with some degree of interest rate smoothing.

values of state variables, along with the diagonal matrix of the policy preference parameters R, we denote W = P'RP;

An optimal policy rule can be derived by the method according to Sargent (1987)[86] for this stochastic linear optimal regulator problem. The optimal policy rule follows,

Equation (5.20) .... $x_t = f + Fz_t$

where the instrument x_t depends on target values (f) and policy targets (z_t) by transforming the matrix of the targets by the transition matrix of F. The matrices f and F are described as follows;

Equation (5.21) .... $f = x^* - Fz^*$

Equation (5.22) .... $F = -(Q + \beta B'MB)^{-1}(H' + G + \beta B'MA)$

Equation (5.23) .... $M = W + F'QF + 2HF + 2F'G + \beta(A + BF')M(A + BF)$.

The method to solve this problem is to substitute Equation (5.22) into Equation (5.23) and then solve it iteratively until the resulting Ricatti equation is convergent. After M has been solved, F and f can be determined recursively. Alternatively, Equation (5.22) and (5.23) can be solved jointly with Gauss-Siedel method. With the constant vector **f**, an optimal policy rule can be attained.

5.3.2. Differences between an optimal policy and the Taylor-type rule

The studies on optimal policy rules can be divided into two main groups, according to the models they mainly used. One is derived from a backward-looking model including new Keynesian – Ball (1997), Rudebusch and Svensson (1999) (RS), Dennis (2001) and Ozlale (2003). The second category is the one derived from the pure-forward looking model typically based on both neo-classical (with imperfect

[86] Also refer to Dennis (2001)

information or some nominal rigidities) and the new Keynesian type – Khan, King and Wolman (2000) (KKW), Dennis (2003).

5.3.2.1. Optimal policy rules in backward-looking models

Backward-looking models, e.g. Rudegbusch and Svensson's (1999) model, are preferred by many policymakers and academics, especially since the paper by Fuhrer (1997) which emphasizes the importance of the backward-looking aspect of most macromodels was published.

Two of the earliest studies deriving an optimal policy rule, based on backward-looking models are Svensson (1996) and Ball (1997). However, Svensson (1996) supports a targeting rule since it is less complicated than an instrument rule[87]. An optimal targeting rule depends only on the parameters in the Phillips curve and the loss function[88] while an optimal instrument rule such as the optimal Taylor-type rule, is also based on an aggregate demand function.

Svensson (1996) argues that if a central bank's policy objective function solely includes inflation, inflation should be set towards the targets. For the multiple goal objective function, e.g. including output, the central bank should allow some weight on the output stabilization and adjust inflation towards the long-run inflation target gradually, instead of weighing only inflation. The more aggressive adjustment of inflation towards its long-run target, the more output fluctuation that occurs.

To explain a mechanism of an optimal policy rule, Svensson describes the mechanism of counteracting the fundamental shocks to the economy. Conventionally, the central bank should neutralize an aggregate demand shock completely, while counteracting a supply shock depends on the weight on output stabilization placed by

[87] It is noteworthy that Svenssons' (1996, 2004) argument on the simplicity of a targeting rule, relative to an instrument rule is based on the optimal instrument rule which can be derived from an optimization problem, not a simple instrument rule, e.g. the original Taylor rule based on backcasting on the US data.

[88] Refer to the definition of a targeting rule and its argument in Section 1.

the central bank in its loss function. A supply shock should be neutralized completely only if the central bank places a zero weight on the variability of output. On the contrary, if the weight on output is positive, the central bank should partially accommodate the shock since output and inflation move in opposite directions. Too aggressive response to the supply shock will increase the output fluctuation rather than reduce it.

However, if the lags are taken into account, the central bank should bring the inflation forecast in line with the long-run inflation target when the economy is hit by either a supply or demand shock, given that the weight on output stabilization is zero. If the central bank also has some preference in stabilizing output, the adjustment towards the long-run target of forecast inflation is gradual.

Similar to Svensson's (1996) model, Ball's (1997) model is composed of two simple aggregate supply and demand functions. The first one is based on a backward-looking new Keynesian Phillips curve, while the latter is based on an IS curve relating the output gap to the real interest rate with one lag. Moreover, a central bank can affect inflation with two lags but affect the output gap with only one lag.

The outcome is that the coefficients in the original Taylor rule are inefficient since the weight on the output gap is less than that on inflation which contrasts to the result derived from Ball's (1997) model. Notably, with the calibration in his model, Ball (1997) suggests that the weight on the output gap should be 1.0 while the weight on inflation is 0.5.

Even though the central bank can affect the output gap more quickly than inflation and it would be optimal to respond to the output gap more aggressively than to inflation, Ball still suggests targeting inflation rather than nominal income. As shown in his paper, targeting either the level or growth of nominal income leads to model instability.

Regarding the backward-looking type model, Rudebusch and Svensson's (1999) model is another widely used among monetary economists. The RS model includes more lags and implements higher frequency dataset than Svensson (1996) and Ball (1997). It is still composed of two main equations representing aggregate demand and supply. With this framework, RS attain a number of policy rules, both forward-looking (forecast) and contemporaneous policy rules. In addition, RS estimate the model with quarterly data (while Ball and Svensson assume the time period in their model is annual) and implement these parameter estimates to calculate the optimal rules, instead of calibrating the model as in Ball (1997).

The optimal policy rules derived using the RS model generally have higher coefficients on both inflation and output gaps than the original Taylor rule. RS also derive the unrestricted optimal policy rule, based on the weight on inflation and output stabilization of 1 and the weight on interest rate smoothing of 0.5 as the policy preference from their backward-looking model, in Equation (5.24). The unrestricted optimal policy rule can obviously incorporate as many lags of inflation as well as the output gap as necessary in order to minimize the objective function constrained only by the structural model, compared to simple instrument rules, which contain just the contemporaneous inflation and output gap.

Equation (5.24)……… $i_t = 0.88\pi_t + 0.30\pi_{t-1} + 0.38\pi_{t-2} + 0.13\pi_{t-3} + 1.30y_t - 0.33y_{t-1} + 0.47i_{t-1} - 0.06i_{t-2} - 0.03i_{t-3}$

Moreover, RS restrict the policy rule to be the Taylor-type rule by specifying a nominal interest rate that depends only on the deviation of inflation from its mean or the target and the output gap contemporaneously and omitting all other lags of inflation and the output gap – i.e. a restricted optimal policy rule. It results in the higher weight on inflation and the output gap, compared with the original Taylor rule of 1.5 and 0.5, respectively. The restricted optimal policy rules are reported in Table 1.19.

Apparently, the Taylor-type rule with some degree of interest rate smoothing dominates the Taylor-type rule without the policy inertia in most cases except in the case that $\lambda = 1$ and $\nu = 0.5$. Also, as pointed out by RS, the parameters of both restricted and unrestricted optimal policy rules are higher than in the original Taylor rule.

Also, RS argue that the policy rules based solely on the inflation forecast performs poorly compared with the (unrestricted) optimal rule and the inflation forecast policy rule incorporating the response to the output gap and interest rate smoothing. Moreover, the policy rule with the response to current inflation alone performs the worst, even though the policy objective function contains only inflation stabilization.

Table 1.19: the restricted optimal policy rule corresponding to the Taylor-type rule

Loss function: $\Lambda_t = (\pi_t - \pi^*)^2 + \lambda(y_t - y^*)^2 + \nu(i_t - i_{t-1})^2$

Optimal policy rule: $i_t = c + \gamma(\pi_t - \pi^*) + \varphi(y_t - y^*) + \rho i_{t-1}$

Preference Parameter	γ	φ	ρ	Std[π]	Std[y]	Std[Δi]	Loss
$\lambda = 1, \nu = 0.5$	2.72	1.57	-	2.18	2.24	1.74	11.27
	2.37	1.44	0.14	2.18	2.25	1.53	11.89
$\lambda = 0.2, \nu = 0.5$	3.17	1.22	-	2.00	2.61	1.65	6.71
	2.34	1.03	0.30	2.00	2.64	1.56	6.60
$\lambda = 5, \nu = 0.5$	2.15	2.17	-	2.69	1.89	2.16	27.46
	1.26	2.35	-0.11	2.68	1.88	2.27	27.39
$\lambda = 1, \nu = 0.1$	3.43	2.50	-	2.01	2.18	2.71	9.51
	2.80	2.80	-0.16	2.00	2.15	2.90	9.46
$\lambda = 1, \nu = 1$	2.44	1.23	-	2.29	2.28	1.42	12.49
	1.12	1.04	0.27	2.29	2.30	1.34	12.33

Note: π^* and y^* are unconditional mean of inflation and output.

In addition, RS exhibit the policy frontier which draws the relationship between the variability of inflation and the output gap with different weights on the preference of the policy objective function. Based on the US historical data, the policy reaction function shows higher variability of inflation and low variability in output, than that of the original Taylor rule. Furthermore, the (unrestricted) optimal policy rule can dominate most policy rules.

Concerning other Taylor-type rules, RS find that the policy rules with a degree of interest rate smoothing of greater than unity, including the one suggested by Rotemberg and Woodford (1999), induce dynamic instability in the RS model. In fact, their derived optimal rule when taking a degree of interest rate smoothing into account suggests only a small value of less than 0.2, compared to 1.3 in Rotemberg and Woodford (1999) and 1.0 in Levin et al (1999).

In sum, the main results drawn from RS are that policymakers should not be what Mervyn King calls "inflation nutters" (the central bank cares only about inflation stabilization regardless of the cost) and should approach the inflation target gradually by adding some degree of interest rate smoothing.

Since the policy objective function cannot be directly estimated due to the unknown welfare loss in the policy objective function, it must be implicitly derived from the first order condition by following a linear-quadratic stochastic dynamic optimization as shown earlier in the general framework. I would label an optimal policy rule obtained from this approach as an "implied optimal policy rule" in order to separate it from the one derived in RS[89] and the earlier literature where an optimal policy rule is derived from the estimated parameters of a structural model and calibrated preference parameters of the policy objective function.

Based on the estimation in the period of 1982:Q1 – 2000:Q2, Dennis (2001) shows that an unrestricted implied optimal policy rule contains all state variables from

[89] Notably, RS (1999) did not estimate the policy preferences in a loss function.

the structural model similar to RS. Recall that Dennis estimates the RS model using quarterly data and obtains the preference parameters on output stabilization and the interest rate smoothing of 2.941 and 4.517, respectively. With the estimated policy preference parameters, the unrestricted optimal policy rule follows Equation (5.25) below and the Taylor-type optimal policy rule is shown in Equation (5.26).

Equation (5.25)....... $i_t = -0.278 + 0054\pi_t + 0.202\pi_{t-1} + 0.293\pi_{t-2} - 0.063\pi_{t-3} +$

(0.234) (0.511) (0.243) (0.095) (0.236)

$0.965y_t - 0.775y_{t-1} + 0.854i_{t-1} - 0.207i_{t-2} + 0.192i_{t-3}$

(0.273) (0.261) (0.099) (0.125) (0.085)

Log – likelihood = -190.587

Equation (5.26) .... $i_t = 0.094 + 0.442\pi^a_t + 0.150y_t + 0.812i_{t-1}$

(0.214) (0.442) (0.150) (0.053)

Log – likelihood = -201.885

where the standard errors are in parentheses

It is noteworthy that the coefficients on inflation and the output gap in the Taylor-type optimal policy rule obtained in Dennis are much lower than the ones in RS even with the high weight on output stabilization. Moreover, the degree of interest rate smoothing in Dennis is more than twice of that in RS.

Finally, Ozlale (2003) presents some results of the optimal policy rules implied from the estimated loss function and the structural model, corresponding to Dennis (2001). The dataset in the study is 1970:Q1 to 1999:Q1. Ozlale also divides the whole sample into two sub-periods depending on the Federal Reserve's chairmen; namely, Burn's period and Volcker-Greenspan period. Moreover, a structural break was found in the estimated loss function when Chairman Volcker was appointed.

Ozlale finds that the preference parameters for the whole sample on inflation, output gap and interest rate smoothing are 0.39, 0.26 and 0.35, respectively, while they are different when the structural break in the third quarter of 1979 is taken into account, which is the beginning of Chairman Volcker's tenure. The parameter estimates from implied optimal policy rules are reported in Table 1.20.

Apparently, the policy preferences in during the Volcker-Greenspan era indicate a higher weight on inflation but a lower weight on output, as can be observed from the weight placed on inflation which doubles that of output in the loss function in Table 1.20.

Comparing Ozlale's result for the whole sample with the RS result in Equation (5.24), the optimal policy rule in RS is slightly more aggressive in response to inflation than that of Ozlale[90]. Even though the optimal rule parameters are quite similar in these two studies, RS (1999) assign only 0.5 to a degree of interest rate smoothing, which is about a half of the weight placed on the interest rate variability in Ozlale.

Table 1.20: Optimal policy rules calculated by Ozlale (2003)

Loss function: $\Lambda_t = \lambda_\pi(\pi_t)^2 + \lambda_y(y_t)^2 + \lambda_i(i_t - i_{t-1})^2$

Policy rule: $i_t = \alpha_1\pi_t + \alpha_2\pi_{t-1} + \alpha_3\pi_{t-2} + \alpha_4\pi_{t-3} + \alpha_5 y_t + \alpha_6 y_{t-1} + \alpha_7 i_{t-1} + \alpha_8 i_{t-2} + \alpha_9 i_{t-3}$

Optimal rule	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9
Whole Sample 1970:Q1-1999:Q1 ***(λ_π=0.39, λ_y=0.26, λ_i= 0.35)***	0.77	0.24	0.21	0.19	1.19	-0.17	0.70	-0.13	-0.06
Burn: 1970:Q1-1978:Q1 ***(λ_π=0.33, λ_y=0.37, λ_i= .30)***	0.63	0.19	0.11	0.20	1.29	-0.12	0.64	-0.06	-0.08
Volcker-Greenspan: 1979:Q3-1999:Q1 ***(λ_π=0.43, λ_y=0.21, λ_i= .36)***	0.81	0.23	0.22	0.15	1.14	-0.17	0.75	-0.09	-0.07

Note: The period of 1978:Q2-1979:Q2 is in Chairman Miller's era which is very brief tenure and then it is dropped off from the sample.

[90] The long-term response to inflation ($\alpha_1+\alpha_2+\alpha_3+\alpha_4$), the output gap ($\alpha_5+\alpha_6$) and a degree of interest rate smoothing ($\alpha_7+\alpha_8+\alpha_9$) in RS (1999) are 1.69, 0.97, and 0.41, whereas the policy rule parameters in Ozlale (2003) are 1.41, 0.98 and 0.51.

5.3.2.2. Optimal policy rules in forward-looking models

Clarida, Gali and Gertler (1999b) (CGG) present the analytical solutions for a forward-looking model with rational expectations. The model is composed of two reduced form equations with two state variables including inflation and the output gap. They also assume persistent demand and supply shocks by imposing a first-order autoregressive (AR(1)) process on these shocks. The entire system can be summarized as follows.

Equation (5.27)................... $x_t = E_t x_{t+1} - \gamma(i_t - E_t \pi_{t+1}) + g_t$

Equation (5.28) .... $\pi_t = \phi E \pi_{t+1} + \lambda x_t + u_t$

Equation (5.29) .... $g_t = \mu g_{t-1} + \varepsilon_t$

Equation (5.30) .... $u_t = \rho u_{t-1} + v_t$

Equation (5.31) .... $i_t = \varphi_1 E_t \pi_{t+1} + \varphi_2 g_t$

Where x_t is the output gap defined as the difference between actual output and its potential level; π_t is inflation; all parameters (γ, ϕ, λ) are greater than zero but less than unity.

The aggregate demand function (Equation (5.27)) is also called the "expectational IS curve" relating the current output gap to the expected output gap and the ex-ante real interest rate. In addition, the inflation adjustment function or the new Keynesian Phillips curve can be derived from the Calvo-type price adjustment introduced in Section 5.2.1.2.

According to Equation (5.31), it is always optimal to counteract the demand shocks entirely, regardless of the policy preference. It leads to unchanged coefficients in response to the demand shock in the optimal policy rules in Table 1. In contrast, the optimal response to the supply (inflation) shock partly depends on the policy preference assigned by the central bank.

CGG provide just the analytical solutions for the optimal policy based on this pure-forward-looking model. Utilizing the CGG's model and the loss function composed of the variability of inflation and output (Equation (5.32)), the first order conditions can be obtained.

Interestingly, the first order conditions also reveal a traditional time-inconsistency problem. At time t, it is optimal for policymakers to choose Equation (5.33) for the current period, relating the *level* of output gap to current inflation, whereas, in the next period, it is optimal to choose Equation (5.34) relating a *change* in output gap to future inflation. When the time t+1 arrives, the policymakers will re-optimize and choose the policy conforming to Equation (5.33) while they have committed to choose the plan according to Equation (5.34) in period t.

To solve this problem, Woodford (1999b) suggests the policymakers follow a "*timeless perspective*"[91] policy by following Equation (5.34) in every period. Basically, the timeless perspective policy is to set the policy chosen optimally by the policymakers in the past for the current period.

Moreover, Equation (5.33) can be interpreted as suggestint that it is optimal for policymakers to raise the real interest rate in response to a rise in inflation and this causes the output gap to be negative and vice versa. Equation (5.34) suggests how aggressively policymakers should reduce the output gap depends positively on the gain from reduced inflation for a unit of output loss (λ) and depends inversely on the weight on the policy preference (α).

Equation (5.32) .... $E_t\Sigma^{\infty}_{i=0}\ \beta^i\ [(\pi_{t+i})^2 + \alpha(x_{t+i})^2]$

[91] McCallum and Nelson (1999) also discuss this issue in depth.

Equation (5.33) ……………… $x_t = -(\lambda/\alpha)\pi_t$

Equation (5.34) ……………… $x_{t+i} - x_{t+i-1} = -(\lambda/\alpha)\pi_{t+i}$ for i = 1, 2, 3, ….

With Equation (5.34) substituted into the CGG's model, the interest rate rule is Equation (5.35).

Equation (5.35) ……………… $i_t = (1 - (\lambda/\alpha\gamma))E_t\pi_{t+1} + (1/\gamma)g_t$

Where $(1 - (\lambda/\alpha\varphi)) < 1$, while $(1/\gamma) > 1$.

Dennis (2001) estimates the CGG's model and derives optimal policy rules corresponding to the different policy preference (α). Dennis implements the loss function with the constraint that the weights on inflation and output should sum to one, while CGG does not restrict the total weight to unity. The restriction results in a slightly different optimal policy rule, of which the coefficient on expected inflation is $(1 - (\lambda(1 - \alpha))/\alpha\gamma$, rather than $(1 - (\lambda/\alpha\gamma))$ in the original CGG's paper. Thus, the parameter in Dennis in response to inflation is greater than that of CGG. Nonetheless, the parameters from both specifications are less than unity.

Equation (5.32') ……… $\Lambda_t = (1 - \beta)E_t\Sigma^{\infty}_{i=0}\, \beta^i\, [(1 - \alpha)(\pi_{t+i})^2 + \alpha(x_{t+i})^2],\ 0 < \alpha < 1$

Table 1.21: The optimal interest rate rule estimated by Dennis (2001)

Policy Preference	**Feedback Coefficients**		**Welfare Loss**
(1 - α)	g_t	$E_t\pi_{t+1}$	L_t
0.0	1.250	1.000	0.000
0.2	1.250	1.248	0.892
0.4	1.250	1.660	1.455
0.6	1.250	2.485	1.595
0.8	1.250	4.960	1.176
1.0	1.250	∞	0.000

Note: -For the simulation, Dennis (2001) sets $\beta = 0.99$; $\gamma = 0.8$; $\lambda = 0.4$; $\mu = \rho = 0.5$; $\sigma_\varepsilon = \sigma_\nu = 0.5$; and $\sigma_{\varepsilon\nu} = 0$.

- (1 - β) is used to normalize the loss function to equal the sum of unconditional variances of inflation and output whenever the discount factor approaches one.

With the less than unit coefficient, the interest rate rule generates indeterminacy as described by Woodford (2001). This issue is, however, beyond the scope of this chapter.

The main point of a forward-looking type model, specifically, the rational expectation model, is that it exploits the ability of the central bank to manipulate private sector expectations of future inflation based on the current monetary policy stance, compared with the backward-looking type which does not have this feature.

Rudebusch (2002) also estimates a model sharing some commonalities with Fuhrer and Moore's (1995) inflation adjustment function or Phillips curve. It contains both the backward-looking aspect similar to RS (1999) and forward-looking aspect of inflation adjustment, according to the argument by McCallum (1999) against Ball (1997) that nominal income targeting induces model instability. Rudebusch (2002) embeds inflation persistence represented by the lags of inflation up to 1 year and also appends 1-year lead of inflation to the Phillips curve. The model follows Equation (5.36) and (5.37).

Equation (5.36).....$\pi_t = \mu E_{t-1}\pi^a_{t+3} + (1 - \mu)(\alpha_1\pi_{t-1} + \alpha_2\pi_{t-2} + \alpha_3\pi_{t-3} + \alpha_4\pi_{t-4}) + \alpha_5 x_{t-1} + \varepsilon_t$

Equation (5.37) ... $x_t = \beta_1 x_{t-1} + \beta_2 x_{t-2} - \beta_3(i_{t-1} - E_{t-1}\pi^a_{t+3}) + \eta_t \quad ,\beta_3 > 0$

Where $E_{t-1}\pi^a_{t+3}$ represents the expectation of average inflation over the next year. π^a_t is four-quarter average inflation. x_t denotes the output gap.

Rudebusch varies μ from 0.0 representing a purely backward-looking model to 0.3 a mildly forward-looking type, and $\mu = 0.6$ which is more forward-looking. Empirically, a small value of μ or a low degree of forward-lookingness rules are supported by most studies including Rudebusch of which the $\mu = 0.29$. Other studies estimating the Phillips curve include Fuhrer (1997), Clark, Laxton and Rose (1996) and Brayton et al (1997). The former obtains μ between 0.02 – 0.2, whereas the estimated parameters in the latter two studies are approximately 0.4.

The Taylor-type rule that Rudebusch imposes is as follows.

Equation (5.38) .... $i_t = r^* + \pi^a_t + g_\pi(\pi^a_t - \pi^*) + g_x x_t$

Where i_t is a nominal interest rate, r^* and π^* are an equilibrium long run real rate and an inflation target, respectively. π^a_t and x_t are defined as above.

For given policy preference parameters of $\lambda = 1.0$ and $v = 0.5$, corresponding to the basic central bank's loss function also implemented in RS (1999), the optimal policy rule can be obtained. For convenience, I re-write the loss function used in the study in Equation (5.39).

Equation (5.39).................... $\Lambda_t = E_t\Sigma^{\infty}_{j=0}\ \beta^j\ (\lambda(x_{t+j})^2 + (\pi_{t+j})^2 + v(i_{t+j} - i_{t+j-1})^2)$

Where the target for the output gap (x^*) and inflation (π^*) are set to equal zero without loss of generality.

The optimal Taylor-type rule based on the model above and the policy objective which includes the variability of interest rate as in Equation (5.38) are reported in Table 1.22.

Table 1.22: The optimal Taylor-type rule corresponding to Rudebusch (2002)

Degree of forward-looking	g_π	g_y
$\mu = 0.0$	1.87	1.53
$\mu = 0.3$	1.70	1.72
$\mu = 0.6$	0.73	1.54

According to Table 1.22, the higher μ is, the lower is the coefficient on inflation. When the degree of forward looking is at 0.6, the weight in response to inflation is below unity. The result is comparable with the unconstrained optimum in CGG.

Nonetheless, the coefficient in response to the output gap is greater than unity in most cases, which is consistent with the analytical solution of the optimal parameter in response to the output gap in the backward-looking type model in Ball (1997).

In addition, Dennis (2001) implements a structural model identical to Rudebusch but imposing the restriction on the objective function that the sum of the preference parameters on inflation and the output gap is unity, similar to the case of CGG. He also adds the interest rate variability into the loss function, conforming to Rudebusch's original loss function. Dennis' results are presented in Table 1.23.

According to Table 1.23, the parameter on inflation in the Taylor-type rule is higher than in the original study by Rudebusch in all cases, owing to the restriction of the sum of the weights on inflation and the output gap is unity.

Furthermore, he conducts sensitivity analysis for the difference in the discount factor (β).The coefficients on inflation and the output gap declines slightly along with the decrease in the discount factor. This can be explained that the lower discount factor, the less the future value will be discounted, the less aggressive needed to curtail inflation and the output expansion since the forward-looking policy rule also stabilizes the economy through the expectation.

Table 1.23: The optimal policy rule obtained by Dennis (2001)

Discount factor (β)	g_π	g_x	**Loss**
1.000	2.870	1.740	3.811
0.990	2.808	1.701	3.629
0.975	2.717	1.644	3.374

Note: - Dennis also uses slightly different Taylor-type rule by setting all constant to be zero. Thus, the Taylor-type rule follows; $i_t = g_\pi \pi^a_t + g_x x_t$.

- The simulations are based on the original parameter estimates by Rudebusch (2002) including the degree of forward-looking (μ) which equals to 0.29.

There are, however, many other studies focusing on optimal policy rules. These include Rotemberg and Woodford implementing the estimated sticky price model (1998), Clark, Goodhart and Huang (1999) in a rational expectations model of the Phillips curve, Khan, King and Wolman (2000) on the new Keynesian model with Friedman's distortions, Clarida, Gali and Gertler (2001) deriving optimal monetary policy in open economies, etc.

6. Implication of the Taylor rule

Having discussed the Taylor rule and its variants, many conclusions can be drawn from this chapter. These include the benefits and drawbacks of the rule and some missing components necessary to achieve more policy objectives than the Taylor rule allows.

6.1. What have we learned from the literature in the Taylor rule?

A major advantage of adopting an instrument rule, particularly the Taylor rule, as a means to conduct monetary policy is that the Taylor rule is simple to verify by the public since there are only few parameters in the rule and the relationship between the policy instrument and the two policy targets is linear. More complex rules, such as optimal rules derived from the loss minimization problem, are much harder to even understand since they sometimes contain many parameters and are based on complicated nonlinear relationships.

Verifiability by the public can promote the credibility of the central bank in conducting monetary policy. In turn, the public forms their expectations of future monetary policy with more certainty. Such expectations help determine longer-term interest rates, which affect aggregate demand directly through the term structure of interest rates. Besides long-term interest rates, the public expectations on future monetary policy are also important in pricing other assets including foreign exchange, equity, etc.

The estimation of policy reaction functions must be interpreted with some caution. Despite the policy reaction function showing the estimates consistent with the Taylor rule, it does not mean that the central bank follows any policy rule or even that they use the same instrument, e.g. German Bundesbank targeted monetary aggregates before the establishment of the European Central Bank.

In the US, the estimation of a policy reaction function tends to follow the Taylor rule well, especially during the early Greenspan era, however, the Federal Reserve never announced following any rule, including the Taylor rule. In stark contrast, it has followed a discretionary policy with sufficiently aggressive response to inflation, conforming to the Taylor Principle – Greenspan (2004). Thus, a central bank can successfully control inflation and reduce the volatility of output, as seen in the Federal Reserve's success, despite adopting a discretionary policy, which is normally plagued with time-inconsistency in policy conduct.

Compared to the original Taylor rule, estimated policy reaction functions in most economies show some degree of interest rate smoothing. Even though the rationales behind the policy inertia are still controversial, its existence leads to lower variability of the interest rate employed as the policy instrument. Moreover, policy inertia leads the policy rule to approach optimality due to the "history dependence" explained by Woodford (1999). Thus, the Taylor-type rule with some degree of the interest rate smoothing can be more efficient than the original Taylor rule because it can achieve lower variability of the instrument without raising the variability of inflation and the output gap, compared to the original Taylor rule, as seen in the optimal policy analyzed in Section 5.3.2.

Even though there are some key advantages of implementing the Taylor-type rules, some problems are also inherent to the rules in practice. The problems can be categorized into two main groups, namely, the practical problems due to implementing a nominal interest rate as a policy instrument, for example, the zero bound constraint on nominal interest rates and the problem due to the nature of the Taylor rule, for instance, the assumption of constant equilibrium real interest rate in the intercept of the rule, which is, in fact, time-varying and unobservable.

6.1.1. The zero bound constraint as the nature of nominal interest rates

The constraint arises from the existence of money which pays a zero return. The private agents can always switch to carry money in case the short-term assets pay a negative return. When Taylor (1993a) introduced his simple interest rate rule, the constraint was not a problem since the federal funds rate was moderately higher than zero. As a consequence, there was a great deal of room to reduce the interest rate further if the economy had fallen into a recession. In addition, the importance of the zero bound constraint on the interest rate rule is small, according the studies including OW, RW and HL[92]. However, it does not mean that it is irrelevant.

The fundamental effect of the zero bound constraint on the Taylor rule can be described as follows. Provided that a central bank conducts monetary policy through the Taylor rule, the zero bound constraint would force the central bank to deviate from the rule-based to zero-percent interest rate whenever the economic environment induces the Taylor rule to prescribe a negative nominal interest rate, leading to too

[92] Refer to Section 4.3.

tight monetary policy, compared with the interest rate prescribed by the rule without the constraint.

Therefore, if the central bank considers implementing the Taylor rule in practice, the Taylor rule has to be modified to take the zero bound constraint into account or has to be modified to prevent the constraint from binding beforehand – RW and HL. The zero bound constraint on a nominal interest rate will be discussed in depth in Chapter 2.

6.1.2. The limitations of the Taylor rule due to the nature of the rule

The simplicity of the Taylor rule as an instrument rule comes with the cost of deviations from optimality in some circumstances since many assumptions are implicit in the rule. Two major issues can be identified. One is the noise in the data used to calculate the rule-based interest rate and the other is the unobservable variables used in the Taylor rule.

The first issue concerns the nature of the data which are released with some lags and have to be revised many times before being finalized. The output gap is a good example. The final or revised real output data is released after 3 months after the fact. These revisions of the data can affect the interest rate prescribed by the rule as pointed out by Kozicki (2004).

The importance of the data used also includes the real-time data which is a main focus of many researchers including Orphanides (1998, 2003c). It could result in different interpretations of the Fed's historical behavior, as discussed in Orphanides (2003c). In addition, agreement is still lacking on which are the appropriate measure of the variables used in the Taylor rule, namely, inflation and the output gap. The different measures of these variables are addressed by Kozicki (1999). The issues of measures of economic indicators, how they are revised and how long it takes before they are revised, should be taken into account when considering the Taylor rule-based interest rate. Otherwise, it could result in misleading or wrong policy recommendations.

The second issue is the assumption about the unobservable variables including potential output and an equilibrium real interest rate. Many studies use the potential output released by Congressional Budget Office (CBO) for calculating the output gap. Other approaches also include Hodrick-Prescott filtered, quadratic trended, etc. These yield different results in the rule-based interest rate, as has been found by Orphanides and Williams (2002) and among others.

Regarding the equilibrium real interest rate or the natural real interest rate, it is assumed to be a constant in the traditional Taylor rule, based on a simple average of (ex post) real interest rates in his whole sample. However, it is not realistic since the natural real interest rate is time-varying depending on the structure of the economy. It can be estimated based on many techniques, e.g. the Kalman filter, a long-term (real) interest rate as a proxy, implied rate from the inflation-indexed bond, etc. The thorough reviews of the estimation of a natural real interest rate are in Amato (2005) and Bernhardsen (2005). This issue is addressed further in Chapter 3.

6.1.3. The Taylor rule as a guideline for monetary policy

Despite the large amount of work dedicated to it, no central banks have committed themselves to the Taylor rule or any of its variants. Moreover, Taylor (2000) emphasizes that the rule he proposed in 1993 is not for mechanical use but must be implemented with some discretion in order to incorporate the new information or changes in economic structure as necessary.

However, the problem is that there is no rule to describe how to appropriately deviate from the rule or explain when discretion is necessary in Taylor's (2000) sense.

In turn, the policy rule would be superseded by discretion and lose its credibility at the end. This point is addressed by Svensson (2002b) on this weakness of an instrument rule, including the Taylor rule. By contrast, he argues in favor of a targeting rule, specifically a specific targeting rule[93].

Nevertheless, the opponents of a targeting rule regime, e.g. McCallum and Nelson (2004), argue that it is impractical to derive a (specific) targeting rule from the optimality condition of the central bank's optimization problem in Svensson's sense. This is because there is no definite objective function defined. In light of the conventional objective function mainly incorporating the output gap and inflation, the preference parameters[94] assigned to each policy targets and whether to include the policy instrument, i.e. a short-term interest rate with or without policy inertia, are still controversial.

Considering the Taylor rule as a guideline for monetary policy but not really as a rule to commit to might be the best compromise for both sides including the instrument rule and targeting rule advocates. With this approach, the policymakers can both gain the main advantage of simplicity and add flexibility to the Taylor rule with some discretion simultaneously.

According to the background of the Taylor rule, the rule originally pertains to describe the behavior the Federal Reserve during a period of time, specifically 1987-1992, not to derive an optimal policy rule for that time. Thus, any assertion on the optimality of the Taylor rule may be misleading.

In order to be used as a guideline for monetary policy, a policy rule must be robust across most standard models. The robustness is defined as tolerably good

[93] Svensson (1997,1999a) defines two terms including a "general targeting rule" – the objective function that explicitly states the central banks' policy objectives, and a "specific targeting rule" – an optimality condition derived from an objective function and a structural model.
[94] Refer to Section 5.1.

performance in the different classes of models. As emphasized by McCallum (1999), a good instrument rule is one which can perform well across a variety of classes of models, even though it might not be optimal in any model. The Taylor rule possesses this attribute, as shown in Levin et al. (1999) and Levin and Williams (2003).

Taylor (2000) suggests the reason for the robustness of the Taylor rule across models widely used by monetary policy analysts and policymakers may be due to the commonality of the interest rate channel as one of the transmission mechanisms in all models. No matter how complicated the model, it basically has to take interest rate effects into account. A change in the interest rate will eventually induce the same type of change in inflation and the output gap[95] in all models.

Hence, it is sufficient to consider the Taylor rule in the context of the robustness rather than optimality of the policy rule, as long as there is no specific model to be agreed on as the best model to describe the economy.

6.1.4. The Taylor Principle

As discussed earlier on the Taylor Principle – a central bank can influence real interest rates in the desired way only if it moves the policy instrument, i.e. a short-term nominal interest rate, more than one-to-one in response to inflation. This becomes the main idea of the Taylor rule as well as necessary condition for dynamic stability of a policy rule.

Empirically, the Federal Reserve's behavior has conformed to the principle since the beginning of Chairman Volcker's term in the end of 1979. Likewise, the estimation of the policy reaction function of the European Central Bank (ECB) also follows the Taylor Principle but not the Taylor rule since the coefficient in response to inflation is greater than unity (actually, very closed to 2) but the coefficient in

[95] Provided that aggregate demand equation has a negative slope, which is a conventional assumption for most models.

response to the output gap is very small and in some cases it is insignificant. This is a result of the emphasis on the response to inflation corresponding to the sole macroeconomic objective of "price stability".

On the other hand, Japan which has suffered from the protracted slump since the asset price bubble burst at the end of 1980s, the estimated policy reaction functions show a slackness of monetary policy stance. This may partly explain the long duration of the post bubble recession.

All this evidence is adequate to draw the conclusion that the Taylor Principle at least ensures the stability of the economy, even though a central bank does not need to follow the Taylor rule or any rules at all.

6.2. What is missing?

One may argue that the Taylor rule is so simple that it does not contain any factors other than inflation and the output gap that describe the economy in detail and central banks should also respond to those factors. As shown in the robustness analysis, inflation and the output gap are sufficient to describe the economy in many circumstances. In order to improve the performance of the Taylor rule, some other variables may be appended.

6.2.1. Discretionary and judgment of central banks

Svensson (2002b) comments that the Taylor rule is insensitive to some rare events such as the oil price shocks, the stock market bubble and so forth. In addition, he argues that there is no rule for how to deviate from the original Taylor rule whenever such rare events happen to take its effect on future inflation and output.

Svensson shows that a (specific) targeting rule, obtained from minimizing a loss function which includes two main policy goals, inflation and the output gap, is robust to the addition of a judgment variable while an optimal instrument rule is not. The robustness of a targeting rule versus an instrument rule can be explained as follows.

He suggests that the optimality condition can be reduced to equality between the marginal rate of substitution (MRS), depending on the parameters of the loss function, and the marginal rate of transformation (MRT), relying on the parameters of the Phillips curve or an aggregate supply equation. Obviously, the parameters in an aggregate demand equation are irrelevant.

Furthermore, he appends an exogenous variable called "deviation" to the new Keynesian framework. This variable can be interpreted as the central bank's judgment which is unobservable. It also includes factors that help determine *future* inflation and the output gap but must be orthogonal to the information contained in inflation and the output gap at the *current* period. With the deviation embodied in the model, an optimal instrument rule exhibits that the optimal interest rate path also depends on the deviation, whereas, a (specific) targeting rule does not depend on this variable since it does not appear in the optimality condition.

Moreover, the "deviation" variable introduced by Svensson can represent the central bank's discretion. It can be interpreted as a systematic part of the economic fluctuation not captured by inflation and output. In this circumstance, the policy rule is more flexible since it allows for adjustment whenever economic conditions deviate enough from the normal stance explained by the policy rule without the deviation. Nonetheless, the central bank's judgment and discretion are unobservable and subjective.

Noticeably, an instrument rule can be perceived as a stricter version of a targeting regime since each instrument rule also contains the policy targets and their targeting levels[96]. For instance, the Taylor rule also implies an inflation target in the constant. In fact, an instrument rule only specifies the level of the policy instrument necessary to maintain or restore the targeting levels of the policy targets, compared to a targeting regime which defines an optimal level for the policy targets.

6.2.2. Asset price volatility

Another widely discussed variable is asset price volatility. It has been of interest to policymakers as well as the public since 1990s, especially when the term "irrational exuberance" was included in the speech of Chairman Greenspan in 1996 revealing his concern about the behavior of asset prices. Bernanke and Gertler (1999) address whether central banks should care about asset price volatility or not by focusing on the US and Japan, based on the argument that the central bank should perceive price stability, measured by inflation, and financial stability as complimentary objectives which should be pursued in a unified framework.

Asset prices can affect aggregate demand by many ways. For instance, the credit channel relates asset prices to the price of collateral that firms can use to expand their external borrowing. They affect expansion of credit to the external finance premium – the difference between the cost of borrowing from outside versus the cost of using their own funding, e.g. retained earnings.

In addition, asset prices can affect consumption through a wealth effect. Higher prices of financial assets, e.g. equity, lead to wealth expansion and a rise in consumption. However, the wealth effect is small empirically.

Whether asset prices should be considered in policy rule design is still an open question. If the capital market is efficient, asset prices reflect underlying economic

[96] The targeting levels of inflation and output are an inflation target and potential output, respectively.

fundamentals including the information which inflation and output growth already contain. Therefore, incorporating asset prices into the policy rule would be redundant.

On the other hand, if two conditions are met, asset prices should be incorporated in the policy design. First, the "non-fundamental" factors, e.g. the irrational behavior of market participants, which can change asset prices, in spite of unchanged economic fundamentals; second, changes in asset prices unrelated to fundamental factors but directly affects the real economy. Thus, central banks should take asset prices into account only if they provide useful information about the state of economy, which are not captured by inflation and the output gap.

Bernanke and Gertler find that a policy rule which aggressively responds to only *expected* inflation and neglects a direct response to stock prices works best among the set of policy rules. This is because it is difficult to distinguish between a fundamental or non-fundamental move of the stock prices. Thus, simultaneously responding to stock prices may more than offset the effect of the movement of stock prices since it might be partly determined by fundamental factors already taken into account by expected inflation.

Empirically, the period of 1960:1-1998:12 shows that the Federal Reserve hardly responded to stock prices, consistent with Bernanke and Gertler's finding. The response to stock prices is insignificant and even has the wrong sign based on the estimation of a policy reaction function, which incorporates stock prices as a policy target.

Siklos, Werner and Bohl (2004) find that adding asset prices to the policy reaction function would result in lower coefficients in response to inflation in the results obtained from Germany, France and Italy, prior to the European Central Bank (ECB) taking control of monetary policy.

They argue that the forward-looking reaction function fits the data in the EU quite well with the inclusion of asset prices as instruments for estimation but not as an additional pre-determined variable in the policy rule, compared with the backward-looking model. This also substantiates Bernanke and Gertler's (1999) result that asset prices should not be directly included in the policy reaction function.

In addition, Siklos et al (2004) point out that there is still no good proxy for asset prices, should they be incorporated into a policy rule. Potential candidates include stock price indices, housing prices, the real exchange rate and the financial condition index which is the combination of all three prices.

In sum, it is accepted that the policy reaction function should *not* include asset price volatility as a policy objective directly, but still it should be taken into account by means of exploiting it as an instrument in estimation or for forecasting (an instrumental variable) since it may contain some useful information about *future* inflation and output.

6.2.3. A real exchange rate

Another asset widely discussed as missing from the Taylor rule is foreign exchange. The industrialized countries or regions; namely, the US, Japan and the EU are such large economies that they affect the foreign exchange markets rather than the foreign exchange markets affecting their conduct of monetary policy. Thus, the foreign exchange rate may not need to be incorporated in policy rules. In contrast, this is not the case for the smaller open economies, which include foreign exchange rate stability into their central banks' objectives.

Nonetheless, including a real exchange rate as a pre-determined variable in the Taylor rule is unnecessary in large economies, as supported by many studies, e.g. Taylor (2001). They find that there is slight improvement the variability of inflation and output when adding a real exchange rate into the Taylor-type rules. Yet, the cases for small economies require further study.

6.3. What could be a candidate for good policy?

A policy strategy, drawn from the relationship between a policy rule and a central bank's discretion, suggests that a central bank can adopt an instrument rule but enhance it with some discretion when transitory shocks hit the economy. With this strategy, Svensson (2002b) suggests the central bank's credibility may not be adversely affected. This is because if the public is rational, it will form its expectations by exploiting all relevant information about economic conditions available up to the current period. In other words, it will anticipate that the central bank follows a policy rule since the central bank adheres to the rule in the normal circumstance (without large shocks). However, if a rare event which is unanticipated occurs, the public will not change its expectations if this event is transitory and expected to dissipate with time. Therefore, exercising discretionary power when transitory shocks hit the economy should not affect the credibility of the central bank in this circumstance.

What if the rare events have permanent effect on the economy? In this case, the central bank should consider adjusting its policy rule, corresponding to the permanent change in economic condition. With this adjustment, the public will eventually learn and adjust its expectations to the new policy rule.

Inclusion of other variables apart from inflation and the output gap into the Taylor-type rules may be unnecessary, even though there are many possible candidates, including asset prices and foreign exchange rates. Nonetheless, employing asset prices as instrumental variables in the estimation of a policy reaction function can be beneficial. This is because the only useful information about *future* inflation and output, not provided by *current* inflation and output, should be added to the rules.

Basically, a policy rule should also follow the Taylor Principle. Even though it may not be a necessary condition, it is a sufficient condition for stabilizing policy actions. The principle is a guarantee to move a real interest rate, taken into account by both consumers and investors, in the same direction as the inflation. In turn, the problem of dynamic instability disappears.

6.4. The Federal Reserve during Greenspan era

Even though the Taylor rule can describe the Federal Reserve's behavior very well, it should be interpreted as an econometric allegory rather than literal description – Taylor (2005). The description of the rule should not be confused with the Fed's approach in conducting monetary policy. In fact, the Fed does not follow any rule. Rather, the discretionary policy seems to be appropriate to explain the Fed's conduct of monetary policy, especially during Chairman Greenspan's term (1987-2006).

Nonetheless, a short-term interest rate has been the policy instrument that the Fed has implemented for a period of time, except for the short periods when it experimented with the different operating procedures, namely, the "free reserves" before 1960s and the "non-borrowed reserves" during 1979-1982.

During Chairman Greenspan's tenure, he balanced the importance of policy targets to satisfy the dual mandate, i.e. price stability and maximum employment, quite well - Blinder and Reis (2005). Notwithstanding the multiple goals that the Fed is mandated to achieve and the implementation of discretionary policy rather than a policy rule, the Fed conducts its monetary policy consistent with the Taylor Principle, according to the estimation of the policy reaction function.

In spite of many disadvantages of the discretionary policy in terms of credibility, Chairman Grenspan could gain high credibility in conducting monetary policy[97]. He exploits all advantages of this type of policy, i.e. its flexibility and adaptability in adjusting to new information about the economy when it arrives, with his own approach, based on risk management, rather than an optimization approach employed by the conventional monetary policy analysis.

The risk management paradigm, similar to the Bayesian theory of decision-making, is basically to identify the sources of risk and uncertainty encompassing both Knightian uncertainty, in which the probability distribution of outcomes is unknown, and uncertainty of outcomes per se, which is based on the known probability distribution. Having realized the sources of risk, subjective probability would be quantified (if possible) and assigned to each outcome in order to calculate the expected utility. A policy is an outcome of the maximum expected utility, given the state of economy.

With this approach, no specific model to describe the economy is required and a specific loss function, normally used for optimization problem, is irrelevant. In fact, Chairman Greenspan (2004) emphasizes that a policy implemented by the Fed should perform acceptably well when the full extent of risk surrounding the optimal path of the policy is taken into account. The robustness to risk and uncertainty is not generally included in the conventional optimization approach[98].

The success of Greenspan era could also be in part a result of the consistency of the policy decisions. Recalling Section 1.2, a policy rule is just technology to express the commitment of a central bank to an optimal decision made in the past for

[97] Blinder and Reis (2005) thoroughly describes the policy during Chairman Greenspan.
[98] Nevertheless, many studies on the robustness of a policy rule attempt to compromise with the robustness to risk concept by implementing some Baynesian approach to optimization problem – Onatski and Stock (2002), Levin and Williams (2003), etc.

every time period (in the timeless perspective manner) so that the time-inconsistency problem would not occur. If the discretionary policy can replicate this decision plan, the rule may not be needed. Unsurprisingly, the estimation of Fed's policy reaction function is consistent with the Taylor rule as if the rule was implemented.

Despite that the Fed has never adopted the Taylor rule, as a main approach for monetary policy conduct, the Taylor rule can still be considered as a guideline or cross-checking for the Fed about its policy stance. If the level of instrument currently set by the Fed is "off the rule", it may signal a significant economic event such as a large shock hitting the economy. More importantly, the difference should also indicate whether the discretion exercised by the Fed is turning the economy in a desirable direction.

Cross-checking between the policy actually implemented and the rule-based policy has been, in fact, adopted by the Fed during the 1990s. By contemplating the rule-based federal funds target calculated from the Taylor rule, published in Monetary Trend[99], released by the Federal Reserve Bank of St. Louis, the public can cross check the policy with the actual federal funds target.

With the preference of flexibility and adaptability attributed to discretionary policy, the Fed has not considered other policy regimes including an inflation targeting regime widely used in many countries. Chairman Greenspan (2004) also comments on the inflation targeting regime that it is too inflexible and too strict given its sole target of price stability. The inflation targeting regime emphasizes only price stability, thus, it may not be suitable for the US economy, given the Fed's dual mandate.

[99] The Monetary Trend also contains the monetary base, calculated from the McCallum rule.

One of the major proponents of an inflation targeting regime is Ben S. Bernanke who succeeded Chairman Greenspan at the beginning of 2006. He proposed to publish an inflation target – Bernanke and Mishkin (1997), Bernanke and Gertler (1999). The Fed may change its conduct of monetary policy from the discretionary policy implemented by Chairman Greenspan to a targeting regime such as an inflation targeting regime. Nevertheless, the big success of the Greenspanian approach still challenges the credibility argument on the discretionary policy and may cause some hesitation in changing the way the Fed conducts monetary policy.

7. Conclusion

Since the introduction of the Taylor rule in 1993, a large volume of literature has examined the rule and its extensions. Not only does the empirical work show that the Taylor rule describes the Federal Reserve's behavior well particularly during the mid 1980s to the beginning of 1990s, but it also explains other industrialized countries central banks' behavior.

Even though no central bank commits to the Taylor rule, it can use the Taylor rule as a guideline for monetary policy conduct owing to its simplicity. For small countries, an inflation targeting regime is an alternative and it is believed to be better in terms of welfare loss. The debate whether the targeting regime or the instrument rule is the best operating procedure is still open.

Nevertheless, the simplicity of the Taylor rule can be a double-edge sword. One is an advantage since the public can understand it easily, no complicated mathematics involved, resulting in verifiability of the behavior and enhancing the credibility of the central bank. The other is a disadvantage due to its inflexibility which may subsequently impact the central bank's credibility, whenever new information on economic fundamentals affects the economy and requires a radical modification to the rule. The need for an adjustment may engender some doubt by the public whether the central bank has to deviate from the rule or not.

In small open economies, inflation and the output gap may not be sufficient to explain the mechanism of the economy well. Other factors may have to be incorporated, for example, the real exchange rate is quite crucial in determining a nominal interest rate by policymakers. As a result, the policy reaction function in these economies may not be well-described by the Taylor rule.

Asset price volatility is another variable focused on by many researchers, based on the principle that financial stability and price stability should compliment each other and they should be contained in the central bank's framework to accomplish these goals simultaneously. Most studies do not support the addition of asset prices into the rule, but they support the use of asset prices as instruments in estimation.

Even though there is tremendous support for the Taylor rule, it has significant problems in practice. These include the problems with the data used in calculating the rule-based nominal interest rate, e.g. the real-time versus revised data, the robustness of the variables implemented in the rule and the zero bound constraint on nominal interest rates.

Notwithstanding these limitations of the Taylor rule, many researchers encourage that it be used as a guideline. The rule should not be used as a strict policy rule without any possible adjustments at all but the policymakers should be flexible enough to update the rule systematically whenever the useful information about economic fundamentals becomes available.

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APPENDICES TO CHAPTER 1

Appendix A

Table A-1: Estimates of weights in Taylor-type rules by Kozicki (1999) ranging 1987-97

Output gap measure	Inflation measure	Inflation weight (α)	Output weight (β)	Mean absolute deviation
CBO	*CPI inflation*	**0.82**	**-0.10**	0.79
CBO	*Core CPI inflation*	**1.05**	0.40	0.52
CBO	*GDP Price inflation*	**0.92**	0.33	0.57
CBO	*Expected inflation*	**0.73**	0.82	0.54
OECD	*CPI inflation*	**-0.37**	**1.10**	0.79
OECD	*Core CPI inflation*	**-0.08**	**1.23**	0.72
OECD	*GDP Price inflation*	**-0.11**	**1.11**	0.77
OECD	*Expected inflation*	0.40	**0.90**	0.69
IMF	*CPI inflation*	**-0.51**	**0.90**	0.60
IMF	*Core CPI inflation*	**-0.38**	**0.93**	0.56
IMF	*GDP Price inflation*	**-0.32**	**0.89**	0.55
IMF	*Expected inflation*	**-0.03**	**0.78**	0.57
DRI	*CPI inflation*	**0.09**	0.60	0.94
DRI	*Core CPI inflation*	0.86	**1.01**	0.65
DRI	*GDP Price inflation*	0.68	**0.82**	0.69
DRI	*Expected inflation*	**1.29**	0.66	0.55
Taylor	*CPI inflation*	**-0.76**	**0.79**	0.59
Taylor	*Core CPI inflation*	**-0.82**	**0.82**	0.62
Taylor	*GDP Price inflation*	**-0.71**	**0.79**	0.60
Taylor	*Expected inflation*	**-0.54**	**0.74**	0.60
Recursive	*CPI inflation*	**-0.39**	**0.83**	0.72
Recursive	*Core CPI inflation*	**-0.10**	**0.91**	0.57
Recursive	*GDP Price inflation*	**-0.08**	**0.85**	0.59
Recursive	*Expected inflation*	0.37	**0.71**	0.55

Note: The entries with bold characters are significantly different from 0.5, set by Taylor (1993).

Appendix B

Table B-1: Estimates of alternative variables in Clarida, Gali and Gertler (2000)

Period	π^*	φ	β	ρ	p-value from J-test
Detrended output					
Pre-Volcker	4.17 (0.68)	0.75 (0.07)	0.29 (0.08)	0.67 (0.05)	0.801
Volcker-Greenspan	4.52 (0.58)	1.97 (0.32)	0.55 (0.30)	0.76 (0.05)	0.289
Unemployment rate					
Pre-Volcker	3.80 (0.87)	0.84 (0.05)	0.60 (0.11)	0.63 (0.04)	0.635
Volcker-Greenspan	4.42 (0.44)	2.01 (0.28)	0.56 (0.41)	0.73 (0.05)	0.308
CPI					
Pre-Volcker	4.56 (0.53)	0.68 (0.06)	0.28 (0.08)	0.65 (0.05)	0.431
Volcker-Greenspan	3.47 (0.79)	2.14 (0.52)	1.49 (0.87)	0.88 (0.03)	0.138

Note: The standard errors are reported in parentheses.
The set of instruments includes four lags of inflation, output gap, the federal funds rate, the short-long spread, and commodity price inflation.

Appendix C

Table C.1: Gerlach and Schnabel`s (1999) estimation of the policy reaction function of the weighted average of 11 EU countries with the specification similar to CGG (1998)

Constant	1.95*** (0.62)	2.36** (0.95)	1.76*** (0.44)	3.68** (1.53)	1.40** (0.57)
Inflation (forecast)	1.51** (0.44)	1.62*** (0.47)	0.98 (0.64)	1.54** (0.72)	1.20* (0.70)
Output gap	0.28* (0.16)	0.22* (0.11)	0.32** (0.14)	0.29 (0.21)	0.23** (0.11)
Lagged interest rate	0.18 (0.20)	0.34** (0.14)	0.46 (0.30)	0.15 (0.36)	0.34 (0.32)
Additional Variable	-	Lagged inflation	Money growth	Federal funds rate	Real Euro/$ rate
		-0.56 (0.56)	-0.07 (0.07)	-0.28** (0.13)	-0.03 (0.02)
Q-stat.*	1.3%	5.5%	3.0%	2.7%	17.8%
Adjusted R^2	0.91	0.91	0.94	0.92	0.95
Implied long-run elasticities ***(with P-values for tests of the hypotheses that the long-run elasticities of inflation and the output gap equal 1.5 and 0.5, respectively)***					
Inflation	1.84 (25.7%)	1.61 (76.6%)	1.81 (41.7%)	1.81 (36.5%)	1.82 (41.4%)
Output gap	0.34 (54.5%)	0.33 (45.6%)	0.59 (84.4%)	0.34 (59.1%)	0.35 (63.1%)

*Note */**/*** denote significance at the 10%/5%/1% level. The equations are estimated using GMM, with forecast inflation instrumented by a constant, current inflation, the output gap and the lagged interest rate and any other variable enetering the model. Money growth and the real euro/US dollar rate are measured as a change over four quarters.*

** P-value, null hypothesis of no fourth-order serial correlations.*

THE TAYLOR RULE AND ITS IMPLICATIONS

VOLUME II

by

Katkate Bunnag

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CHAPTER 2

THE SUSTAINABILITY OF THE TAYLOR RULE WHEN THE ZERO BOUND CONSTRAINT BECOMES A CONCERN

1. Introduction

A monetary policy rule is defined as "a contingency plan that lasts forever unless there is an explicit cancellation clause" (Taylor 1993a, p. 199), or it could be more specific as "a description – expressed algebraically, numerically, graphically – of how the *instruments* of policy, such as the monetary base or the federal funds rate, change in response to economic variables" (Taylor 1999a, p. 319).

Following the introduction of a simple interest rate rule by Taylor in 1993, subsequently called the Taylor rule, research in monetary policy analysis implementing the short-term interest rate as a policy instrument has grown enormously, e.g. Taylor (1993a, 1999a), Kozicki (1999), Hetzel (2000), Carlstrom and Fuerst (2003), and Orphanides (2003a). The Taylor rule is a simple interest rate rule, which has tracked the Federal Reserves' behavior quite well and has been used as a benchmark for many variants of interest rate rules with different degrees of responsiveness to key economic variables.

Basically, the Taylor rule sets a short-term interest rate to respond to two economic variables, namely inflation and the output gap. The rule is designed, based on the so-called "Taylor Principle" that the nominal interest rate should respond more than one-to-one to inflation. In other words, the real interest rate has to rise or fall adequately to overcome inflation rate changes.

However, a practical problem of an interest rate rule is that it is constrained by a zero lower bound since the nominal interest rate cannot fall below zero percent. The immediate effect of the zero bound constraint, as pointed out by Sellon (2003), is that the overnight market would cease to function as every depository institution would hold their excess reserves instead of lending them out.

Problems caused by the zero bound constraint were not a concern until the end of the 1990s when the asset price bubble burst in Japan and other industrialized economies, including the US, were weakened at the beginning of the millennium, especially after the large adverse shock owing to the tragedy on September 11th, 2001. With weak economies coupled with low nominal interest rates, the zero bound constraint was perceived to be a threat to monetary policy effectiveness.

Figure 2.1: Inflation, output gaps and federal funds rates and the recessions

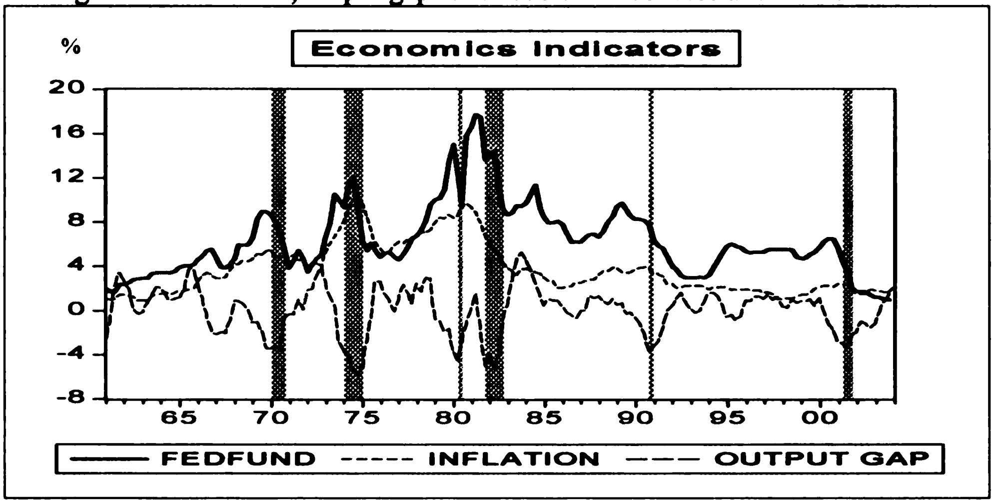
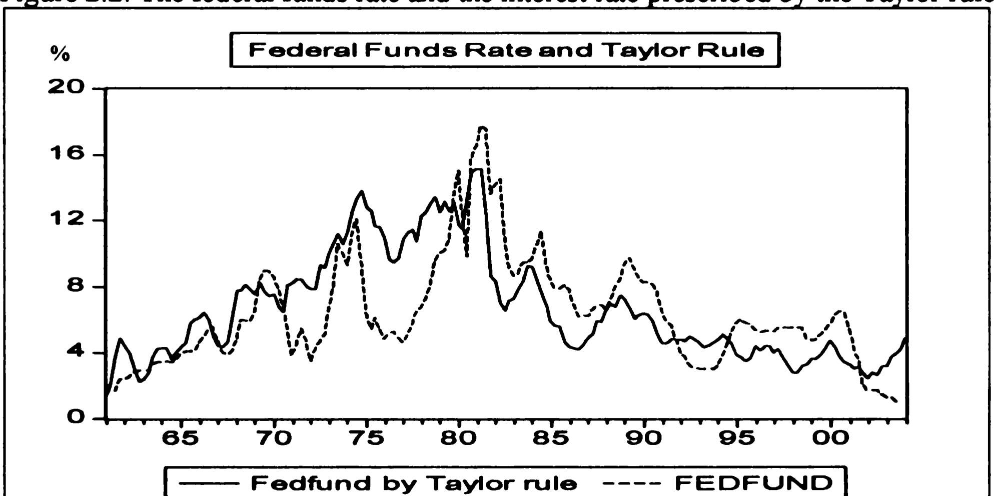


Figure 2.2: The federal funds rate and the interest rate prescribed by the Taylor rule



Typically, the zero bound constraint on the nominal interest rate becomes a concern once the short-term interest rate approaches zero percent, while the economy remains in recession. As a result, the interest rate rule still calls for an interest rate reduction, whereas the nominal interest rate cannot be reduced much further. Without any help from other policy stimuli, the economy may be stuck in recession.

Figure 2.1 shows the recessions in the US starting from the first quarter of 1960. The recessionary periods are shaded and are obtained from the NBER in their business cycle studies. The Taylor rule has prescribed easier monetary policy than the Fed actually took by prescribing a lower federal funds rate in the US, compared to the actual market rate plotted in Figure 2.2 before the recession took place in the beginning of 2000, while it has called for tighter monetary policy recently. Therefore, the zero bound constraint may not be of that much present concern for the US.

On the other hand, Figure 2.3 exhibiting Japan's case, the rule suggested such a low call rate in the late 1990s that it was below zero. As a result, the concern about the nominal short-term interest rate hitting a zero bound and the Bank of Japan running out of the policy options to fight against the deflationary pressure was triggered.

It is worth noting that the historically low call rate in Japan was a result of the banking crisis rather than monetary policy mistakes, as discussed in Krugman (1998), Cargill (2001), and McCallum (2003).

Since the nominal interest rate cannot go below zero[100], some modification to the rule must be made. The simplest one is to apply a bound to the policy rule by

[100] In the absence of both the cost of carrying currency and short-term assets, the public could always choose to hold money paying zero return rather than the assets paying below zero return, if nominal interest rates were below zero. As a consequence, the prices of those short-term assets are driven down while their returns conversely rise until they reach the zero bound or higher. Nevertheless, there exist some costs of carrying currency and transactions in short-term assets. If the cost of the former is higher than the latter, the bound could possibly be at a mildly negative number such as discussed in Ullersma

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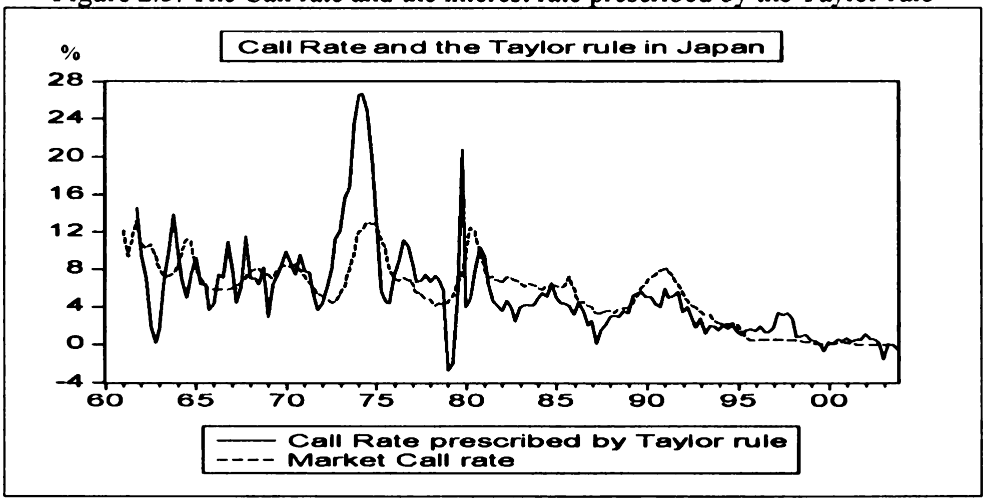
setting the interest rate to be zero whenever the Taylor rule calls for a negative rate, and return to the standard Taylor rule whenever the constraint is not binding. This modification will be used throughout the present chapter and has also been applied to other interest rate rules proposed by other monetary economists. Thus, I refer to the Taylor rule in this chapter as, in fact, the modified Taylor rule with the zero bound constraint.

Figure 2.3: The Call rate and the interest rate prescribed by the Taylor rule



Due to the historically low short-term interest rates and recent recessions in the industrialized countries, many research papers regarding monetary policies when the zero bound constraint binds have been published, e.g. Clouse et al (2000), Goodfriend (2000), McCallum (2000a), Oda and Okina (2001), Sellon (2003) and Svensson (2003). These papers proposed alternative policies when the zero bound constraint binds. Their recommendations rely on the claim that interest rate rules, such as the one introduced by Taylor in 1993, may not be appropriate monetary policies to implement when the bound is hit and thus they recommend abandoning the interest rate rule in favor of other alternative policies.

(2001). Thus, a zero bound constraint might not be literally zero but some floor below which a nominal interest rate cannot fall below this level.

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To the contrary, the main issues to be addressed in Chapter 2 are the importance of the zero bound constraint and its effects on the economy. I will tackle the question of whether the interest rate rule could still be an effective tool for the central bank to counteract (negative) shocks to the economy, in spite of a binding zero bound constraint.

The purpose of this chapter is to provide a laboratory for monetary policy analysis when the zero bound constraint binds. It intends to address a potential problem in the original Taylor rule which was not recognized when the rule was first introduced. Moreover, it explores the effects of the zero bound constraint on the the Taylor-type rule with different parameters including the ones with some degree of interest rate smoothing in a backward-looking model framework.

A key policy implication from this chapter is that the effect of a zero bound constraint may not be as harmful as it was at first thought. Even though the zero bound constraint could be binding for a period of time, it is likely that the economy could be resuscitated with interest rate rules without the need to implement other policies. Before abandoning interest rate rules entirely and implementing other policies, central banks should also take the possible continued effectiveness of these rules into account. This is because there are some implicit costs of policy change – noted by Taylor (1993a) among others.

Nonetheless, I will not claim that any particular policy rule in this chapter is optimal. The main result is presented in terms of effectiveness represented by the ability of the rule to resuscitate the economy rather than the efficiency of the rules based on minimizing a loss function, defined over the variability of both inflation and the output gap. Yet, many researchers including Rudebusch and Svensson (1999) and Levin and Williams (2003) found that the simple rules used in this chapter are also s

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optimal in their model setup, consistent with the business cycle studies[101] which found that the simple policy rules come close to the fully optimal rule.

Chapter 2 is divided into 9 sections. The first section discusses the earlier literature on this subject regarding the effects of the zero bound constraint. The second section describes the methodology to be used. In the third section, the model setup is introduced. In the fourth section, I follow Reifschneider and Williams (2000) in the analysis of how the zero bound constraint changes the equilibrium condition of the model. Then, I analyze some data with simple descriptive statistics in the fifth section. Subsequently, I estimate the model to obtain the baseline parameters for the simulation exercises in the seventh section. After that, the implications for monetary policy rule design are discussed. Finally, conclusions are drawn.

2. Background on related literature

This chapter is most akin to Orphanides and Wieland (1998) (OW), Reifschneider and Williams (2000) (RW), Hunt and Luxton (2001) (HL). They focus on the effects of the zero bound on nominal interest rates on the economy, in terms of the probability of hitting the zero bound and the distributions of the interest rate, inflation and the output gap, depending on the inflation target set by central banks. While OW implements a small-scale forward-looking model, RW employs the FRB/US model – the large-scale macroeconometric model currently used by the Federal Reserve. The MULTIMOD, implemented by the IMF, was employed in HL and they also focused solely on the Japanese economy.

RW conclude that during particularly severe contractions that cause the economy to fall into self-perpetuating deflation, open-market operations alone may be

[101] These studies also substantiate the use of the two factor model in this chatper since they found that it could explain business cycle variance quite well.

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insufficient to restore equilibrium; some other stimulus is needed such as fiscal policy. Abstracting from such circumstances, if a policymaker follows the Taylor rule and targets a zero-inflation rate, there is a significant increase in the variability of inflation but not the output gap, while there is not much effect of the zero bound constraint if the monetary authority targets higher inflation (2%). In addition, they propose a simple modification of the Taylor rule to lower the negative effect of the zero bound constraint. They adjust the original Taylor rule to be sufficiently accommodative, offsetting the upward bias caused by the central bank's inability to reduce a nominal interest rate any further when the zero bound constraint binds.

Likewise, OW (1998) focus on the effect of the zero bound constraint on the economy. They find that its effect is greatest when the monetary authority targets very low inflation (0% or 1%). In spite of the forward-looking type model, OW ends up with a conclusion similar to RW.

On the other hand, HL focuses only on Japan, which experienced a binding zero bound constraint between 1999 and 2001[102]. HL also find that for inflation targets below 2%, the effect of the zero bound constraint is more pronounced than at other levels of the inflation target since the constraint hinders the endogenous variables from adjusting toward to the steady state equilibrium after being hit by adverse shocks. This result is consistent with the earlier studies including OW and RW.

Moreover, HL show that with the errors in the measurement of potential output, the probability of hitting a zero bound increases, especially, when the errors are persistent and correlated with the business cycle. The intuitive explanation is that

[102] In fact, the Bank of Japan adopted the Zero Interest Rate Policy in February 1999 and tightened the policy stance by raising the target call rate to 0.25% in August 2000. However, they returned to the zero interest rate policy again in March 2001 and changed their operating procedure to reserves targeting instead of an interest rate targeting regime. Sellon (2003) describes the economic theory in different countries having experienced the zero bound constraint in detail.

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policymakers hesitate to follow an aggressive rule[103] in response to inflation and the output gap in this situation.

Notwithstanding many results which shed some light on the importance of a zero bound constraint, most papers still do not include other features of policy rules in their analyses, such as rules with interest rate smoothing. Moreover, a possible structural break caused by the change in Federal Reserve's operating procedure in the period 1979-1982 should be considered since it changes some of the dynamics of the economy[104].

3. Methodology

In this chapter, I implement a general framework similar to Taylor (1999b). It can be divided into two main sets of equations. The first one is the reduced form model of the economy, represented in equation (1). The other is the policy rule, which is assumed to be known and taken as given by all households and firms involved in the economy, represented by Equation (2). However, if it represents the policy reaction function implemented by the central bank, the residual is appended into Equation (2).

Equation 1.............. $y_t = A(L,g)y_t + B(L,g)x_t + u_t$

Equation 2.............. $x_t = G(L)y_t$

where y_t is a vector of endogenous variables (the rate of inflation and the real output gap in this chapter);

x_t is the policy variable (the short-term interest rate in the interest-rate rule).

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[103] Generally, aggressiveness in a policy rule in this dissertation is referred to putting more weight on the coefficient of the policy rule in response to inflation, unless there is a specific definition following, e.g. the aggressive policy rule in response to the output gap.

[104] In fact, those studies, e.g. OW (1998) and RW (2000) test for a structural change in their model, they do not find a structural break. However, the result is different in the present chapter.

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u_t is a serially uncorrelated vector of random variables with some variance-covariance matrix

A(L, g), B(L, g) and G(L) are matrix or vector polynomials in the lag operator (L). The vector g consists of all the parameters in G(L).

This general framework embraces most models used in monetary policy analysis. In case the model is not a rational expectations model, Equation (1) is the reduced form model, similar to Ball (1997) and Rudebusch and Svensson (1999). If it contains some forward-looking expectation variables, such as the model used by OW, it is to be assumed that these expectation variables have been solved out using a rational expectation solution method before collapsing to the form in Equation (1).

Because the zero bound constraint never bound in the US and the Federal Reserve never publicy announced that any policy rules are implemented, we cannot examine the effect of the zero bound constraint directly from any historical data. One approach to evaluate the policy rules in light of a binding zero bound constraint is to build a structural model and then simulate it. With this approach, either estimation or calibration is necessary to obtain the parameter estimates to be used in the simulation that are consistent with the real economy. Since I use a small, simple backward-looking model originally used by Rudebusch and Svensson (1999), estimation is not so complicated that this is infeasible. Thus, the model will be estimated.

After the model parameters are estimated, the steady state equilibrium is calculated and the dynamic stability of the model is examined. The ranges of the parameters leading to stable systems will be found by calculating the eigenvalues of the matrix of coefficients of lagged variables. Initially, the dynamic stability is addressed without the zero bound constraint.

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I separate the simulations into three main parts, namely, the dynamic responses, the counterfactual historical simulation and the stochastic stimulation based on random shocks. For the first part, I calculate the time-paths after perturbing the model from the steady state equilibrium with a one-time shock. With this method, the time paths of each variable can be observed across the policy rules for comparisons of their behaviors towards the steady state. Only the stable policy rules are considered in this exercise.

In the second part, provided that the monetary authority commits to following the policy rules, I conduct a stochastic simulation by exploiting US historical shocks, corresponding to the period 1960:Q1 – 2004:Q2. The procedure is similar to McCallum (1988) and Judd and Motley (1991, 1992). The results show counterfactual behaviors of the endogenous variables when imposing an alternative policy rule such as the modified Taylor rule into the economy, instead of the current policy used by the Federal Reserve. This sub-section is intended to answer the question of how the endogenous variables would have behaved if the Federal Reserve had imposed policy rules.

Basically, the approaches to studying the counterfactual behavior of the economy can be divided into two major strains. The first one is *an historical approach*, based on fitting the data into a policy rule directly and calculating the rule-based interest rate without implementing any structural model. With this approach, inflation and the output gap (policy targets) are treated as the pre-determined variables in the policy rule. The examples of studies based on this approach include Stuart (1996), Taylor (1999a) and McCallum (2000) and Figure 2.2 and 2.3 in this chapter. The advantage of this approach is that it does not depend on any specific model. The disadvantage is that it does not allow any changes of the policy targets including inflation and the output gap in response to the interest rate prescribed by the rules.

The second approach is *a simulation-based approach*. This approach requires a structural model describing the economy. The model can be either structural, e.g. New Keynesian or Real Business Cycle models, or atheoretical model, e.g. Vector Autoregressive model (VAR). However, this approach requires that the parameters estimated in the structural or atheoretical models do not change along with the policy rules and the models used in the simulation are sufficient to explain the economy.

The instability of the parameters in the structural model due to a change in policy is addressed by the "Lucas Critique". However, it can be alleviated by some rational expectation models, allowing the policy rule to affect the economy through the public's expectations, while the public forms their expectation based on the policy rule. Nonetheless, the main problem of those models is that they do not fit the data well.

Yet, Taylor (1984) found stability of the parameters across the Fed's policy regime change in 1979 and argued that the critique may not be empirically important in the monetary policy rule context. The unimportance of the Lucas Critique in practice is also supported by the recent finding of Rudebusch (2005). Thus, the critique is not a concern, though the simulation approach is implemented in this research.

Lastly, I simulate the model stochastically with a number of sets of randomly drawn shocks. These shocks are transformed into the same distribution as the estimated residuals from US history during the period of 1960:Q1-2004:Q2 before being used in the simulation. With this method, the unconditional variance of the endogenous variables can be inferred, which in turn, can be plugged into a central

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bank's loss function to compare the performance of each policy rule [105]. The simulation procedure is explained in detail in the Appendix F.

Stochastic simulation is an important and widely used approach to study the counterfactual behavior of the economy. It is used to answer the question of how an economy, with the similar structure to the one of interest, behaves *on average* when the central bank implements different policy rules. An historical simulation is performed to obtain only one time path of each variable, based on the estimated residuals of the model, whereas, a stochastic simulation is performed as many times as necessary in order to obtain stationary distributions of the variables derived from many time paths. With these distributions, the probabilities of a deflationary trap and the binding zero bound constraint to happen can also be inferred.

4. Model setup

The model follows a simple empirical model utilized by Rudebusch and Svensson (1999) (henceforth RS), conforming to a dynamic new-Keynesian framework widely used in many monetary policy analyses. The model is also a general equilibrium model and contains nominal rigidities through price setting. The features of the New Keynesian framework are described recently in Clarida, Gali and Gertler (1999) and Gali (2002). Apart from the sound theoretical base of the New Keynesian framework, it is considered to fit the US economy sufficiently well, as illustrated in Söderström et al (2003).

Ball (1997) and Svensson (1997) also apply a similar model specification but they calibrate the model to annual data. On the other hand, the RS model contains more lags in both inflation and the output gap equations than in the model utilized by

[105] The performance and the optimality of policy rules will be not be emphasized much since the purpose of the paper is to illustrate the effect of the zero bound constraint, not to find an optimal policy rule.

Ball (1997) and Svensson (1997), corresponding to dynamic behavior inherent in the quarterly data. Other studies which estimate a similar specification to the RS model include Dennis (2001), Rudebusch (2001), Ozlale (2003) and Stock and Watson (2003)

The model consists of two sets of equations, according to a general framework described by Taylor (1999b). The first set, composed of two core equations, describes the economy. The other is a policy rule. In this case, the modified Taylor rule with the zero bound constraint. The constraint restricts the interest rate at zero or any figure flooring the nominal interest rate[106] whenever the rule calls for a negative value or lower than this figure and returns to the original Taylor rule when the interest rate is positive. The model can be described as follows.

Equation 3............................... $\pi_t = \Sigma^4_{i=1}\beta_i\pi_{t-i} + \beta_5 x_{t-1} + v_t$,

Equation 4............................... $x_t = \Sigma^2_{j=1}\alpha_j x_{t-j} + \alpha_3(i_{t-k} - \bar{\pi}_{t-k} - r^*) + u_t$,

Equation 5............................... $i_t = \max(0, i^{Taylor}_t)$

Equation 6............................... $i^{Taylor}_t = (1 - \rho)*(r^* + (1-\gamma)\pi^T + \gamma\pi_t + \varphi x_t) + \rho i_{t-1}$

where π_{t-k} is inflation at time t-k; $k \in [0, 4]$

$\bar{\pi}_{t-k}$ is average inflation at time t-k: $\bar{\pi}_{t-k} = \sum_{i=0}^{3}\pi_{t-i}$;

x_{t-k} is an output gap measured in terms of the difference between real GDP and potential output at time t-k;

i_{t-k} is a short-term interest rate at time t-k;

v_t and u_t are serially uncorrelated stochastic shocks with zero mean;

r^* is an equilibrium real interest rate or the natural real interest rate;

π^T is an inflation target set by the central bank.

[106] Refer to Section 4.3.1.

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Equation (3), representing aggregate supply, is derived from the price adjustment function of a representative firm. The equation incorporates the nominal rigidities in price adjustment, assuming that the firms cannot adjust their prices in every period. In this model, inflation follows a backward-looking accelerationist Phillips curve since the sum of the lag coefficients equals unity and there is no constant.

The absence of a constant and sum of the inflation lags equalling unity implies that there is no long-run tradeoff between inflation and output. Any attempt to increase output more than its potential level, i.e. a positive output gap, will permanently increase inflation. Further, this guarantees that output equals its potential level at the steady state.

Equation (4) represents the IS curve (indicating equilibrium in the goods market) in the new-Keynesian model, relating the real interest rate to the output gap. The output gap can be affected by the real interest rate with a one period lag. The interest rate channel is the only transmission channel in this model and monetary policy can affect the economy only through aggregate demand with some lags. Thus, the real interest rate can affect inflation with two lags or two quarters later.

The LM curve disappears from this model setup. The reason is that if the policy rule implemented by the central bank is an interest rate rule, then the money supply is endogenously determined because the central bank must provide as much money as necessary in order to maintain its interest rate target. In other words, the LM curve representing equilibrium in the money market is irrelevant in this type of monetary policy rule. Therefore, the IS curve or Equation (4) represents the aggregate demand function in this model.

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Equations (5) and (6) are the policy rule, the modified Taylor rule in this case. The zero bound constraint is taken into account via the function. This equation states that a zero rate will prevail whenever the interest rate prescribed by the Taylor rule is less than or equal to zero. There is no stochastic disturbance appended to the third equation since the purpose of this chatper is not to estimate a policy reaction function of the Federal Reserve but to implement different policy rules counterfactually. In this chapter, I use the same set of policy rules as Taylor (1999b) and some alternative policy rules.

The constant in Equation (6) is composed of two main components. The first one is an equilibrium real interest rate or the natural real interest rate. In the case of the original Taylor rule, it was assumed to be 2%. In the Monetary Trend released by the Federal Reserve Bank of St. Louis, the equilibrium real interest rate is 2.5%, which is quite close to a simple average of the ex post real interest rate – the difference between the nominal federal funds rate and the ex post inflation – in the whole period of the dataset, that I am currently using, of 2.56%.

The second component is long-run inflation – also interpreted as the policymakers' inflation target. I assume it be constant at 2%, conforming to the original Taylor rule's parameters. The constant in the policy rule can be inferred from the estimation of the policy reaction function. However, an equilibrium real interest rate and an inflation target cannot be determined independently. Alternatively, Judd and Rudebusch (1998) determine these parameters through a linear function, based on the estimated constant in the policy reaction function ($c = r^* - (\gamma - 1)^*\pi^T$).

All rules to be evaluated are tabulated in Table 2.1. The first rule is the original Taylor rule, corresponding to Taylor (1993a). Rule 2 is the Henderson and McKibbin rule (1993) (henceforth HM rule), introduced in the same year as the

Taylor rule[107] but less popular due to high implied variability in the interest rate, notwithstanding lower variability in inflation and the output gap, relative to the original Taylor rule.

Table 2.1: The parameters corresponding to the different interest rate rules

Rule	γ	φ	ρ
Taylor Rule	**1.5**	**0.5**	**0.0**
Henderson and McKibbin rule	2.0	2.0	0.0
III	3.0	0.8	1.0
IV	1.2	1.0	1.0
V	1.5	1.0	0.0
VI	1.2	0.06	1.3
VII	3.0	3.0	0
VIII	1.5	0.5	0.5

The next two rules include a degree of interest rate smoothing of unity. The coefficient on inflation is doubled in Rule 3, while Rule 4 doubles the weight on the output gap but slightly lowers the weight on inflation, relative to the Taylor rule. These rules are favored in Levin, Wieland, and William (1999) and known as "first-difference rules" because the policy rules use a change in interest rate in response to inflation and the output gap rather than the level of nominal interest rate. In fact, it is a special case of a policy rule with a degree of interest rate smoothing of unity. The parameters in these rules are close to the optimal policy rules derived from the FRB/US model.

The fifth rule, which places twice the weight on the output gap whereas the weight on inflation is the same as Taylor's, is used by Ball (1997). It is also called the revised Taylor rule. Rule 6 is preferred by Rotemberg and Woodford (1999) which responds meagerly to the output gap but imposes a high degree of interest rate smoothing. This rule is also known as "super inertial rule".

[107] Throughout this dissertation, I refer the original Taylor rule as the Taylor rule for convenience. On the other hand, the Taylor-type rules are referred to any interest rate rule responding to two policy targets, namely, inflation and the output gap.

For the last two rules, I add to experiment with the more aggressive response to both inflation and the output gap and a higher degree of interest rate smoothing, compared to the Taylor rule. Their results would more clearly illustrate how a more aggressive and/or a more inertial policy affect the economy.

More or less, Rules III, IV, VI and VII share some commonalities with the rest of the rules in Table 2.1. However, these rules are more extreme in the sense that they are more aggressive and incorporate some degree of interest rate smoothing. Thus, I report their results from simulation in the appendices instead.

5. Data and stylized facts

The data are from the Federal Reserve Bank of St.Louis' database. While a short-term interest rate is a quarterly average of the federal funds rate, inflation is represented by changes in GDP chained price index [108] (year 2000 = 100) in logarithms and averaged for the whole year[109]. Similar to Clark and Kozicki (2004), the real interest rate is calculated by the difference between the federal funds rate in the current period and the whole year average of the annualized quarterly inflation, compared to the difference between the whole year average of the annualized quarterly federal funds rate and a change in GDP chained price index used by RS (1999).

For the output gap, defined as the difference between the log of real GDP and the log of potential output in percentage terms, I employ the chain weighted real GDP with the base year of 2000 (=100), similar to the GDP chained price index, while

[108] With the GDP price deflator (2000 as the base year), the estimation results are slightly different and less persistent than the chained price index.
[109] The average of a whole year is also used as a proxy for the expected inflation, as widely employed by many researchers, e.g. RS (1999)

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potential output is the series released by Congressional Budget Office. All are in logarithms except the federal funds rate representing the short-term interest rate.

However, in some papers, e.g. Gali and Gertler (1999) and Gali (2002), they suggest using the representative firm's marginal cost by using labor's share as a proxy for the output gap. This suggestion arises because of the difference in the definition of the traditional output gap - the deviation of the output from the potential output or trend, and the New Keynesian approach - the deviation of the output from the fully flexible price output or natural output. In this chapter, since this is not the key issue examined, I decide to use the traditional output gap definition due to the availability of the data and the simplicity of interpretation.

Descriptive statistics are shown in Appendix A. These include the histograms of all variables, stationarity (unit root) tests and autocorrelations. These histograms show the non-normality of all variables except the output gap in A-3 and the real interest rate in A-4 which are sufficiently close to the normal distribution, so one cannot reject normality with Jarque-Bera test[110] at 1%.

The Augmented Dickey Fuller (ADF) unit root test for inflation, the real interest rate and the federal funds rate indicate non-stationarity. As the ADF test is prone not to reject the null hypothesis of non-stationarity often, the KPSS test, which imposes stationarity as the null hypothesis, is also applied. The results are contradictory to the ones obtained from the ADF test in most cases except the output gap in which the test indicates stationarity. Therefore, it cannot be concluded robustly whether the data are stationary or not. One explanation is the low power of the unit root tests. The test results are also reported in Appendix A.

[110] Jarque-Bera test imposes the null hypothesis of normality condition on the variable.

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Another possible cause of the non-stationarity (in ADF while stationarity in KPSS test) is structural breaks in the data. A structural break can possibly add to the persistence of the variables and may cause the conventional unit root tests to yield the non-stationarity conclusion. I perform two unit root tests with a structural break; namely, the Perron (1989) test for a known breakpoint and the Zivot and Andrews (1992) (henceforth ZA) for an unknown breakpoint.

Unsurprisingly, most breakpoints found by the ZA test are in between 1979:Q4 to 1982:Q3, when the Federal Reserve experimented with a non-borrowed reserves targeting regime, except for the break in the output gap series which occurs around 1973:Q1, corresponding to the first oil shock. The ZA test also rejects non-stationarity in most series used in this chapter.

Interestingly, the ZA test cannot reject the null hypothesis of non-stationarity in average inflation, whereas quarterly inflation is stationary. Consequently, I perform the Perron test for a known breakpoint at 1980:Q3 to 1981:Q2 to confirm the result for two reasons.

The unit root with an unknown breakpoint, e.g. ZA test, has lower power in rejecting non-stationarity than the test with a known breakpoint (provided that the breakpoint is known a priori). It is also possible that the wrong breakpoint was implemented when I tested for the stationarity using the Perron test earlier. Unsurprisingly, with the Perron test, the null hypothesis of non-stationarity can be rejected at the confidence level of 90%. Therefore, I conclude that all data I use in this chapter are stationary with a structural break. The unit root tests with a structural break are discussed in depth in Appendix B.

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6. Dynamic analysis

This section is to examine the effect of the zero bound constraint on dynamics of an economy, following the analytical method used in RW (2000). The model in this section is a simpler version of the RS model in the sense that it contains only one lag for each variable.

I, first, replicate RW's (2000) results by implementing a model similar to Ball (1997) and Svensson (1997)[111] to depict the dynamics of the model. Then, I extend some analyses in order to emphasize the importance of the zero bound constraint and how it affects the dynamics of the model.

Model:

Equation 7.............. $\Delta\pi_t = \beta x_t + v_t, \qquad \beta>0$

Equation 8..............$x_t = \alpha x_{t-1} + \phi(i_{t-1} - \pi_{t-1} - r^*) + u_t$, $0<\alpha<1, \phi<0$

Equation 9..............$i_t = \max(0, i^*_t)$,

Equation 10..............$i^*_t = \rho i_{t-1} + (1 - \rho)(r^* + (1 - \gamma)\pi^T + \gamma\pi_t + \varphi x_t)$, $0<\rho<1, \gamma>1, \varphi>0$

Equation (7) which corresponds to Equation (3), the size of the output gap affects the change in the inflation, whereas Equation (8) is equivalent to Equation (4) except that it contains just one lag of the output gap, which is sensible if the frequency of data is annual rather than quarterly.

By ignoring the zero bound constraint for a moment, a steady state equilibrium can be derived by taking the first difference of Equations (7), (8) and (10) and setting all equations and shocks to zero.

Equation 11.............. $\Delta\pi_t = 0 = \beta x_{t-1}$

[111] Despite that the model contains only one lag, it can be generalized to the RS model which contains more lags of the endogenous variables. The reason that I choose Ball's (1997) model rather than the RS model is that it can be depicted in the phase diagram, which will enormously assist in explaining the results in the later sections.

Equation 12 .... $\Delta x_t = 0 = (\alpha-1)x_{t-1} + \phi(i_{t-1}-\pi_{t-1}-r^*)$

Equation 13 .... $\Delta i_{t-1} = 0 = (\rho-1)i_{t-1} + (1-\rho)(r^*+(1-\gamma)\pi^T + \gamma\pi_t + \varphi x_t)$

Equation (11) becomes, $x^s = 0$, then plug in Equation (12),

Equation 14 .... $i_{t-1} = \pi_{t-1} + r^*$

Plug this in Equation (13), then

Equation 15 .... $0 = (\rho - 1)(\pi_{t-1} + r^*) + (1 - \rho)(r^* + (1-\gamma)\pi^T + \gamma\pi_{t-1} + \varphi x_{t-1})$

Equation 16............. $\pi^s = \pi^T$ and $i^s = r^* + \pi^T$

Hence, the steady state equilibrium is at $\pi^s = \pi^T$, $x^s = 0$, $i^s = r^* + \pi^T$. The steady state equilibrium is invariant across policy rules. To draw the phase diagram in Figure 2.4, which is similar to RW's (2000), I assume $\rho = 0$, i.e. the past behavior of the interest rate is not allowed to influence the dynamics of the model.

In order to illustrate the dynamics of the model, the iso-cline of π ($\Delta\pi = 0$ line) and x ($\Delta x = 0$ line) can be obtained by plugging in Equation (10) into Equation (12). As a result,

Equation 17 ...... $0 = ((\alpha - 1) + \phi\varphi)x - \phi r^* + \phi(1-\gamma)\pi^T + \phi(\gamma-1)\pi$.

Solving for π_t,

Equation 18......... $\pi = \dfrac{(\alpha - 1 + \phi\varphi)x \ - \phi r^*) + \phi(1-\gamma)\pi^T}{(1-\gamma)}$.

The slope of the $\Delta x_t = 0$ line is

Equation 19 .... $\dfrac{\partial \pi}{\partial x} = \dfrac{(\alpha - 1 + \phi\varphi)}{(1-\gamma)} < 0.$

Equation (11) and (18) are drawn in Figure 6.1.

Then, imposing the zero bound constraint or the $i_t = 0$ line, Equation (12) becomes,

Equation 20.......... $0 = (\alpha-1)x_{t-1} + \phi(-\pi_{t-1}-r^*)$

Solving for π_{t-1},

Equation 21.......... $\pi_{t-1} = \dfrac{(\alpha-1)x_{t-1} - \phi r^*}{\phi}$

and the slope of aggregate demand is now,

Equation 22 .... $\dfrac{\partial \pi}{\partial x} = \dfrac{\alpha - 1}{\phi} > 0$

Hence, the $\Delta x = 0$ line has a positive slope, compared to the negative one when the zero bound constraint is not imposed and the inflection point of the slope is where the $i_t = 0$ and $\Delta x = 0$ lines cross. Next, the second equilibrium can be obtained by solving for π^s in Equation (20) when $x^s = 0$ from Equation (11), as a result, $\pi^s = -r^*$. All these steady state equilibrium schedules and the iso-clines are drawn in Figure 2.4.

From this dynamic analysis, two equilibria can be obtained. The stability of the first equilibrium depends on the parameters of the policy rule ($i_t > 0$). Since the closed-form solution for this system is complicated, with three roots for E_1 ($i_t > 0$) and two roots for E_2 ($i_t = 0$), I employ numerical techniques by estimating the model with annual data and imposing the original Taylor rule as the policy rule in this model[112]. I also assume an equilibrium real interest rate and an inflation target of both 2%.

[112] The estimation results are as follows,

Given the parameters in the model and the policy rule, the steady state equilibrium without the zero bound constraint is locally stable and locates on the π_t axis at some positive rate of inflation, according to Figure 2.4. Hence, I label it a positive steady state equilibrium (E_1).

On the contrary, the steady state equilibrium, when the zero bound constraint is binding, is a saddle point, which is unstable and does not depend on the policy rule's parameters at all. I label it the negative steady state equilibrium (E_2) because the steady state inflation rate is negative at this equilbrium.

Given that the economy is in equilibrium, if a negative shock leads the economy to lie between the dashed line and i = 0 line in F, G and D regions, the zero bound constraint is binding. While the interest rate rule prescribes zero rates for a period of time, the policy rule is still effective in bringing the economy back to E_1. On the other hand, the interest rate rule is always effective in counteracting a negative shock, possibly without ever hitting the zero bound constraint, if the shock induces the economy to be in the shaded area above i = 0 line in A, B and C regions.

According to Figure 2.4, region H represents the deflationary trap. Any shocks which cause the economy to be in this area have divergent time paths. In this case, the

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$$\Delta\pi_t = 0.206678x_{t-1}$$
$$(0.048093)$$

Adjusted $R^2 = 0.305395$, $\sigma_\pi = 0.884663$, Durbin-Watson = 1.589249

$$x_t = 0.233810 + 0.699581x_{t-1} - 0.214888(i_{t-1} - \pi_{t-1})$$
$$(0.415327) \quad (0.102987) \quad (0.119904)$$

Adjusted $R^2 = 0.551475$, $\sigma_x = 1.671405$, Durbin-Watson = 1.158545

Note: 1) The sample period is 1960-2003.

2) All data are average for the whole year and Chained price index (base year = 2000), the difference between chain price weighted real GDP and potential GDP released by CBO, the federal funds rate represent π_t, x_t and i_t, respectively.

3) The estimation method is to apply OLS individually.

4) Standard errors are in parentheses.

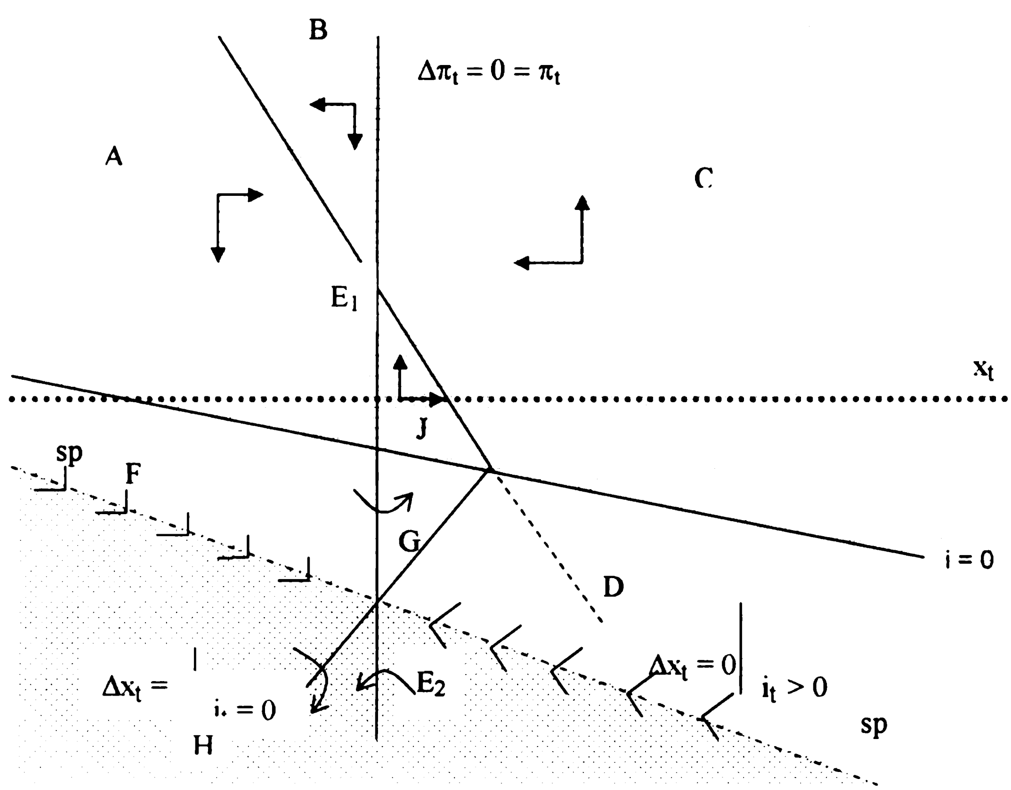
5) RW's (2000)'s estimates are slightly higher than the ones in this chapter since there are some revisions and the sample sizes are different.

6) From these estimates, it is simple to show that E_2 is a saddle point with one positive and one negative characteristic root.

interest rate rule alone is not able to resuscitate the economy. The stable equilibrium E_1 cannot be restored without aid from other policies such as fiscal policy as pointed by RW (2000).

On the other hand, any initial values, located at the upper edge of the area (the sp line), converges to E_1 but a nominal interest rate at zero percent will be prescribed for a period of time before the economy returns to E_1. In turn, this time path demarcates the regions into the deflationary trap (H) and the region of stability (the rest of the areas in Figure 2.4). In fact, this time path represents the stable branch of E_2.

Figure 2.4: the phase diagram of the stylized model dynamic



Since E_2 also has a stable branch (or an eigenvector corresponding to the less than unity eigenvalue) and an unstable branch (or an eigenvector, corresponding to the greater than unity eigenvalue), it is called a "saddle point"[113]. Any initial value jumping on the stable branch of the saddle point (E_2) converges towards the equilibrium, while the others diverge. This stable branch is also known as a "saddle path", i.e. the sp line in Figure 2.4.

Some additional issues can be inferred from this phase diagram. Firstly, the stability of E_1 depends on the parameters of the model and the policy rule. On the contrary, E_2 does not depend on the policy rule but the natural real interest rate since this steady state emerges when the zero bound constraint is binding. No matter which interest rate rule is used, E_2 will be the equation when the zero bound constraint binds.

Secondly, it is quite straightforward, starting from the stable equilibrium, to find the size of a negative shock leading the economy to each region in the phase diagram. For example, the maximum inflation shock maintaining stability is the distance between E_1 and E_2, while the maximum output shock doing the same is the distance between E_1 and the point where the saddle path crosses the x_t axis.

The second outcome would be, however, different if the assumption of no interest rate smoothing is relaxed because there is also the effect of interest rate adjustment from the previous period. This two-dimensional phase diagram is incapable of describing the dynamics of the model with some degree of interest rate smoothing. Therefore, for inferences drawn from results of negative shocks in either inflation or output, including, distributions of inflation, output and the interest rate, the policy rule evaluations and the probability of hitting the zero bound and falling into the deflationary trap, I rely on numerical exercises, including stochastic simulations.

[113] Chiang, Alpha C. (1984) explains a saddle point in details.

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7. Estimation

I estimate a system of two equations (Equation (1) and (2) only) with quarterly data starting from 1960:Q1 to 2004:Q2, 178 observations for each variable. As the model contains only pre-determined variables in terms of lagged variables, there should not be any endogeneity problems. Therefore, Ordinary Least Squares (OLS)[114] can be used in this case without losing the consistency of the estimates.

The third equation enters the system only in the simulation procedures in the next section. The estimation excluding the policy rule function because the main purpose of this chapter is to counterfactually simulate the model with alternative policy rules not attempt to investigate or estimate the current policy rule. Therefore, the policy rule is not included in the estimation.

For the aggregate supply function, I also test the assumption of the accelerationist Phillips curve (i.e. the sum of the inflation lags is unity) along with the absence of the constant. The null hypothesis cannot be rejected at 10% level[115]. With this assumption imposed, the restricted regression is estimated, instead. Hence, there is no standard error in the fourth lag of inflation.

Equation 23……… $\pi_t = 0.601657\pi_{t-1} + 0.080698\pi_{t-2} + 0.105620\pi_{t-3} + 0.212026\pi_{t-4}$

$(0.118967) \quad (0.099850) \quad (0.081615)$

$+ 0.106626x_{t-1}$

(0.034235)

$\sigma_\pi = 1.0376$, Adjusted $R^2 = 0.8228$, Log-Likelihood = -251.2881, AIC = 2.9343, SIC = 3.0068, LM test for serial correlation (12) = 0.8433 (0.6058)

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[114] Nevertheless, I also apply different estimation methods including Seemingly Uncorrelated Regression (SUR) and Full Information Maximum Likelihood estimation (FIML) and find insignificantly different results.

[115] I test for the null hypothesis of zero constant and the sum of lag coefficient of unity with Wald test. The F-statistic is 2.224457 (0.1113) and Chi-Square is 4.448915 (0.1081). The p-values are in parentheses.

Equation 24……$x_t = 0.082476 + 1.194105x_{t-1} - 0.267467x_{t-2} - 0.068733(i_{t-1} - \bar{\pi}_{t-1})$

$$(0.106504) \quad (0.092757) \quad (0.094320) \quad (0.035053)$$

$\sigma_X = 0.7896$, Adjusted $R^2 = 0.9072$, Log-Likelihood = -206.1412, AIC = 2.3880, SIC = 2.4600, LM test for serial correlation (12) = 2.2124 (0.0134)

Note: - The standard errors are in parentheses except the LM-test for serial correlation showing the p-values.
- The standard errors are based on the Heteroskedasticity and Autocorrelation Consistent Covariances (HAC) matrix estimated Newey-West method.
- AIC and SIC are Akaike and Schwatz Information Criterion, respectively.

The slope of aggregate supply function based on Equation (23) is significant at a high level of confidence of 99%, while the slope of aggregate demand is significant at a 90% confidence level. The slopes of both the aggregate supply and demand functions are lower in magnitude than the ones reported in RS (1999) owing to the revisions of the data and the sample period.

The importance of the constant in this model is that it determines the real interest rate. In this model specification, it is implicitly assumed that the real interest rate is constant. Even though it contradicts economic theory stating that the real interest rate varies over time in response to shifts in preferences and technology, e.g. Williams (1999), Laubach and Williams (2001), a constant real interest rate is assumed in most models since the uncertainty or time-varying real interest rate is not the focus of their studies, nor that of this chapter. Therefore, I will preserve this assumption throughout this chapter, but investigate the issue next chapter.

Even though the equilibrium real interest rate can be implied from the estimated constant in the aggregate demand equation, the estimate is insignificant at any confidence level. As a result, the estimation of the constant would be imprecise[116].

[116] Nonetheless, the equilibrium real interest rate is 1.2%, based on the estimation in Equation (24). Even though it is seemingly low compared to the studies by RW (2000) of 2.5% and the average of the

Thus, I will use the equilibrium real interest rates of 2.0% and 2.5%, based on the earlier literature.

7.1 The stability of the estimates

Since many significant economic events have occurred throughout US economic history, examining the stability of estimates to account for the possibility of a structural break[117] is an interesting exercise. One of the most widely recognized economic events is the experiment of a change in the Federal Reserve's operating procedure to target non-borrowed reserves instead of the federal funds rate during 1979:Q4 – 1982:Q3[118].

I perform two types of tests for structural breaks in the estimation. The first one is Chow test to test for a known structural break. The second is the test for multiple unknown structural breaks based on the work of Bai and Perron (1998). The Chow test can reject[119] the null hypothesis of no structural break from 1982:Q3 at 99% confidence level, which is one quarter before the Federal Reserve formally returned to target the federal funds rate, in the aggregate demand function. However, there is no evidence of the structural break in aggregate supply.

A disadvantage of Chow test is that the breakpoint to be tested must be known a priori. Even though it is quite obvious that a breakpoint could occur in 1979:Q4 to 1982:Q3 when the Federal Reserve changed their operating procedure in conducting monetary policy, it is difficult to pinpoint the exact date in this period. Thus, tests for

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whole period of 1960:Q1 – 2004:Q2, it is consistent with Orphanides and Wieland (1998) of 1% in their simulation.

[117] Recall that a structural break in the model is different from the structural break in the unit-root tests. The former represents the stability of the *model*, i.e. a structural change, while the latter indicates the stationarity of the *data or series*. For instance, inflation is found stationary with a structural break, however, there is no a structural break in aggregate supply function.

[118] In fact, the Federal Reserve experimented with targeting non-borrowed reserve during October 1979 – October 1982.

[119] The F-statistics of the Chow breakpoint test is 3.2543 with the p-value of 0.0133.

multiple structural breaks without prior knowledge of the breakpoint can resolve this problem.

I apply a test for unknown multiple breakpoints based on Bai and Perron (1998) (BP). By allowing breaks in the slope of aggregate demand or testing for a partial structural break model, the BP test finds only one structural break at 1982:Q3. Three statistics are as follows.

1. $SupF_T$ test for (k); k = number of breaks: $SupF_T$ (1) = 18.0918*, $SupF_T$ (2) = 20.1481*, $SupF_T$ (3) = 13.1046*, $SupF_T$ (4) = 14.8814*, $SupF_T$ (5) = 9.9305*.

2. UDmax = 20.1481*, WDmax = 29.5465*

3. Sequential tests; SupF(2|1) = 9.3276***, SupF(3|2) = 9.3276****, SupF(4|3) = 2.3503.

*Note: *, **,***,**** represents the significance level of 1%, 2.5%, 5%, and 10%, respectively.*

First, consider $SupF_T(k)$ test in (1). We can reject the null hypothesis of no break against any specific number of breaks. Then, the double max test shows that we can also reject the null hypothesis of no break to at least one break. Lastly, the sequential test chooses 2 breaks at 1982:Q3 and 1995:Q4, while the Bayesian Information Criterion (BIC) chooses one break at 1982:Q3, while the modified Schwatz Criterion (LWZ) does not detect any break.

According to this result, I choose the breakpoint at 1982:Q3 as the only breakpoint for the whole sample because it corresponds to the approximate date that the Federal Reserve changed their operating procedure back to targeting non-borrowed reserve, whereas the breakpoint at 1995:Q4 represents the change in productivity of the US economy.

Equation 25..........$x_t = 0.108901 + 1.055161x_{t-1} - 0.117083x_{t-2} - 0.173843(i_{t-1} - \bar{\pi}_{t-1})$

$$(0.098533) \quad (0.123230) \quad (0.108432) \quad (0.036266)$$

$$+ 0.142324*D*(i_{t-1} - \bar{\pi}_{t-1}) + 0.263196*D*x_{t-1} - 0.272306*D*x_{t-2}$$

$$(0.039575) \qquad (0.172379) \qquad (0.162826)$$

where D = 1, after 1982:Q3;

0, otherwise.

$\sigma_X = 0.7578$, Adjusted $R^2 = 0.9145$, Log-Likelihood = -197.3495, AIC = 2.3221, SIC = 2.4482, LM-test of serial correlation (4) = 2.8196 (0.0268).

Note: - The standard errors are in parentheses except the LM-test for serial correlation where the parentheses represent the p-values.

- The standard errors are based on the Heteroskedasticity and Autocorrelation Consistent Covariances (HAC) with Newey-West estimates.

One way to treat a structural break is to enter a dummy variable. I re-estimate the model with a dummy at the breakpoint of 1982:Q3 in all variables and find that the slope dummies for aggregate demand is significant at 95% confidence level while the dummy on lag variables are close to being rejected at 90% confidence level. Equation (24) becomes Equation (25).

7.2 The stability of the equilibria

Before further exploring the behaviors of each policy rule, the stability of the equilibrium is examined by calculating the eigenvalues of the coefficient matrix of the lagged variables. Even though the model contains a maximum of four lags of the variables, it can be re-defined as a system of first-order-difference equations which is simpler to handle. Then, eigenvalues or the characteristic roots can be calculated. If all the eigenvalues are less than a unity, the system is stable. Writing out the model in matrix form as follows:

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ -(1-\rho)\gamma & 0 & 0 & 0 & -(1-\rho)\varphi & 0 & 1 \end{bmatrix} \begin{bmatrix} \pi_t \\ \pi_{t-1} \\ \pi_{t-2} \\ \pi_{t-3} \\ x_t \\ x_{t-1} \\ i_t \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ -\alpha_3 r^* \\ 0 \\ (1-\rho)(r^* + (1-\gamma)\pi^T) \end{bmatrix} + \begin{bmatrix} \beta_1 & \beta_2 & \beta_3 & 1-\beta_1-\beta_2-\beta_3 & \beta_4 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ -\frac{\alpha_3}{4} & -\frac{\alpha_3}{4} & -\frac{\alpha_3}{4} & -\frac{\alpha_3}{4} & \alpha_1 & \alpha_2 & \alpha_3 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \rho \end{bmatrix} \begin{bmatrix} \pi_{t-1} \\ \pi_{t-2} \\ \pi_{t-3} \\ \pi_{t-4} \\ x_{t-1} \\ x_{t-2} \\ i_{t-1} \end{bmatrix} + \begin{bmatrix} v_t \\ 0 \\ 0 \\ 0 \\ u_t \\ 0 \\ 0 \end{bmatrix}$$

Equation 26…… $A \quad X_t \quad = \quad C \quad + \quad B \quad X_{t-1} \quad + \quad E_t$

Considering the stability of the system without the zero bound constraint, or E_1 in Figure 6.1, the stability of the system is determined by the eigenvalues of the coefficient matrices of $A^{-1}B$. The system is stable if and only if the absolute values of all eigenvalues are less than unity when the roots are real. For the complex roots, the modulus or ($\sqrt{a^2+b^2}$), where a and b are the real and imaginary parts of the complex number a+bi, must be less than unity to guarantee the stability of the system.

From Table 2.2, five out of eight rules including the Taylor rule are stable. Rule III, IV and VI are unstable in this particular model setup. Therefore, only five stable policy rules are considered in the rest of this chapter. It is noteworthy that the unstable rules have a high degree of interest rate smoothing. The result does not vary when the dummy variables are appended for the breakpoint at 1982:Q3.

Table 2.2: The stability without the constraint

Rule	**Whole sample**		**Pre-1982:Q3**		**Post-1982:Q3**	
	Max |λ|	**Condition**	**Max |λ|**	**Condition**	**Max |λ|**	**Condition**
Taylor rule	**0.9813**	**Stable**	**0.9649**	**Stable**	**0.9896**	**Stable**
HM rule	0.9816	Stable	0.9767	Stable	0.9866	Stable
III	1.0369	Unstable	1.0727	Unstable	1.0205	Unstable
IV	1.0369	Unstable	1.0727	Unstable	1.0205	Unstable
V	0.9864	Stable	0.9797	Stable	0.9913	Stable
VI	1.3261	Unstable	1.3565	Unstable	1.3138	Unstable
VII	0.9720	Stable	0.9672	Stable	0.9779	Stable
VIII	0.9801	Stable	0.9606	Stable	0.9893	Stable

Note: λ represents an eigenvalue of the lag coefficient matrix.

Moreover, the positive steady state equilibrium (E_1) for the model can be computed based on the matrix form in Equation (26) and setting all shocks to zero and $X_t = X_{t-1}$, the result is as follows.

Equation 27............................$\pi^S = \pi^T$, $x^S = 0$, $i^S = r^* + \pi^T$

This result is identical to the outcome obtained from Equations (11) and (16). The steady state equilibria are equal in every policy rule. They depend only on an inflation target and the equilibrium real interest rate. The steady state equilibrium will be useful when simulating the model later, especially the dynamic responses because the steady state equilibrium is used as an initial value in deriving the dynamic responses.

In addition, I explore the local stability of policy rules based on different parameters in response to inflation and the output gap along with the degree of interest rate smoothing and report the results in Appendix C in order to generalize the result of stability analysis carried out in this section. The model is unstable whenever the policy rules require a response to inflation of less than unity. The result strongly substantiates the need for the Taylor Principle to guarantee the dynamic stability of the model.

Interestingly, with a high degree of interest rate smoothing such as $\rho = 0.8$, which is close to the one estimated by Sack and Wieland (2000)[120] on US data, the policy rules with no response to output gap but high responses to inflation (higher

[120] Sack and Wieland (2000) estimated the degree of interest rate smoothing with the model akin to the model used in this chapter. Their estimate is approximately 0.795. Rudebusch (2002b) also estimated a similar specification with longer sample and find that the degree of interest rate smoothing is around 0.73 during Chairman Greenspan. The dynamic stability of the system with the degree of interest rate smoothing conforming to Rudebusch (2002b) shows the similar result to $\rho = 0.8$, i.e. unstable whenever the response to inflation is high and the output gap is nil.

than 2.5) leads to instability of the model[121]. It may suggest that the central bank should also put some weight in response to output whenever high interest rate smoothing is present in order to avoid economic instability, given the backward-looking type model.

The negative equilibrium (E_2), conforming to Figure 2.4, can be determined in the same manner as E_1, by considering the eigenvalues of the system. As shown in the dynamic analysis, the second equilibrium emerged due to the zero bound constraint and does not depend on the policy rule's parameters. At E_2, there are only 6 eigenvalues since the policy rules are irrelevant when considering the steady state at $i=0$. I calculate all eigenvalues based on the parameter estimates. The result shows that the maximum eigenvalue is greater than unity (1.07265), E_2 is unstable.

The reason for multiple equilibria in this system differs from that in Benhabib et al's (1999, 2001) forward-looking rational expectation model. The reason is that the multiple equilibria in Benhabib et al are caused by the self-fulfilling rational expectation, while there is no forward-looking aspect in this model. The multiple equilibria in this model emerge due to the dynamics of the model only if the zero bound constraint is binding.

8. Simulation

As discussed earlier, the simulations can be divided into three parts, including, the dynamic responses depicting the effect of the zero bound constraint on the time paths of the endogenous variables converging to their steady state equilibrium, the

[121] The instability induced by a high degree of interest rate smoothing means the dynamic instability of the model. It is a different issue from the purpose of improving stability that the policy inertia is introduced into the policy rule in the first place. In fact, the stochastic simulations will show that the variability of interest rate declines along with a higher degree of interest smoothing, while the variability of inflation and the output gap slightly change. In other words, the interest rate volatility is successfully reduced by interest rate smoothing.

historical simulation emphasizing the counterfactuals and answering the question of what if the central bank could have imposed an alternative policy rule and committed to it throughout the sample, the stochastic simulation focusing on probability of hitting the zero bound constraint and the probability of falling into the deflationary trap. Also, it is used for evaluating the performance of each policy rule when taking the zero bound constraint into account by means of unconditional variances of each variable (uncertainty).

In addition, many studies including McConnell and Perez-Quiros (2000) and Boivin and Giannoni (2000), find a break in the output volatility in the mid 1980s. It would not be sensible to neglect such an effect in the stochastic simulation since the simulation is based on the covariance matrix of the estimated residuals. Therefore, I split the whole sample into two periods based on the breakpoint of the variance of the output gap, namely, Pre- and Post- 1984:Q1.

However, I will ignore Rule III, IV and VI in the simulations since they induce the dynamic instability in the model, as pointed out earlier.

8.1 Dynamic responses of the endogenous variables

This part of the simulation investigates the difference between imposing the zero bound constraint (the modified Taylor rule) and the hypothetical[122] unconstrained economy. By entering a one-time shock *sufficiently large* to induce the policy rule to prescribe a negative nominal interest rate, the dynamic responses of both economies

[122] Realistically, a nominal interest rate cannot go below zero percent, therefore, the comparison between the unconstrained and constrained economy would be a hypothetical exercise. Nevertheless, considering the zero bound constraint as a lower bound with a positive number, which is more realistic, since the federal funds or other short-term assets market would collapse before nominal interest rates reach zero percent, would not change any behaviors of the dynamic responses except that the lower bound is shifted up arbitrarily.

can be calculated. At the inflation target of 0% and an equilibrium real interest rate of 2%, I assume 3.5% decline in either inflation or output.

The purpose of illustrating the dynamic responses corresponding to the policy rules is to answer the question of whether a policy rule can still be effective in resuscitating the economy from recession, even though the rule-based interest rate is constrained at 0% for a period of time. This circumstance corresponds to region D, F and G, while the explosive solutions or divergent paths are located in region H, according to Figure 2.4.

The dynamic responses in this chapter are analogous to the impulse response function of the Vector Autoregression (VAR) framework. However, the methods to choose a one-time shock to model are different. I impose sufficiently large negative shock which causes the policy rule to trigger a negative nominal interest rate, but not too large to induce instability to the system. In contrast, the VAR framework assumes a normally positive stochastic shock based on one standard error of the individual regression.

Unsurprisingly, the policy rule without the zero bound constraint approaches the steady state equilibrium more rapidly than the one with the constraint, according to Figure D-1 to D-3 in Appendix D. And the larger the negative shock (but not so large that leads the economy to the deflationary trap), the longer time spent at the zero bound and more slowly approaches the steady state equilibrium.

The time paths in Figure D-1 to D-3 can be explained as follows. A negative inflation or supply shock, which enters the system through the inflation adjustment function, causes inflation to adjust by falling instantly, and gradually return to the steady state equilibrium due to the inflation persistence. On the other hand, the output gap increases in the next period as a result of a decline in real interest rate in the current period. The output gap is not affected by the inflation shock directly but through the real interest rate, composed of the decrease of nominal interest rate prescribed by the policy rule and the inflation rate. The real interest rate declines if the Taylor Principle holds. The increase in the output gap mitigates the reduction of the nominal interest rate in the next period which is opposite of the effect of the decrease in inflation. These two effects offset each other gradually and lead the output gap and inflation to converge towards the steady state equilibrium.

When an output or demand shock hits the aggregate demand function, as illustrated in Figure D-4 to D-6, the output gap is affected directly and it transfers this effect to the interest rate rule contemporaneously. Since the sum of coefficients of lagged output gap is smaller than one, the next period's output gap is smaller due to both the effect of its current period and the lower real interest rate.

The negative output gap also reduces inflation but with some lags, noticing from Figure D-4 that in the first period inflation does not change. Both negative output gap and lower inflation call for reductions in nominal interest rate in the policy rule. Large reductions of the real interest rate lead the output gap to become positive after some periods. Thereafter, the negative output gap begins to shrink by the effect of both lagged output gap and the fall in the real interest rate.

The conventional wisdom and also supported by Svensson (1996), states that when inflation and the output gap move in the same direction, such as when the economy is hit by an output shock as shown in Figure D-4 to D-6, a central bank can neutralize an output shock completely since the movement of each variable enhances the other. In contrast, a central bank cannot counteract an inflation shock completely, as a result of the opposite movement of inflation and the output gap, as depicted in

Figure D-1 to D-3, which in turn, slowing inflation and the output gap to approach the steady state equilibrium.

The more aggressive is the rule[123], the longer the time spent at a zero bound interest rate would be, relative to the less aggressive ones, given the same size of shocks. Once the dynamic responses of the nominal interest rate prescribed by the more aggressive rules rise above the zero bound constraint, they adjust towards the steady state equilibrium more quickly than the less aggressive rules. This is because the more aggressive policy rules call for larger increases or decreases in the interest rates to affect inflation and the output gap, which accelerates the time path towards the steady state equilibrium, once it departs from the zero bound. These results are shown in Figures D-7 to D-12.

The dynamic responses of more aggressive policy rules in response to the output gap, given the same weight associated with inflation, suggest the opposite results of the aggressive response to inflation. The more aggressive the rules, the more slowly the economy approaches the steady state, but the shorter time zero bound constraint binds. Interestingly, more aggressive rules in response to the output gap can bring the output gap towards its steady state more rapidly if it is the output shock entering the economy, notwithstanding the slow adjustment towards the steady state of inflation and the interest rate.

Therefore, being aggressive on the output gap is not such a good idea in this model. Since the effect of monetary policy on inflation is through the aggregate demand equation, the interest rate affects inflation indirectly and with two lags. As a

[123] I also simulate an extreme rule by setting the weights on the inflation and the output gap of 5 in order to depicting the comparisons more vividly.

result, placing higher weight on the output gap may lead to less stability[124] of the economy than placing higher weight on inflation. In addition, this result partly substantiates the argument against a nominal income targeting regime, e.g. Ball (1997), because inflation may still be off the target, though output equals its potential level.

There are few differences in economic behavior when the degree of interest rate smoothing below 0.5. The significant difference occurs between the rule with ρ = 0.8 and the ones with lower degree of interest rate smoothing, as exhibited in Figures D-19 to D-24. The rule with ρ=0.8 tends to converge to the steady state more quickly than the others. This is because a change in the interest rate prescribed by the rule with a high degree of interest rate smoothing mostly stems from the response from the previous period, thus, a shock to either inflation or the output gap will be counteracted more aggressively and for longer in a rule with policy inertia, compared with the rules with no persistence in the interest rate.

8.2 Stochastic Simulation

Having examined the dynamic responses of the policy rules in the last section, the more aggressive policy rules tend to prescribe the nominal interest rates at the zero bound constraint more often than the less aggressive ones. However, those dynamic responses represent the time paths of the endogenous variables based on a one-time shock and the steady state equilibrium as the initial values. This scenario does not happen in the real world since the economy does not begin from the steady state and it encounters a series of shocks instead of a one-time shock. Thus, a set of shocks

[124] The stability of the economy means fewer fluctuations or deviations from its mean. It is different from the dynamic stability used in the dynamic analysis. In the latter, it can be a result of very large negative shocks or the policy rules in which the Taylor Principle does not hold.

corresponding to the historical data is needed in order to examine what if the central bank had imposed a different policy rule. This requirement brings the stochastic simulation into consideration.

In this section, I divide the stochastic simulation results into two parts. One follows McCallum (1988) and Judd and Motley (1991, 1992). Only one set of historical shocks is used to counterfactually replicate the economy. This method is different from the historical approach performed by Stuart (1996), Taylor (1999a) and McCallum (2000) because it allows interactions between a structural model and a policy rule, unlike the historical approach which needs only a policy rule and excludes the information about a structural model.

Another part of the simulation is the one similar to much literature in monetary policy analysis – the stochastic simulation based on a series of stochastic shocks. A set of shocks are drawn randomly from the distribution of the residuals and put into the model to calculate the time path of each variable dynamically as one trial. Then, we re-do the whole procedure as many times as necessary to obtain stationary distributions of the variables, from which other statistics can subsequently be inferred.

8.2.1 Stochastic simulation with the historical shocks

For the historical simulation, I begin with the simulated values with the modified Taylor rule entering the economy by setting the equilibrium real interest rate at 2%.

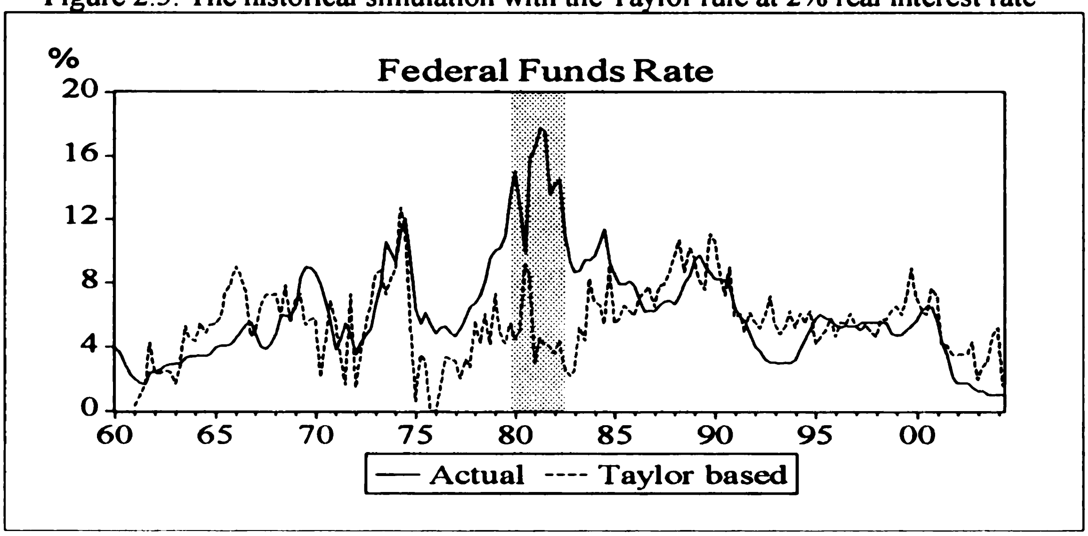
Figure 2.5 indicates that the Federal Reserve could possibly have avoided high inflation during the beginning of the 1970s or the "Great Inflation" era by being more contractionary in fighting against inflation. A too expansionary monetary policy stance[125] can be illustrated by too a low real interest rate during the 1970s. Even

[125] It is worth noting that the data used in the present chapter are based on the data available now which was finalized and revised many times. Whether is the case, different conclusions from those drawn

though the simulated federal funds rate tracked the data quite well, it does not mean that the policy was sufficiently contractionary, observing from low ex post real interest rate, compared to the simulated one in Figure 2.5 (A)-(C). Therefore, inflation would have been lower in the 1970s if the Federal Reserve had followed the Taylor rule to curb inflationary pressure.

The shaded are in Figure 2.5 represents the change in the Federal Reserve's operating procedure to target non-borrowed reserves. In this period, the real interest rate shot up to the highest of the whole period. One plausible explanation for this spike is that the Federal Reserve intended to correct their policy mistake made earlier during the Great Inflation. As a result, inflation was tamed in the later period. In fact, the spike in the real interest rate in the early 1980s could have been avoided, if the Federal Reserve had followed the rule before the Great Inflation even happened.

Figure 2.5: The historical simulation with the Taylor rule at 2% real interest rate



(A)

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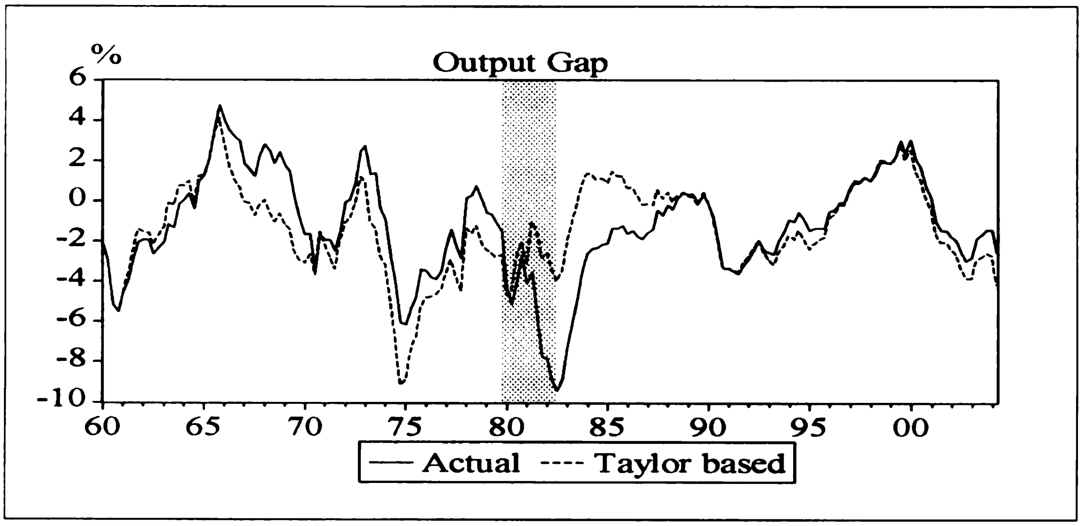
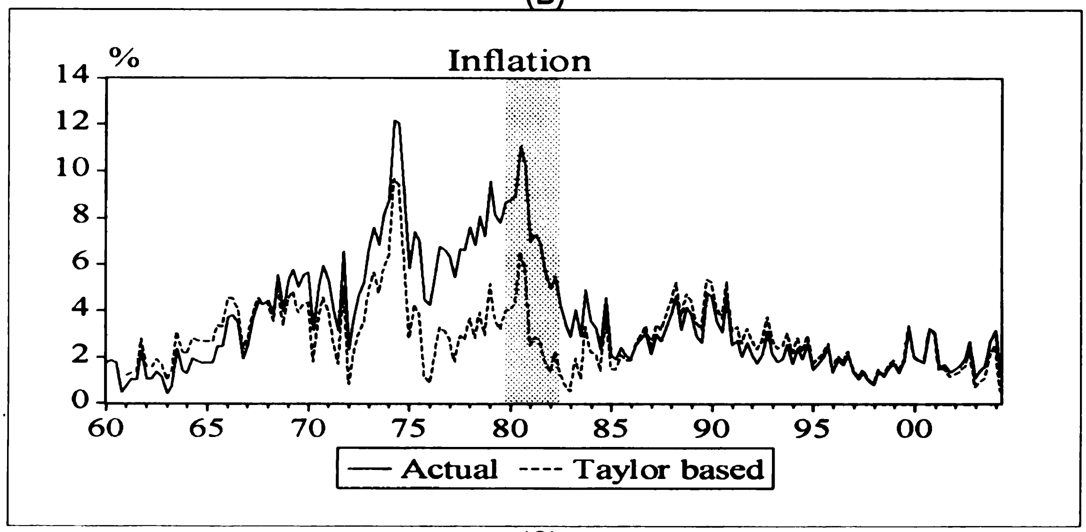
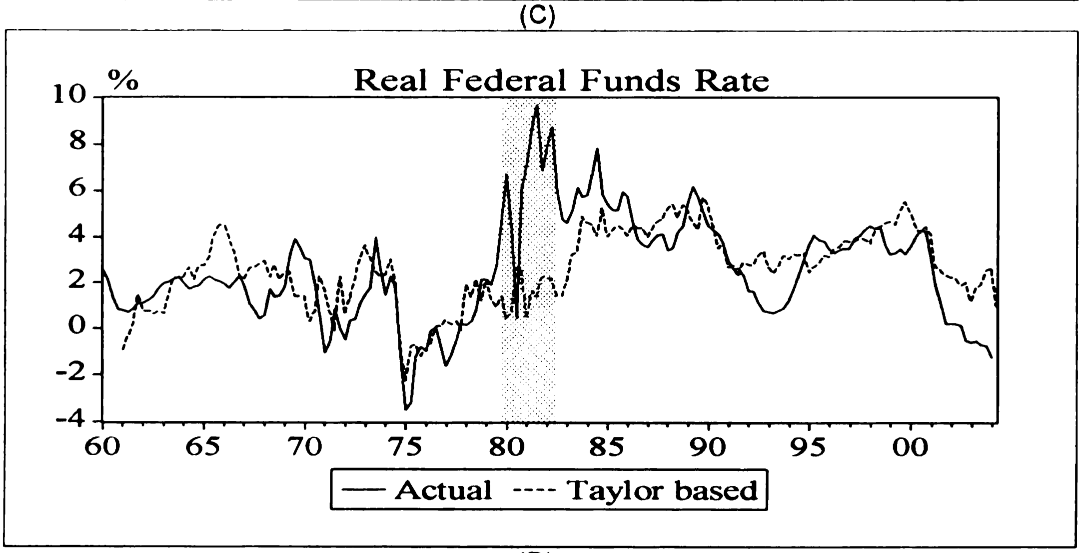
from the historical simulation would prevail, as shown in Orphanides (2002, 2003c). He argues that, by implementing the real-time data in the output gap as well as the inflation forecasts by the Greenbook prepared by the Federal Reserve Board staff, monetary policy during the Great Inflation in the 1970s, in stark contrast, followed the forward-looking Taylor rule very closely. These data represent the data available at the time that the Federal Reserve made the policy decision. The Great Inflation may have been caused by using the data at that time, which may have contained the mis-measurement, especially in the output gap, in lieu of conducting too expansionary monetary policy as pointed out by most studies. I have discussed this issue in Chapter 1, Section 4.2.1.


%
Output Gap
6
4
2
0
-2
-4
-6
-8
-10
60
65
70
75
80
85
90
95
00
— Actual ---- Taylor based

(B)


%
Inflation
14
12
10
8
6
4
2
0
60
65
70
75
80
85
90
95
00
— Actual ---- Taylor based

(C)


%
Real Federal Funds Rate
10
8
6
4
2
0
-2
-4
60
65
70
75
80
85
90
95
00
— Actual ---- Taylor based

(D)

Nevertheless, Figure 2.5 also shows that the simulated series can track the actual data reasonably well after the Taylor period, even though there are some slight differences in some periods of time, for example, after 2002 to the present, the Taylor rule suggests that monetary policy is slightly too expansionary.

In addition, I have drawn a line to account for a structural break in variance of output. It may not be clearly seen how the volatility of the output gap declines after this date. The formal tests for equality of variances between Pre- and Post- 1984:Q1 will be presented later on.

The counterfactual simulation of different policy rules both in terms of aggressiveness to response to the policy targets and the degree of interest rate smoothing are reported in Appendix E. From Figure E-1 and E-2, the more aggressive rules can successfully decrease the volatility of inflation and the output gap, noticing from the movements of the variables deviating not too far from their means. Besides, a very volatile short-term rate, the simulated federal funds rate prescribed by the more aggressive rules, relative to the Taylor rule, tend to hit the zero bound constraint more often, as seen in Figure E-3. Also, Figure E-4 illustrates how the rule-based rates are higher than the actual data before the 1970s.

For the Taylor rule with a positive degree of interest rate smoothing, the difference from the original Taylor rule cannot be seen clearly when the degree of interest rate smoothing is below 0.5. The main difference is in the Taylor rule with high degree of interest rate smoothing of 0.8, for example. The simulated federal funds rate is prone to move more slowly but more smoothly than the original Taylor rule. This result is shown in Figure E-8.

8.2.2 Stochastic Simulations with random shocks

With the stochastic simulation, the distributions of the endogenous variables including inflation, the output gap and nominal interest rate can be inferred. Based on these distributions, the unconditional variances can be calculated. By using only the number of trials with non-explosive time paths to calculate the number of times that a policy rule prescribes a zero or negative nominal interest rate, the probabilities of hitting the zero bound in each policy rule, and the probability of falling into the deflationary trap is calculated from the number of the explosive time paths from the simulations.

8.2.2.1 The probability of hitting the zero bound

The probabilities of falling into the deflationary trap are quite similar across the rules because the probability of deflation depends on the two steady state equilibria as pointed out earlier. The positive equilibrium (E_1) depends on both an equilibrium real interest rate and an inflation target, while the negative one (E_2) depends solely on the former. The parameters in response to inflation and the output gap in the policy rules are irrelevant. Thus, the results from the simulations are quite similar, provided that the equilibrium real interest rate and inflation target are the same. The results are reported in Table 2.3.

Table 2.3 contains three major cases sufficient to cover all key characteristics of the policy rules, compared to the Taylor rule. These include the HM rule, which aggressively responds to both inflation and the output gap, the revised Taylor rule, which doubles the weight on the output gap in the Taylor rule while maintaining the same weight on inflation, and Rule 8, which adds some degree of interest rate smoothing. I put the results from other policy rules in Appendix G.

Generally, the lower the inflation target and/or the equilibrium real interest rate, the higher are the probabilities of the zero bound constraint binding and the economy falling into the deflationary trap. Moreover, more aggressive policy rules also contribute to higher probabilities, though the identical probability of falling into the deflationary trap across the rules is identical, since the rules prescribe a large fall of the nominal interest rate whenever a negative shock hits the economy. As a result, the rule-based interest rate tends to hit zero percent more often than that of the less aggressive rules.

From Table 2.3, the maximum probability of hitting the zero bound is approximately 15% of the time in the HM rule at the 0% inflation target and 2% equilibrium real interest rate, compared to around 10% of the time prescribed by the Taylor rule, given the same inflation target and the equilibrium real interest rate.

Interestingly, for the revised Taylor rule the probability of hitting the zero bound is slightly smaller than the original Taylor rule. This is because an empirical inflation shock has a higher standard error than an empirical output shock. As a consequence, it is more likely that the effect of the inflation shock would dominate the effect of output shock. The response of the variables would correspond to the dynamic responses in Figure D-13 to D-15, exhibiting the shorter time spent at the zero bound in the rule with a more aggressive response to the output gap, given the weight on inflation[126].

For rules with some degree of interest rate smoothing including Rule 8, the probability of a zero bound constraint binding is slightly smaller, compared with the Taylor rule. The reason could be that the higher interest rate smoothing is, the less weight that is placed on current period inflation and the output gap, and the more

[126] Recall that the standard error of the residual in inflation equation (σ_v = 1.0376) is higher than that in the output gap equation (σ_u = 0.7896). Thus, it is more chance that a large inflation shock hits the economy than a large output shock.

weight that is placed on the past. Even though the current period policy targets call for a large fall in the interest rate, the rule prescribes a smaller reduction in the interest rate due to interest rate smoothing.

Table 2.3: The probability of hitting the zero bound constraint and falling into the deflationary trap

Rule	Real Rate = 2%		Real Rate = 2.5%		Real Rate = 3%	
	ZB	**Deflat**	**ZB**	**Deflat**	**ZB**	**Deflat**
Inflation Target of 0%						
Taylor rule (1.5,0.5,0)	0.098	0.106	0.075	0.063	0.054	0.036
HM rule (2.0,2.0, 0)	0.152	0.102	0.121	0.057	0.096	0.029
Revised Taylor rule (1.5,1.0,0)	0.085	0.095	0.065	0.055	0.045	0.033
Rule 8 (1.5,0.5,0.5)	0.080	0.106	0.058	0.064	0.041	0.040
Inflation Target of 1%						
Taylor rule (1.5,0.5,0)	0.054	0.036	0.040	0.017	0.025	0.015
HM rule (2.0,2.0, 0)	0.096	0.029	0.072	0.017	0.054	0.014
Revised Taylor rule (1.5,1.0,0)	0.045	0.033	0.032	0.017	0.020	0.014
Rule 8 (1.5,0.5,0.5)	0.041	0.040	0.031	0.020	0.020	0.016
Inflation Target of 2%						
Taylor rule (1.5,0.5,0)	0.025	0.015	0.017	0.014	0.011	0.014
HM rule (2.0,2.0, 0)	0.054	0.014	0.041	0.014	0.031	0.013
Revised Taylor rule (1.5,1.0,0)	0.020	0.014	0.013	0.014	0.009	0.014
Rule 8 (1.5,0.5,0.5)	0.020	0.016	0.013	0.014	0.009	0.014
Inflation Target of 3%						
Taylor rule (1.5,0.5,0)	0.011	0.014	0.008	0.013	0.005	0.013
HM rule (2.0,2.0, 0)	0.031	0.013	0.023	0.013	0.017	0.013
Revised Taylor rule (1.5,1.0,0)	0.009	0.014	0.006	0.013	0.004	0.013
Rule 8 (1.5,0.5,0.5)	0.009	0.014	0.006	0.014	0.004	0.013
Inflation Target of 4%						
Taylor rule (1.5,0.5,0)	0.005	0.013	0.004	0.013	0.002	0.013
HM rule (2.0,2.0, 0)	0.017	0.013	0.013	0.013	0.010	0.013
Revised Taylor rule (1.5,1.0,0)	0.004	0.013	0.002	0.013	0.002	0.013
Rule 8 (1.5,0.5,0.5)	0.004	0.013	0.003	0.013	0.002	0.013

Note: ***ZB represents the probability of hitting the zero bound constraint.***
Deflat represents the probability of falling into the deflationary trap

Since I employ the model similar to RS (1999), it is worthwhile to compare my results to theirs. The RS results are based on optimal policy rules derived from the similar model but with different policy rule specifications including the forecast-based rules, inflation targeting rules with different forecasting horizons, etc. The most relevant rule to the policy rules used in this chapter is the optimal Taylor-type rule[127].

[127] However, a zero bound constraint is not their focus, they reported very briefly on the probability of hitting the zero bound of their Taylor-type optimal rule which is more aggressive than the Taylor rule.

According to their result, the probability of a binding zero bound constraint is as high as 20%, with 2% inflation target and 2.5% equilibrium real interest rate. I obtain a much smaller probability for the RS optimal rule. The replicated results from their optimal rule are also reported in Appendix G.

The difference of my results and those of RS possibly stem from the differences in parameter estimates of the model[128] caused by the revisions of the data, especially, in potential output and the change of the base year of chained price index from 1996 in their study to 2000 in this chapter. Moreover, I allow a structural break at 1982:Q3, which was not found in their estimation.

Many studies, e.g. RW (2000), HL (2002) and Yates (2002), have pointed out that with the inflation target higher than 2%, the zero bound constraint is not a concern, consistent with Table 2.3. However, more aggressive rules, e.g. the HM rule, the probability of hitting the zero bound at 2% inflation target is still approximately 4%.

From Table 2.4, the standard deviation of inflation declines monotonically in most cases with a higher inflation target, whereas, that of the output gap is not much affected. For the interest rate, the higher is the inflation target, the higher is its variability. This can be explained by the dynamic responses that the interest rate is cut off at the zero bound whenever the inflation target is low, instead of going below zero

The weights in response to inflation and the output gap are 2.37 and 1.44, respectively, with a mild degree of interest rate smoothing of 0.14.

[128] Based on Rudebusch and Svensson (2002) in which they updated the estimates from the paper in 1999, the estimates from the sample period of 1960:Q1 – 1999:Q4 are as follows.

$$\pi_t = \underset{(0.083)}{0.675}\pi_{t-1} - \underset{(0.103)}{0.077}\pi_{t-2} + \underset{(0.107)}{0.286}\pi_{t-3} + \underset{(0.088)}{0.115}\pi_{t-4} + \underset{(0.037)}{0.152}x_{t-1}$$

Adjusted R^2 =0.81; σ_π=1.084; DW=1.99;

$$x_t = \underset{(0.079)}{1.161}x_{t-1} - \underset{(0.077)}{0.259}x_{t-2} - \underset{(0.032)}{0.088}(\bar{i}_{t-1} - \bar{\pi}_{t-1} - r^*);$$

Adjusted R^2 =0.90; σ_x=0.823; DW=2.08:

Furthermore, they use the demeaned variables in the first equation. I experimented with at set of variables and found a similar result to this chapter except that the residuals are biased due to the shift in the intercept of the regression.

percent. Thus, the response to the shock is relatively small compared with the hypothetically unconstrained one.

However, the changes in the standard deviation of inflation and the output gap in the original Taylor rule across the inflation targets and the equilibrium real interest rate are not seen clearly, unlike the more aggressive rule such as the HM rule. In this rule, the higher is the inflation target, the lower are the standard deviation of inflation and the output gap.

On the other hand, the revised Taylor rule shows the lower variability of the output gap but higher variability in inflation, compared with the original Taylor rule, even though the effect on the variability of the output gap of the zero bound constraint is small, as seen from Table 2.4. The standard deviation of the output gap does not change much with the higher inflation target.

Since more aggressive rules, relative to the Taylor rule, trade off higher variability of the interest rate with lower variability of the policy targets, i.e. inflation and the output gap, both the variability of policy targets and instruments should be incorporated into the central bank's loss function, with different weights, determined by the central bank's policy preference in order to design an optimal rule. The loss function presented in this chapter is only an example to show how the zero bound constraint can affect the welfare loss. Many studies focus on the central banks' preference in the loss function both theoretically and empirically, e.g. Dennis (2001, 2003), Ozlale (2003), etc.

Thus, with the variability of interest rate as the policy instrument encompassed into a central bank's loss function, a very aggressive rule may not be a good choice to employ because high variability in the interest rate may supersede the gain from lower variability of inflation and the output gap.

Table 2.4: The standard deviations of inflation, the output gap and federal funds rate and welfare loss[129]

Rules	Real Interest Rate of 2%				Real Interest Rate of 2.5%				Real Interest Rate of 3%			
	π_t	x_t	i_t	*Loss*	π_t	x_t	i_t	*Loss*	π_t	x_t	i_t	*Loss*
Inflation Target of 0%												
Taylor rule (1.5,0.5,0)	2.965	1.996	3.896	27.957	2.960	2.000	4.026	28.971	2.965	2.000	4.128	29.834
HM rule (2.0,2.0,0)	2.764	1.652	4.724	32.688	2.724	1.644	4.865	33.792	2.726	1.642	4.977	34.899
Revised Taylor rule (1.5,1.0,0)	3.073	1.794	4.177	30.109	3.097	1.789	4.287	31.171	3.033	1.782	4.355	31.344
Rule 8 (1.5,0.5,0.5)	3.087	2.060	3.866	28.718	2.991	2.057	3.988	29.079	3.051	2.062	4.088	30.277
Inflation Target of 1%												
Taylor rule (1.5,0.5,0)	2.965	2.000	4.128	29.834	2.979	2.002	4.202	30.539	2.926	2.001	4.234	30.492
HM rule (2.0,2.0,0)	2.726	1.642	4.977	34.899	2.699	1.637	5.044	35.407	2.664	1.634	5.088	35.650
Revised Taylor rule (1.5,1.0,0)	3.033	1.782	4.355	31.344	3.021	1.778	4.408	31.719	3.002	1.776	4.431	31.799
Rule 8 (1.5,0.5,0.5)	3.051	2.062	4.088	30.277	3.026	2.061	4.169	30.787	3.010	2.064	4.199	30.956
Inflation Target of 2%												
Taylor rule (1.5,0.5,0)	2.926	2.001	4.234	30.492	2.930	2.005	4.249	30.654	2.914	2.006	4.257	30.635
HM rule (2.0,2.0,0)	2.664	1.634	5.088	35.650	2.646	1.633	5.114	35.829	2.641	1.633	5.139	36.051
Revised Taylor rule (1.5,1.0,0)	3.002	1.776	4.431	31.799	2.993	1.776	4.441	31.836	2.988	1.776	4.449	31.880
Rule 8 (1.5,0.5,0.5)	3.010	2.064	4.199	30.956	3.030	2.069	4.216	31.237	3.005	2.070	4.224	31.158
Inflation Target of 3%												
Taylor rule (1.5,0.5,0)	2.914	2.006	4.257	30.635	2.913	2.007	4.268	30.731	2.906	2.007	4.272	30.725
HM rule (2.0,2.0,0)	2.641	1.633	5.139	36.051	2.635	1.633	5.156	36.190	2.631	1.633	5.169	36.303
Revised Taylor rule (1.5,1.0,0)	2.988	1.776	4.449	31.880	2.989	1.776	4.457	31.957	2.987	1.776	4.461	31.972
Rule 8 (1.5,0.5,0.5)	3.005	2.070	4.224	31.158	2.993	2.071	4.230	31.137	2.991	2.071	4.237	31.189
Inflation Target of 4%												
Taylor rule (1.5,0.5,0)	2.906	2.007	4.272	30.725	2.904	2.007	4.277	30.753	2.903	2.007	4.280	30.773
HM rule (2.0,2.0,0)	2.631	1.633	5.169	36.303	2.628	1.632	5.179	36.396	2.626	1.632	5.188	36.471
Revised Taylor rule (1.5,1.0,0)	2.987	1.776	4.461	31.972	2.985	1.776	4.463	31.985	2.985	1.776	4.464	31.993
Rule 8 (1.5,0.5,0.5)	2.991	2.071	4.237	31.189	2.988	2.072	4.241	31.207	2.987	2.072	4.245	31.228

[129] The welfare loss in this chapter is calculated by summing all the variances of inflation, the output gap and the federal funds rate without imposing any preference on any particular variable.

8.2.2.2 Distributions of the endogenous variables

It is apparent that the zero bound constraint affects the performance of policy rules in counteracting adverse shocks to either inflation or output, as seen in the stochastic simulation result in Table 2.4. The constraint deters the rule-based negative nominal interest rate whenever it binds. In other words, the monetary policy stance tends to be too tight on average. It results in unsuccessfully mitigating the negative output gap or low inflation which normally happens in a recession. Thus, the economy may not recover as soon as it would if the constraint was absent without any aid from other policy stimulus. Or even worse, it could diverge to a deflationary trap.

The effect of the zero bound constraint can also be shown in the distribution of endogenous variables. When the probability of hitting the zero bound is high, it is similar to being hit by a series of positive shocks[130] until the nominal interest rate begins to revert to its steady state as pointed out by RW (2000). As a result, the constrained distributions by the zero bound are negatively skewed and the means tend to lower than the hypothetical economy without the constraint.

The negative skewness of the zero bound constrained distributions of the endogenous variables occurs due to two possible reasons; first, the constraint leads to the existence of the second equilibrium which is unstable (or a saddle point). Whenever a sufficiently large shock hits the economy and drags it below this point, the economy would fall into the deflationary trap and inflation and the output gap would be divergent. By contrast, this circumstance does not happen in the economy without the zero bound constraint or with a high inflation target where the zero bound constraint is not a problem. To calculate the distribution constrained at the zero bound on the nominal interest rate, these divergent time paths are excluded.

[130] This is because the monetary policy stance cannot be as expansionary as called for by the rule.

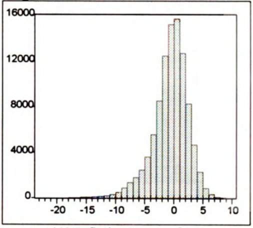
Second, the policy rules with the zero bound constraint would prescribe zero interest rate with a large negative shock but not sufficiently large to cause the economy to fall into the deflationary trap, which in turn, slows the trajectories of inflation and the output gap to return to their steady state values, while the interest rate is fixed at the zero bound, instead of being negative. Thus, these two circumstances bring in the asymmetry in the distribution of the simulated endogenous variables.

To illustrate the effects of a zero bound constraint upon the stationary distribution of inflation and the output gap, I simulate the RS model, starting from the steady state equilibrium, given the equilibrium real interest rate at 2.5%. Then, I enter the mean zero residuals into inflation and the output gap functions. As a result, the distributions of inflation and the output gap are shown in Figure 2.6.

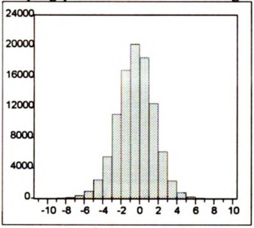
With a lower inflation target, the means of distributions of inflation deviate more from their targets[131]. In contrast, the distributions of the output gap are not skewed, even though the means differ from the target. The deviations from the targets are not as high as those of inflation. Thus, the effect of the zero bound constraint on the output gap cannot be discerned as clearly as on inflation.

[131] I also simulate the model stochastically without imposing the zero bound constraint to compare with the results presented in this section. I find that the distributions do not skew and the standard deviations of each endogenous variable are identical across the inflation targets.

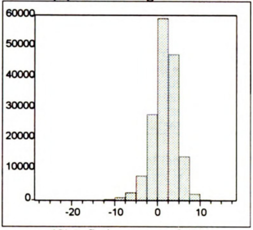
Figure 2.6: Distribution of inflation and the output gap with different inflation target



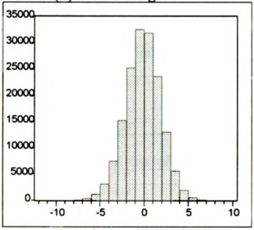
(A) Inflation target of 0%



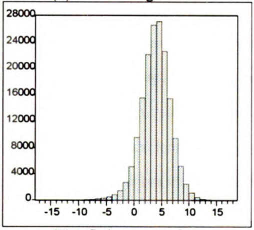
(B) Inflation target of 0%



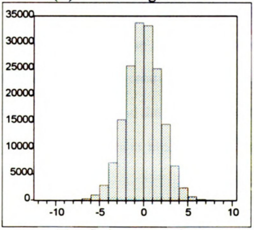
(C) Inflation target of 2%



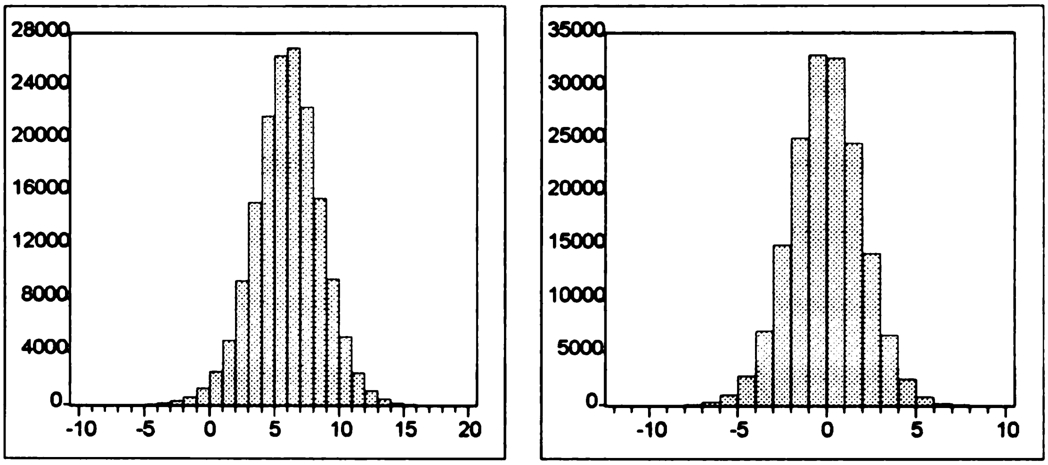
(D) Inflation target of 2%



(E) Inflation target of 4%



(F) Inflation target of 4%



(G) Inflation target of 6% (H) Inflation target of 6%

Note: the left hand side exhibits the distributions of the inflation, while the distributions of the output gap are on the right hand side.

Table 2.5: Deviations of inflation from the steady state across inflation targets

Rule	*0% of IT*	*2% of IT*	*4% of IT*	*6% of IT*
Taylor rule	-0.639677	-0.344443	-0.087310	-0.013844
HM rule	-0.753738	-0.485627	-0.177500	-0.051960
Revised Taylor rule	-0.789553	-0.416585	-0.100529	-0.014850
Rule 8	-0.563146	-0.331806	-0.091424	-0.020845

Table 2.6: Deviations of the output gap from the steady state across inflation targets

Rule	*0% of IT*	*2% of IT*	*4% of IT*	*6% of IT*
Taylor rule	-0.467532	-0.157388	-0.057824	-0.041464
HM rule	-0.519167	-0.203346	-0.071321	-0.039374
Revised Taylor rule	-0.525270	-0.184359	-0.047800	-0.019008
Rule 8	-0.461453	-0.160944	-0.063447	-0.045726

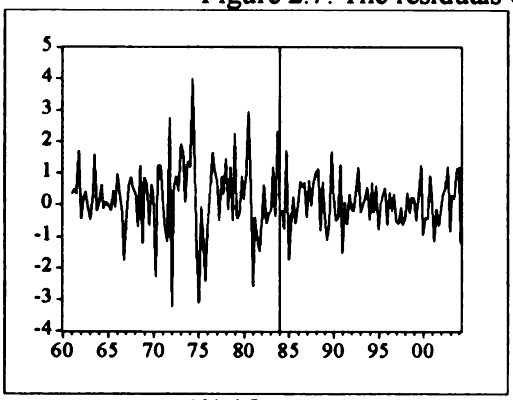
With more aggressive policy rules, the deviations from the targets are larger but declining with a higher inflation target. Therefore, if the central bank sets its inflation target very low, such as 0%, it is likely that inflation and the output gap can be off the target in the long-run since the zero bound constraint binds more often leading to large deviations from the target.

8.2.2.3 A structural break in the output variance in 1984:Q1

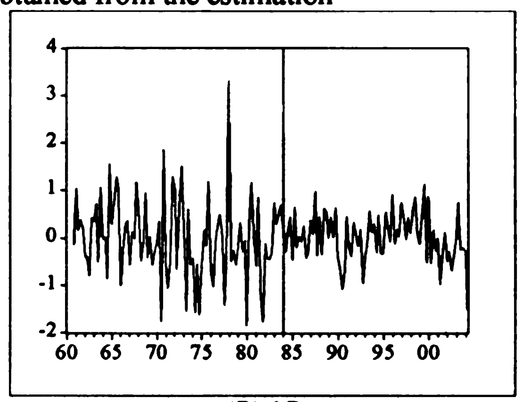
Recently, some studies, e.g. McConnell and Perez-Quiros (2000) and Boivin and Giannoni (2002) focus on a structural break of the variance of the output gap at 1984:Q1. It would be sensible to account for this breakpoint. I find the difference in variance between the two sub-samples including 1960:Q1 to 1983:Q4 and 1984:Q1 to 2004:Q2.

The break in the variance does not affect the estimation in this model since it does not change the conditional mean of the estimates, even though it affects the standard errors. However, I employed the Newey-West Heteroskedasticity and Autocorrelation Consistent (HAC) covariance to correct the standard errors of the estimates, therefore, they should be robust to this problem.

Figure 2.7: The residuals obtained from the estimation



(A) AS



(B) AD

I split the whole sample of estimated residuals into two sub-samples and apply three types of tests for equality of variances; namely, conventional F-test for the variances, Levene test and Brown-Forsythe test. The latter two allow the difference in the mean and median, respectively.

Table 2.7:Test for equality of the variance of residuals

Method	*Aggregate Supply*			*Aggregate Demand*		
	Df	*Value*	*Probability*	*Df*	*Value*	*Probability*
F-test	(81, 91)	2.899501	0.0000	(81, 91)	3.151688	0.0000
Levene	(1, 172)	9.759938	0.0021	(1, 172)	19.01500	0.0000
Brown-Forsythe	(1, 172)	9.613376	0.0023	(1, 172)	19.06606	0.0000

Note: 1) F-test is to test the variances of two sub-samples under the null hypothesis of equal variance and independent normal samples.

2) Levene test is based on an analysis of variance (ANOVA) and allowing the difference in absolute mean - (Levene, 1960))

3) Brown-Forsythe test is to modify the Levene test by replacing the difference in mean by the difference in median which is more robust and higher power than the Levene test - Brown and Forsythe (1974a, 1974b).

Thus, I incorporate the structural break of the variance into the simulation by using two separate covariance matrices for each sub-sample instead of the one covariance matrix for the whole sample.

Table 2.8: The probability of hitting the zero bound constraint and falling into the deflationary trap the break in the variance of output at 1984:Q1

Rule	*Real Rate at 2%*		*Real Rate at 2.5%*		*Real Rate at 3%*	
	ZB	*Deflat*	*ZB*	*Deflat*	*ZB*	*Deflat*
Inflation Target of 0%						
Taylor rule (1.5,0.5,0)	0.079	0.037	0.059	0.019	0.040	0.015
HM rule (2.0,2.0,0)	0.131	0.040	0.103	0.023	0.078	0.016
Revised Taylor rule (1.5,1.0,0)	0.053	0.035	0.038	0.021	0.027	0.013
Rule 8 (1.5,0.5,0.5)	0.068	0.035	0.050	0.019	0.034	0.015
Inflation Target of 1%						
Taylor rule (1.5,0.5,0)	0.040	0.015	0.028	0.014	0.019	0.013
HM rule (2.0,2.0,0)	0.078	0.016	0.059	0.013	0.044	0.013
Revised Taylor rule (1.5,1.0,0)	0.027	0.013	0.018	0.013	0.011	0.013
Rule 8 (1.5,0.5,0.5)	0.034	0.015	0.023	0.014	0.016	0.014
Inflation Target of 2%						
Taylor rule (1.5,0.5,0)	0.019	0.013	0.013	0.013	0.009	0.012
HM rule (2.0,2.0,0)	0.044	0.013	0.034	0.012	0.025	0.012
Revised Taylor rule (1.5,1.0,0)	0.011	0.013	0.008	0.012	0.005	0.012
Rule 8 (1.5,0.5,0.5)	0.016	0.014	0.011	0.013	0.008	0.012
Inflation Target of 3%						
Taylor rule (1.5,0.5,0)	0.009	0.012	0.006	0.012	0.004	0.012
HM rule (2.0,2.0,0)	0.025	0.012	0.018	0.012	0.013	0.012
Revised Taylor rule (1.5,1.0,0)	0.005	0.012	0.003	0.012	0.002	0.012
Rule 8 (1.5,0.5,0.5)	0.008	0.012	0.005	0.012	0.003	0.012
Inflation Target of 4%						
Taylor rule (1.5,0.5,0)	0.004	0.012	0.002	0.012	0.001	0.012
HM rule (2.0,2.0,0)	0.013	0.012	0.009	0.012	0.006	0.012
Revised Taylor rule (1.5,1.0,0)	0.002	0.012	0.001	0.012	0.001	0.012
Rule 8 (1.5,0.5,0.5)	0.003	0.012	0.002	0.012	0.001	0.012

Note: ZB represents the probability of hitting the zero bound constraint.
Deflat represents the probability of falling into a deflationary trap

From Table 2.8, the probability of hitting the zero bound constraint and the probability of falling into a deflationary trap in the Taylor rule are smaller, compared with those obtained from the simulations without a break in the variance. However, the differences are so small that they are negligible at the inflation target higher than 2%.

Table 2.9: The standard deviations of inflation, the output gap and federal funds rate and welfare loss with the break in the variance of output at 1984:Q1

Rules	*Real Interest Rate of 2%*				*Real Interest Rate of 2.5%*				*Real Interest Rate of 3%*			
	π_t	x_t	i_t	*Loss*	π_t	x_t	i_t	*Loss*	π_t	x_t	i_t	*Loss*
Inflation Target of 0%												
Taylor rule (1.5,0.5,0)	2.914	1.922	3.808	26.679	2.891	1.927	3.852	26.903	2.842	1.932	3.877	26.836
HM rule (2.0,2.0,0)	2.758	1.532	4.424	29.530	2.748	1.533	4.484	30.005	2.691	1.530	4.528	30.082
Revised Taylor rule (1.5,1.0,0)	2.976	1.664	3.982	27.484	2.955	1.662	4.010	27.574	2.949	1.667	4.026	27.689
Rule 8 (1.5,0.5,0.5)	3.061	2.004	3.824	28.001	3.011	2.008	3.862	28.012	2.961	2.012	3.891	27.957
Inflation Target of 1%												
Taylor rule (1.5,0.5,0)	2.842	1.932	3.877	26.836	2.820	1.935	3.896	26.877	2.823	1.938	3.915	27.054
HM rule (2.0,2.0,0)	2.691	1.530	4.528	30.082	2.663	1.532	4.560	30.231	2.644	1.532	4.586	30.372
Revised Taylor rule (1.5,1.0,0)	2.949	1.667	4.026	27.689	2.911	1.666	4.029	27.482	2.901	1.667	4.035	27.480
Rule 8 (1.5,0.5,0.5)	2.961	2.012	3.891	27.957	2.936	2.016	3.906	27.939	2.921	2.019	3.920	27.974
Inflation Target of 2%												
Taylor rule (1.5,0.5,0)	2.823	1.938	3.915	27.054	2.802	1.940	3.925	27.021	2.796	1.941	3.933	27.052
HM rule (2.0,2.0,0)	2.644	1.532	4.586	30.372	2.636	1.534	4.608	30.538	2.626	1.535	4.623	30.625
Revised Taylor rule (1.5,1.0,0)	2.901	1.667	4.035	27.480	2.955	1.673	4.048	27.915	2.896	1.669	4.045	27.531
Rule 8 (1.5,0.5,0.5)	2.921	2.019	3.920	27.974	2.929	2.021	3.935	28.144	2.914	2.022	3.944	28.141
Inflation Target of 3%												
Taylor rule (1.5,0.5,0)	2.796	1.941	3.933	27.052	2.788	1.942	3.937	27.050	2.785	1.943	3.940	27.055
HM rule (2.0,2.0,0)	2.626	1.535	4.623	30.625	2.620	1.535	4.635	30.705	2.616	1.536	4.644	30.767
Revised Taylor rule (1.5,1.0,0)	2.896	1.669	4.045	27.531	2.894	1.669	4.046	27.531	2.892	1.670	4.047	27.534
Rule 8 (1.5,0.5,0.5)	2.914	2.022	3.944	28.141	2.904	2.023	3.948	28.113	2.899	2.024	3.951	28.109
Inflation Target of 4%												
Taylor rule (1.5,0.5,0)	2.785	1.943	3.940	27.055	2.782	1.943	3.942	27.059	2.781	1.943	3.943	27.060
HM rule (2.0,2.0,0)	2.616	1.536	4.644	30.767	2.613	1.536	4.650	30.814	2.611	1.536	4.655	30.848
Revised Taylor rule (1.5,1.0,0)	2.892	1.670	4.047	27.534	2.892	1.670	4.048	27.536	2.891	1.670	4.048	27.538
Rule 8 (1.5,0.5,0.5)	2.899	2.024	3.951	28.109	2.896	2.024	3.953	28.109	2.894	2.024	3.954	28.106

Similar to the case of no-break in variance, the much more aggressive rules in response in inflation, such as the HM rule and the revised Taylor rule[132], the probabilities when both the constraint binds and when the economy falls into a deflationary trap are lower when the break in variance is taken into account. Likewise, the probabilities are very small and negligible at an inflation target above 2%.

While the standard deviations of inflation decreases with inflation targets, those of the output gap do not move consistently across the policy rules. For the Taylor rule and Rule 8, they even rise but insignificantly. Similar to the case with no break in the variance, it is less obvious how the zero bound constraint affects the variability of the output gap, compared with the variability of inflation and the interest rate.

The decline of the standard deviation of inflation with an increase in the inflation target can be explained by the skewness in the distribution of inflation caused by the zero bound constraint at a low inflation target, as illustrated in Figure 2.6. In contrast, the distributions of the output gap are quite symmetric across all inflation targets, thus, the standard deviations do not change much[133].

9. Discussion and extension

In a simple framework used by Ball (1997) and Svensson (1997), incorporating only one lag of each endogenous variable and allowing a real interest rate, assumed to be the sole transmission mechanism of monetary policy, to affect the economy through aggregate demand with one lag, the dynamic analysis yields an interesting mechanism. By imposing a zero bound constraint, it engenders a saddle

[132] The results of other policy rules are shown in Appendix G.

[133] Even though there are some changes with inflation targets and equilibrium real interest rates, in particularly when the structural break in variance is taken into account, it might be due to some rounding effects when simulating the models.

path which demarcates the stable and unstable regions called "Deflationary trap" by RW (2000). Thus, there exist two equilibria, one stable and the other unstable, corresponding to without and with the zero bound constraint, respectively. This exercise is insightful in illustrating the behavior of the economy given the zero bound constraint.

If the economy starts, or a large negative shock leads it to fall, into the deflationary regions, an alternative policy must be taken into consideration since interest rate rules are not capable of resuscitating the economy. This circumstance has been discussed by RW (2000) as a requirement for other stimulus apart from the open market operation. Also, it can be concluded that interest rate rules fail entirely in this situation.

9.1 Implication from the simulations

From the simulation, the economy is susceptible to hit the zero bound and/or falling into the deflationary trap without a large negative shock when an inflation target and/or an equilibrium real interest rate are very low. This implies that a central bank may not want to set their inflation target too low. Thus, the zero bound constraint becomes another reason why a central bank should not set its inflation target at 0%, besides the downward rigidity in the labor market – Gramlich (2003) and measurement problems in inflation – King (2002).

Furthermore, the variability of inflation is high at the 0% inflation target where the zero bound constraint is more likely to bind than at higher inflation targets, as seen from the simulation. Therefore, a central bank should pursue a small positive inflation target, rather than a zero inflation target, in order to avoid higher variability of inflation, which is also incorporated into most central banks' macroeconomic objectives.

In fact, the European Central Bank's target is 1%-2%, while the Federal Reserve's is 2% inflation target, as can be implied from Monetary Trends, Federal Reserve Bank of St. Louis, in the calculation of the Taylor rule-based nominal interest rate target, in spite of no formally announced inflation target in the US.

For Japan, there is also no formal inflation target. Taylor [134] (2000) recommended that the BoJ should have an explicit inflation target and the appropriate number should be near that of the ECB and the Federal Reserve in order to prevent expected appreciation in the currency in the long run.

Another factor leading to a higher probability of hitting the zero bound constraint is a low equilibrium real interest rate or the natural real interest rate, which is unobservable. This factor depends on economic conditions and is beyond a central bank's control. Because an equilibrium real interest rate corresponds to the level of output at a potential level and no deviation of inflation from its target, it also represents a benchmark for whether a monetary policy is too contractionary or expansionary. However, the rate can be estimated. Thus, the implication is that it is crucial to find a reliable estimate, consistent with the true equilibrium real interest rate. Using a different rate from the true rate can bring in larger variability in both inflation and the output gap as shown in Laubach and Williams (2001).

One may argue that more aggressive rules may work in curbing the variability of inflation and output. But it is not that simple, since these rules also generate larger

[134] Taylor (2000) emphasizes the difference between having an inflation target and adopting an inflation targeting regime. The inflation targeting regime is stricter in the sense that the central bank is committed to its inflation target set forth. The inflation targeting regime also strengthens the central bank's credibility. Even though the central bank has an inflation target higher than zero percent, where the zero bound constraint has a very small chance of binding, such a level of inflation target may not be sufficiently credible since there is no commitment to stick with the announced target. Thus, the inflation targeting regime might be one way to lessen the probability of the zero bound.

variability in the policy instrument. More importantly, if more aggressive rules were used, a binding zero bound constraint can be a major concern for policymakers. As shown in the variability of the variables, measured by the standard deviations in Table 2.4 and 2.9, more aggressive rule such as the Henderson and McKibbin rule induces large variability in the interest rate, relative to the original Taylor rule. It is worse when the inflation target is very low which leads to greater likelihood of hitting the zero bound constraint and falling into a deflationary trap. Thus, the central bank should also take the zero bound constraint problem into consideration when determining how aggressive a policy rule should be, owing to the effect caused by the zero bound constraint.

Recently, policy inertia is one of the issues widely discussed among monetary economists. I also incorporate it to study of the effect of the zero bound. From the simulations, the policy rule with some degree of interest rate smoothing successfully lower the interest rate variability, without increasing the variability of inflation and the output gap considerably. However, the degree of interest rate smoothing must be less than unity in this model, to maintain the dynamic stability of the model. This may not be true for more forward-looking type models, as seen in other studies including Levin et al (1999) and Rotemberg and Woodford (1999) who proposed optimal interest rate rules with the degree of interest rate smoothing equal or greater than one.

Hence, incorporating some degree of interest rate smoothing would be beneficial since the interest rate volatility decreases without causing higher volatility of inflation and the output gap in light of the zero bound constraint binding at a low inflation target.

It is worth noting that all the policy rules considered in this chapter have the weight associated with inflation of greater than unity, conforming to the Taylor

Principle. In the model used in this chapter, it is also a necessary condition to attain dynamic stability.

9.2 Relevant experiences

As mentioned earlier, the fear of the zero bound constraint binding as well as deflation was spurred by the prolonged recession in Japan and low *nominal* interest rates in most industrialized economies prior to the new millennium, the comparisons between the past experiences and the results from the present chapter would be a valuable lesson for policymaking.

After the asset price bubble burst in the late 1980s, Japanese economy has suffered from recession for over a decade, despite many attempts from both Bank of Japan (BoJ) and the Ministry of Finance to resuscitate the economy. These attempts were, however, not adequately stimulative to restore the economy. Worse, the timing of the responses was too slow to prevent a deeper recession in the late 1990s.

The insufficient aggressiveness and too slow response of the BoJ can be discerned more vividly when compared with the recent recession in the US – Ahearne et al. (2002), Orphanides (2003b), Harrigan and Kuttner (2004) (HK), etc. HK pointed out that the BoJ did not lower the call rate adequately to keep up with the decline in expected inflation in the mid 1990s, as a consequence the ex ante (expected) real interest rate did not fall enough to stimulate the economy[135]. Compared to the recession in the US in 2000, the Federal Reserve cut their federal funds rate aggressively to reduce the ex ante real federal funds rate after 2000.

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[135] Alternatively, the BoJ was not aggressive enough to convince the public that it was serious in stimulating the economy. In fact, the real interest rate based on the ex post (observed) inflation was not even as high as the ex ante (expected) inflation. The ex ante real interest rate was higher than the ex post real interest rate during the 1990s.

Ahearne et al. (2002) and Kuttner and Posen (2003) (KP) explain monetary policy in Japan by estimating a forward-looking policy reaction function[136] and find the result consistent with HK and others that the BoJ did not conduct an expansionary enough policy to drive down the real interest rate in the mid- 1990s.

Two key lessons from the Japanese economic history can be learned. First, if the BoJ had implemented the estimated policy reaction function from the period of 1980 to the present, the monetary policy stance would have been more expansionary than it was in the mid- 1990s. According to KP, the BoJ should have cut its uncollaterized call rate further to 0% in the beginning of 1995, whereas, the BoJ actually decided to maintain their rate at a slightly positive value.

The reluctance to ease its monetary policy stance further probably stemmed from a number of reasons; first, the scare of the repeated history of the asset price bubbles caused by too easy monetary policy; second, the protracted slump in Japan was unanticipated, noticing that forecast inflation and real output growth had been high the first half of 1990s, relative to the actual rates – Ahearne et al. (2002) and Ito (2004); lastly, as pointed by Ahearne et al (2002), the BoJ's discomfort with the short-term interests rate approaches zero and the comfort with zero inflation, observed from the statement of the staff many occasions emphasizing the objective of price stability and the argument against the concept of the zero interest rate that it would deteriorating the financial institutions reformation.

Comparing the monetary policy stance in Japan after the recession to that of the US during the economic downturns in 2000, the Federal Reserve instantly and

[136] Ahearne et al use the sample of 1981:Q1 - 2001:Q3, whereas, Kuttner and Posen (2003) estimated using a sample of 1986:Q1 - 2001:Q1. And both employ the expected inflation with four-quarter ahead, measured by CPI. Interestingly, Ahearne et al (2002) also estimated the Taylor-type rule with the real-time data available at that quarter and find that the monetary policy stance in the first half of the 1990s was, in fact, *too loose*, compared with other studies. This is because the deflation is unanticipated to happen at that time. As a consequence, the expected inflation and real-time output are prone to be too high.

aggressively cut the federal funds rate after the onset of recession. In fact, the aggressiveness in fighting against the recession in the US conformed to the policy reaction function which followed the Taylor Principle[137].

Second, after adopting the Zero Interest Rate Policy (ZIRP) in February 1999 formally, the BoJ raised the call rate again in August 2000 after the economy showed some signs[138] of recovery. The rise of the call rate became the second policy mistake since it provoked the recession in 2001. Hence, if the BoJ had still maintained the ZIRP instead of raising the call rate, there might have been a chance that the economy would not have ended up with such a prolonged recession. Orphanides (2003b) compared the mistakenly increase of the call rate to the Federal Reserve's mistake in tightening monetary policy stance in 1937-38 due to the enormous gold inflows.

Considering the dynamic responses of this chapter, if the zero bound constraint is binding, such as in the case of Japan, and the central bank still maintains a zero percent rate for a period of time, the economy still has a chance to recover, given that the negative shock is not too large that it leads to the deflationary trap. The BoJ could have embraced this case and might have reconsidered their decision in raising the call rate in 2000.

Another difference in the economic history between the US and Japan is the timing of the negative shocks to the economies. While Japan started recovering in the mid-1990s, the Asian financial crisis hit every country hard, including Japan. The crisis deterred the economy from recovering after the first negative shock when the

[137] The Federal Reserve' behaviour in conducting monetary policy must be interpreted with some caution. It would be a big mistake if we state that the Federal Reserve has implemented any rule since there never exists such an explicit policy. Instead, the Fed follows a discretionary policy rather than a rule during the Greenspan's period – Greenspan (2004) and Blinder and Reis (2005). Nevertheless, one of the key successes of the Federal Reserve during the 1990s hitherto is their aggressiveness in responding to inflation, as stated in Greenspan (2004) and discussed in Taylor (2005). This could be the reason why the Taylor rule can track the Fed's behavior so well during Chairman Greenspan's tenure.

[138] These include the narrower negative output gap and increases in the price in equity market, according to Ahearne et al (2002).

asset price bubble burst. Therefore, there were two large negative shocks hitting Japanese economy separated by approximately 5 year period.

On the contrary, the negative shock from September 11th, 2001 hit the US economy at the beginning of the recession after the US experienced the recession after the IT boom turned bust. Thus, two negative shocks successively entered the economy at one time. This timing could affect the conduct of monetary policy differently. However, this difference in timing and the size of the shocks in each economy is not incorporated in this chapter's analysis. It could be an extent for the further study.

9.3 Where should we go from here?

The results in the present chapter can be extended in a number of ways. These include using more complicated models to describe the economy better. Recall that the model used in this chapter is a simple standard one, it is not meant to describe the economy or fit the data perfectly, even though many studies show that the RS model could replicate the US economy quite well, e.g. Rudebusch and Svensson (1999, 2002), Rudebusch (2002). It is a standard model lying between the theoretical model based on forward-looking type and the pure empirical model such as VAR(p) model.

Importantly, the effect of the public expectations is excluded in this model. They can tremendously impact the dynamics of the economy, for example, whenever a zero bound constraint is binding, the expectation can possibly lead the economy into a self-perpetuating deflationary path as pointed out by Benhabib et al (1999, 2001, 2002). Yet, the expectation can also be manipulated as a policy tool of the central bank to prevent the deflation or from hitting the zero bound constraint beforehand – Eggertson and Woodford (2003).

With the expectation incorporated in the model, the results may be different. One example is the dynamic response which would converge more quickly towards its steady state or the probability of the zero bound would be lower since the expectation would help mitigate the recession from the beginning, as shown in and Fuhrer and Madigan (1997) and OW (1998).

In addition, other transmission mechanisms and the variables abstracted from in this model may be responsible for the extremely slow convergence of the dynamic responses. This is because the inflation adjustment function is explained by only its lags and a lag of the output gap. While the coefficient on the lags of inflation is very large, indicating inflation persistence, the coefficient on output is very small. Therefore, the adjustment of inflation mostly comes from its own lags rather than the effect of the output gap. As a result, inflation adjusts very slowly towards the steady state equilibrium. Likewise, the lags of the output gap are mostly responsible for the movement of the aggregate demand function.

In this chapter, another unrealistic assumption is that of the constant real interest rate. An interesting extension is to estimate a real interest rate with more sophisticated methods such as Kalman filter, or from other structural models along with unobservable potential output.

Apart from the change in the real interest rate, the uncertainty in the model parameters as well as the uncertainty in the measurement of output gaps may produce different results. The study of uncertainty affecting monetary policy design has been explored since the 1990s. This strain of literature include Levin et al (1999) and Laubach and Williams (2001). Moreover, the uncertainty in the output gap measurement can possibly have tremendous effects on the performance of the monetary policy rules. This issue is addressed nicely in the study by the Fed's staff, Orphanides et al (1999).

10. Conclusion

Chapter 2 investigates the effectiveness of the interest rate rules, whether they could successfully resuscitate the economy out of a recession when the zero bound on the short-term interest rate binds. Also, I examined the importance of the zero bound constraint as well as the probability of it binding.

The finding is that interest rate rules still remain effective even though the zero bound constraint is binding if the size of negative shock is not so large that it leads to a deflationary trap. Given the model and their estimates used in this chapter, there is a slight chance that the short-term interest rate would hit the zero bound, if less aggressive interest rate rules, e.g. the Taylor rule, were used. But if the constraint is binding, there is a much smaller chance that the interest rate rules would be ineffective and other policies would be called for.

Based on a backward-looking model implemented by RS (1999), three types of simulations are presented to evaluate the policy rules. First, the dynamic responses or the time paths in the paper depict the effectiveness of an interest rate rule. If the time paths still converge to the steady state equilibrium, it means that the interest rate is still capable of resuscitating the economy. If not, the alternative policy either standard policies, e.g. the quantitative easing, longer-term interest rate targeting or other non-standard policies, e.g. exchange-rate targeting, or coordinating with the fiscal policy, should be considered. Also, the dynamic responses illustrate the rate of convergence towards the steady state equilibrium.

Second, the historical simulation shows whether imposing a policy rule could have improved economic performance by avoiding inflation or a recession. We have illustrated the Taylor rule could have mitigated the Great Inflation by prescribing tighter policy stance before that period.

Lastly, using the unconditional variances inferred from the stochastic simulation as a metric of the variability of these variables, the interest rate rules can be compared to find the interest rate rule which incurs the lowest variability of inflation and output. According to the simulation results, the zero bound constraint affects the variability of these variables tremendously when the inflation target is low, specifically at a zero inflation target.

Interestingly, the effect of the zero bound is more pronounced in the inflation than the output gap, as seen from the distributions of the endogenous variables. In addition, the variability measured by the standard deviations does not differ much in the output gap while they change considerably in inflation and the interest rate.

This chapter should shed some different light in studying the zero bound constraint on a nominal interest rate from the existing literature, which mostly focuses on an alternative policy when the constraint is binding. In particular, it presents the effect of the zero bound by means of simulating a backward-looking model, widely used among the monetary economists. It also demonstrates another reason why an inflation target should not be set too low such as zero percent, apart from the conventional explanations of measurement bias of the inflation and downward rigidity in the labor market.

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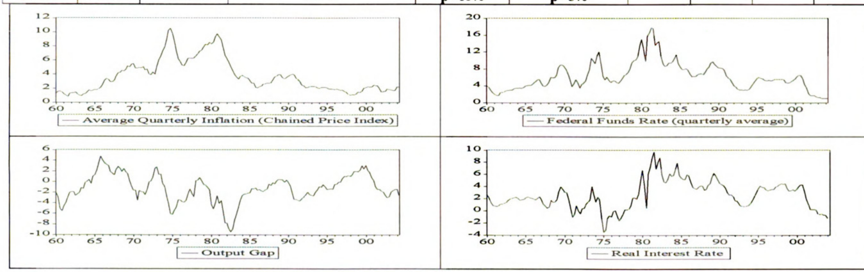
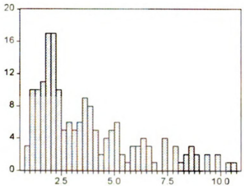
APPENDICES TO CHAPTER 2

Appendix A

Stationarity test and Auto-correlations

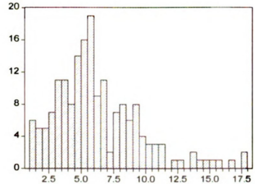
	ADF (none)	ADF (Intercept)	ADF (Intercept and Trend)	KPSS	KPSS (Trend)	ρ(1)	ρ(2)	ρ(3)	ρ(4)
π_t	-0.9380	-2.2445	-2.5340	0.4260	0.3062	0.9823	-0.4776	-0.0940	-0.0342
p-value	**0.3091**	**0.1916**	**0.3115**	**10%<p<5%**	**p <1%**				
i_t	-0.9925	-2.4082	-1.9370	0.3083	0.3076	0.9448	-0.2221	0.1183	-0.1420
p-value	**0.2869**	**0.1410**	**0.6308**	**p >10%**	**p <1%**				
gap	-3.3943	-3.6550	-3.6446	0.1439	0.1443	0.9465	-0.3036	-0.2002	-0.0055
p-value	**0.0008**	**0.0056**	**0.0290**	**p >10%**	**5% < p <10%**				
r_t	-1.5685	-2.1412	-1.9984	0.2924	0.1604	0.9085	-0.1549	0.2125	-0.0826
p-value	**0.1096**	**0.2290**	**0.5978**	**p >10%**	**p <5%**				





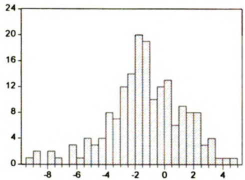
Series ADEF1
Sample 1960 1 2004 1
Observations 177

Mean	3 701565
Median	2 991485
Maximum	10 53096
Minimum	0 817943
Std Dev	2 343884
Skewness	1 050534
Kurtosis	3 237492
Jarque-Bera	32 97279
Probability	0 000000



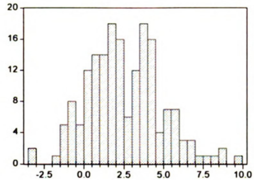
Series: FFR
Sample 1960:1 2004:1
Observations 177

Mean	6.262712
Median	5.530000
Maximum	17.78000
Minimum	1.000000
Std. Dev.	3.300010
Skewness	1.087709
Kurtosis	4.447138
Jarque-Bera	50.34655
Probability	0.000000



Series: GAP
Sample 1960:1 2004:1
Observations 177

Mean	-1.292805
Median	-1.422616
Maximum	4.779875
Minimum	-9.456018
Std. Dev.	2.586258
Skewness	-0.446167
Kurtosis	3.591732
Jarque-Bera	8.454741
Probability	0.014591



Series: RR
Sample 1960:1 2004:1
Observations 177

Mean	2.561147
Median	2.173865
Maximum	9.701534
Minimum	-3.499839
Std. Dev.	2.319759
Skewness	0.342970
Kurtosis	3.198140
Jarque-Bera	3.759567
Probability	0.152623

ADEF1 = Average Quarterly inflation is calculated from the average of the whole year of annualized quarterly inflation
FFR = Federal Funds rate is computed from average for quarterly.
GAP = The output gap is computed from the log of actual output/potential output *100
RR = Real interest rate is the difference between federal funds rate and the average inflation

Appendix B

Test for the stationarity with structural breaks

Since the structural breaks tend to reduce the power to reject the null hypothesis of non-stationarity of the data in the unit root tests including Augmented Dickey Fuller tests, Phillips and Perron test and the KPSS test, the modified unit roots to capture this influence are necessary. This is because the structural breaks can be perceived as the permanent shocks in the economic system and the unit root tests are to detect some persistence of the data. Thus, if the structural breaks are not taken into account, the unit root tests tend to show the non-stationarity in the economic data.

The unit root tests with the structural breaks considered in this chapter include Perron (1989)'s test with a known breakpoint, Zivot and Andrews (1992)'s test for an unknown breakpoint.

Perron (1989)'s test of unit root with a known structural break

Perron (1989) performs the unit-root test with a structural break in the Nelson and Plosser's (1982) macroeconomic data. Nelson and Plosser originally cannot reject the null hypothesis of the non-stationarity on the data but Perron does the opposite by negating the null hypothesis of non-stationarity on 11 out of 14 macroeconomic series.

Perron's test is based on three models, A, B and C. He labels Model A as "Crash model", representing a change only in an intercept of the data. For, Model B, he labels it as the "Changing growth model" and the mixed model on Model C. The three models can be written as follows;

Model A: $y_t = \mu^A + \theta^A DU_t + \beta^A t + d^A D(T_b)_t + \alpha^A y_{t-1} + \Sigma^k_{i=1} c_i \Delta y_{t-i} + e_t$

Model B: $y^e_t = \mu^B + \theta^B DU_t + \beta^B t + \gamma^B DT^*_t + v_t$

$y^d_t = \alpha^B y_{t-1} + \Sigma^k_{i=1} c_i \Delta y_{t-i} + e_t$

where $y^d_t = y_t - y^e_t$

Model C: $y_t = \mu^C + \theta^C DU_t + \beta^C t + d^C D(T_b)_t + \gamma^C DT^*_t + \alpha^C y_{t-1} + \Sigma^k_{i=1} c_i \Delta y_{t-i} + e_t$

Where y_t is the variable to be tested

$DU_t = 1$ if $t > T_b$, 0 otherwise; $D(T_b)_t = 1$ if $t = T_b + 1$, 0 otherwise; $DT^*_t = t - T_b$ if $t > T_b$, 0 otherwise and T_b is the breakpoint.

I test the federal funds rate, inflation, average inflation, the output gap and real interest rate for a unit root with a structural break based in either 1979:Q4 or 1982:Q3. The null hypothesis of the non-stationarity with a known structural break can be rejected in most cases except average inflation. The output gap is not needed to be tested again because the conventional unit-root tests have sufficient power to reject the non-stationarity. However, the drawback of this test is that the structural break must be known a priori. Thus, I add another test for an unknown breakpoint – Zivot and Andrews (1992) to test these variables again.

The programs used for testing the unit root with a structural break are written by Junsoo Lee (2004).

Zivot and Andrews (1992)'s test of an unknown structural break

In Zivot and Andrews (ZA), the breakpoint is endogenized by choosing based on the data. The method is to choose a minimum t-statistic from regression of T-2 times and compare with the critical values. The models to be tested are similar to Perron (1989). However, ZA (1992) trim the data by dropping off the first and last 10% of the data to avoid all the breakpoint to fall at each end point.

Table B-1: The unit root test with a known structural break (a priori) based on Perron (1989)

Variables	Model	Lags	t-statistic	Lagged	Constant	DU	$D(T_b)$	DT*	Time Trend
Breakpoint at 1979:Q4									
FFR	C	5	-5.2618^{a}	0.7658 (0.0445)	0.5508 (0.2549)	0.4572 (0.3309)	0.6713 (0.9391)	- 0.0434 (0.0098)	0.0205 (0.0058)
	B	5	-5.1639^{a}	0.7984 (0.0390)	1.6178 (0.4377)	-	-	-0.2004 (0.0126)	0.1126 (0.0078)
Average Inflation	C	8	-3.0462	0.9273 (0.0239)	0.0503 (0.0804)	-0.3280 (0.1049)	-0.0230 (0.2975)	-0.0104 (0.0043)	0.0076 (0.0030)
Inflation	C	4	-4.1082^{d}	0.7343 (0.0647)	0.2218 (0.2592)	-1.2138 (0.3697)	0.8018 (1.0799)	-0.0366 (0.0120)	0.0272 (0.0086)
Real Interest Rate	C	5	-3.9526^{d}	0.7717 (0.0578)	0.4388 (0.2618)	1.1910 (0.4453)	0.6200 (0.9240)	-0.0094 (0.0059)	-0.0030 (0.0050)
Breakpoint at 1982:3									
FFR	C	5	-5.1838^{a}	0.7824 (0.0420)	0.4241 (0.2206)	-0.2956 (0.2988)	-0.1864 (1.0196)	-0.0419 (0.0100)	0.0222 (0.0062)
	B	5	-5.2556^{a}	0.7956 (0.0389)	2.1822 (0.4160)	-	-	-0.1975 (0.0125)	0.0927 (0.0067)
Average Inflation	C	8	-3.0636	0.8967 (0.0337)	0.1358 (0.0744)	-0.5467 (0.1867)	0.1043 (0.3173)	-0.0106 (0.0048)	0.0083 (0.0036)
Inflation	C	6	-4.1786^{d}	0.5694 (0.1030)	0.4943 (0.2579)	-2.1784 (0.6384)	-0.0822 (1.0916)	-0.0468 (0.0146)	0.0356 (0.0112)
Real Interest Rate	C	5	-3.2765	0.8514 (0.0454)	0.1086 (0.2184)	0.4391 (0.3353)	-0.9904 (0.9638)	-0.0142 (0.0062)	0.0040 (0.0040)

Note: 1) The maximum number of lags is chosen based on that Schwatz and Akaike Information Criterions are both at minimum.
2) The standard errors are in parentheses
3) Subscript a, b, c and d represent the significant level of 1%, 2.5%, 5.0% and 10%

Two steps of ZA test can be conducted including, searching for a minimum t-statistic in order to search for an optimal breakpoint and testing for the unit root.

Seeking for an optimal breakpoint: $t_\alpha[\lambda^i_{inf}] = \inf t_\alpha(\lambda)$, $i = A, B, C$

Model A: $y_t = \mu^A + \theta^A DU_t(\lambda) + d^A D(T_b)_t + \beta^A t + \alpha^A y_{t-1} + \Sigma^k_{i=1} c_i \Delta y_{t-i} + e_t$

Model B: $y_t = \mu^B + \beta^B t + \gamma^B DT^*_t(\lambda) + \alpha^B y_{t-1} + \Sigma^k_{i=1} c_i \Delta y_{t-i} + e_t$

Model C: $y_t = \mu^C + \theta^C DU_t(\lambda) + d^B D(T_b)_t + \beta^C t + \gamma^C DT^*_t(\lambda) + \alpha^C y_{t-1} + \Sigma^k_{i=1} c_i \Delta y_{t-i}$ $+ e_t$

Where y_t is the variable to be tested

$DU_t(\lambda) = 1$ if $t>T_b(\lambda)$, 0 otherwise; $D(T_b)_t(\lambda) = 1$ if $t = T_b(\lambda) + 1$, 0 otherwise; $DT^*_t(\lambda) = t-T_b(\lambda)$ if $t>T_b(\lambda)$, 0 otherwise and $T_b(\lambda)$ is the breakpoint.

The maximum lag in the augmented part of the first difference y_t is chosen by the first variable of the difference y_t to be greater than 1.645 in absolute term. The results of the test are reported in the Table B-2 below.

The ZA test can reject the null hypothesis of non-stationarity in all the cases rejected by Perron's test. For the breakpoints, most the breakpoints chosen by the ZA test is in the period of 1979:Q4–1982:Q3, except the output gap found the breakpoint in 1973, corresponding to the first Oil Shock.

Likewise, the average inflation is non-stationary with Zivot and Andrews' test. However, when considering the breakpoint at 1980:Q3 and 1980:Q4, we can reject the null-hypothesis at 10% with Perron's test for model C. This can be explained by the lower power to reject the null-hypothesis in the ZA test since it loses some degree of freedom when estimating the unknown breakpoint. With such breakpoint dates, the average inflation can be concluded to be stationary.

Table B-2: The unit root test with an unknown structural break by Zivot and Andrews (1992)

Variables	breakpoint	lags	$y_{t-1}-1$	Constant	DU_t	$D(T_b)$	t	DT^*_t
Federal funds rate (C)	1981:Q1	5	-0.2606^{a} (-6.5730)	0.6660 (3.1717)	-0.0090 (-0.0323)	5.8298 (5.6171)	0.0249 (4.6785)	-0.0468 (-5.1347)
Federal funds rate (C)	1984:Q2	5	-0.2462^{a} (-5.8964)	0.5488 (2.7526)	-0.9332 (-3.1009)	-	0.0263 (4.5415)	-0.0436 (-4.6001)
Average inflation (C)	1980:Q3	8	-0.1096 (-4.6360)	0.1367 (2.0777)	-0.6006 (-5.4969)	0.7637 (2.5828)	0.0120 (4.2441)	-0.0148 (-3.6545)
Average Inflation (C)	1980:Q4	8	-0.1092 (-4.6325)	0.1322 (2.0314)	-0.6198 (-5.5839)	-	0.0121 (4.3032)	-0.0150 (-3.6940)
Inflation (C)	1980:Q3	4	-0.3762^{a} (-5.6347)	0.3542 (1.5565)	-2.1292 (-5.4497)	2.1034 (1.9741)	0.0407 (4.8502)	-0.0500 (-4.3264)
Inflation (C)	1980:Q4	4	-0.3764^{a} (-5.6625)	0.3564 (1.5839)	-2.1772 (-5.5090)	-	0.0407 (4.8716)	-0.0500 (-4.3409)
Real interest rate I (C)	1980:Q2	12	-0.3732^{b} (-5.4566)	0.7060 (2.8582)	2.1863 (4.6815)	-4.3966 (-4.8892)	-0.0069 (-1.2993)	-0.0139 (-2.3617)
Real Interest rate I (C)	1980:Q3	12	-0.3964^{a} (-5.7441)	0.8164 (3.2974)	2.4322 (5.2409)	-	-0.0101 (-1.9228)	-0.0120 (-2.0142)
Real interest rate II (C)	1980:Q2	8	-0.4901^{a} (-5.6276)	0.8596 (2.5661)	3.2086 (4.7631)	-6.5897 (-4.9895)	-0.0081 (-1.1410)	-0.0242 (-2.8593)
Real interest rate II (C)	1980:Q3	8	-0.5281^{a} (-6.0393)	1.0168 (3.0297)	3.5953 (5.3959)	-	-0.0125 (-1.7639)	-0.0220 (-2.5653)
Output Gap (A)	1973:Q1	10	-0.1851^{c} (-4.8171)	0.0551 (0.4447)	-0.9637 (-3.5671)	-1.1755 (-1.4433)	0.0054 (2.4709)	-
Output Gap (A)	1973:Q1	10	-0.1927^{b} (-5.0436)	0.0443 (0.3564)	-1.0397 (-3.9102)	-	0.0060 (2.7970)	-

Note: *1) The superscript a, b, c, and d represent the significant levels of t-statistic of 1%, 2.5%, 5% and 10%, corresponding to Zivot and Andrews (1992).*

2) Real interest rate I represents the difference between federal funds rate and the average of inflation at the current period of previous four quarters, whereas the real interest rate II is the difference between the federal funds rate and the current inflation.

Table B-3: Perron's test with the given breakpoints for average inflation

Breakpoint	**$D(T_b)$**	**Max lags**	**Dummy on trend**	**t-statistic**	**ADF t-statistic**	**Significant level**
1980:Q3	Without	8	-0.0148	-3.6545	-4.6360	2.5%
	With	8	-0.0131	-3.2032	-4.0427	10%
1980:Q4	Without	8	-0.0140	-3.3688	-4.0822	10%
	With	8	-0.0150	-3.6940	-4.6325	2.5%
1981:Q1	Without	8	-0.0152	-3.5105	-4.5104	5%
	With	8	-0.0136	-3.1890	-4.1337	10%
1981:Q2	Without	8	-0.0147	-3.3204	-4.1749	10%
	With	8	-0.0151	-3.5082	-4.5161	5%

Appendix C

Table C-1: Stabilty of the policy rules with no zero bound constraint and the parameters for the whole sample

	γ										
ρ = 0	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
φ = 0	u	u	u	s	s	s	s	s	s	s	s
φ = 0.5	u	u	u	s	s	s	s	s	s	s	s
φ = 1	u	u	u	s	s	s	s	s	s	s	s
φ = 1.5	u	u	u	s	s	s	s	s	s	s	s
φ = 2	u	u	u	s	s	s	s	s	s	s	s
φ = 2.5	u	u	u	s	s	s	s	s	s	s	s
φ = 3	u	u	u	s	s	s	s	s	s	s	s
φ = 3.5	u	u	u	s	s	s	s	s	s	s	s
φ = 4	u	u	u	s	s	s	s	s	s	s	s
φ = 4.5	u	u	u	s	s	s	s	s	s	s	s
	γ										
ρ = 0.5	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
φ = 0	u	u	u	s	s	s	s	s	s	s	s
φ = 0.5	u	u	u	s	s	s	s	s	s	s	s
φ = 1	u	u	u	s	s	s	s	s	s	s	s
φ = 1.5	u	u	u	s	s	s	s	s	s	s	s
φ = 2	u	u	u	s	s	s	s	s	s	s	s
φ = 2.5	u	u	u	s	s	s	s	s	s	s	s
φ = 3	u	u	u	s	s	s	s	s	s	s	s
φ = 3.5	u	u	u	s	s	s	s	s	s	s	s
φ = 4	u	u	u	s	s	s	s	s	s	s	s
φ = 4.5	u	u	u	s	s	s	s	s	s	s	s
	γ										
ρ = 0.8	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
φ = 0	u	u	u	s	s	s	s	s	s	s	s
φ = 0.5	u	u	u	s	s	s	s	s	s	s	s
φ = 1	u	u	u	s	s	s	s	s	s	s	s
φ = 1.5	u	u	u	s	s	s	s	s	s	s	s
φ = 2	u	u	u	s	s	s	s	s	s	s	s
φ = 2.5	u	u	u	s	s	s	s	s	s	s	s
φ = 3	u	u	u	s	s	s	s	s	s	s	s
φ = 3.5	u	u	u	s	s	s	s	s	s	s	s
φ = 4	u	u	u	s	s	s	s	s	s	s	s
φ = 4.5	u	u	u	s	s	s	s	s	s	s	s
	γ										
ρ = 1	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
φ = 0	u	u	u	u	u	u	u	u	u	u	u
φ = 0.5	u	u	u	u	u	u	u	u	u	u	u
φ = 1	u	u	u	u	u	u	u	u	u	u	u
φ = 1.5	u	u	u	u	u	u	u	u	u	u	u
φ = 2	u	u	u	u	u	u	u	u	u	u	u
φ = 2.5	u	u	u	u	u	u	u	u	u	u	u
φ = 3	u	u	u	u	u	u	u	u	u	u	u
φ = 3.5	u	u	u	u	u	u	u	u	u	u	u
φ = 4	u	u	u	u	u	u	u	u	u	u	u
φ = 4.5	u	u	u	u	u	u	u	u	u	u	u

Note: U represents unstable, while S represents stable.

Table C-2:Stabilty of the policy rules in the case that the zero bound is not the problem with the parameter before 1982:Q3

	γ										
ρ = 0	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
φ = 0	u	u	u	s	s	s	s	s	s	s	s
φ = 0.5	u	u	u	s	s	s	s	s	s	s	s
φ = 1	u	u	u	s	s	s	s	s	s	s	s
φ = 1.5	u	u	u	s	s	s	s	s	s	s	s
φ = 2	u	u	u	s	s	s	s	s	s	s	s
φ = 2.5	u	u	u	s	s	s	s	s	s	s	s
φ = 3	u	u	u	s	s	s	s	s	s	s	s
φ = 3.5	u	u	u	s	s	s	s	s	s	s	s
φ = 4	u	u	u	s	s	s	s	s	s	s	s
φ = 4.5	u	u	u	s	s	s	s	s	s	s	s
	γ										
ρ = 0.5	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
φ = 0	u	u	u	s	s	s	s	s	s	s	s
φ = 0.5	u	u	u	s	s	s	s	s	s	s	s
φ = 1	u	u	u	s	s	s	s	s	s	s	s
φ = 1.5	u	u	u	s	s	s	s	s	s	s	s
φ = 2	u	u	u	s	s	s	s	s	s	s	s
φ = 2.5	u	u	u	s	s	s	s	s	s	s	s
φ = 3	u	u	u	s	s	s	s	s	s	s	s
φ = 3.5	u	u	u	s	s	s	s	s	s	s	s
φ = 4	u	u	u	s	s	s	s	s	s	s	s
φ = 4.5	u	u	u	s	s	s	s	s	s	s	s
	γ										
ρ = 0.8	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
φ = 0	u	u	u	s	s	u	u	u	u	u	u
φ = 0.5	u	u	u	s	s	s	s	s	s	s	s
φ = 1	u	u	u	s	s	s	s	s	s	s	s
φ = 1.5	u	u	u	s	s	s	s	s	s	s	s
φ = 2	u	u	u	s	s	s	s	s	s	s	s
φ = 2.5	u	u	u	s	s	s	s	s	s	s	s
φ = 3	u	u	u	s	s	s	s	s	s	s	s
φ = 3.5	u	u	u	s	s	s	s	s	s	s	s
φ = 4	u	u	u	s	s	s	s	s	s	s	s
φ = 4.5	u	u	u	s	s	s	s	s	s	s	s
	γ										
ρ = 1	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
φ = 0	u	u	u	u	u	u	u	u	u	u	u
φ = 0.5	u	u	u	u	u	u	u	u	u	u	u
φ = 1	u	u	u	u	u	u	u	u	u	u	u
φ = 1.5	u	u	u	u	u	u	u	u	u	u	u
φ = 2	u	u	u	u	u	u	u	u	u	u	u
φ = 2.5	u	u	u	u	u	u	u	u	u	u	u
φ = 3	u	u	u	u	u	u	u	u	u	u	u
φ = 3.5	u	u	u	u	u	u	u	u	u	u	u
φ = 4	u	u	u	u	u	u	u	u	u	u	u
φ = 4.5	u	u	u	u	u	u	u	u	u	u	u

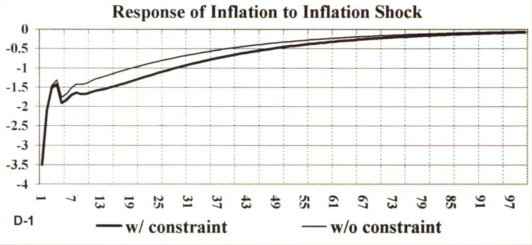
Note: U represents unstable, while S represents stable.

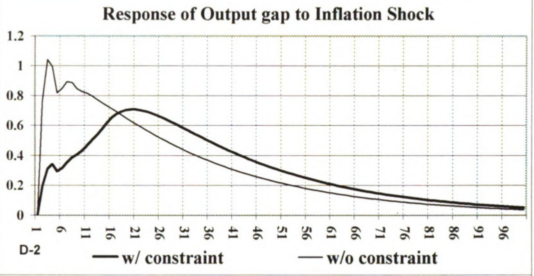
Table C-3:Stabilty of the policy rules in the case that the zero bound is not the problem with the parameter after 1982:Q3

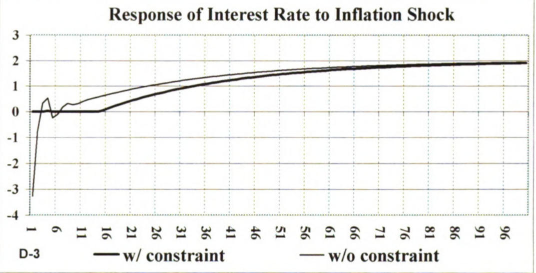
	γ										
$\rho = 0$	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
φ = 0	u	u	u	s	s	s	s	s	s	s	s
φ = 0.5	u	u	u	s	s	s	s	s	s	s	s
φ = 1	u	u	u	s	s	s	s	s	s	s	s
φ = 1.5	u	u	u	s	s	s	s	s	s	s	s
φ = 2	u	u	u	s	s	s	s	s	s	s	s
φ = 2.5	u	u	u	s	s	s	s	s	s	s	s
φ = 3	u	u	u	s	s	s	s	s	s	s	s
φ = 3.5	u	u	u	s	s	s	s	s	s	s	s
φ = 4	u	u	u	s	s	s	s	s	s	s	s
φ = 4.5	u	u	u	s	s	s	s	s	s	s	s
	γ										
$\rho = 0.5$	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
φ = 0	u	u	u	s	s	s	s	s	s	s	s
φ = 0.5	u	u	u	s	s	s	s	s	s	s	s
φ = 1	u	u	u	s	s	s	s	s	s	s	s
φ = 1.5	u	u	u	s	s	s	s	s	s	s	s
φ = 2	u	u	u	s	s	s	s	s	s	s	s
φ = 2.5	u	u	u	s	s	s	s	s	s	s	s
φ = 3	u	u	u	s	s	s	s	s	s	s	s
φ = 3.5	u	u	u	s	s	s	s	s	s	s	s
φ = 4	u	u	u	s	s	s	s	s	s	s	s
φ = 4.5	u	u	u	s	s	s	s	s	s	s	s
	γ										
$\rho = 0.8$	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
φ = 0	u	u	u	s	s	u	u	u	u	u	u
φ = 0.5	u	u	u	s	s	s	s	s	s	s	s
φ = 1	u	u	u	s	s	s	s	s	s	s	s
φ = 1.5	u	u	u	s	s	s	s	s	s	s	s
φ = 2	u	u	u	s	s	s	s	s	s	s	s
φ = 2.5	u	u	u	s	s	s	s	s	s	s	s
φ = 3	u	u	u	s	s	s	s	s	s	s	s
φ = 3.5	u	u	u	s	s	s	s	s	s	s	s
φ = 4	u	u	u	s	s	s	s	s	s	s	s
φ = 4.5	u	u	u	s	s	s	s	s	s	s	s
	γ										
$\rho = 1$	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
φ = 0	u	u	u	u	u	u	u	u	u	u	u
φ = 0.5	u	u	u	u	u	u	u	u	u	u	u
φ = 1	u	u	u	u	u	u	u	u	u	u	u
φ = 1.5	u	u	u	u	u	u	u	u	u	u	u
φ = 2	u	u	u	u	u	u	u	u	u	u	u
φ = 2.5	u	u	u	u	u	u	u	u	u	u	u
φ = 3	u	u	u	u	u	u	u	u	u	u	u
φ = 3.5	u	u	u	u	u	u	u	u	u	u	u
φ = 4	u	u	u	u	u	u	u	u	u	u	u
φ = 4.5	u	u	u	u	u	u	u	u	u	u	u

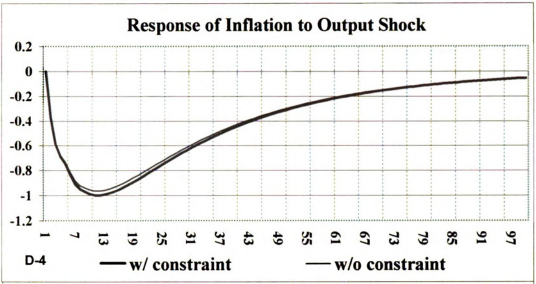
Note: U represents unstable, while S represents stable.

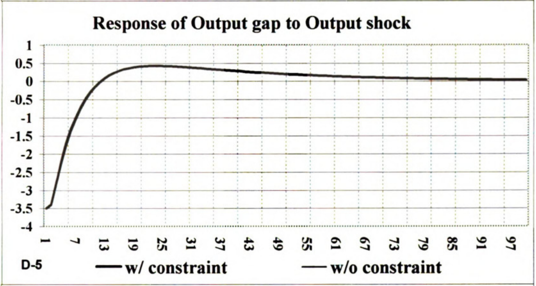
Appendix D

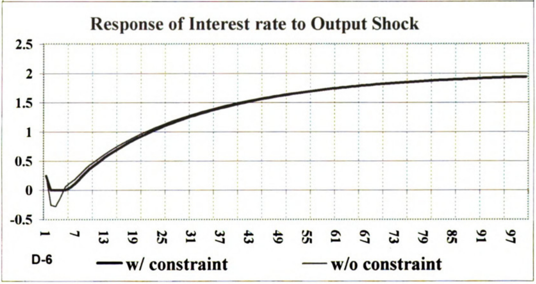

Response of Inflation to Inflation Shock
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
1 7 13 19 25 31 37 43 49 55 61 67 73 79 85 91 97
D-1
w/ constraint
w/o constraint

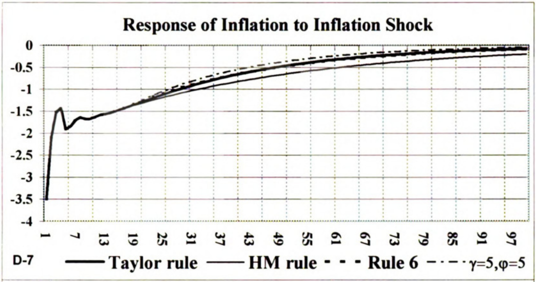

Response of Output gap to Inflation Shock
1.2
1
0.8
0.6
0.4
0.2
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96
D-2
w/ constraint
w/o constraint

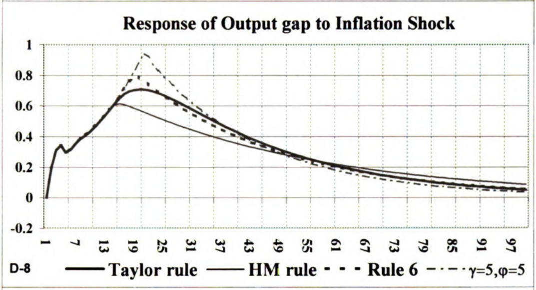

Response of Interest Rate to Inflation Shock
3
2
1
0
-1
-2
-3
-4
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96
D-3
w/ constraint
w/o constraint

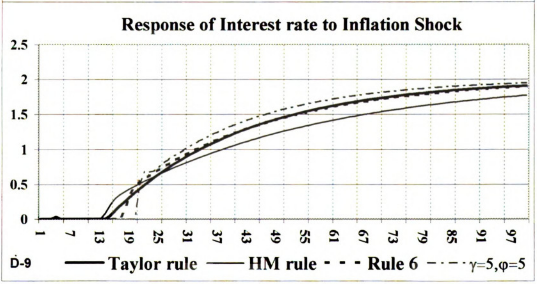

Response of Inflation to Output Shock
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
1
7
13
19
25
31
37
43
49
55
61
67
73
79
85
91
97
D-4
w/ constraint
w/o constraint

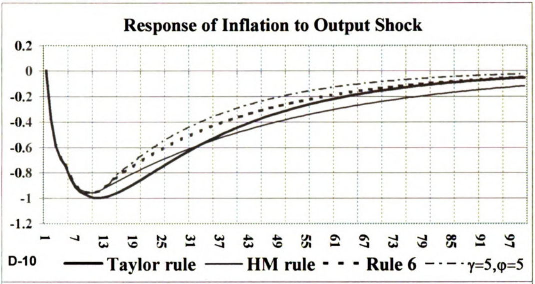

Response of Output gap to Output shock
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
1
7
13
19
25
31
37
43
49
55
61
67
73
79
85
91
97
D-5
w/ constraint
w/o constraint

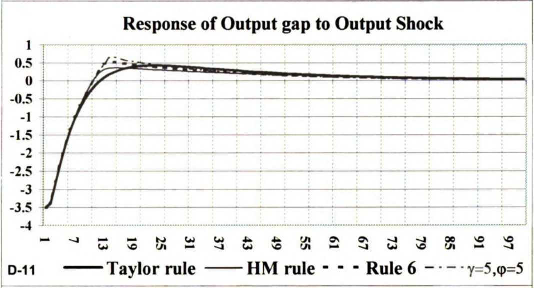

Response of Interest rate to Output Shock
2.5
2
1.5
1
0.5
0
-0.5
1
7
13
19
25
31
37
43
49
55
61
67
73
79
85
91
97
D-6
w/ constraint
w/o constraint

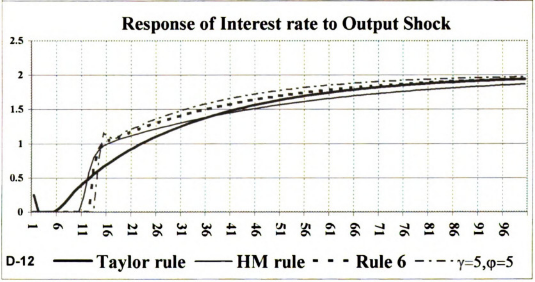

Response of Inflation to Inflation Shock
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
1 7 13 19 25 31 37 43 49 55 61 67 73 79 85 91 97
D-7
Taylor rule
HM rule
Rule 6
γ=5,φ=5

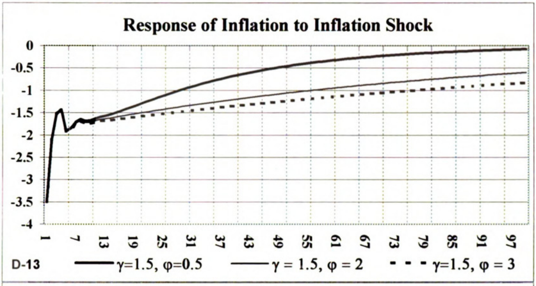

Response of Output gap to Inflation Shock
1
0.8
0.6
0.4
0.2
0
-0.2
1 7 13 19 25 31 37 43 49 55 61 67 73 79 85 91 97
D-8
Taylor rule
HM rule
Rule 6
γ=5,φ=5


Response of Interest rate to Inflation Shock
2.5
2
1.5
1
0.5
0
1 7 13 19 25 31 37 43 49 55 61 67 73 79 85 91 97
D-9
Taylor rule
HM rule
Rule 6
γ=5,φ=5

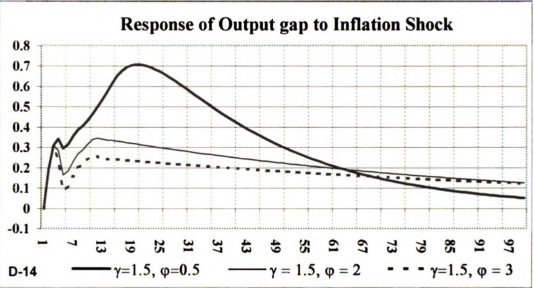

Response of Inflation to Output Shock
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
1 7 13 19 25 31 37 43 49 55 61 67 73 79 85 91 97
Taylor rule
HM rule
Rule 6
γ=5,φ=5
D-10


Response of Output gap to Output Shock
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
1 7 13 19 25 31 37 43 49 55 61 67 73 79 85 91 97
Taylor rule
HM rule
Rule 6
γ=5,φ=5
D-11

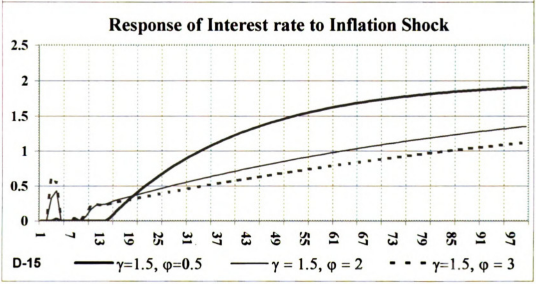

Response of Interest rate to Output Shock
2.5
2
1.5
1
0.5
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96
Taylor rule
HM rule
Rule 6
γ=5,φ=5
D-12


Response of Inflation to Inflation Shock
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
1
7
13
19
25
31
37
43
49
55
61
67
73
79
85
91
97
γ=1.5, φ=0.5
γ = 1.5, φ = 2
γ=1.5, φ = 3

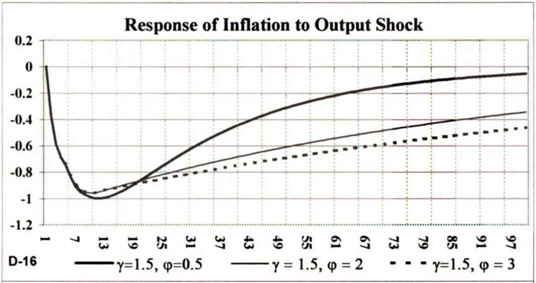
D-13

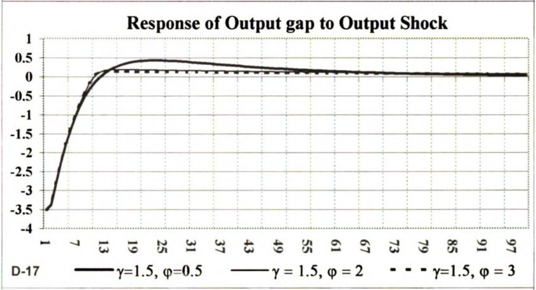

Response of Output gap to Inflation Shock
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
1
7
13
19
25
31
37
43
49
55
61
67
73
79
85
91
97
γ=1.5, φ=0.5
γ = 1.5, φ = 2
γ=1.5, φ = 3

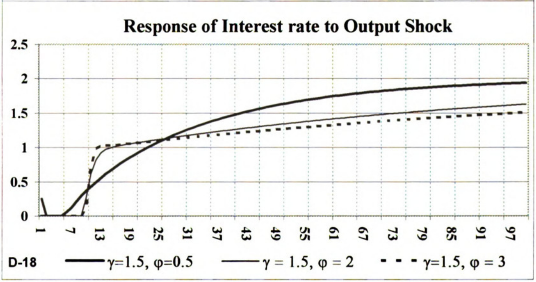
D-14

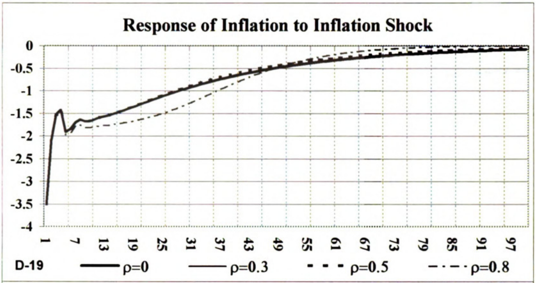

Response of Interest rate to Inflation Shock
2.5
2
1.5
1
0.5
0
1
7
13
19
25
31
37
43
49
55
61
67
73
79
85
91
97
γ=1.5, φ=0.5
γ = 1.5, φ = 2
γ=1.5, φ = 3

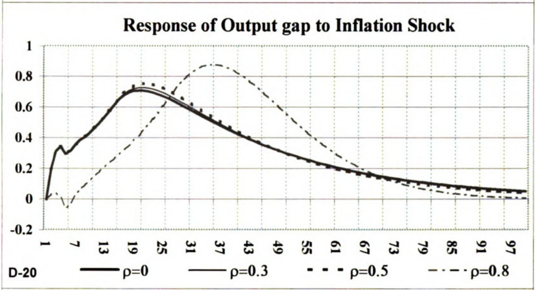
D-15

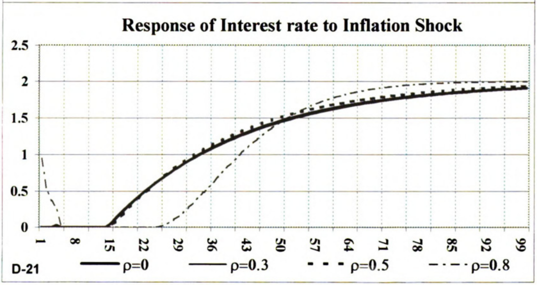

Response of Inflation to Output Shock
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
1 7 13 19 25 31 37 43 49 55 61 67 73 79 85 91 97
D-16
γ=1.5, φ=0.5
γ = 1.5, φ = 2
γ=1.5, φ = 3

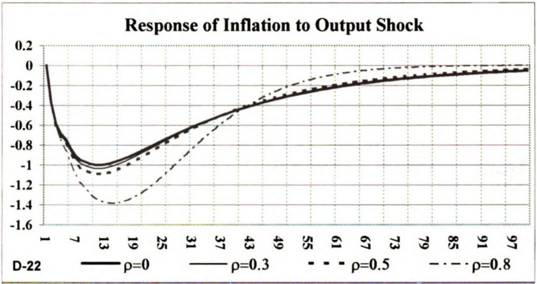

Response of Output gap to Output Shock
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
1 7 13 19 25 31 37 43 49 55 61 67 73 79 85 91 97
D-17
γ=1.5, φ=0.5
γ = 1.5, φ = 2
γ=1.5, φ = 3

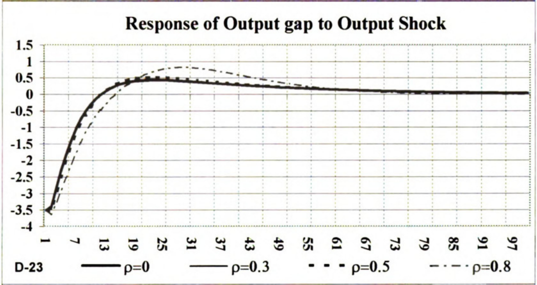

Response of Interest rate to Output Shock
2.5
2
1.5
1
0.5
0
1 7 13 19 25 31 37 43 49 55 61 67 73 79 85 91 97
D-18
γ=1.5, φ=0.5
γ = 1.5, φ = 2
γ=1.5, φ = 3

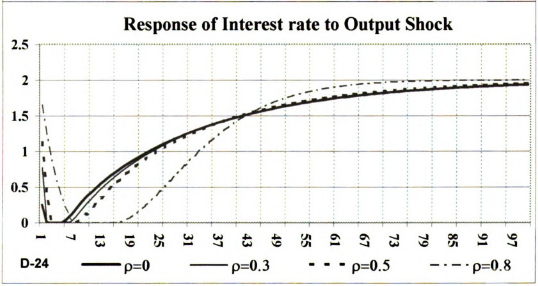

Response of Inflation to Inflation Shock
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
1 7 13 19 25 31 37 43 49 55 61 67 73 79 85 91 97
D-19
ρ=0
ρ=0.3
ρ=0.5
ρ=0.8


Response of Output gap to Inflation Shock
1
0.8
0.6
0.4
0.2
0
-0.2
1 7 13 19 25 31 37 43 49 55 61 67 73 79 85 91 97
D-20
ρ=0
ρ=0.3
ρ=0.5
ρ=0.8


Response of Interest rate to Inflation Shock
2.5
2
1.5
1
0.5
0
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99
D-21
ρ=0
ρ=0.3
ρ=0.5
ρ=0.8

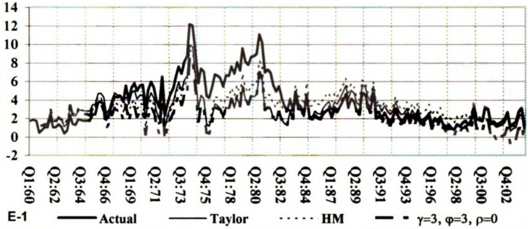

Response of Inflation to Output Shock
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
1
7
13
19
25
31
37
43
49
55
61
67
73
79
85
91
97
D-22
ρ=0
ρ=0.3
ρ=0.5
ρ=0.8


Response of Output gap to Output Shock
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
1
7
13
19
25
31
37
43
49
55
61
67
73
79
85
91
97
D-23
ρ=0
ρ=0.3
ρ=0.5
ρ=0.8

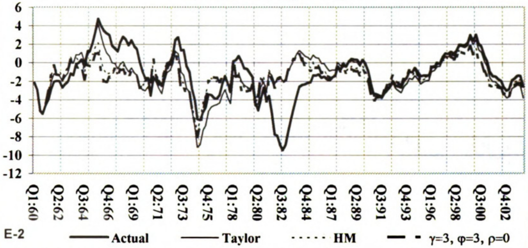

Response of Interest rate to Output Shock
2.5
2
1.5
1
0.5
0
1
7
13
19
25
31
37
43
49
55
61
67
73
79
85
91
97
D-24
ρ=0
ρ=0.3
ρ=0.5
ρ=0.8

Appendix E

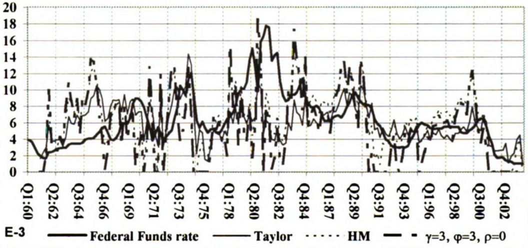
Simulated Inflation

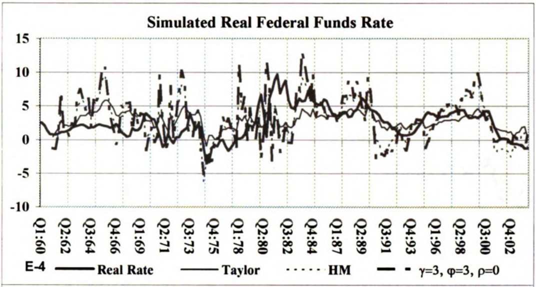


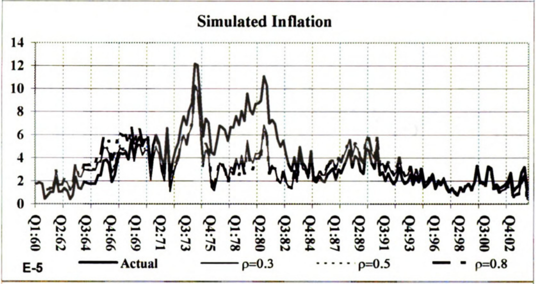
Simulated Output Gap

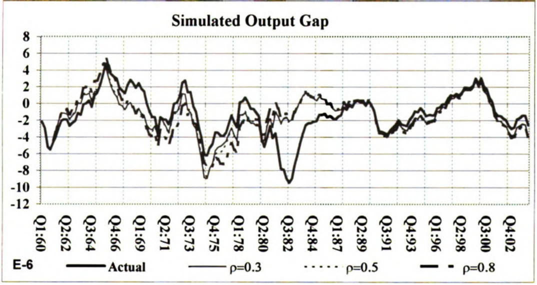


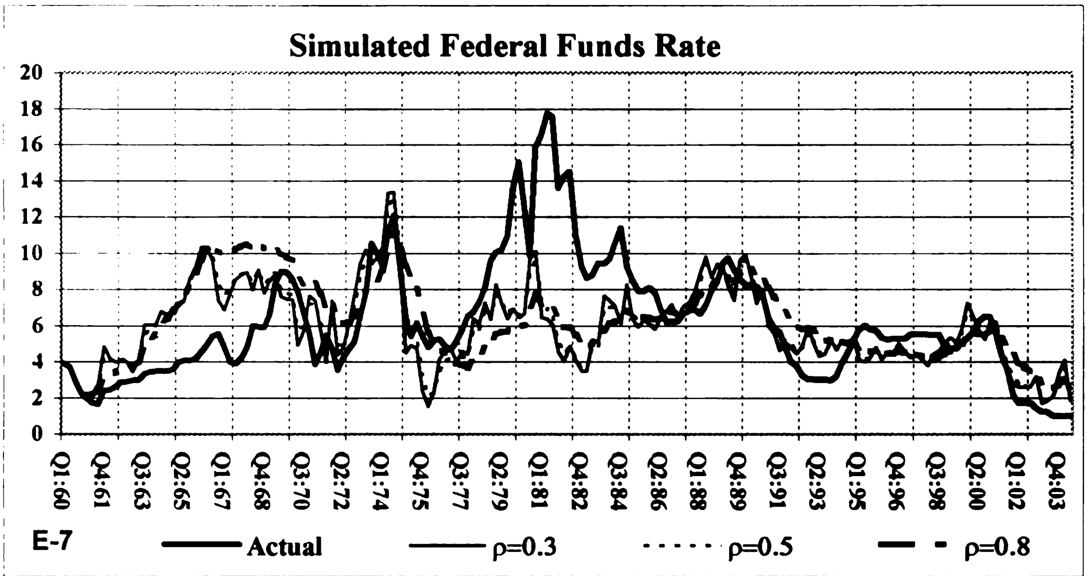
Simulated Federal Funds Rate

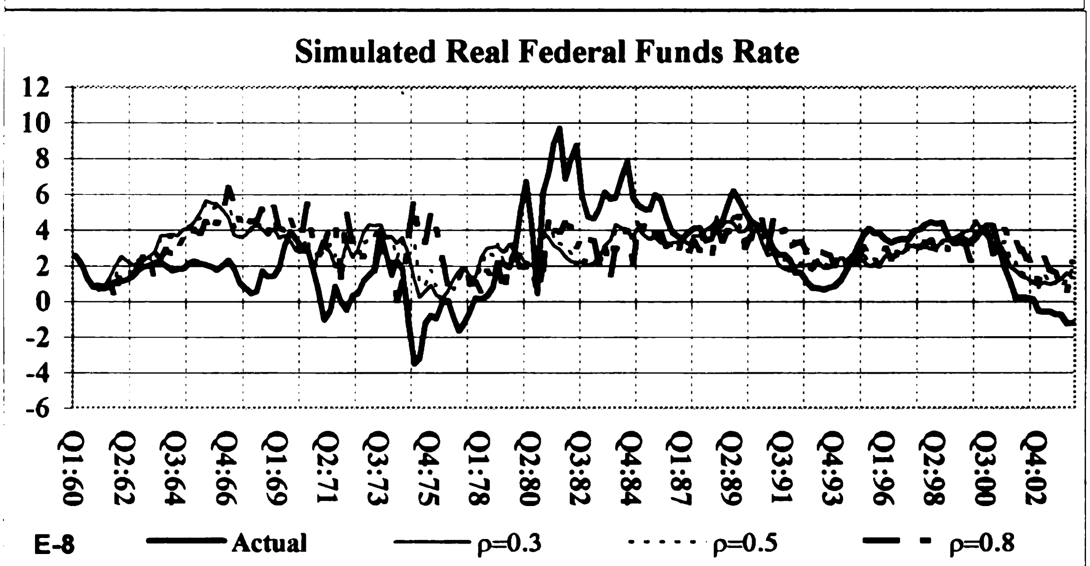



Simulated Real Federal Funds Rate
15
10
5
0
-5
-10
Q1:60
Q2:62
Q3:64
Q4:66
Q1:69
Q2:71
Q3:73
Q4:75
Q1:78
Q2:80
Q3:82
Q4:84
Q1:87
Q2:89
Q3:91
Q4:93
Q1:96
Q2:98
Q3:00
Q4:02
E-4
Real Rate
Taylor
HM
γ=3, φ=3, ρ=0


Simulated Inflation
14
12
10
8
6
4
2
0
Q1:60
Q2:62
Q3:64
Q4:66
Q1:69
Q2:71
Q3:73
Q4:75
Q1:78
Q2:80
Q3:82
Q4:84
Q1:87
Q2:89
Q3:91
Q4:93
Q1:96
Q2:98
Q3:00
Q4:02
E-5
Actual
ρ=0.3
ρ=0.5
ρ=0.8


Simulated Output Gap
8
6
4
2
0
-2
-4
-6
-8
-10
-12
Q1:60
Q2:62
Q3:64
Q4:66
Q1:69
Q2:71
Q3:73
Q4:75
Q1:78
Q2:80
Q3:82
Q4:84
Q1:87
Q2:89
Q3:91
Q4:93
Q1:96
Q2:98
Q3:00
Q4:02
E-6
Actual
ρ=0.3
ρ=0.5
ρ=0.8


Simulated Federal Funds Rate
20
18
16
14
12
10
8
6
4
2
0
Q1:60
Q4:61
Q3:63
Q2:65
Q1:67
Q4:68
Q3:70
Q2:72
Q1:74
Q4:75
Q3:77
Q2:79
Q1:81
Q4:82
Q3:84
Q2:86
Q1:88
Q4:89
Q3:91
Q2:93
Q1:95
Q4:96
Q3:98
Q2:00
Q1:02
Q4:03
E-7
Actual
ρ=0.3
ρ=0.5
ρ=0.8


Simulated Real Federal Funds Rate
12
10
8
6
4
2
0
-2
-4
-6
Q1:60
Q2:62
Q3:64
Q4:66
Q1:69
Q2:71
Q3:73
Q4:75
Q1:78
Q2:80
Q3:82
Q4:84
Q1:87
Q2:89
Q3:91
Q4:93
Q1:96
Q2:98
Q3:00
Q4:02
E-8
Actual
ρ=0.3
ρ=0.5
ρ=0.8

Appendix F

Simulation procedure

I employed the stochastic simulations similar to earlier studies, e.g. Judd and Motley (1991, 1992), OW (1998) and RW (2000), by using the drawn shocks from the historical residuals to perturb the model from the steady sate. Each set of the shocks contains T shocks for each type of shocks, including, supply or inflation shocks – the shocks to the aggregate supply curve and demand shocks – the shocks to the IS curve. Then, I calculate the time path for each simulation and store all the observations for the statistical inferences and re-do this process again. The steps are explained in details below.

Step 1: Set up the model which I am currently utilizing the variant of the model that RS (1999) used in evaluating policy rules in an optimal framework. However, the parameter estimates are different from the original estimation by RS (1999) due to the data revisions and the sample period.

The model:

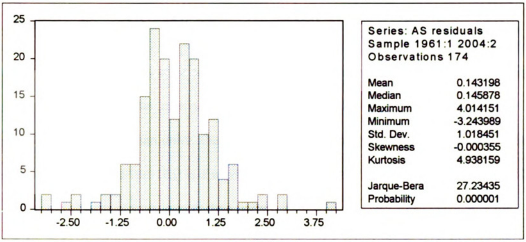
Equation F-1 ...Aggregate Supply: $\pi_t = \beta_1\pi_{t-1} + \beta_2\pi_{t-2} + \beta_3\pi_{t-3} + (1-\beta_1-\beta_2-\beta_3)\pi_{t-4} + \beta_4 x_{t-1} + v_t$

Equation F-2....Aggregate demand: $x_t = \alpha_1 x_{t-1} + \alpha_2 x_{t-2} + \alpha_3(i_{t-1} - \bar{\pi}_{t-1} - r^*) + u_t$

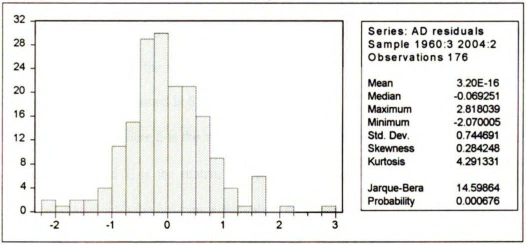
The variables are defined as in the text.

Step 2: Estimate the model with Ordinary Least Square (OLS) while the estimation with the whole system method such as the Full Information Maximum Likelihood method does not yield different result.

Step 3: Calculate the variance-covariance matrix of the errors (historical shocks). The residuals' histograms are shown in Figure F-1 and F-2.



F-1



F-2

The reason why the mean of the residuals are not zero is that the restrictions of zero constant and sum of inflation lags being unity are imposed. Therefore, the historical residuals have the distribution as follows.

Equation F-3......... $\begin{bmatrix} v_t \\ u_t \end{bmatrix} \approx \text{IID}\left\{\begin{bmatrix} 0.143198 \\ -9.97E-17 \end{bmatrix}, \begin{bmatrix} 1.03128 & 0.00229 \\ 0.00229 & 0.53253 \end{bmatrix}\right.,$

IID represents the identically independent distribution

On the other hand, the distributions of the residuals Pre- and Post-1984:Q1 follow Equations F-4 and F-5, respectively.

Equation F-4......... $\begin{bmatrix} v_t \\ u_t \end{bmatrix} \approx \text{IID}\left\{\begin{bmatrix} 0.231984 \\ 0.091967 \end{bmatrix}, \begin{bmatrix} 1.479541 & 0.032917 \\ 0.032917 & 0.775165 \end{bmatrix}\right.$

Equation F-5......... $\begin{bmatrix} v_t \\ u_t \end{bmatrix} \approx IID\left\{ \begin{bmatrix} 0.043584 \\ -0.074652 \end{bmatrix}, \begin{bmatrix} 0.509591 & -0.048669 \\ -0.048669 & 0.245623 \end{bmatrix} \right.$

Step 4: Calculate steady state equilibria and check the stability of the model by using the eigenvalues of the matrix of the coefficients of the lagged variable. If all eigenvalues are less than unity, then the system is stable. Nevertheless, we know that the negative equilibrium (E_2) is always unstable irrelevant to policy rules since one of the eigenvalues is always greater than unity.

Step 5: Draw a set of shocks from a standard normal distribution ~N(0,1) and convert this standard normal into the distribution similar to the shocks calculated in Step 3. The way to transform the standard normal distribution is to decompose the variance-covariance matrix obtained in Step 3 as follows;

$\Sigma = C\Lambda C'$ where Σ is the variance-covariance matrix of the residuals estimated by the model and C is the matrix containing the eigenvectors corresponding to Λ diagonal matrix with the ordering eigenvalues on the diagonal.

Then decompose Σ into $C\Lambda^{1/2}\Lambda^{1/2}C'$, and let $C\Lambda^{1/2}$ be P

Multiply this decomposed part into the residuals drawn from the standard normal (Ω_t). Hence the result is as follows;

$V_t = \Omega_t P'$

The variance of this transformed residuals or pseudo-random residuals can be checked by

$E(V'_t V_t) = E(\Omega_t P')'(\Omega_t P') = E(P \Omega_t' \Omega_t P') =$ but $E(\Omega_t'\Omega_t) =$ Identity matrix due to the variance-covariance matrix of standard normal, thus, $E(P \Omega_t' \Omega_t P')$ is $E(C \Lambda C') = \Sigma$.

Step 6: Plug in the first iteration of the simulation.

Step 7: Calculate the time paths of the endogenous variable including inflation, output gaps and interest rate, setting the steady state equilibrium as the initial values. At this stage, I also implement the policy rule, starting with the original Taylor rule and also the constraint at the zero bound to truncate the value of interest rate at a zero rate.

Policy rule - modified interest rate rule: $i_t = \max(0, i^{Taylor}_t)$

Generalized Taylor rule: $i^{Taylor}_t = (1-\rho)(r^{*}+(1-\gamma)\pi^{T} + \gamma\pi_t + \varphi x_t) + \rho i_{t-1}$

Noticeably, in Taylor rule equation, there is no stochastic residual at the end as the policy rule is not estimated but to impose it deterministically.

Step 8: Calculate iteratively until time T (T = 174). That is one simulation.

Step 9: Check the condition whether the time path hits the zero bound or it diverges to infinity; if it does, count it as a fail trial or a deflationary time path; if not, store the values for deriving a stationary distribution of each variable.

Step 10: Redo Step 5 until J times (the number of simulations necessary to obtain a stationary distribution of each variable)

Step 11: Store all observations for statistical inferences in the next step

Step 12: Infer the distribution of endogenous variables from these J simulations and determine the effects of a zero bound constraint on them

Appendix G

Table G-1: Probability of hitting the zero bound and falling into the deflationary trap

Rule	Without the Break in Variances						With the Break in Variances					
	Real Rate = 2%		Real Rate = 2.5%		Real Rate = 3%		Real Rate = 2%		Real Rate = 2.5%		Real Rate = 3%	
	ZB	Deflat	ZB	Deflat	ZB	Deflat	ZB	Deflat	ZB	Deflat	ZB	Deflat
Inflation Target of 0%												
Taylor rule (1.5,0.5,0)	0.098	0.106	0.075	0.063	0.054	0.036	0.079	0.037	0.059	0.019	0.040	0.015
Rule 7 (3.0,3.0,0)	0.279	0.115	0.233	0.063	0.194	0.030	0.289	0.049	0.244	0.028	0.204	0.018
Rule 9 (1.5,3.0,0)	0.130	0.104	0.103	0.070	0.085	0.040	0.077	0.048	0.062	0.028	0.048	0.019
RS optimal rule (2.37,1.44,0.14)	0.194	0.106	0.152	0.053	0.120	0.026	0.216	0.043	0.178	0.024	0.141	0.015
Inflation Target of 1%												
Taylor rule (1.5,0.5,0)	0.054	0.036	0.040	0.017	0.025	0.015	0.040	0.015	0.028	0.014	0.019	0.013
Rule 7 (3.0,3.0,0)	0.194	0.030	0.159	0.017	0.129	0.015	0.204	0.018	0.170	0.014	0.141	0.013
Rule 9 (1.5,3.0,0)	0.085	0.040	0.065	0.026	0.051	0.017	0.048	0.019	0.036	0.015	0.027	0.013
RS optimal rule (2.37,1.44,0.14)	0.120	0.026	0.089	0.016	0.068	0.015	0.141	0.015	0.112	0.014	0.089	0.013
Inflation Target of 2%												
Taylor rule (1.5,0.5,0)	0.025	0.015	0.017	0.014	0.011	0.014	0.019	0.013	0.013	0.013	0.009	0.012
Rule 7 (3.0,3.0,0)	0.129	0.015	0.107	0.014	0.089	0.013	0.141	0.013	0.116	0.012	0.095	0.012
Rule 9 (1.5,3.0,0)	0.051	0.017	0.038	0.014	0.029	0.013	0.027	0.013	0.021	0.012	0.015	0.012
RS optimal rule (2.37,1.44,0.14)	0.068	0.015	0.052	0.014	0.040	0.013	0.089	0.013	0.069	0.012	0.053	0.012
Inflation Target of 3%												
Taylor rule (1.5,0.5,0)	0.011	0.014	0.008	0.013	0.005	0.013	0.009	0.012	0.006	0.012	0.004	0.012
Rule 7 (3.0,3.0,0)	0.089	0.013	0.073	0.013	0.060	0.013	0.095	0.012	0.078	0.012	0.063	0.012
Rule 9 (1.5,3.0,0)	0.029	0.013	0.021	0.013	0.016	0.013	0.015	0.012	0.011	0.012	0.008	0.012
RS optimal rule (2.37,1.44,0.14)	0.040	0.013	0.031	0.013	0.024	0.013	0.053	0.012	0.041	0.012	0.031	0.012
Inflation Target of 4%												
Taylor rule (1.5,0.5,0)	0.005	0.013	0.004	0.013	0.002	0.013	0.004	0.012	0.002	0.012	0.001	0.012
Rule 7 (3.0,3.0,0)	0.060	0.013	0.050	0.013	0.041	0.013	0.063	0.012	0.052	0.012	0.042	0.012
Rule 9 (1.5,3.0,0)	0.016	0.013	0.012	0.013	0.009	0.013	0.008	0.012	0.006	0.012	0.004	0.012
RS optimal rule (2.37,1.44,0.14)	0.024	0.013	0.019	0.013	0.015	0.013	0.031	0.012	0.023	0.012	0.017	0.012

Table G-2: Standard Deviation and Welfare loss with different rules

Rule	Real Rate = 2%				Real Rate = 2.5%				Real Rate = 3%			
	p_t	x_t	i_t	Loss	p_t	x_t	i_t	Loss	p_t	x_t	i_t	Loss
Inflation Target of 0%												
Taylor rule (1.5,0.5,0)	2.965	1.996	3.896	27.957	2.960	2.000	4.026	28.971	2.965	2.000	4.128	29.834
Rule 7 (3.0,3.0,0)	2.491	1.657	5.286	36.896	2.507	1.659	5.520	39.505	2.421	1.650	5.701	41.091
Rule 9 (1.5,3.0,0)	3.480	1.440	5.511	44.549	3.486	1.427	5.603	45.583	3.535	1.427	5.691	46.916
RS optimal rule (2.37,1.44,0.14)	2.628	1.876	4.444	30.174	2.511	1.874	4.639	31.340	2.516	1.883	4.776	32.686
Inflation Target of 1%												
Taylor rule (1.5,0.5,0)	2.965	2.000	4.128	29.834	2.979	2.002	4.202	30.539	2.926	2.001	4.234	30.492
Rule 7 (3.0,3.0,0)	2.421	1.650	5.701	41.091	2.365	1.648	5.821	42.191	2.322	1.648	5.911	43.047
Rule 9 (1.5,3.0,0)	3.535	1.427	5.691	46.916	3.473	1.407	5.746	47.056	3.489	1.402	5.792	47.686
RS optimal rule (2.37,1.44,0.14)	2.516	1.883	4.776	32.686	2.412	1.880	4.858	32.958	2.402	1.886	4.907	33.404
Inflation Target of 2%												
Taylor rule (1.5,0.5,0)	2.926	2.001	4.234	30.492	2.930	2.005	4.249	30.654	2.914	2.006	4.257	30.635
Rule 7 (3.0,3.0,0)	2.322	1.648	5.911	43.047	2.302	1.648	5.980	43.780	2.288	1.648	6.041	44.439
Rule 9 (1.5,3.0,0)	3.489	1.402	5.792	47.686	3.482	1.397	5.820	47.946	3.473	1.394	5.840	48.105
RS optimal rule (2.37,1.44,0.14)	2.402	1.886	4.907	33.404	2.373	1.889	4.943	33.628	2.358	1.890	4.974	33.872
Inflation Target of 3%												
Taylor rule (1.5,0.5,0)	2.914	2.006	4.257	30.635	2.913	2.007	4.268	30.731	2.906	2.007	4.272	30.725
Rule 7 (3.0,3.0,0)	2.288	1.648	6.041	44.439	2.276	1.649	6.090	44.986	2.268	1.649	6.131	45.450
Rule 9 (1.5,3.0,0)	3.473	1.394	5.840	48.105	3.460	1.392	5.851	48.144	3.457	1.391	5.862	48.247
RS optimal rule (2.37,1.44,0.14)	2.358	1.890	4.974	33.872	2.347	1.891	4.999	34.075	2.340	1.892	5.020	34.256
Inflation Target of 4%												
Taylor rule (1.5,0.5,0)	2.906	2.007	4.272	30.725	2.904	2.007	4.277	30.753	2.903	2.007	4.280	30.773
Rule 7 (3.0,3.0,0)	2.268	1.649	6.131	45.450	2.261	1.648	6.166	45.850	2.256	1.648	6.196	46.196
Rule 9 (1.5,3.0,0)	3.457	1.391	5.862	48.247	3.456	1.390	5.871	48.336	3.454	1.389	5.878	48.409
RS optimal rule (2.37,1.44,0.14)	2.340	1.892	5.020	34.256	2.335	1.893	5.036	34.399	2.331	1.893	5.049	34.510

Table G-3: Standard Deviation and Welfare loss with different rules with a break in the variance of output at 1984:Q1

Rule	Real Rate = 2%				Real Rate = 2.5%				Real Rate = 3%			
	x_t	i_t	Loss	p_t	x_t	i_t	Loss	p_t	x_t	i_t	Loss	p_t
Inflation Target of 0%												
Taylor rule (1.5,0.5,0)	2.914	1.922	3.808	26.679	2.891	1.927	3.852	26.903	2.842	1.932	3.877	26.836
Rule 7 (3.0,3.0,0)	2.692	1.587	4.929	34.061	2.571	1.584	5.058	34.705	2.501	1.585	5.170	35.490
Rule 9 (1.5,3.0,0)	3.575	1.254	5.120	40.572	3.572	1.251	5.159	40.942	3.563	1.248	5.187	41.151
RS optimal rule (2.37,1.44,0.14)	2.649	1.805	4.117	27.225	2.571	1.814	4.218	27.694	2.514	1.822	4.300	28.125
Inflation Target of 1%												
Taylor rule (1.5,0.5,0)	2.842	1.932	3.877	26.836	2.820	1.935	3.896	26.877	2.823	1.938	3.915	27.054
Rule 7 (3.0,3.0,0)	2.501	1.585	5.170	35.490	2.454	1.588	5.265	36.263	2.412	1.591	5.344	36.905
Rule 9 (1.5,3.0,0)	3.563	1.248	5.187	41.151	3.538	1.244	5.195	41.052	3.525	1.242	5.207	41.080
RS optimal rule (2.37,1.44,0.14)	2.514	1.822	4.300	28.125	2.460	1.829	4.366	28.458	2.436	1.836	4.419	28.835
Inflation Target of 2%												
Taylor rule (1.5,0.5,0)	2.823	1.938	3.915	27.054	2.802	1.940	3.925	27.021	2.796	1.941	3.933	27.052
Rule 7 (3.0,3.0,0)	2.412	1.591	5.344	36.905	2.385	1.594	5.410	37.500	2.362	1.597	5.466	38.006
Rule 9 (1.5,3.0,0)	3.525	1.242	5.207	41.080	3.526	1.241	5.220	41.220	3.510	1.241	5.221	41.117
RS optimal rule (2.37,1.44,0.14)	2.436	1.836	4.419	28.835	2.392	1.840	4.463	29.022	2.367	1.843	4.496	29.211
Inflation Target of 3%												
Taylor rule (1.5,0.5,0)	2.796	1.941	3.933	27.052	2.788	1.942	3.937	27.050	2.785	1.943	3.940	27.055
Rule 7 (3.0,3.0,0)	2.362	1.597	5.466	38.006	2.346	1.599	5.512	38.446	2.334	1.601	5.551	38.820
Rule 9 (1.5,3.0,0)	3.510	1.241	5.221	41.117	3.505	1.241	5.225	41.131	3.503	1.241	5.229	41.153
RS optimal rule (2.37,1.44,0.14)	2.367	1.843	4.496	29.211	2.350	1.846	4.523	29.385	2.338	1.848	4.544	29.531
Inflation Target of 4%												
Taylor rule (1.5,0.5,0)	2.785	1.943	3.940	27.055	2.782	1.943	3.942	27.059	2.781	1.943	3.943	27.060
Rule 7 (3.0,3.0,0)	2.334	1.601	5.551	38.820	2.325	1.602	5.583	39.141	2.318	1.603	5.610	39.415
Rule 9 (1.5,3.0,0)	3.503	1.241	5.229	41.153	3.500	1.241	5.232	41.172	3.499	1.241	5.235	41.186
RS optimal rule (2.37,1.44,0.14)	2.338	1.848	4.544	29.531	2.329	1.850	4.561	29.645	2.322	1.851	4.573	29.733

CHAPTER 3

THE EFFECTS OF DIFFERENT MEASURES IN TIME-VARYING NATURAL REAL INTEREST RATE ON THE TAYLOR RULE

1. Introduction

The Taylor rule is a policy rule implementing a short-term nominal interest rate, e.g. the federal funds rate in the US, in response to inflation and the output gap, defined as the difference between actual and potential output or output at full-employment. In addition, the weight in response to inflation must be greater than unity to uphold the Taylor Principle. The Taylor rule can simply be described algebraically as follows.

Equation 1........................... $i_t = r^* + \pi^T + \gamma(\pi_t - \pi^T) + \varphi x_t$

where i_t is a nominal interest rate, π_t and x_t are inflation and the output gap, respectively. Lastly, r^* and π^T represent a natural real interest rate (NRR) and an inflation target, respectively.

In the original version of the Taylor rule, the NRR is assumed to be constant. Recall that since Taylor (1993) uses a small sample in his original analysis, utilizing a constant rate as a proxy for the NRR could be considered sensible in this circumstance. This is not the case when applying the rule to a longer sample period. Based on economic theory, an equilibrium real interest rate should vary across time and be affected by real factors, representing the structure of the economy, e.g. productivity and household preferences over inter-temporal substitution of consumption – Laubach and Williams (2001).

The concept of the natural real interest rate (NRR) was proposed by Knut Wicksell (1898). It is defined as the real interest rate consistent with output at full employment and stable inflation. Controlling these two variables is the major macroeconomic objective of many central banks, in particular, the Federal Reserve of the US. They are also the objectives embodied in the Taylor rule.

The NRR is also represented the monetary policy stance whether it is neutral, expansionary or contractionary. For example, a decline in the NRR can correspond to comparatively contractionary monetary policy if a central bank does not sufficiently influence a nominal interest rate to induce lower real interest rate to follow the change of NRR and vice versa. Therefore, the NRR is important in assessing the conduct of monetary policy. Interestingly, the NRR is also a foundation of many important concepts in macroeconomics, for instance, the natural rate of unemployment concept developed by Friedman (1968).

Nonetheless, including the time-varying NRR in the policy rule, especially in the Taylor rule, is complicated due to its being unobservable. Recent literature, e.g. Bomfim (1997, 2001), Laubach and Williams (2001) (LW), Neiss and Nelson (2003), Clark and Kozicki (2004) (CK) and among others, attempts to estimate the NRR using different methods. However, the different methods also result in different estimated NRRs, which in turn, cause more uncertainty in the design of policy.

Two purposes of this chapter are to investigate some measures of time-varying NRRs and to compare them to the constant one in the Taylor rule framework in order to improve the economic stability. I present three pieces of evidence showing that the time-varying NRR is an important concept even though there is no agreeable method to measure it since the NRR is unobservable. These pieces of evidence include simple and partial correlations among the real interest rate gap and changes in inflation and the output gap, the historical approach illustrating how the Taylor rule would prescribe the rule-based interest rate when replacing the constant NRR with the time-varying NRR and the stochastic simulations showing how the time-varying NRR helps to reduce the welfare loss, given a certain loss function and a model.

The main finding in this chapter is that the time-varying NRR should be implemented in the Taylor rule framework rather than using the constant one. This is because the time-varying NRR is superior to the constant one, no matter what measure of estimation is used, based on ample evidence presented in this chapter, compared to other studies not emphasizing this issue and scoping only few estimation methods, e.g. LW, CK, etc. In addition, I take real-time issue and the structural break into account. This chapter also suggests that employing the time-varying NRR should be put forward and considered as another main focus of policymakers when designing an interest rate rule.

However, the present chapter does not establish which measure of the NRR is best to use. This is because the model focused on this chapter is one of many standard models used in monetary policy analysis. It may not provide sufficient robustness to draw such a conclusion.

Chapter 3 begins with the discussions of some background on the NRR used in the Taylor rule briefly. Next, the estimation methods employed in this chapter will be described. In this section, I will include the advantages and disadvantages of each measure. In the next section, I discuss the prediction power of the real interest rate gap on inflation and the output gap – the main components of the Taylor rule. The key findings of this chapter are the effects of the time-varying NRR on the Taylor rule in the following two sections, the historical approach describing how the time-varying NRR changes the Taylor rule-based nominal interest rate and the stochastic simulation to infer the welfare loss implied by different measures of NRR. In addition, I examine the real-time NRR which a central bank has at the time of making policy decisions. Lastly, implications from these exercises are drawn.

2. Some background on the NRR used in the Taylor rule

As summarized by Amato (2005), Wicksell simply defines the NRR in three ways, namely, the rate of interest that equates saving to investment, the rate of interest that equals the marginal productivity of capital, and the rate of interest that is consistent with aggregate price stability.

Recently, Woodford (2002, 2003) posits the Wicksellian NRR in the New-Keynesian framework by incorporating the real interest rate gap into the aggregate demand equation. This type of model is also known as the "Neo-Wicksellian" framework because monetary policy has an impact on the economy through the real interest rate gap, instead of a real interest rate in the aggregate demand function.

Woodford also formally defines the NRR as the real rate of interest derived from an ideal economy in which the nominal adjustment is complete. However, he derives the NRR from the optimality condition from a particular objective function period by period, compared to the Wicksell's definition which is consistent with the long-run.

Since I focus on the NRR in the Taylor rule framework throughout this chapter and the dissertation, the natural real interest rate only refers to a real interest rate at a zero output gap and stable inflation in the absence of all economic disturbances. This definition is more consistent with Wicksell's rather than Woodford's because none of the NRRs here is derived from the optimality conditions of any objective function of a central bank.

What influences the NRR?

The NRR can be affected by real factors which have an impact on the structure of an economy and output at full-employment, which in turn, changing the output gap. These factors include total factor productivity and population growth, marginal productivity of capital and the level of capital, technological change and the time preference of consumers and firms.

For instance, when productivity is higher, it increases the demand for capital investment, which in turn, raises output at full-employment. As a result, the NRR must move to restore zero output gap. On the contrary, if the capital stock increases, the marginal productivity of capital decreases, the output gap shrinks. As a consequence, the NRR would move to satisfy the zero output gap. The studies summarizing the effects on the NRR in depth include Archibald and Hunter (2001), Berhardsen (2005) and Amato (2005).

3. Methodology

The methodology used to study the effect of different measures of the NRR in the Taylor rule begins with the estimation of the NRR following the earlier literature. The estimation can be divided into three approaches, namely, stochastic dynamic general equilibrium (SDGE) model-based approach, financial market-based approach and the statistical approach.

First of all, I shall discuss briefly the SDGE model-based approach and financial market-based approach. The studies focusing on the SDGE approach include Rotemberg and Woodford (1997), Gerlach and Schnabel (2000) and Neiss and Nelson (2003). Most studies implement a New Keynesian framework. In this context, the NRR is defined as the real interest rate consistent with fully flexible prices (when nominal rigidities are absent) which is consistent with the definition in Woodford (2003).

While this approach replicates the structure of economy quite well due to exploiting all parts of the economy, especially the capital market which directly determines the NRR according to the original definition by Wicksell, there are many assumptions imposed on the parameters of these models. As a result, the estimated NRR is sensitive to changes in assumptions on the structure of the economy.

Another approach developed recently after the introduction of inflation-indexed securities is the financial market-based approach. The papers implementing this approach include Bomfim (1997, 2001). He extracts the information about the NRR from inflation indexed-long-term bonds, to eliminate any distortions caused by inflation and the inflation risk premium, similar to Shiller's (1979) model. However, the drawback is that it requires the existence of inflation-indexed bonds which were not issued until 1998 in the US (1992 in the UK). This approach would be more problematic in other countries with the less developed financial markets.

Nonetheless, this chapter examines only the statistical approach. Even though this approach does not take the real factors influencing the NRR into account directly, it should be suitable for this chapter that focuses on the NRR solely in the context of the Taylor rule. This is because the statistical approach is based on the same set of information as the pre-determined variables included in the Taylor rule. This information set includes observed inflation, a nominal interest rate and the output gap. Each measure categorized in this approach is described in depth in the next section.

With the different methods of estimation of the time-varying NRR, I substitute the estimated NRR into the Taylor rule, to calculate and to analyze the rule-based nominal interest rates and compared them with the Taylor rule-based nominal interest rate derived from the constant NRR. This method follows the historical approach used by Stuart (1996) and Taylor (1999b). The advantage of applying this method is that it is *model independent*, unlike the stochastic simulation method requiring a structural model of the economy and sets of shocks. Nonetheless, its drawback is that it neglects interaction between the policy rule and economic shocks.

In addition, I also calculate simple correlations among the real interest rate, its gap, and other economic indicators, i.e. inflation and the output gap, to examine their predictive power on the economic indicators. If the real interest rate gap has significantly high correlations with both a change in inflation and the output gap, relative to only real interest rate, it can be better to include the real interest rate *gap* rather than only the real interest rate, normally used in many empirical models. This method is introduced by Neiss and Nelson (2003). Furthermore, I calculate the partial correlations by eliminating effects of lags of inflation and the output gap, while allowing the serial correlation in the policy instrument, i.e. the real interest rate gap.

In order to compute the welfare improvement affected by using a time-varying NRR rather than a constant, I simulate the model based on Rudebusch and Svensson (1999) (henceforth RS). It is composed of three equations, namely, the aggregate supply function, the aggregate demand function, and a policy rule. The model can be described as follows.

Equation 2......... $\pi_t = \beta_1\pi_{t-1} + \beta_2\pi_{t-2} + \beta_3\pi_{t-3} + (1-\beta_1-\beta_2-\beta_3)\pi_{t-4} + \beta_4 x_{t-1} + v_t$

Equation 3... $x_t = \alpha_1 x_{t-1} + \alpha_2 x_{t-1} + \left(\frac{\alpha_3}{2}\right)((i_{t-1} - \bar{\pi}_{t-1} - r^n_{t-1}) + (i_{t-2} - \bar{\pi}_{t-2} - r^n_{t-2})) + u_t$

Equation 4.......... $i_t = r^n_t + \pi^T + \gamma(\pi_t - \pi^T) + \varphi x_t$

The notation is similar to that defined in Equation 1. In addition, $\bar{\pi}_t$ represents the average annualized quarterly GDP chained price index.

Equation 2 represents an accelerationist backward-looking Phillips curve. The coefficients of lagged inflation are summed to unity to ensure that actual output equals its potential level in equilibrium and inflation is on target (π^T).

Equation 3 is the aggregate demand function relating the output gap to its lags and the real interest rate gap. In this model, monetary policy can affect the real economy through the real interest rate gap by directly affecting the output gap in aggregate demand and having an indirectly impact on inflation through the aggregate supply function.

Finally, the policy rule in Equation 4 relates how the central bank sets its policy. In this chapter the Taylor rule is implemented. It is slightly different from Equation 1 since the constant NRR is replaced by the time-varying NRR.

The model is used to infer the welfare loss associated with different measures of NRR. This method partly follows LW (2001) assuming that the two-sided Kalman filtered NRR is the correct model perceived by the economy. Their method allows the central bank to implement different NRRs including the one-sided Kalman filter, representing real-time data – the data available at the time of making policy decisions, and the constant NRR at 2.0%. They find that the constant performs the worst with the highest welfare loss based on the same loss function as specified in RS (1999).

In this chapter, I present a different aspect of the stochastic simulation by assuming that the central bank always uses the NRR identical to a(n) (unobservable) true NRR. I estimate the model for each measure of the NRR and use the parameter estimates to simulate the model following Equation 2-4, given that the NRRs estimated earlier are pre-determined.

I also examine the NRR based on real time and on revised data, based on LW (2001). With this method, the true model is assumed to employ revised data or a smoothed series from Kalman filtering, whereas, the central bank uses the NRR based on real-time data since the revised data is not available until some quarters later.

Moreover, the simulation also incorporates a structural break in both the parameter estimates and the variance of output and inflation. The candidate for the break date tested takes place during the period of targeting non-borrowed reserves. I test the break date for multiple unknown structural breakpoints with the Bai and Perron test (2003) and a known structural break by the Chow test. For the break date in the variance of the output gap, I use simple inequality variance tests.

4. Estimation results of the time-varying NRR

I present some results from four measures of the NRR based on the statistical approach. This approach mainly exploits the information from an ex post real interest rate[139]. Given a definition of the NRR being a trend of an ex post real interest rate, the statistical approach basically smooths the observed real interest rate.

The measures within the statistical approach presented in this chapter are a constant – Taylor (1993) and Monetary Trend, the estimated NRR from a ten-year Treasury bond – Basdevant et al (2004), Hodrick-Prescott filter – Wu (2005) and semi-structural time-varying parameter model based on the Kalman filter – LW (2001), CK (2004) and Kozicki (2004).

4.1 The constant and a simple average of the ex post real rate

Since the purpose of this chapter is to explore how the relaxation of the assumption that the natural real interest rate is constant affects the Taylor rule, I will use constant values of 2.0% and 2.5% as benchmarks for the comparisons with other

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[139] It can, however, depend on a small *partial* equilibrium model such as an aggregate demand function or the financial instrument – a long-term bond.

measures. The natural real interest rate of 2% is used in the original Taylor rule in 1993. In addition, a simple macroeconomic model similar to RS (1999) also yields the implied rate of 2%[140]. Noticeably, Taylor (1993) uses the NRR of 2% in his original paper, which was close to the assumed steady state economic growth rate of 2.2% at that time[141].

On the other hand, the natural real rate of 2.5% is employed by the Federal Reserve Bank of St. Louis for calculating the Taylor rule-based federal funds rate target in their published Monetary Trend. The figure is also consistent with a simple average of the ex post real interest rate obtained from the difference between the nominal federal funds rate and an annualized quarterly change in GDP chained price index during the period of 1960-2005.

In spite of the popularity in using a constant as a proxy for the NRR, e.g. RS (1999), Reifschneider and Williams (2000) among others, there are many drawbacks in this method. The first problem is over how long a period the real interest rate should be averaged to eliminate the cyclical behavior of the economy. If we average the (ex post) real interest rate over too short a period, it may not cancel out the all cyclical behavior in the real interest rate.

On the contrary, if we use too long a sample to calculate a simple average, it may encompass changes in economic structure which also influences the NRR. As a consequence, we may end up with the midpoint, which does not represent the true NRR, but rather corresponds to an average of interest rates before and after the structural change.

The appropriate time-horizon for a simple average is unknown. Different researchers may use different time-horizons. For instance, Stuart (1996) implements a

[140] The estimation results are in Table C1 in the appendix.
[141] Refer to Taylor (1993), p. 8.

2 year average of the 10-year indexed bond and Blinder (1998) suggests a very long horizon from 30 to 50 years.

4.2 Hodrick-Prescott filtered natural real interest rate

The Hodrick-Prescott filtering method (HP filter), following Hodrick and Prescott (1997), is a widely used method to extract the trend out of a time-series. The HP filter is univariate filtering, therefore, it is model-independent. However, its drawback is the assumption that the NRR is based on only a trend of an ex post real interest rate and ignores other economic information content of the series. Therefore, the interpretation from this measure must be done with some caution. The algorithm of the HP filter is described in Appendix A, whereas the estimation result is illustrated in Figure 3.1. The estimation of the NRR by the HP filter is also used by Basdevant et al (2004) and Wu (2005).

4.3 Long-term bond-based natural real interest rate

Conventionally, a long-term bond is composed of three major parts, including average expected short-term interest rates, average expected inflation and a risk premium. I re-group these three parts into a more simple relation by relating the *real* 10-year bond rate, i.e. the nominal 10-year bond rate less the actual inflation, to an unobservable NRR and other factors, based partly on Basdevant et al (2004). To estimate the unobservable NRR, the Kalman Filter algorithm is exploited to smooth the ex post real interest rate.

It is worth noting that the second part of the component of the *real* 10-year bond as described above, apart from the NRR, can be broken down into smaller components, namely, the average *future* real short-term interest rate, average *expected* *future* inflation and a risk premium. Following Basdevant et al (2004), I substitute the current real interest rate in the term structure of the interest rate with the NRR and put all the error explaining the difference between the actual real interest rate and the NRR into the error term of the real long-term bond rate.

The difference between the model in Basdevant et al (2004) and the one in this chapter is that I extract a trend, representing the NRR, out of the *ex post real* 10-year bond rate, instead of the nominal 10-year bond rate. In addition, they employ four different specifications of expected inflation, whereas I use the average inflation of the previous four quarters as a proxy for one-period ahead expected inflation.

The 10-year bond rate is also commonly used in many studies, for example, Stuart (1996) and Basdevant et al (2004), as a proxy for the NRR. This is because it is more liquid than other longer-term bonds, e.g. the 30-year bond which the US Treasury discontinued issuing on February 18, 2002[142]. Moreover, the market for long-term bonds is not so thick, so their prices embody high liquidity premia, relative to the short-term bonds. As a consequence, the estimation of the NRR from long-term rates is more complicated and imprecise.

I also implement survey data as a proxy for the expected inflation[143], however the dataset (also obtained from the Federal Reserve Bank of St. Louis) started in the first quarter of 1978 which does not cover my whole sample (1960:Q1-2005:Q2) and the series is one-year expected inflation, which is inconsistent with the maturity of the long-term bond used in the present chapter.

The model used in this part is composed of two measurement equations and two transition equations as follows.

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[142] However, the 30-year bond was re-introduced on February 9, 2006.

[143] Also, the expected inflation estimated by an ARMA model does not yield significantly different results from the benchmark model below in estimating the NRR (not shown in this chapter).

Measurement or signal equations:

Equation 5……… $r_t = r^*_t + \varepsilon_{1t}$, $\varepsilon_{1t} \sim N(0, \sigma^2_{\varepsilon 1})$

Equation 6……… $R_t = r^*_t + \alpha_t + \varepsilon_{2t}$, $\varepsilon_{2t} \sim N(0, \sigma^2_{\varepsilon 2})$

Transition or state equations:

Equation 7………. $r^*_t = r^*_{t-1} + \eta_{1t}$, $\eta_{1t} \sim N(0, \sigma^2_{\eta 1})$

Equation 8………. $\alpha_t = \delta_0 + \delta_1\alpha_{t-1} + \eta_{2t}$, $\eta_{2t} \sim N(0, \sigma^2_{\eta 2})$

Equation 9………. $\sigma_{\eta 1} = \sigma_{\varepsilon 2}/\lambda_1$

Equation 10……… $\sigma_{\eta 2} = \sigma_{\varepsilon 2}/\lambda_2$

Where r_t is the (ex post) real interest rate

R_t is the (ex post) real rate of 10-year bond.

α_t is the term premium

r^*_t is an unobservable time-varying natural real interest rate

The AR(1) process of the term premium (α_t) also includes a random walk (δ_0=0, δ_1=1) and a constant term premium ($\delta_0 = 0$, $\delta_1 = 1$ and η_{2t}= 0).

Equation 5 supplies some information about the NRR based on the short-term real interest rate, while Equation 6 supplies the information of the NRR inherent in the real bond rate – the difference between the 10-year nominal rate and the actual (current) inflation. Equation 6 explains the real bond rate as a function of the NRR and a term premium (α_t) which is composed of the average expected *future* short-term *real* interest rate, average expected *future* inflation and a risk premium. Equation 7 explains how the NRR evolves, which is assumed to be a random walk. Equation 8 describes the term premium with the AR(1) process.

Lastly, Equations 9 and 10 relate the variance of the state equations to the signal equations. I assume that the variance of both state equations depends on the variance of the long-term interest rate. This is because long-term interest rates, e.g. 10-year bond rate, should contain more information corresponding to the NRR than the short-term interest rate since the NRR is medium- rather than short-term concept. The estimation results are reported in Table 3.1.

Table 3.1: Estimation results from 10-year bond model

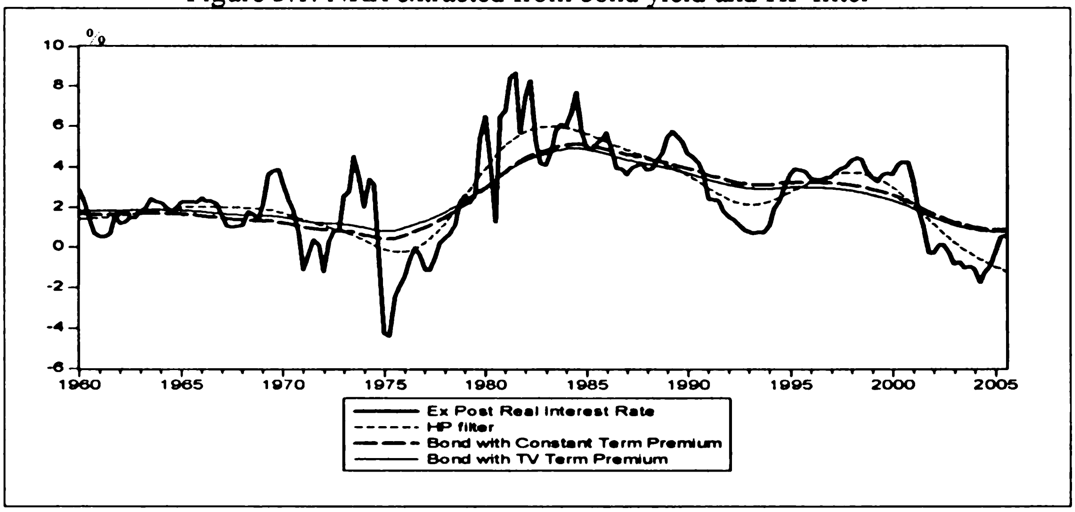
Variables	Coefficient	Std. Error	z-Statistic	Prob.
$\sigma_{\varepsilon 1}$	1.392472	0.053418	26.06732	0.0000
$\sigma_{\varepsilon 2}$	1.600446	0.064038	24.99224	0.0000
	Final State	**Root MSE**	**z-Statistic**	**Prob.**
NRR	0.770513	0.371544	2.073815	0.0381
Term Premium	1.189019	0.379473	3.133342	0.0017
Log likelihood	-694.2231	**Akaike info criterion**		7.608996
Parameters	2	**Schwarz criterion**		7.644072
Diffuse priors	2	**Hannan-Quinn criterion**		7.623214

However, with the maximum likelihood estimation, the variance of a signal equation in Equation 6 approaches zero, while the variances of both state equations grow too large to attain reasonable estimates since all the variance of the *real* long-term bond in Equation 6 is explained by both state equations. As a result, the estimated NRR is too close to the ex post real interest rate while the term premium is almost identical to the yield spread between 10-year bond and the federal funds rate. In this circumstance, we cannot gain any information from filtering the long-term bond rate.

In order to solve this problem, I pre-specify the smoothing parameter to define the variance of the state equation to be proportionate to that of the signal equation (similar to the signal-to-noise ratio specification by CK (2004) in the semi-structural model, to be discussed in the next sub-section).

Nonetheless, any change in the proportion of the variance of the term premium (σ^2_{η}) to the variance of *real* bond rate ($\sigma^2_{\varepsilon 2}$) does not change the result of the estimation of the natural real interest rate significantly. As shown in Figure 3.1, there is no significant change in the estimated NRR when the term premium is even a constant. I chose the proportion of the variance of the measurement function in the long-term interest rate of 1/200 and 1/400 for the real long-term interest rate for the NRR and the term premium, respectively, since they are close to the ones used by Basdevant et al (2004), in which they obtain these figures from Hodrick and Prescott (1997).

Figure 3.1: NRR extracted from bond yield and HP filter



Recall that the term premium in this model is composed of three components including the average expected *future* short-term *real* interest rate, average expected *future* inflation and a risk premium. According to Appendix B3, the term premium has increased abruptly since 1975:Q1 and leveled off at the higher level since 1982:Q3.

As shown in Appendix B2, the estimated term premium conforms to the yield spread between the 10-year bond and the federal funds rate which was higher on average but less volatile after 1982:Q3. The increases in both the NRR and the term premium after that date partly stem from the higher expected inflation after the public experienced two successive oil shocks in the 1970s and the expectation of very high nominal short-term interest rate as a result of the more aggressive monetary policy after the second oil shock during Volcker's chairmanship.

The limitations of this model are a result of the assumptions imposed on the use of the long-term interest rate as an auxiliary equation (Equation 6). Importantly, the model used in this section is not intended to describe the term structure of interest rates and estimate the term premium or other components of the long-term bond perfectly. It is an example of a simple model to estimate the NRR based on the information contained in the real long-term interest rate. There are many models explaining the long-term interest rate much better than the naïve one in this sub-section, yet they are more complicated, e.g. Rudebusch and Wu (2004) and among others.

In addition, the financial market-based approach can be more accurate in estimating the NRR; however, the data is limited since inflation-indexed bonds have only been issued since 1998 in the US and 1992 in the UK. Hence, the current method to extract the NRR from a real 10-year bond, based on the naïve model, is the best alternative for this chapter.

4.4. The time-varying parameter model

This method is considered a semi-structural model approach since it is a compromise method between a purely filtering approach, e.g. the HP filter, and the structural model approach within the SDGE framework. As described in Equations 2-

4, the semi-structural model approach is developed by LW (2001) and then employed by CK (2004), based originally on the RS (1999) model.

LW (2001) estimate both the NRR and potential output jointly by modifying the RS model by using the average of the two previous periods real interest rate gaps and using the state-space representation method[144]. Furthermore, they also relax the constant NRR assumption imposed by RS. Other studies, employing methods similar methods to LW (2001) include Manrique and Marqués (2004), Mésonnier, Renne (2004) and Garnier and Wilhelmsen (2005).

However, in this chapter, I use the potential output estimated by the Congressional Budget Office (CBO), similar to CK (2004). As a consequence, CK's model exploits only the aggregate demand function as a measurement equation and the process explaining the NRR as the state equation, compared to the model used by LW (2001), which also includes the aggregate supply function in order to explain potential output. CK's model can be described as follows.

Equation 11.................. $x_t = \alpha_1 x_{t-1} + \alpha_2 x_{t-2} + \frac{\alpha_3}{2}(r_{t-1} - r^*_{t-1} + r_{t-2} - r^*_{t-2}) + \varepsilon_t$

Equation 12.................. $r_t = i_t - \overline{\pi_t}$

Equation 13.................. $\varepsilon_t \sim (0, \sigma^2_\varepsilon)$

IS/CBO1:

Equation 14.................. $r^*_t = 4\alpha_4 g_t + z_t$

Equation 15.................. $z_t = \rho z_{t-1} + \eta_t$, $\sigma_\eta \equiv$ standard deviation of η_t

Equation 16.................. $\sigma_\eta = \lambda_z \frac{\sqrt{2}}{\alpha_3} \sigma_\varepsilon$

IS/CBO2:

[144] The state-space representation is discussed in detail in Appendix A.

Equation 17.................. $r^*_t = r^*_{t-1} + \eta_t$

Equation 18.................. $\sigma_\eta = \lambda_z \frac{\sqrt{2}}{\alpha_3} \sigma_\varepsilon$

Where x_t is the output gap (the difference between actual output and the potential output estimated by CBO – observable in this context).

r_t is the (ex post) real interest rate – defined as the difference between the quarterly federal funds rate and the average quarterly (observed) inflation.

r^*_t is the time-varying natural real interest rate (unobservable).

g_t is the quarterly growth rate of potential output obtained from the CBO estimates (observable).

λ_Z is the signal-to-noise ratio or the smoothing parameter, specifying the variance of the state variable in terms of the proportion of variance of the dependent variable in the measurement equation.

Following CK (2004), I use two versions of the model. The first relates the time-varying NRR to the growth of potential output and an AR(1) process (IS/CBO1). The second relates the time-varying NRR to a random walk without drift process (IS/CBO2). These models can be written in terms of the state-space representation and estimated with the Maximum Likelihood Estimation (MLE) method.

Generally, the model cannot be directly estimated by the Maximum Likelihood Estimation due to the pile-up problem described by Stock (1994) if the initial values are too low (e.g. the λ_z starts approximately 0.01) and to the problem of excessive variance of the estimated NRR, which conflicts with the intuition that the NRR should have smaller variance, relative to the ex post real interest rate, since it is assumed to be a smoothed trend of the ex post real interest rate. Therefore, the MLE fails to estimate the NRR with this model.

Table 3.2: Estimation Results based on IS/CBO1 and IS/CBO2

Variables	IS/CBO I	IS/CBO II
α_1	1.164161 (0.065998)	1.159561 (0.064025)
α_2	-0.231227 (0.067484)	-0.233399 (0.067261)
α_3	-0.093837 (0.025975)	-0.093004 (0.026491)
α_4	0.607328 (0.227526)	
ρ	0.933244 (0.094780)	
σ_ε	0.751092 (0.032555)	0.755826 (0.033287)
σ_η	0.271136	0.279502
λ_z	0.046	0.046
Log-likelihood	-207.4003	-215.3986
Akaike Information Criterion	2.371114	2.437762
Schwatz Information Criterion	2.477546	2.508716

Alternatively, LW and CK employ the method suggested by Stock and Watson (1998) by testing for a shift in the intercept of the aggregate demand function and then map it to the statistics simulated by Stock and Watson (1998). In the present chapter, I assume $\lambda_z = 0.046$ for the IS/CBO I and IS/CBO II. This figure is similar to CK (2004) in IS/CBOI. However, it is higher than that assumed in CK (2004) (0.017) for IS/CBOII.

Figure 3.2 illustrates the NRR estimated from IS/CBO1, while Figure 3.3 exhibits the NRR estimated from IS/CBO2. Unsurprisingly, the higher the smoothing parameter, the closer the NRR is to the ex post real interest rate. This is because a smoothing parameter represents the proportion of variance from the measurement equation explained by the variance from the state equation. With very low smoothing parameter, the estimated NRR is close to the average of 2.0%, similar to the rate assumed by Taylor (1993).

From both models, the US economy experienced low NRR in two periods, the first period is during the first oil shock, and the second is the recent period after 2000. Since the semi-structural model approach is to derive the NRR from the output gap and the trend of the ex post real interest rate, when the output gap is negative and the real interest rate is low, such as the period during the first and second oil shocks, the estimated NRR is low. However, in the recent period, especially after the Great Moderation in 1984:Q1, productivity increases, which in turn raise the NRR, as seen in Figure 2.2 and 2.3. The estimated NRR from the two models shows some differences. The one obtained from IS/CBO1 is higher than the IS/CBO2 on average since the IS/CBO1 also incorporates productivity growth as a pre-determined variable in the model.

Comparing with LW, the estimated NRR in this chapter is on average lower than those in LW (2001) and Wu (2005). The difference stems from the difference in measures of inflation to calculate the ex post real interest rate. While I employ the GDP chained price index, they use the core Personal Consumption Expenditure index (PCE).

Figure 3.2: Estimated NRR from IS/CBO1

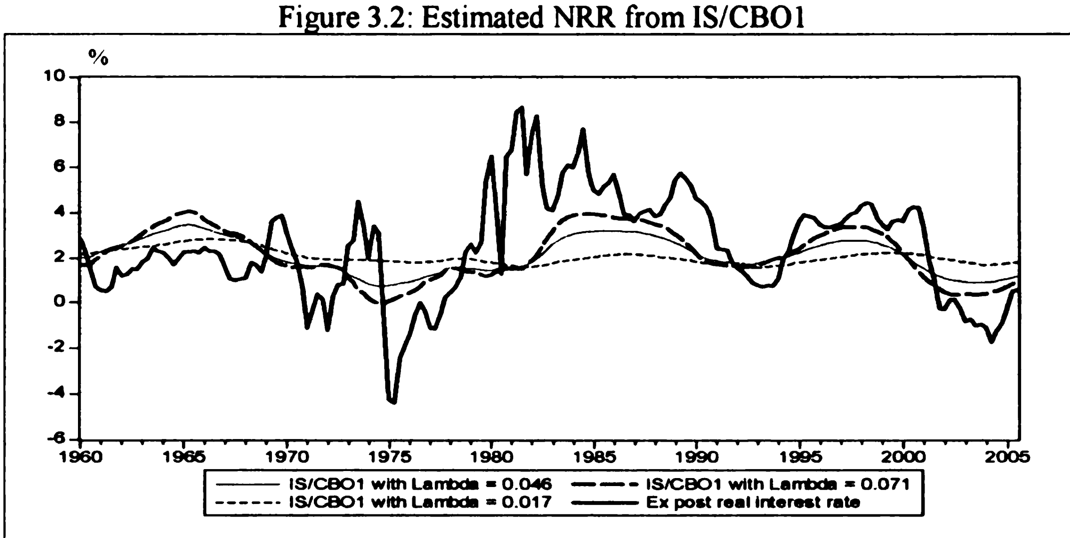
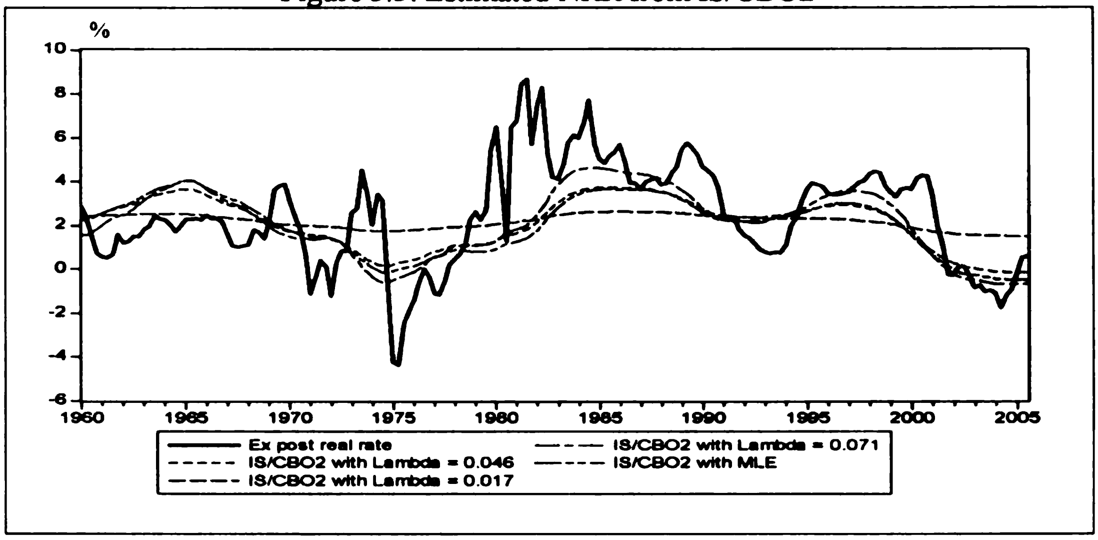


Figure 3.3: Estimated NRR from IS/CBO2



The NRR estimated by both the IS/CBO models also depends tremendously on the smoothing parameters or the ratio of variance in the state equation to the measurement equation. Therefore, I pre-specified it based on the study by CK (2004). This figure is subject to some confidence interval ranging from as low as 0.01 to around 0.1. It is one of the major drawbacks of this method.

5. Comparison across time-varying natural real interest rates in the real interest rate and the monetary policy stance

I consider four measures leading to four different estimated natural real interest rates (NRR), leading to a spectrum of Taylor rule-based nominal interest rates. I begin with the constant, based solely on a simple average of the ex post real interest rate, and proceed through the estimation methods to the semi-structural model, taking the economic structure into account. Nonetheless, all estimated NRRs can be roughly divided into three segments or trends, as shown in Figure 3.4.

The first segment encompasses the period prior to the first oil shock in 1974. The second segment encompasses the change in the Fed's operating procedure with an increasing ex post real interest rate and the second oil shock in 1980, while the last segment includes the decline in output volatility after 1984:Q1, exhibiting the downward trend of the ex post real interest rate.

Figure 3.4: Real Interest Rate and Trends

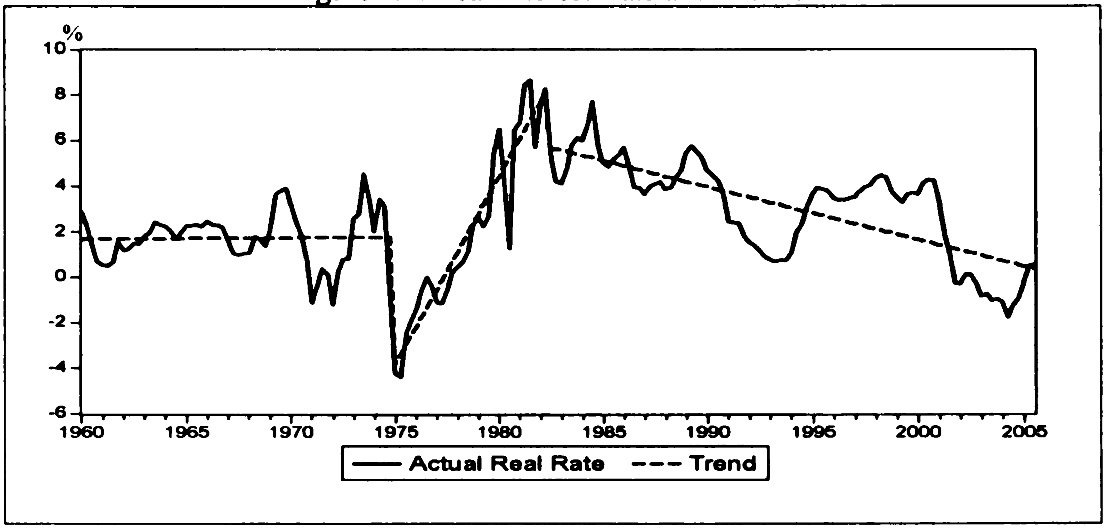
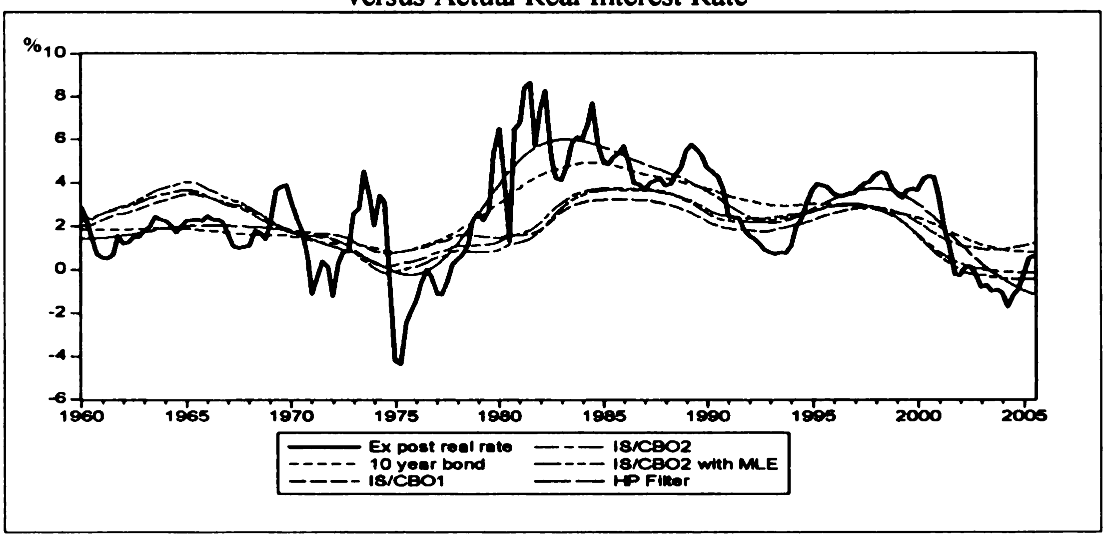


Figure 3.5: Time-Varying Natural Real Interest Rate versus Actual Real Interest Rate



The constant, which is implemented by the Federal Reserve Bank of St. Louis based on a simple average of 2.5%, compared with 2.0% employed in the original Taylor rule, is based on the belief that with a sufficiently long sample size, all the cyclical behavior will cancel out. As a consequence, only the long-term trend will remain. However, if there is a permanent shift in the economic structure, the simple average yields only the midpoint, while neglecting other useful information on both endpoints of the sample.

The Hodrick-Prescott filter contains least information about the economic structure, compared to the NRR, extracted from the 10-year bond. This is because the NRR estimated from 10-year bond exploits larger information set, i.e. 10-year bond, additional to the ex post real interest rate, while the HP filter only extracts the NRR out of an ex post real interest rate. Nonetheless, the term premium in the 10-year bond based NRR is also unobservable. Hence, there are two unobservable components in this method.

Lastly, the semi-structural estimation of the NRR sheds a different light. With this method, the NRR is extracted from an aggregate demand function, which relates the output gap to its lags and the real interest gap – defined as the difference between a nominal short-term interest rate and inflation. In this model, the interest rate channel is the only transmission channel for monetary policy.

The semi-structural estimation method also encompasses the real factors affecting the NRR indirectly through potential output. This is because any changes in potential output including technological or productivity changes also affect the estimated NRR. Therefore, this method should contain most information about the economy and be close to the true NRR, compared to other statistical approaches presented earlier.

6. Predictive power of the real interest rate gap

Neiss and Nelson (2003) and Basdevant et al (2004) discuss the prediction power of the real interest rate gap on inflation. They argue that the real interest rate gap has more leading-indicator properties than the output gap. In most sticky price models, the real interest rate moves to affect the output gap with some lags, while Inflation is affected by the output gap in the subsequent periods. Focusing on the real interest rate gap as the leading indicator should give more information in advance about both the output gap and inflation.

Unlike Neiss and Nelson (2003) and others, I utilize the difference in inflation rather than the inflation level, owing to the persistence of inflation leading to a near random walk process. Thus, correlations, based on an inflation level are hard to interpret.

According to Figure 3.6, the real rate gaps in the previous 6 quarters in five out of six measures have the highest predictive power for inflation, whereas the real rate gaps have the highest correlations with the output gap with longer lags – approximately 7 quarters. Moreover, the real interest rate gap estimated from IS/CBO1 and IS/CBO2 dominates the one derived from the constant. Observe the higher correlations between changes in inflation and the real interest rate gap in Figure 3.6.

Figure 3.6: Simple correlations between changes in inflation and the NRR with lag k

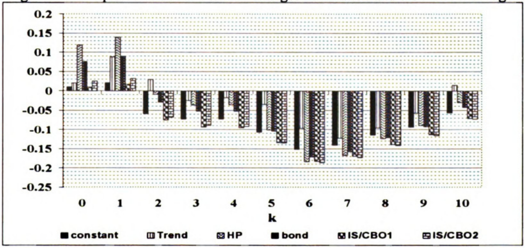
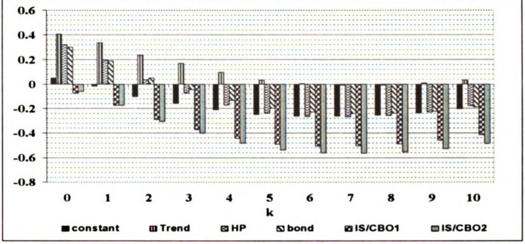


Figure 3.7: Simple correlations between the output gap and the NRR with lag k



Nevertheless, these simple correlations also encompass each variable's autocorrelations. To consider the relationship among the real interest rate gap, inflation and the output gap without the influence of their own lags, these autocorrelations must be eliminated before calculating the simple correlations. One method is to regress inflation and the output gap on their lags and then use the residuals to calculate the partial correlation with the current and lags of the real interest rate gap.

By conditioning on three lags of differenced inflation[145], Figure 3.8 exhibits the partial correlations between the real interest rate gap and changes in inflation, while Figure 3.9 shows the partial correlations between the real interest rate gap and the output gap, conditioning on the AR(3)[146] process of the output gap.

[145] The equation follows AR(3) process of the *first-difference (change)* of annualized quarterly inflation. The number of lags is chosen, based on the Akaike information criterion. The estimation is as follows.

$$\Delta\pi_t = -0.347347\Delta\pi_{t-1} - 0.255385\Delta\pi_{t-2} - 0.146400\Delta\pi_{t-3}$$
$$(0.074636) \quad (0.076686) \quad (0.074565)$$

Adjusted R^2 = 0.118382, Log-likelihood = -265.7953, Akaike Information Criterion = 3.003300, Schwatz Information Criterion = 3.056720, Durbin-Watson = 1.949055.

[146] In order to eliminate the effect of the lags of the output gap, I regress the output gap on its lags as follows.

$$x_t = 1.167084x_{t-1} - 0.037323x_{t-2} - 0.212645x_{t-3}$$
$$(0.073376) \quad (0.114203) \quad (0.072893)$$

Adjusted R^2 = 0.907959, Log-likelihood = -207.5023, Akaike Information Criterion = 2.338915, Schwatz Information Criterion = 2.392131, Durbin-Watson = 1.985834

Figure 3.8: Partial correlations between changes in inflation and the NRR with lag k, conditioned on its lags of changes in inflation

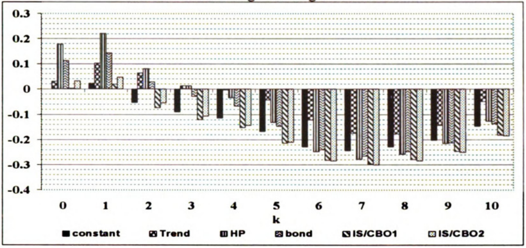


Figure 3.9: Simple correlations between the output gap and the NRR with lag k, conditioned on the lag of output gap

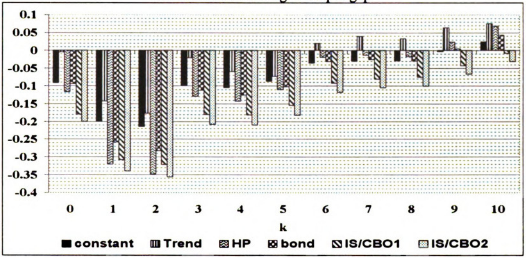


Figure 3.8 is slightly different from Figure 3.6 as the real interest rate gap affects changes in inflation more slowly. On the contrary, Figure 3.9 shows the effect of the real interest rate gap occurs more quickly than in Figure 3.7. It is noteworthy that the real interest rate gaps from IS/CBO1 and ISCBO2 are better predictors of changes in inflation than those from the HP filter or even the constant, according to the partial correlations in Figure 3.8.

7. What difference does it make in the Taylor rule?

Even though no central bank ever announces a commitment to following the Taylor rule or any other policy rule, the Taylor rule can still be used as a guideline for central banks to set their monetary policy, abstracting from the real-time problem as addressed by Orphanides (2001) and CK (2004).

However, the original Taylor rule employs a constant as a proxy for the natural real interest rate, leading to policy mistakes whenever there is a shift in the economic structure or a change in the true natural real interest rate. If the true NRR increases, whereas the Taylor rule does not incorporate the change, it results in the Taylor rule specifying too expansionary policy on average, which in turn, causes the inflation off-target and output deviating from its potential level more frequently (i.e. higher variability of inflation and the output gap), even though the central bank follows a policy rule consistent with the Taylor Principle.

Examining the Taylor rule-based nominal federal funds rates calculated from different measures of the natural rate of interest, including a constant, and the actual nominal federal funds rate, three episodes, corresponding to historical economic events, can be drawn. These episodes are slightly overlapping with the three episodes for the estimated NRR in Section 5 of this chapter.

The first episode starts at the beginning of the 1960s until the last quarter of 1979 prior to the change in the Federal Reserve's operating procedure. This period also spans the Burn's and Miller's[147] chairmanships. The Taylor rule-based interest rate shows that the Federal Reserve conducted too expansionary monetary policy regardless of the measures of NRR used. This result confirms the results of other

[147] Chairman Miller was in the office for very brief period of time (1978:Q2 – 1979:Q2) and there was no significantly different policies from the earlier period. Thus, I combine the periods of Chairman Burn and Chairman Miller together without losing any generality.

studies using both the historical approach, e.g. Taylor (1999b), and the simulation-approach, e.g. Orphanides (2003).

The first episode, see in Figure 3.10, also encompasses the Great Inflation, starting with the first oil shock in 1974. The Taylor rule, based on the NRR estimated from the IS/CBO, 10-year bond and the HP filter, call for a rise in the federal funds rate greater than the increase in the actual federal funds rate. This is because the policy reaction function as estimated by many studies including Judd and Rudebusch (1998), Kozicki (1999) and Clarida, Gali and Gertler (2000) has a coefficient in response to inflation of less than unity, in contradiction of the Taylor Principle. However, in this episode, the Taylor rule calls for similar rates across different measures of the NRR.

The second episode embraces the period of the change in the Federal Reserve operating procedure from targeting a short-term interest rate to targeting non-borrowed reserves during 1979:Q4-1982:Q3 and the second oil shock in 1980. This episode ends at the beginning of Chairman Greenspan's period. It is striking that the Taylor rule explains the federal funds rate's behavior very poorly.

One reason that the Taylor rule explains the federal funds rate poorly in this episode is that the Federal Reserve, during Chairman Volcker's tenure, was very aggressive in responding to inflation, especially after the second oil shock, owing partly to the Fed's poor monetary policy performance during high inflation period following the first oil shock. This period is also known as "Volcker's Disinflation Period".

The aggressiveness in policy against inflation can also be observed by the coefficient on inflation in the estimated policy reaction function, which is much greater than unity while the coefficient on the output gap is mostly insignificant – Judd and Rudebusch (1998) and CGG (2000).

Nonetheless, interpretation of the rule-based interest rate during the change of operating procedure must be done with some caution because the Fed did not implement the short-term interest rate as its policy instrument. Even though the Fed had an interest rate target in mind[148] during its targeting of non-borrowed reserves regime, the behavior of the federal funds rate just followed the behavior of non-borrowed reserves through the money market mechanism, not the Fed's conduct of monetary policy directly.

According to Figure 3.11, the Taylor rule with different measures of the NRR prescribes significantly different rates of interest after 1982:Q3, when the Federal Reserve changed the operating procedure back to the targeting of the federal funds rate.

Unsurprisingly, the Taylor rule-based rate with the time-varying NRR follows the actual federal funds rate more closely than the rule-based rate with a constant NRR since the time-varying NRR basically follows the trend of ex post real interest rate, given the statistical approach used in this chapter.

From Figure 3.11, the NRR estimated with the HP filter is closer to the ex post real interest rate and the Federal Reserve also responded to inflation more than one-to-one, conforming to the Taylor Principle, though the economic objective of the output gap is less important. In addition, the Taylor rule-based interest rate using the HP filter NRR is not much different from the actual nominal interest rate.

On the contrary, the NRR estimated from the IS/CBO1 and IS/CBO2 is based on the information from the output gap function, to which the Federal Reserve did not

[148] Non-borrowed reserves and a short-term interest rate target can be linked through demand for money, however, a central bank can target only one instrument and must allow the other to be determined by the money market.

respond to during this period. Thus, the NRR with IS/CBO1 and IS/CBO2 should relate to the actual nominal interest rate less than the one obtained from HP filter, while the NRR derived from the constant has the least relationship with the actual nominal interest rate since the constant in the Taylor rule of 2.5% is much lower, compared with the average of actual real interest rate of 5.473 (1979:Q3 – 1987:Q2).

As shown in Figure 3.12, the last episode corresponds to the period when the Taylor rule with estimated NRR across all four measures calls for a federal funds rate consistent with the actual federal funds rate[149]. This episode is consistent with Chairman Greenspan's tenure. It is one of the well-known successful periods of the Federal Reserve policy making.

After 1984:Q1 when the output gap shows significantly lower volatility, the estimated NRR, especially the ones estimated from the IS/CBO1 and IS/CBO2 shows a decreasing trend. Inflation is more stable at the lower rate after very aggressive monetary policy at the end of the 1970s. In this period, the nominal interest rate does not move significantly, thus the NRR estimated from different measures are similar.

It is noteworthy that the US experienced strong economic growth, in particular in the 1990s, after inflation had been tamed, in spite of the Fed's negligence of the wider negative output gap prior 1984:Q1[150]. This policy can partly support the priority of price/inflation stability rather than output growth as a long-run target as suggested by Barro (1995) and Taylor (1997).

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[149] However, there are slight differences between the rule-based rates and the actual federal funds rate in the periods of before 1990 and after 2000 when the Taylor rule called for easier and tighter monetary policy than that actually conducted by the Fed, respectively.

[150] In fact, the negative output gap is the widest slightly before 1984:Q1.

Figure 3.10: the Taylor rule-based interest rate during Burn's and Miller's tenure

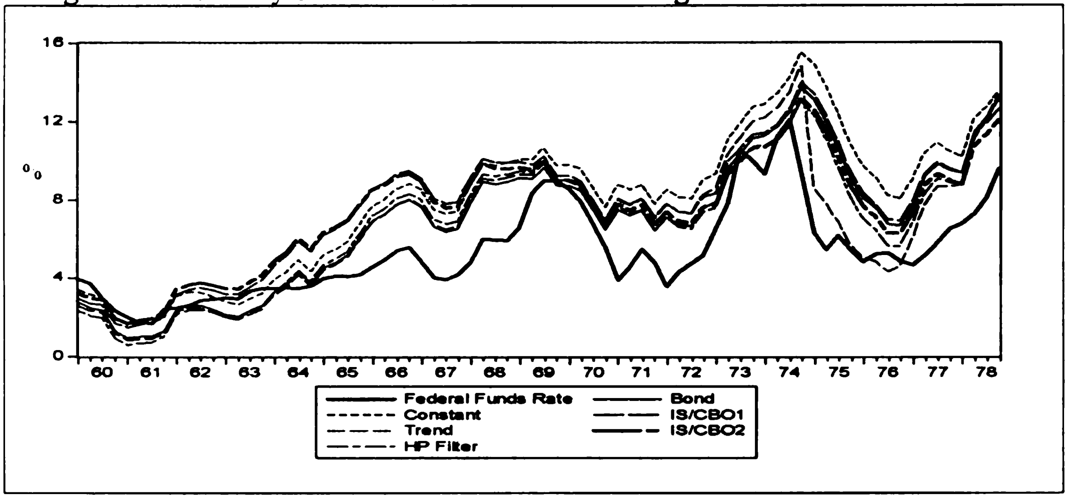


Figure 3.11: the Taylor rule-based interest rate during Volcker's tenure

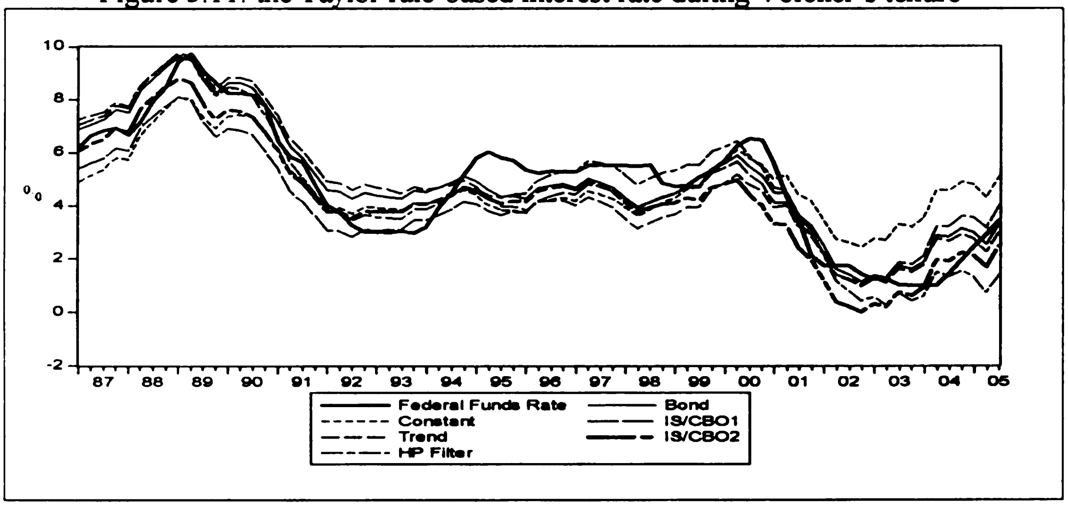
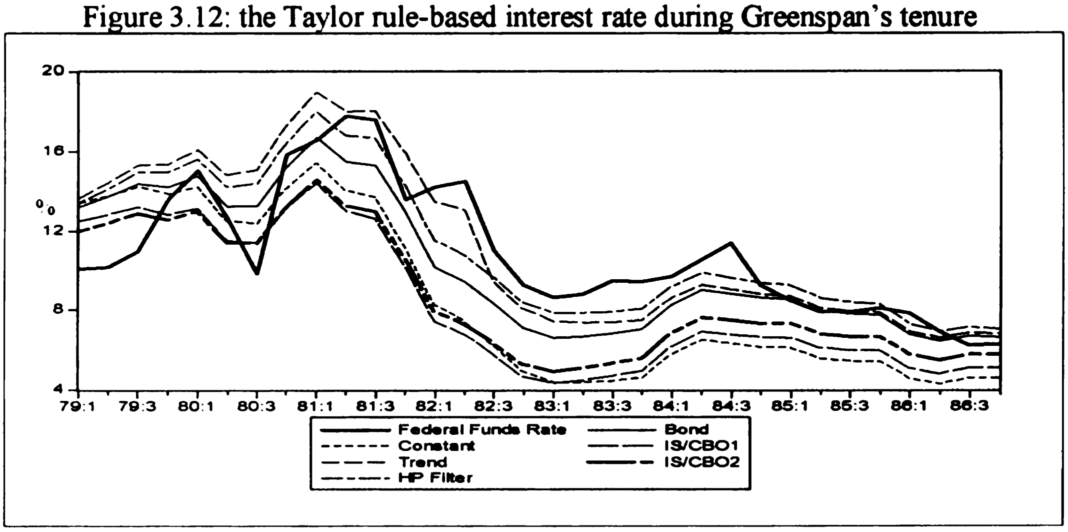


Figure 3.12: the Taylor rule-based interest rate during Greenspan's tenure



Note: The rule-based rate from the constant is to employ 2.5%, conforming to the Monetary Trend, released by the Federal Reserve Bank of St. Louis, while the one derived from trend is to implement three-segment time trend model.

In sum, the Taylor rule-based rates depend largely on the measures used to estimate the NRR. The closer is the estimated NRR to the actual real interest rate, the closer the Taylor rule-based rate is to the actual federal funds rate, as shown in the NRR based on HP filter. However, it can be less useful for economic interpretation.

On the contrary, the estimated time-varying NRR with semi-structural model method, such as the estimation based on IS/CBO model, has more economic meaning but it is more complicated and model-dependent.

8. Evidence from simulations

In this section, I simulate the model following Equation 2 – 4 to evaluate the performance of the Taylor rule with the time-varying NRR estimated from different measures. I use the welfare loss, based on one of the loss functions used in RS (1999), as a criterion to determine the performance. The loss functions (Loss A) are composed of three components, namely, the variability of inflation, the output gap and a change in a nominal interest rate. The last term is added to take the variability of the policy instrument into account to encompass some degree of interest rate smoothing[151]. Moreover, I add another example of a loss function (Loss B) composed of the variability of inflation and the output gap only in order to determine the variability of two macroeconomic objectives, i.e. inflation and the output gap.

The simulations are based on the parameters estimated corresponding to each measure of the NRR, provided that the estimated NRR is exogenously determined earlier. It is also assumed that the central bank uses the correct NRR (the central bank perceives the same rate as the economy does) and I have also taken the zero bound constraint into account.

[151] For the discussion of the inclusion of interest rate variability into a loss functions, refer to Section 5.1.1 in Chapter 1.

Table 3.3: Simulation results from the second type, provided that the NRR is correctly derived from each model and the central bank implements the correct rate

Variability	2.5%	Trend	HP	Bond	IS/CBO1	IS/CBO2	2.0%
π_t	2.625088	2.366000	1.984287	2.208084	2.407910	2.308771	2.793639
x_t	2.133544	2.269382	1.979142	2.096139	1.885290	1.825046	2.141740
Δi_t	0.606352	0.729491	0.651135	0.636022	0.633170	0.635899	0.617241
Loss A*	11.62693	11.01413	8.066387	9.471696	9.552800	8.863399	12.58196
Loss B*	11.4431	10.74805	7.854398	9.269434	9.352349	8.661216	12.39147

Note: 1) Row 1 and Row 2 represent the standard deviation of inflation and the output gap, respectively.

2)Loss A is calculated by $\pi^2 + x^2 + 0.5*\Delta i^2$.

3) Loss B is calculated by $\pi^2 + x^2$

2) Shaded entries are the minimum across that row.

From Table 3.3, the NRR estimated with HP filter performs the best among other measures.This can be attributed partly to the highest adjusted R^2 and the lowest in both Akaike Information Criterion and Schwatz Information Criterion of the model using the NRR estimated with HP filter. In other words, the model with this measure is the best fit, relative to other measures, given all the specifications. In this circumstance, the time-varying NRR can improve the performance[152] of the policy rule, i.e. the Taylor rule, compared to implementing a constant NRR.

However, the loss function in this section is just an example in order to illustrate how the different measures of the NRR influence welfare losses. The preference on each macroeconomic objective depends wholly on central banks. When the weights placed on each objective change, the welfare losses change spontaneously. For example, if the central bank places high weight on the variability of output, as was the policy during Chairman Burns, the welfare loss obtained from the simulation with the NRR estimated with the HP filter can be higher than that calculated from the one with the NRR estimated with IS/CBO1.

[152] The standard deviation of the annualized quarterly chained price index (base year = 2000) and the output gap are 2.4317 and 2.5288, respectively. Thus, comparing with the simulated standard deviations derived from different measures of the NRR, only time-varying NRR (except the three-segment time trends) can reduce the variability of inflation and the output gap. .

Nonetheless, if only macroeconomic objectives including inflation and the output gap are considered as shown in Loss B, the time-varying NRR always *dominates* the welfare loss calculated from the model with a constant NRR.

I simulate the model again but take the structural break into account. I chose the date at 1982:Q3 which was the last quarter before the Federal Reserve changed their operating procedure from targeting non-borrowed reserves to targeting a short-term interest rate. I also test for the structural break with both Chow breakpoint test and Bai and Perron's unknown breakpoint test. The tests are shown in Appendix D along with the test for the inequality of variances between two sub-samples separated by the first quarter of 1984, which is suppo rted by many studies, e.g. McConnell and Perez-Quiros (2000) and Boivin and Giannoni (2002).

Table 3.4: The variability of the endogenous variables and welfare loss with the dummy in 1982:Q3 and the break in the output volatility in 1984:Q1

Variability	2.5%	Trend	HP	Bond	IS/CBO1	IS/CBO2	2.0%
π_t	5.937605	18.87404	1.998223	2.350235	2.488810	2.400685	4.664207
x_t	2.182269	4.728452	1.943217	2.000699	1.759769	1.737724	2.074802
Δi_t	0.531068	0.534236	0.642920	0.627090	0.605634	0.614795	0.562427
Loss A*	40.15846	378.7303	7.975660	9.723023	9.474359	8.971959	26.21780
Loss B*	40.01745	378.5876	7.768987	9.526401	9.290962	8.782973	26.05963

Note: 1) Row 1 and Row 2 represent the standard deviation of inflation and the output gap, respectively.
2)Loss A is calculated by $\pi^2 + x^2 + 0.5*\Delta i^2$.
3) Loss B is calculated by $\pi^2 + x^2$
2) Shaded entries are the minimum across that row.

Similar to the result in Table 3.4, the welfare losses based on the time-varying NRR are much lower than those derived from the constant NRR. It is noteworthy that the welfare loss inferred from the constant NRR and three-segment time trends of NRR are gigantic, comparing with the ones obtained from time-varying NRR. This could be explained partly by the difference in the slope coefficients in the aggregate demand functions.

Considering the slope coefficients in Appendix C3, the coefficients in the aggregate demand function with the real interest rate gap derived from the constant of 2.0% and 2.5% are close to zero in the second half of the sample or after 1982:Q3. In other words, the real interest rate gap has very little explanatory power on the output gap, while the output gap depends entirely on its own lags. As a consequence, the effect of the Taylor rule on the output gap via the real interest rate gap, which in turn, affects inflation, is very small. Thus, if we use the constant to represent the NRR, we could neglect some information related to the real economy. As a result, the model could be mis-specified.

That the Taylor rule with the constant and time trend NRR adds huge fluctuations to inflation and slightly increase the variability in the output gap seems to contradict the historical approach discussed earlier. In fact, the contradiction between these two approaches contributes to the limitations of the simulation one, which is model-dependent. In this circumstance, the RS model performs poorly in explaining the economy especially after 1982:Q3.

In addition, it would not be surprising if the impulse response functions of all endogenous variables would converge very slowly or even would not converge at all. Thus, the slow convergence becomes a major drawback of this simple backward-looking model. Therefore, it would be difficult to conclude which measure of the time-varying NRR is the best, albeit the one derived from the HP filter shows the lowest welfare loss in all tables, provided that the central bank employs the loss function similar to RS (1999).

Despite some limitations set forth, the simulation approach exercises can clearly distinguish the effects of using a time-varying NRR instead of the constant NRR. The finding in this section substantiates the implementation of the time-varying

NRR rather than the constant NRR. This is because all measures of time-varying NRR, except the three-segment time trend which is quite inflexible compared with other time-varying measures of NRR, exhibit lower welfare losses than the ones obtained from the constant NRR. This result can be seen more clearly if only the variability of inflation and the output gap are considered. The time-varying NRR dominates the constant NRR in all cases.

9. Real-time issue

As shown in the stochastic simulation in the last section, the time-varying NRR generates a lower welfare loss, especially when the structural break in the output gap is incorporated. In reality, a central bank does not have complete information about the economy since there are many revisions and delays in data collections. Therefore, the central bank must rely on only the available data at the time it makes policy decisions. This type of data is called "real-time" data.

In this section, I follow LW (2001) by using the one-sided filtered series as a proxy for the real-time NRR and examine whether the result from the simulations would be different from when the central bank is assumed to have complete information about the NRR. One-sided filtered series can basically be obtained by filtering the series with Kalman filter algorithm. Furthermore, LW (2001) also assume that the true model, to be estimated, is based on the NRR estimated from the two-sided or smoothed real interest rate.

Following Harvey (1985), the HP filter can also be written as the state-space model, which in turn, can be estimated with Kalman filter algorithm. Therefore, it is feasible to obtain the one-sided filter series for all time-varying NRR except for the three-segment time trend model. I will drop the real-time NRR obtained from three-segment time trend model due to lack of an appropriate measure to represent the real-time data.

Likewise, the one-sided filter series can also be obtained from the 10-year bond and two IS/CBO models since they all have already been written in the state-space representation, according to the naïve model considered in Section 4.3.

It is worth noting that this section intends to focus on the real-time data or the data available at the time of making policy decisions versus the smoothed data or the data for the whole time period, not to examine the effect of the real-time data for both inflation and the output gap, as discussed in CK (2004). Thus, I still maintain the assumption that there is no revision or delay in data collection in inflation and the output gap.

According to Table 3.5, no matter which time-varying measure is used to estimate the NRR, the welfare loss using a time-varying NRR is always lower than when a constant NRR is used, similar to the result from Table 3.3. Nonetheless, the welfare losses from all measures of the real-time NRR are higher than those obtained from the smoothed NRR in all cases.

Interestingly, the NRR estimated from HP filter has the lowest variability in inflation since the HP filter is closer to the ex post real interest rate, comprised of the nominal interest rate and the ex post inflation, more than the rest of the measures. By contrast, the IS/CBO1 encompasses the aggregate demand function relating the output gap to its lags and the real interest rate gap. Therefore, it is correlated with the output gap the most, leading to the lowest variability of the output gap.

When taking the structural break in the parameters as well as the variances of the output gap into account as shown in Table 3.4, Table 3.6 shows results similar to

Table 3.5, except that the NRR estimated from IS/CBO2 has the lowest welfare loss, compared with the NRR estimated from IS/CBO1 in Table 3.5.

Table 3.5: The variability of the endogenous variables and welfare loss with the real-time NRR

Variability	2.5%	HP	Bond	IS/CBO1	IS/CBO2	2.0%
π_t	2.658375	2.150052	2.327222	2.445018	2.342623	2.807385
x_t	2.148520	2.472628	2.303142	1.928233	2.124355	2.147992
Δi_t	0.607967	0.743750	0.650897	0.671152	0.809175	0.616813
Loss A*	11.86790	11.01320	10.93226	9.921419	10.32815	12.68551
Loss B*	11.6831	10.73661	10.72043	9.696196	10.00077	12.49528

Note: 1) Row 1 and Row 2 represent the standard deviation of inflation and the output gap, respectively.
2)Loss A is calculated by $\pi^2 + x^2 + 0.5*\Delta i^2$.
3) Loss B is calculated by $\pi^2 + x^2$
2) Shaded entries are the minimum across that row.

Table 3.6: The variability of the endogenous variables and welfare loss with the real-time NRR and the break point in the parameters and variances of the output gap

Variability	2.5%	HP	Bond	IS/CBO1	IS/CBO2	2.0%
π_t	9.554377	2.148175	2.564247	2.522480	2.369871	7.053673
x_t	2.655325	2.432015	2.198884	1.779264	1.911959	2.312222
Δi_t	0.511756	0.741834	0.650692	0.641851	0.794037	0.547211
Loss A*	98.46781	10.80451	11.62215	9.734672	9.587125	55.25039
Loss B*	98.33687	10.52935	11.41045	9.528686	9.271876	55.10067

Note: 1) Row 1 and Row 2 represent the standard deviation of inflation and the output gap, respectively.
2)Loss A is calculated by $\pi^2 + x^2 + 0.5*\Delta i^2$.
3) Loss B is calculated by $\pi^2 + x^2$
2) Shaded entries are the minimum across that row.

Even though the NRR in real-time incurs welfare losses greater than the smoothed NRR does, it is still better to implement the time-varying NRR rather than the constant NRR. One reason is that the time-varying NRR helps decrease the mis-specification problem of the model with the constant NRR.

10. Implications

Having examined the difference between the constant and the time-varying NRR in its effect on the real interest rate gap and the Taylor rule, the time-varying

NRR tends to dominate the constant NRR in all senses. Thus, implementing a constant NRR, as a benchmark for monetary policy stance, can be misleading and may end up with higher variability of inflation and the output gap than implementing the time-varying one. The evidence supporting the time-varying NRR can be presented as follows.

The simple as well as partial correlations among the ex post real interest rate[153], the real interest rate gap, changes in inflation and the output gap show that the prediction power of the real interest rate gap on the change in inflation and the output gap is higher than that of the ex post real interest rate.

From the viewpoint of the historical approach, if monetary policy conducted by the central bank follows the Taylor rule closely and there is no structural break or significant changes in the economic structure, the historical approach suggests that the NRR are not too different across the measures of time-varying NRR, as illustrated during the Greenspan's period.

By contrast, if there is a structural break or a change in economic environment such as the change in the Federal Reserve's operating procedure, as seen in the second episode, there are non-trivial differences in the Taylor rule-based interest rate between the constant and time-varying NRR and among the time-varying NRR per se.

Unfortunately, in most cases, we do not know when a structural break would happen. A change in policy in response to a structural change is always delayed since a structural break cannot be detected until the data used to estimate are sufficiently large. Using the constant NRR misses the opportunity to update the new information about changes in the factors affecting the NRR. Therefore, the central bank should not

[153] In the correlations context, the ex post real interest rate can be interpreted as the difference between the ex post real interest rate and a constant NRR. Since the constant NRR has zero variability, the correlations between the real interest rate gap with the constant NRR and the ex post real interest rate are equal.

be worse off using the time-varying NRR, in spite of no structural break, provided that the uncertainty caused by estimation is not too large. This is because the Taylor rule would prescribe interest rate targets similar to those prescribed by a constant NRR.

According to the stochastic simulation, the time-varying NRR generates the lowest welfare loss, compared to the constant rate in all cases, provided that the simple backward-looking model, similar to RS (1999), is well-specified and the assumptions that the NRR is pre-determined and the central bank realizes all information at the time of decision making hold.

The results of the stochastic simulations still hold when a central bank employs the time-varying NRR, based on real time data, in making policy decisions. Thus, the time-varying NRR should be another essential issue to focus on when a central bank makes a policy decision, apart from the size of the coefficient in response to inflation, consistent with the Taylor Principle and the measures of inflation and the output gap.

Nonetheless, I do not identify which measure is the best, in spite of the NRR estimated from HP filter showing the lowest welfare loss. Since I employ a simple backward-looking model in this chapter, different models with other transmission mechanisms built in may result in different conclusions being drawn. To confirm the robustness result of the time-varying NRR in a policy rule, in particular, the Taylor rule, other models should also be considered. Comparisons across a wide range of models, following Taylor (1999a) and Levin, Volcker and Williams (1999) would be an interesting exercise.

More importantly, the welfare loss calculated in this part is just an example to illustrate how the time-varying NRR affects policy implementation. The results may vary across the different weights placed on each variable of the welfare loss function. Noticeably, the time-varying NRR is still better, relative to the constant NRR, when considering only the variability of inflation and output, no matter what weights are placed on these two variables.

The time-varying NRR is a useful and important concept but it needs more study focusing on estimation as there is still no consensus on the method to estimate. In this chapter, I have shown that different measures of the NRR yield different results depending how information is incorporated into the estimation. Yet, all evidence confirms that the time-varying NRR still dominates the constant one in the Taylor rule framework, regardless of estimation methods. Hence, the next task for policymakers is to find a reliable and robust method to estimate the NRR to this gap.

Another issue not investigated in this chapter is that of the difference between the backward-looking type Taylor rule versus the forward-looking type Taylor rule. The information used as the pre-determined variables are assumed to be known at the current period. As a result, the rule-based rate can be different from the one derived from the forward-looking rule. The forward- versus backward-looking policy rule is discussed nicely in Batini and Haldane (1998) and Carlstrom and Fuerst (2000).

11. Conclusion

The aim of this chapter is to investigate the effects of replacing the constant natural real interest rate (NRR) with the time-varying NRR estimated using the information from the ex post real interest rate, i.e. the statistical approach. I focus totally on this approach, in spite of other widely used approaches including the stochastic dynamic general equilibrium approach and the financial market-based approach, because it requires a very small information set and in some cases it does not depend on the model used to explain the economy.

In the context of the Taylor rule, the definition of the NRR needs to satisfy only two conditions, namely, actual output equaling its potential level and stable inflation.

I explore the time-varying NRR in two ways, namely, its predictive power via real interest rate gap, defined as the difference between actual real interest rate and the NRR, and the effect on the Taylor rule via the historical approach and stochastic simulations.

Two conclusions can be drawn from simple and partial correlations. One is that the real interest rate gap takes a longer time to have an impact on inflation than the output gap, which supports the backward-looking model, including the one used in this chapter. The other supports the Neo-Wicksellian type model using the real interest rate gap with time-varying NRR, rather than the model implementing the real interest rate gap with a constant NRR, based on the correlations of the real interest rate gap with inflation and the output gap.

Regarding the effects on interest rates implied by the Taylor rule, I first present the historical approach exercise by substituting the data for each period into the Taylor rule and calculating the rule-based interest rate. In this model-independent method, the interactions between economic shocks and the policy instrument are omitted.

Following the historical approach, three episodes of the Taylor rule-based interest rate can be drawn. These episodes can be grouped by three main features, namely, the rule-based rate being consistent across the measures but differing from the actual real rate, the rule-based rate both being inconsistent across the measures of

NRR and deviating from the actual real rate and lastly the rule-based rate both being close to the actual real rate and consistent across the measures.

In addition, the stochastic simulation illustrates that the Taylor rule with time-varying NRR can reduce the variability of inflation and output more than the original Taylor rule with the constant NRR, based on the standard backward-looking model implemented by RS (1999). In some cases, e.g. when incorporating the structural break at 1982:Q3, the Taylor rule with the constant NRR even adds some fluctuation to the economy.

Since a central bank does not have complete information about the economy at the time it makes policy decisions, it has to depend only on the available data, i.e. the real-time data. The simulations from this type of data, which I use the one-sided filtered to represent, following LW (2001), also support the use of time-varying NRR rather than the constant NRR.

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APPENDICES TO CHAPTER 3

Appendix A

1. Estimation with Hodrick-Prescott Filter

Hodrick-Prescott filter is a univariate filtering method to extract a trend out of a variable by minimizing a function, composed of the deviation from a (unobservable) trend and a (observable) change in the growth rate of the variable. It is purely based on the statistical procedure and economic theory is irrelevant.

By imposing some weight as the noise-to-signal ratio in the minimization problem, the unobservable trend part can be estimated. This ratio of the weights depends on the frequency of the data[154]. The loss function can be written as follows.

Equation (A1)................ $\text{Min} \; \Sigma_{t=1}^{T} \; [\frac{1}{\sigma_0^2} (y_t - y^*_t)^2 + \frac{1}{\sigma_1^2} ((y^*_t - y^*_{t-1}) - (y^*_{t-1} - y^*_{t-2}))^2]$

where y_t is the variable on focus

y^*_t is an unobservable trend.

$\lambda = \frac{\sigma_0^2}{\sigma_1^2}$ is the ratio of the weights, placed on the noise and signal – a smoothing parameter. Hodrick and Prescott (1997) suggest it be 1600 for quarterly data.

For comparison across other measures, Harvey (1985) suggests an alternative form of the HP filter by writing the model in terms of the state-space representation as follows

<u>Measurement function</u>

Equation (A2)......................... $y_t = y^*_t + \varepsilon_t$ where $\varepsilon_t \sim N(0,\sigma^2_\varepsilon)$

---

[154] Hodrick and Prescott suggest 6400, 1600, 400 for monthly, quarterly and annually data, respectively.

Transition Function

Equation (A3)........................ $\Delta y^*_t = \Delta y^*_{t-1} + v_t$ where $v_t \sim N(0, \sigma^2_\varepsilon/\lambda)$

Then, transforming it into the standard form – corresponding to Hamilton (1994),

Equation (A4) .... $Y_t = A'X_t + H_t'\xi_t + w_t$

Equation (A5) ....$\xi_t = F\xi_{t-1} + v_t$

Where $Y_t = y_t$, $\xi_t = \begin{bmatrix} y^*_t \\ g_t \end{bmatrix}$, $H = [1\ 0]$, $A = 0$, $X_t = [1]$ (vector of 1), $F = \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix}$

and $Var(w_t) = \sigma^2_\varepsilon$, $Var(v_t) = \begin{bmatrix} 0 & 0 \\ 0 & \frac{\sigma^2_\varepsilon}{\lambda} \end{bmatrix}$, and λ is a smoothing parameter,

From this representation, it can be estimated with the Kalman filter algorithm discussed in the semi-structural model approach.

2. Estimation the semi-structural approach with the Kalman filter algorithm

Based on Clark and Kozicki (2004), the time-varying model to estimate a natural real interest rate can be written in the standard state-space representation following Equation (A4) and (A5) with the re-defined matrices as follows.

$Y_t = x_t$. $X_t' = [x_{t-1}, x_{t-2}, r_{t-1}, r_{t-2}, g_{t-1}, g_{t-2}]$, $A' = [\alpha_1. \alpha_2, \alpha_3/2, \alpha_3/2, -\alpha_3\alpha_4/2, -\alpha_3\alpha_4/2]$,

$H_t' = [-\alpha_3/2,\ \ -\alpha_3/2]$, $\xi_t' = [z_{t-1}, z_{t-2}]$, $F = \begin{bmatrix} \rho & 0 \\ 1 & 0 \end{bmatrix}$ $Var(w_t) = \sigma^2_w$, $Var(v_t) = \begin{bmatrix} \sigma^2_v & 0 \\ 0 & 0 \end{bmatrix}$ for CBO-I

and $Y_t = x_t$, $X_t' = [x_{t-1}, x_{t-2}, r_{t-1}, r_{t-2}]$, $A' = [\alpha_1. \alpha_2, \alpha_3/2, \alpha_3/2]$,

$H_t' = [-\alpha_3/2, -\alpha_3/2]$, $\xi_t' = [r^*_{t-1}, r^*_{t-2}]$ and $F = \begin{bmatrix} 1 & 0 \\ 1 & 0 \end{bmatrix}$, $w_t = \sigma^2_w$, $v_t = \begin{bmatrix} \sigma^2_v & 0 \\ 0 & 0 \end{bmatrix}$ for CBO-II

From this state-space representation, the model can be estimated with Kalman filter algorithm, which minimizes the mean squared error forecasts of a given model. Harvey (1989), Hamilton (1994) and Lutkepohl (1993) explain a state-space model as well as the Kalman filter algorithm in detail.

The filtering results in two types of estimates. One is a filtered estimate, which exploits the information in the sample up to time t. The other is a smoothed estimate which utilizes information from the whole sample (to the end of time). The algorithm can be carried out recursively.

Basically, the algorithm begins with initializing the parameters used in filtering for the past values at time t-1 (Equation A6-A7). Then, we use the information at time t-1 as the best predictor for time t (Equation A8-A10). A prediction error (Equation A11) as well as its variance (Equation A12) can be computed. We use a part of the prediction error to update the predictor and the variance from conditional on time t-1 to time t (Equation A13-A14).

Initializing

Equation (A6)......... $P_{1|0} = P_0$, hence, $P_{1|0} = (I_{r^2} - F \otimes F)^{-1} Q$

Equation (A7).......... $\xi_{1|0} = \xi_0$

Prediction

Equation (A8).......... $\xi_{t|t-1} = F\xi_{t-1}$

Equation (A9).......... $P_{t|t-1} = E[(\xi_t - \xi_{t|t-1})(\xi_t - \xi_{t|t-1})'] = FP_{t-1}F' + Q$

Equation (A10).......... $\hat{y}_t = A x_t + H_t \xi_{t|t-1}$

Equation (A11).......... $w_t = y_t - \hat{y}_t$

Equation (A12).......... $Var(w_t) = \Xi_t = HP_{t|t-1}H' + R$

Updating

Equation (A13)..........$\xi_t = \xi_{t|t-1} + P_{t|t-1}H' (HP_{t|t-1}H' + R)^{-1}w_t$

Equation (A14)..........$P_t = P_{t|t-1} - P_{t|t-1}H' (HP_{t|t-1}H' + R)^{-1}HP_{t|t-1}$

In order to estimate the model, Maximum Likelihood Estimation (MLE) is used with the likelihood function of:

Equation (A15)...........$\ln L_t = -\frac{Tn}{2}\ln(2\pi) - \frac{1}{2}\ln|\Xi| - \frac{1}{2}(w_t \Xi^{-1} w'_t)$

Where T is total number of observations and n is the number of the observed parameters.

On the other hand, the smoothed estimate can be derived by estimating recursively backward, based on basic filtering above.

Equation (A16)............$\xi_{t|T} = \xi_{t|t} + P_{t|t}F'P^{-1}_{t+1|t}(\xi_{t+1|T} - F\xi_{t|t})$

Equation (A17)............$P_{t|T} = P_{t|t} + P_{t|t}F'P^{-1}_{t+1|t}(P_{t+1|T} - P_{t+1|t})P^{-1}_{t+1|t}'FP'_{t|t}$

Where $P_{t+1|t} = (FP_tF' + Q)$ and $\xi_{t+1|t} = F\xi_t$

$\xi_{t+1|T}$ and $P_{t+1|T}$ can be derived from the basic filtering.

Appendix B

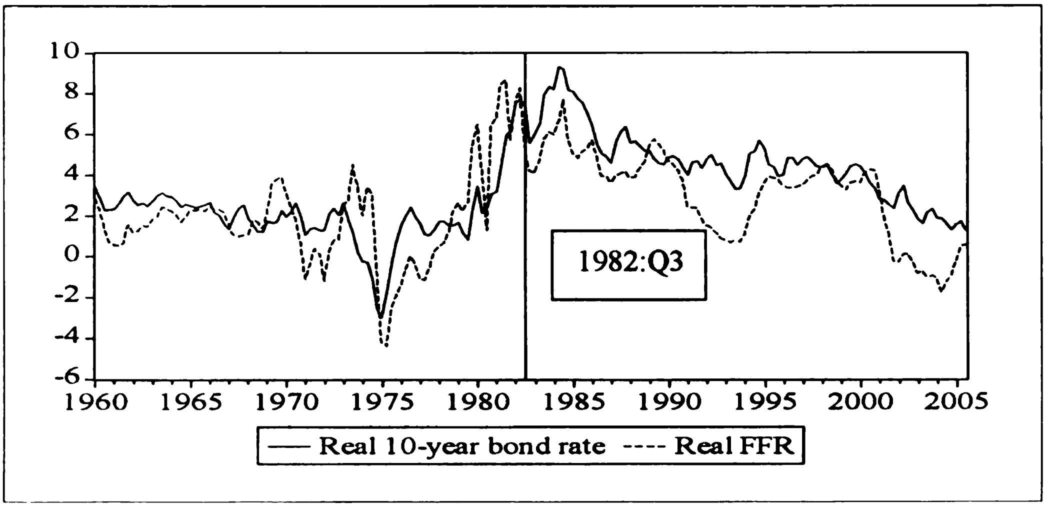

Figure B1: The real rates

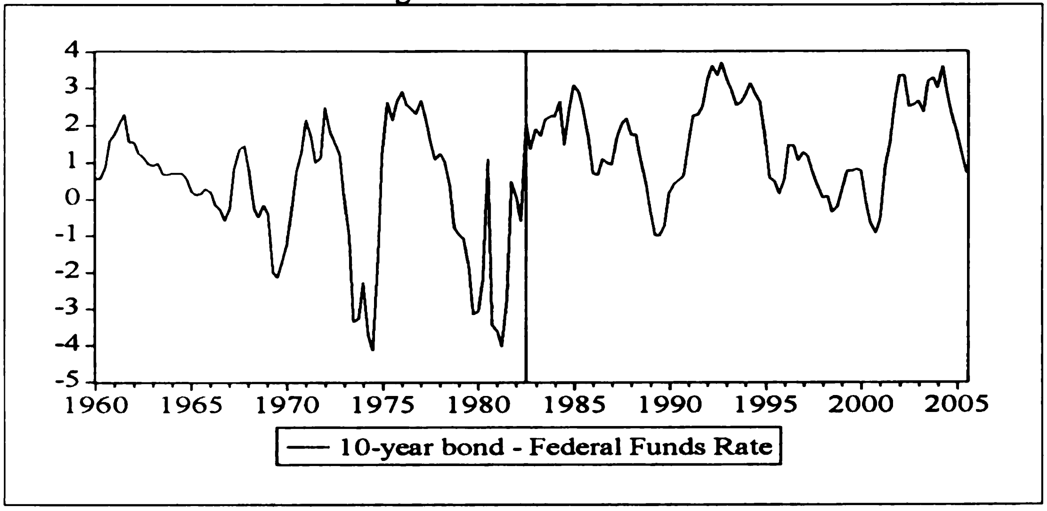

Figure B2: Yield spread

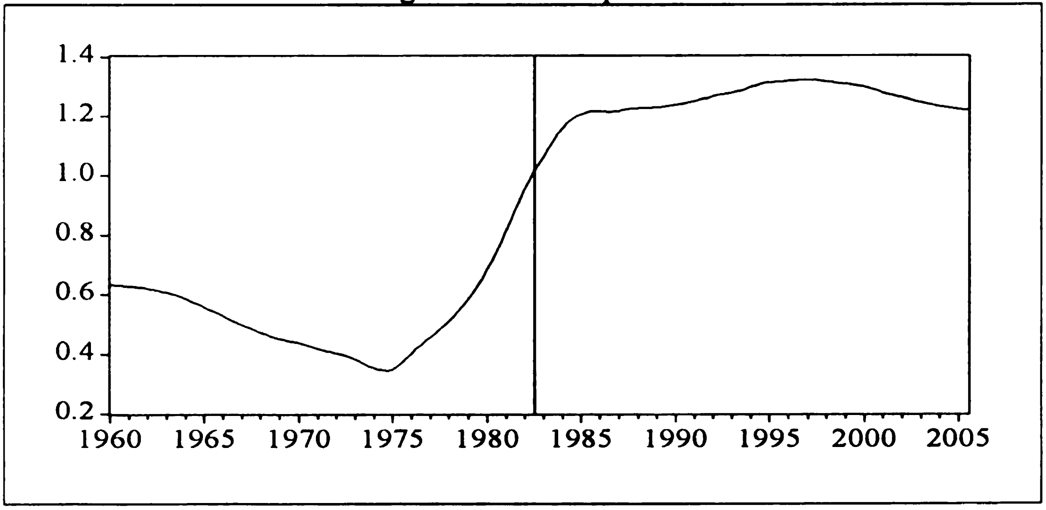

Figure B3: Term premium

Appendix C

Appendix C1: The estimation of the accelerationist Phillips Curve

$$\pi_t = \beta_1 \pi_{t-1} + \beta_2 \pi_{t-2} + \beta_3 \pi_{t-3} + (1-\beta_1-\beta_2-\beta_3)\pi_{t-4} + \beta_4 x_{t-1}$$

Variables	Coefficient	Standard Error	P-value
β_1	0.573025	0.073543	0.0000
β_2	0.078326	0.085031	0.3582
β_3	0.125650	0.085084	0.1415
β_4	0.136132	0.031634	0.0000
Adjusted R^2		0.822377	
Log-likelihood		-256.7925	
Akaike Information Criterion		2.913883	
Schwatz Information Criterion		2.985110	
LM test for Serial Correlation (lag 4)		0.487047 (0.745238)*	

*Note: * P-value is in parenthesis for the LM test for serial correlation with the lags up to 4 periods.*

Appendix C2: The estimation of the model with different measures of NRR based on Neo-Wicksellian aggregate demand function

$$x_t = \alpha_1 x_{t-1} + \alpha_2 x_{t-2} + \left(\frac{\alpha_3}{2}\right)(i_{t-1} - \bar{\pi}_{t-1} - r^n_{t-1} + i_{t-2} - \bar{\pi}_{t-2} - r^n_{t-2})$$

Variable	2.5%	Trend	HP	Bond	CBO1	CBO2	2.0%
α_1	1.21443 (0.0698)	1.2232 (0.0696)	1.1309 (0.0670)	1.1742 (0.0687)	1.1599 (0.0689)	1.1377 (0.0685)	1.2125 (0.0698)
α_2	-0.2785 (0.0701)	-0.2627 (0.0713)	-0.1498 (0.0696)	-0.2095 (0.0706)	-0.2371 (0.0686)	-0.2140 (0.0682)	-0.2792 (0.0699)
α_3	-0.0698 (0.0253)	-0.1343 (0.0509)	-0.3120 (0.0521)	-0.1790 (0.0405)	-0.1287 (0.0279)	-0.1535 (0.0292)	-0.0698 (0.0247)
Adjusted R^2	0.9075	0.9071	0.9197	0.9131	0.9138	0.9164	0.9076
Log-Likelihood	-208.74	-209.06	-195.92	-203.09	-202.27	-199.50	-208.56
AIC	2.3396	2.3432	2.1980	2.2772	2.2682	2.2376	2.3377
SIC	2.3926	2.3962	2.2510	2.3303	2.3212	2.2906	2.3907

Appendix C3: The estimation of the model with different measures of NRR based on Neo-Wicksellian aggregate demand function with the dummy variable on 1982:Q3

$$x_t = \alpha_1 x_{t-1} + \alpha_2 x_{t-2} + \left(\frac{\alpha_3}{2}\right)(i_{t-1} - \bar{\pi}_{t-1} - r^n_{t-1} + i_{t-2} - \bar{\pi}_{t-2} - r^n_{t-2}) + \left(\frac{\alpha_4}{2}\right) * D * (i_{t-1} - \bar{\pi}_{t-1} - r^n_{t-1} + i_{t-2} - \bar{\pi}_{t-2} - r^n_{t-2})$$

Variable	2.5%	Trend	HP	Bond	CBO1	CBO2	2.0%
α_1	1.1784 (0.0697)	1.2062 (0.0699)	1.1244 (0.0670)	1.1462 (0.0684)	1.1174 (0.0688)	1.1069 (0.0684)	1.1656 (0.0696)
α_2	-0.2374 (0.0703)	-0.2832 (0.0700)	-0.1473 (0.0695)	-0.1823 (0.0703)	-0.1896 (0.0688)	-0.1791 (0.0684)	-0.2224 (0.0704)
α_3	-0.1428 (0.0361)	-0.0873 (0.0285)	-0.3534 (0.0601)	-0.2614 (0.0508)	-0.2040 (0.0367)	-0.2137 (0.0368)	-0.1640 (0.0380)
α_4	0.1401 (0.0504)	0.0899 (0.0678)	0.1376 (0.1003)	0.1975 (0.0756)	0.1674 (0.0548)	0.1534 (0.0584)	0.1607 (0.0501)
Adjusted R^2	0.9108	0.9078	0.9201	0.9152	0.9177	0.9191	0.9122
Log-Likelihood	-204.86	-207.84	-194.96	-199.66	-197.63	-196.04	-203.44
AIC	2.3079	2.3408	2.1985	2.2504	2.2279	2.2104	2.2922
SIC	2.3786	2.4115	2.2691	2.3211	2.2986	2.2811	2.3629

Note: 1) AIC is Akaike Information Criterion and SIC is Schwatz Information Criterion
3) The standard errors are in parentheses
4) D is the dummy variable at the breakpoint of 1982:Q3, thus, the slope of the aggregate demand function is $\alpha_3+\alpha_4$

Appendix D

Chow test for the structural break at 1982:Q3

Statistics	2.5%	Trend	HP	Bond	CBO1	CBO2	2.0%
F-test	3.3595	4.3977	1.7897	3.9971	4.4464	3.6635	4.4212
	(0.0201)	(0.0052)	(0.1509)	(0.0088)	(0.0049)	(0.0135)	(0.0050)
LR test	10.1350	13.1557	5.4698	11.9960	13.2960	11.0246	13.2235
	(0.0175)	(0.0043)	(0.1405)	(0.0074)	(0.0040)	(0.0116)	(0.0042)

Note: P-values are in parentheses.

Bai and Perron's test for unknown multiple breakpoints

Statistics	2.5%	Trend	HP	Bond	CBO1	CBO2	2.0%
Break date	1982:Q4	1981:Q4	1982:Q4	1982:Q4	1982:Q4	1982:Q4	1982:Q4
UDmax test	15.63**	14.43**	10.99	20.65****	20.17****	18.10***	17.64***
Sup F-test[&]	4.6707	7.8715	7.4411	5.5687	9.5584	11.4017	4.9461

*Note: *, **, *** and **** are significant level of 10%, 5%, 2.5%, and 1%, respectively.*
[&] is the Sup F-test for 2 breakpoints versus 1 breakpoint.

Variance ratio test between for the break date at 1984:Q1

Statistics	2.5%	Trend	HP	Bond	CBO1	CBO2	2.0%
F-test	3.6350	3.6855	3.1929	3.1907	3.1957	3.2069	3.6255
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Siegel-Tukey	3.7693	3.5422	4.0079	3.6132	3.7410	3.9511	3.7551
	(0.0002)	(0.0004)	(0.0001)	(0.0003)	(0.0002)	(0.0001)	(0.0002)
Bartlett	34.1652	34.8505	28.0052	27.9730	28.0454	28.2039	34.0363
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Levene	21.5450	20.9799	20.7031	19.1455	18.4513	19.6101	21.3887
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Brown-Forsythe	21.5024	19.7974	20.5589	19.1515	18.5708	18.7076	21.3961
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)

Note: P-values are in parentheses.

Appendix E

Choosing a smoothing parameter in the semi-structural model (λ_z)

As discussed in LW (2001) and CK(2004), the maximum likelihood estimation (MLE) of the semi-structural model method in Equation (11)-(18), results in a near zero variance of the state variable, i.e. the unobservable NRR. Yet, I encounter such a problem when the estimation with maximum likelihood method starts with very low initial values of λ_z – the smoothing parameter representing the ratio between the variance of NRR equation and the output gap equation. As a consequence, the parameter estimates are close to the ones in Equation (2), which does not allow the NRR time-varying.

On the contrary, at high initial value of λ_z, the MLE yields so high variance of the NRR that the Kalman filter is counter-smoothing the ex post real interest rate. In this case, it contradicts the economic theory that the NRR should be less volatile than the ex post real interest rate since it represents economic structure in the medium-run, considered as a trend of the ex post real interest rate in the context of the statistical approach.

Based on the semi-structural model estimated with the Kalman filter algorithm, the MLE yields inconsistent estimates of the NRR depending on the initial parameter, especially the initial values of λ_z. The higher is the smoothing parameter, the higher standard deviation of the estimated NRR as shown in Table E1 and E2.

It is worth noting that the NRR follows a random walk process in the IS/CBO2, unlike the one in the IS/CBO1 which is composed of the growth of potential output and an AR(1) process. It would be more meaningful to consider the standard deviation of the NRR obtained from the IS/CBO2 based on the *first-difference* NRR rather than the *level* of NRR because the standard deviation of the level depends on time if the series is non-stationary. Nonetheless, the higher smoothing parameter still causes both analytical and empirical standard deviations derived from the first-difference NRR in IS/CBO2 higher, comparable to the case of the level of NRR.

Table E1: The standard deviations of the NRR based on IS/CBO1

λ_Z	Analytical r^*_t	Empirical r^*_t
0.01	0.282408	0.313639
0.03	1.222062	0.462514
0.046	2.31442	0.721643
0.05	2.560595	0.785639
0.07	3.874744	1.173073
0.09	5.002394	1.481332
0.1	5.441018	1.602433
0.2	7.725174	2.354365
0.5	12.43239	3.155915

Note: *The standard deviation of r^*_t is* ***2.343100.***
The analytical variance is calculated from $\sigma^2_r = \alpha^2_4\sigma^2_g + (\sigma^2_\eta/(1-\rho^2))$.

Table E2: The standard deviations of the NRR based on IS/CBO2

λ_Z	Empirical r^*_t	Analytical Δr^*_t	Empirical Δr^*_t
0.01	0.222672	0.179788	0.008602
0.03	0.825806	0.43508	0.054996
0.046	1.217260	0.568674	0.096750
0.05	1.294568	0.593457	0.106719
0.07	1.572311	0.671677	0.148678
0.09	1.779665	0.73869	0.187401
0.1	1.797668	0.699682	0.190591
0.2	2.254312	0.913823	0.332781
0.5	2.907617	1.378569	0.703887

Note: *The standard deviation of the change in ex post real interest rate is* ***1.326938.***
The analytical standard deviation of the NRR is calculated from $\Delta r^*_t = \eta_t$

When the initial value is as high as 0.2, the empirical standard deviation of the NRR almost equals the standard deviation of the ex post real interest rate. As a result, there is no gain from using the Kalman filter to estimate the unobservable NRR since the NRR follows the output gap too closely and fluctuates too much to infer any information from it. An example of estimated NRR from the MLE is illustrated in Figure E1, based on the parameter estimates in Table E3.

In spite of the difference in estimated NRR from the semi-structural method depending on the smoothing parameter (λ_z), this difference is irrelevant in the context of this chapter because the issue focused on is to compare the time-varying to the constant NRR, not to compare across different parameter of any particular method.

Table E3: Estimation Results based on IS/CBO1 and IS/CBO2

Variables	IS/CBO I	IS/CBO II
α_1	0.523990 (0.181487)	0.738405 (0.129343)
α_2	0.201363 (0.135785)	0.066142 (0.082618)
α_3	-0.250728 (0.063744)	-0.282825 (0.063179)
σ_ε	0.532689 (0.082073)	0.571847 (0.050581)
ρ	0.827071 (0.087045)	
α_4	0.533296 (0.290570)	
λ_z	0.896679 (0.431980)	0.464059 (0.177876)
σ_η	2.386788	1.326938
Log-likelihood	-201.1087	-212.3436
Akaike Information Criterion	2.312319	2.414929
Schwatz Information Criterion	2.436489	2.503623

Note: The standard errors are in parentheses.

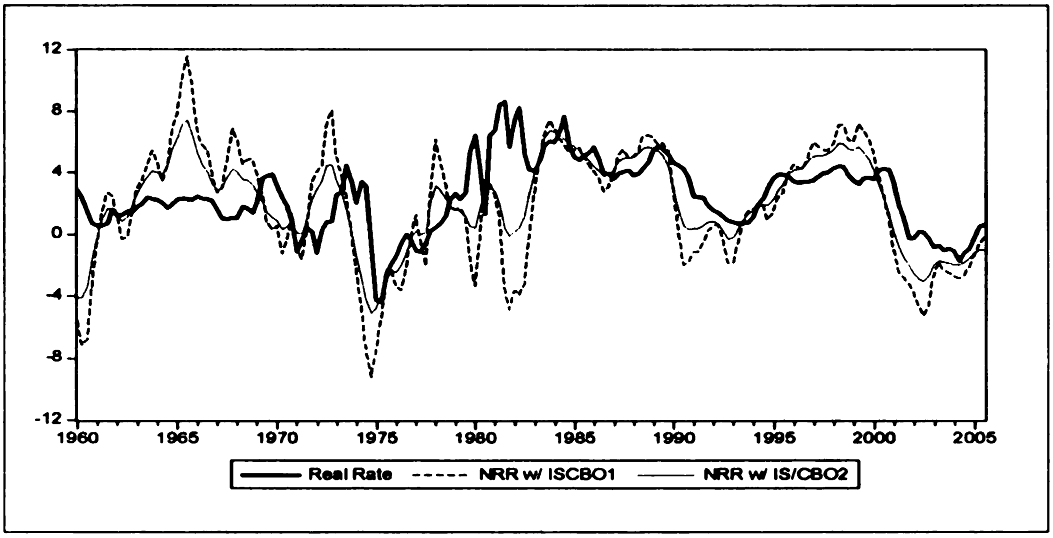

Figure E1: The ex post real interest rate and the NRR estimated with IS/CBO1 and IS/CBO2

Nonetheless, I experiment estimating the NRR with different smoothing parameter and conducting the same exercise as I did in this chapter. The conclusions are still identical in all values of λ_Z. In fact, they are more supportive in the sense that the time-varying NRR dominates the constant NRR in all exercises when the λ_z is higher.

The intuition behind is that a higher smoothing parameter corresponds to not only higher volatility of the NRR, but also the larger weight on the information concerning an economic structure, measured by the output gap, As a consequence, the estimated NRR with a high smoothing parameter fluctuates and follows the output gap more than that with a low smoothing parameter, as a result, it is more correlated with the output gap and the change in inflation[155]. In addition, the higher volatility of the NRR leads to more aggressiveness in the Taylor rule, resulting in the lower volatility in both inflation and the output gap, albeit higher variability in the change in interest rate.

Thus, I choose the pre-specified smoothing parameter used in LW (2001) and CK (2004) of 0.046 for both IS/CBO1 and IS/CBO2. Even though CK (2004) use 0.017 for IS/CBO2, the weight placed on the output gap is too small, observing from the similarity between the NRR based on the constant and the one based on very small λ_Z, as shown in Figure 3.2 and 3.3 in the text.

[155] Recall that the output gap relates to the change in inflation by means of the aggregate supply function.