Modelling the Links between Inflation, Output Growth, Inflation Uncertainty and Output Growth Uncertainty in the Frameworks of Regime-Switching and Multiple Structural Breaks: Evidence from the G7 Countries

KUSHAL BANIK CHOWDHURY

A dissertation submitted to the
Indian Statistical Institute
in partial fulfillment of the requirement for
the award of the degree of
Doctor of Philosophy

Indian Statistical Institute
Kolkata, India
July, 2014

Dedicated to

My Parents

Acknowledgements

First of all, I would like to express my sincere gratitude to my thesis supervisor Professor Nityananda Sarkar. He has all along guided me with enthusiasm and commitment so that I could write a good thesis. During the course of this period, he has nurtured and motivated me so that I could develop myself to become a good researcher. Needless to say, this thesis is the outcome of his constant guidance and tremendous academic support to me. I take this opportunity to also acknowledge that apart from academics, his ideals and humane attitude have made significant impact in other aspects of my life as well.

I also express my thankfulness to the authorities of the Indian Statistical Institute, Kolkata, for providing me with a research fellowship and the necessary infrastructure for this work.

I take this opportunity to acknowledge the help and suggestions I have received from Dr. Samarjit Das, Professor Dipankor Coondoo and Professor Amita Majumder.

I must express my heartiest gratitude to my senior colleague and dear friend, Srikanta da, for his immense help at every stage of my work. To my good friends Sandip and Manushree, I owe a lot because of their enthusiastic support all throughout the period of this work.

I deeply acknowledge the influence of the loving company of all my co-research fellows: Somnath da, Conan da, Sattwik da, Trishita di, Debasmita, Priya Brata, Rajit, Mannu, Debojyoti, Parikshit, Chandril, Tanmoy, Mahamitra, Arindam, GopaKumar A C, Dripto, Ranojoy and Chayanika.

I would also like to mention the names of my friends at RS Hostel with a deep feeling of oneness for their jovial company during the entire period of my journey. They are: Sudip, Tridib, Kaushik, Buddhananda, Anindita, Rituparna di, Sourav, Amiya, Sudipto, Abhijit da, Tapas da, Sayantan da, Sanjoy, Navonil, Pulak, Bidesh, Soumitra, Zinna, Manik, Sourav Sasmal, Ankita, Palash da, Swapan da, Abhisekh da, Chintan and Raju. Thanks are also due to our beloved football coach Trijit da for his enthusiastic encouragement in all my activities. I would like to thank all the workers at RS hostel, especially Utpol da and Punno da.

I take this opportunity to express my heartfelt love and best wishes to every one in the ERU office for their cooperation and help.

I must also mention about my childhood friends from my home town, Krishnendu, Arpan, Amit and Avik, who have inspired me a lot for completing the thesis.

Having acknowledged the contribution of all, I solemnly state at this point that for all slips and mistakes that may exist and for any dispute that may arise, the responsibility is entirely mine.

Though it may sound superfluous, yet I humbly submit that the chain of my acknowledgements would be definitely incomplete if I forget to express my love and gratitude towards my parents and my brother who have always encouraged me for higher studies. Other than taking direct interest in my work, they have always motivated and supported me.

July, 2014 Kolkata Kushal Banik Chowdhury

Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1 Introduction

One of the long-standing and most investigated issues in macroeconomics is the nature of the relationship between inflation and output growth. Given this relationship as a central point of intense interest, one strand of studies has focused on the levels of the two series, while, more recently, an overgrowing body of research has highlighted the importance of the effects which are due to both the levels and the uncertainties associated with these two variables. These studies raise a number of interesting issues regarding the relationship between inflation and output growth. First, is there any direct effect of inflation on output growth, and vice versa? Second, is there any relationship between inflation and nominal (inflation) uncertainty, and if so, is it unidirectional or bi-directional? Third, does inflation uncertainty inhibit output growth? Fourth, can a more stable and less uncertain, i.e., less volatile output growth lead to more output growth? Fifth, is the reduction in output growth related to the reduction in real (output growth) uncertainty? Last, is there any trade-off between the uncertainties of inflation and output growth? Over the last three decades, an extensive body of theoretical and empirical literature has examined the above issues in great details. Consequently, many theories have been proposed to understand the above linkages, and at the same time, a large number of empirical works have been carried out to verify these theories. This thesis is primarily concerned with studying empirically the relationship involving these four variables, *viz.*, inflation, output growth, inflation uncertainty and output growth uncertainty, and consequently the different links involving them so as to be able to provide further answers to some of the issues mentioned above.

The format of the first chapter of this thesis is as follows. The next two sections give a brief overview of the important literature on these topics. While Section 1.2 presents a brief review of the major theoretical works involving inflation, inflation uncertainty, output growth and output growth uncertainty, Section 1.3 summarizes the findings of the important empirical studies. The motivation behind this thesis is stated in the next section. This chapter ends with a chapter-wise description of the thesis in Section 1.5.

1.2 Review of theoretical works on inflation, output growth and their uncertainties

This section presents a brief review of the important theoretical works done on the relationships involving inflation, output growth, uncertainty in inflation and uncertainty in output growth.

Economic theory provides mixed evidence regarding the impact of inflation on output growth. Depending on how money is introduced in the model, the effect could be either positive, negative or zero. Introducing money in the underlying utility function, Sidrauski (1967) constructed a model of the super-neutrality of inflation[1]. Tobin (1965) argued that when money is regarded as a substitute for capital, a higher monetary growth increases capital accumulation, causing inflation to have a positive effect on output growth. Stockman (1981), on the other hand, stated that when money is required for purchasing capital goods, higher inflation decreases steady-state real balances and capital stock, and hence a reverse Tobin effect occurs. More recently, studies based on endogenous growth models have provided rationale for the negative growth effect of inflation (see, Gomme (1993), Jones and Manuelli (1995), and Gillman and Kejak (2005), for details). In endogenous growth models, higher inflation acts as a tax on capital (either physical capital or human capital, or both) and thus it reduces the rate of return on capital which, in turn, lowers the output growth. On the other hand, output growth also affects inflation. Although the traditional short-run Phillips curve implies that an increase in output above its natural level would tend to increase inflation, another strand of literature analyses how a rise in output growth can affect inflation. Briault (1995) argued that there is a positive relation between output growth and inflation, at least over the short run[2].

One of the interests of the policy-makers is to minimize the uncertainties about inflation and output growth around their target levels. Accordingly, macroeconomic theory has given emphasis on studying the relationship between nominal (inflation) uncertainty and real (output growth) uncertainty. For instance, Taylor (1979) argued that if an exogenous shock hits the

---

[1] The same effect has been obtained by Ireland (1994) considering a cash-in-advance economy with an explicit credit sector.

[2] See also, Bruno and Easterly (1996), Haslag (1997), Temple (2000) and Klump (2003), for more details on the inflation-growth relationship.

economy, then in the situation of real wage rigidity a large fluctuation of output growth can only be avoided at the cost of higher inflation uncertainty. This effect, called the 'Taylor effect', thus prescribes that inflation uncertainty would negatively affect output uncertainty. According to Fuhrer (1997), a trade-off between the variances of inflation and output growth would exist depending on central bank's relative importance to tackle inflation and output volatilities. If the policy-makers wish to make the variance in output growth small, it must allow shocks that affect inflation to persist, thus increasing the variance in inflation. On the other hand, if the variance in inflation is to be contained in the face of demand and supply shocks, the policy-makers would be required to vary real output a great deal in order to stabilize inflation. Logue and Sweeney (1981) argued that in a high inflationary situation producers might be unable to differentiate between nominal and real demand shifts, which, in turn, increases the uncertainty about the relative prices. This increasing uncertainty about relative prices tends to create more volatility in production, investment and marketing decisions, and thus lead to a greater uncertainty in output growth. Thus, in contrast to 'Taylor effect', Logue and Sweeney hypothesis postulated that greater uncertainties of inflation would positively affect output uncertainty[3].

It is well recognized that uncertainty about future inflation puts a greater burden on the decision making of consumer and business by distorting their efficient allocation of resources, and thus it reduces economic well-being. Economists have frequently argued that a rise in the current inflation leads to a greater uncertainty about future inflation. The origin of this relationship goes back to the studies of Johnson (1967) and Okun (1971), but it is only after Friedman's (1977) Nobel address that the relationship gained prominence and it was studied by many analysts. In this address Friedman (1977) provided a twofold argument regarding the real effects of inflation, which is known as the Friedman hypothesis. The first part of this hypothesis states that an increase in inflation may induce an erratic policy response by the monetary authority and therefore lead to more uncertainty about the future rate of inflation, while the second part states that increasing uncertainty about inflation inhibits economic growth. Thus, according to the Friedman hypothesis, the negative welfare effects of inflation works indirectly *via* nominal uncertainty channel. These informal ideas advanced by Friedman were subsequently presented with elegant theoretical models. For instance, Ball (1992) formalized the first part of the Friedman hypothesis by

---

[3] See also, Cecchetti and Ehrmann (1999), and Clarida et al. (1999) for further expositions on the short-run trade-off nominal (inflation) and real (output growth) uncertainties.

introducing a game theoretic framework involving public and policy makers about their responses to high inflationary situation. In the model by Ball (1992), there are two types of policy-makers - a weak type and a tough type - who stochastically alternate in power, and the public knows that only the tough type is willing to bear the economic costs of disinflation. When current inflation is high, the public faces increasing uncertainty about future inflation as it is not known which policy-maker will be in office in the next period and consequently what the response to the high-inflation rate will be. Such an uncertainty does not arise in the presence of a low inflation rate because during the period of low inflation both types of policy-makers will try to keep it low, and hence uncertainty concerning future inflation will also be low[4]. In contrast to the Friedman hypothesis, the effect of inflation on its uncertainty can also be negative. The argument put forward by Pourgerami and Maskus (1987) and Ungar and Zilberfarb (1993) is that higher inflation leads economic agents to allocate more resources in generating better forecast of inflation, which, in turn, reduces their prediction error and lowers the uncertainty about inflation. In summary, the effect of inflation on inflation uncertainty is ambiguous. Similarly, the effect of inflation on output growth uncertainty is also ambiguous. In particular, a rising inflation rate would be expected to have a negative impact on output uncertainty *via* a combination of the Friedman and Taylor effects mentioned earlier. According to Ball et al. (1988), a higher rate of inflation induces firms to adjust their prices more frequently to keep up with the rising average price level. In short, prices adjust more quickly to the nominal shock, which leads to reduction in the real effects of nominal disturbances, and this, in turn, lowers the volatility of output growth. The impact could also be positive as higher inflation reduces inflation uncertainty due to the Pourgerami and Maskus effect and increases output uncertainty according to the Taylor effect.

Similar is the case for the impact of output growth on inflation uncertainty and output growth uncertainty. More precisely, the sign of the effect of output growth on macroeconomic uncertainty is ambiguous. Consider first the effect of higher output growth on inflation uncertainty. A higher growth rate raises inflation according to the Briault hypothesis and, therefore, increases inflation uncertainty, as predicted by the Friedman hypothesis. Hence the impact of output growth on nominal uncertainty is positive. On the contrary, the increased inflation rate arising from higher output growth might reduce rather than increase inflation uncertainty according to the Pourgerami

---

[4] Demetriades (1988) showed that in the presence of asymmetric information between the policy-maker and the public, a positive correlation holds between inflation and its uncertainty.

and Maskus hypothesis. In this case, the effect will be negative. Two more theories have argued for a negative effect. First, Brunner (1993) postulated that a reduction in economic activity generates uncertainty about the response of the monetary authority and hence the rate of inflation. Second, if an increase in output growth leads to a reduction in inflation because of the inflation-stabilization motive of the central bank, then inflation uncertainty also falls due to the Friedman hypothesis. Finally, consider now the effect of output growth on output growth uncertainty. An increase in output growth, given that the Briault hypothesis and the Friedman hypothesis hold, pushes inflation uncertainty upwards and output uncertainty downwards due to the Taylor effect. However, if the impact of inflation on its uncertainty is negative, the opposite conclusion holds.

Insofar as the impact of inflation uncertainty on inflation is concerned, a higher inflation uncertainty can also raise inflation rate, which is contrary to the causal link of the Friedman hypothesis. The arguments for this kind of impact have been given by Cukierman and Meltzer (1986) and Cukierman (1992). Both studies are based on the Barro-Gordon framework, where the policy-maker maximizes his own objective function which is positively related to economic stimulation through monetary surprises and negatively related to monetary growth. However, the relative weights attached to each target evolve stochastically over time. Further, due to imprecise monetary control procedure, the money supply process is also random. Thus the public faces uncertainty about both the rate of money supply growth and the objective function of the policy maker. In this scenario, a higher inflation uncertainty provides the policy-maker with an incentive to adopt an expansionary monetary policy in order to create an inflation surprise to achieve output gains. The above argument about the positive effect of inflation uncertainty on inflation has been dubbed by Grier and Perry (1998) as the Cukierman-Meltzer hypothesis. Contrary to the above view, Holland (1995) has argued that the central banks whose overriding objective is price stability and which are independent from the political processes, would tend to adopt a tighter monetary policy in the situation of higher inflation uncertainty which is often called the ‘stabilizing Fed hypothesis’. As soon as uncertainty increases after inflation, central bank reacts by contracting money supply to avoid the welfare loss due to uncertainty. Hence, Holland’s view supports the existence of a negative effect of inflation uncertainty on inflation.

Concerning the feedback effect from inflation uncertainty on output growth, two opposing sets of hypotheses have been advocated in the literature. One of these two has been proposed by

Friedman (1977) who argued that an increase in inflation uncertainty would tend to reduce the output growth. Based on the irreversibility aspect of investment, this has been formalized by Pindyck (1991) and Huizinga (1993) who have shown that inflation uncertainty increases the uncertainty regarding the potential returns on investment projects, and thus it provides an incentive to delay these projects resulting in a lower investment and output growth. Blackburn and Pelloni (2004), using a model with nominal rigidities, have also argued that nominal uncertainty exerts a negative effect on growth, channeled through its adverse impact on aggregate employment. In contrast, based on a cash-in-advance model with risk-averse agents, Dotsey and Sarte (2000) have shown that higher inflation uncertainty leads to higher output growth. The argument runs as follows. An increase in the volatility of monetary growth, and consequently of inflation, makes the return to money balances more uncertain and this leads to a fall in the demand for real money balances and consumption. Hence, agents increase precautionary savings and the pool of funds available to finance investment increases, and these two lead to a greater output growth[5].

Finally, we discuss briefly the important theoretical studies on the effect of output growth uncertainty on inflation and output growth. In the context of studying the impact of output uncertainty on inflation, Devereux (1989) showed, by introducing endogenous wage indexation in a Barro-Gordon framework, that real uncertainty increases the rate of inflation. He demonstrated that an exogenous increase in the uncertainty of real shocks causes workers to lower the optimal amount of wage indexation. The lower is the degree of wage indexation, the greater is the incentive for monetary authorities to cause surprise inflation which translates into a higher rate of average inflation[6]. Higher output uncertainty, however, may also lead to a lower inflation. This channel combines the Taylor effect with the Cukierman-Meltzer hypothesis. As the Taylor effect suggests a negative association between output uncertainty and inflation uncertainty and the Cukierman-Meltzer hypothesis illustrates a positive effect of inflation uncertainty on inflation, the combination of the two yields a negative impact of output uncertainty on inflation.

There is also a diverse view on the effect of output growth uncertainty on output growth in the sense that this effect could be negative, zero or positive. Based on the theory of saving under

---

[5] Way back in 1983, Abel studied the positive effect of inflation uncertainty on output growth.

[6] The hypothesis of Devereux regarding the causal effect of output uncertainty on inflation has also been corroborated in a recent paper by Cukierman and Gerlach (2003).

uncertainty, Sandmo (1970) and Mirman (1971) supported a positive link. According to their view, a higher uncertainty in output growth causes higher precautionary savings and subsequently rates of investment increase which, in turn, have positive impact on output growth. Black (1987) also provided argument in favour of the positive effect. His argument is based on the hypothesis that investments in riskier technologies will be pursued only if the expected returns on these investments and thus output growth are large enough to compensate for the extra risk. On the other hand, business cycle theories suggest that there is no relationship between output uncertainty and output growth. For instance, Friedman (1968) argued that the output uncertainty is due to the result of price level misperceptions by workers and firms in response to monetary shocks, while, on the other hand, change in the growth rate of output arises from the real factors such as technology. In other words, the determinants of the two variables are different from each other.

The scenario of a negative association between output volatility and output growth may be traced back to Keynes (1936), who argued that entrepreneurs should take into account the fluctuations in economic activity when estimating investment returns. The larger the output fluctuation, the larger is the risk associated with investment projects, which, in turn, lowers the demand for investment and output growth. According to Bernanke (1983) and Pindyck (1991), the negative relationship between output volatility and output growth arises from investment irreversibility at the firm level. Ramey and Ramey (1991) have shown that in the presence of commitment to technology in advance, higher real uncertainty induces firms to produce at the suboptimal level and thus lower output growth. Using the endogenous growth models to identify the nature of the relationship between output volatility and output growth, recent studies have also concluded that the relationship could be either positive or negative depending on the economic fundamentals governing the behavior of agents and the structural characteristics of the economy. The latter includes the agents’ attitudes toward risk, their preferences for learning, and the type of technology shocks. Smith (1996), de Hek (1999) and Jones et al. (2005) have argued that the effect of volatility on output growth depends on the magnitude of the elasticity of relative risk aversion. In an environment of high (low) degree of risk aversion, an increase in volatility causes an increase (decrease) in precautionary investments in physical or human capital, implying an increase (decrease) in output growth. In terms of a stochastic monetary growth model, Blackburn and Pelloni (2004) have shown that the impact depends on the type of shocks buffeting the economy.

This study has also concluded that the effect will be positive (negative) depending on whether the real (nominal) shocks dominate or not.

The references of major theoretical studies regarding the causal relationship between inflation, output growth and their respective uncertainties are presented in Table 1.1.

Table 1.1 Summarization of the theoretical literature

	Sign of the effect
Effect of inflation on output growth	
Stockman (1981), Gomme (1993), Jones and Manuelli (1995), and Gillman and Kejak (2005).	Negative
Tobin (1965), and Ireland (1994).	Positive
Effect of output growth on inflation	
Briault (1995)	Positive
Effect of inflation on inflation uncertainty	
Friedman (1977), and Ball (1992).	Positive
Pourgerami and Maskus (1987), and Ungar and Zilberfarb (1993).	Negative
Effect of inflation uncertainty on inflation	
Cukierman and Meltzer (1986), and Cukierman (1992)	Positive
Holland (1995)	Negative
Effect of inflation uncertainty on output growth	
Friedman (1977), Pindyck (1991), and Huizinga (1993)	Negative
Dotsey and Sarte (2000)	Positive
Effect of output growth uncertainty on inflation	
Devereux (1989)	Positive
Taylor (1979), Cukierman and Meltzer (1986)	Negative
Effect of output growth uncertainty on output growth	
Sandmo (1970), Mirman (1971) and Black (1987)	Positive

(Continued on the next page)

Table 1.1 (continued from the previous page)

Bernanke (1983), and Pindyck (1991)	Negative
Effect of inflation uncertainty on output growth uncertainty	
Taylor (1979)	Negative
Logue and Sweeney (1981)	Positive
Effect of output growth uncertainty on inflation uncertainty	
Fuhrer (1997)	Negative
Devereux (1989)	Positive

1.3 Review of empirical studies

The theoretical literature including the hypotheses proposed and the subsequent observations by the researchers naturally gave rise to many empirical studies examining the various relationships involving inflation, output growth and their respective uncertainties. In this section, we present a brief review of the empirical literature concerning these relations.

One primary issue to start with, in this kind of literature, is the measurement of uncertainty. Early empirical studies on the relationship between inflation, nominal uncertainty, output growth and real uncertainty (see, among others, Okun (1971), Gordon (1971), Logue and Willett (1976), Logue and Sweeney (1981), Taylor (1981), Zarnowitz and Moore (1986), Clark (1997), and Judson and Orphanides (2003)) used the standard deviation or variance as a measure of inflation and output uncertainty. Obviously then it is a measure of variability, but not of uncertainty. Similar problems beset with the survey-based analysis where uncertainty is proxied by the variability across the individual forecasts. Holland (1993), Golob (1993), and Davis and Kanago (2000) have compiled many of these earlier studies and their main finding related to the relationship between inflation, inflation uncertainty and output growth is that the Friedman hypothesis, i.e., higher inflation raises inflation uncertainty, which, in turn, reduces output growth, holds in most of these studies[7].

---

[7] See, Chew et al. (2011), for a survey article on measures of macroeconomic uncertainty.

The early measurements of uncertainty, namely, the cross-sectional dispersion of individual forecasts from surveys or the moving standard deviation of the variable under study, were subsequently replaced by a more formal time series measurement. It is only after Engle's (1982) seminal paper on autoregressive conditional heteroskedasticity (ARCH) and its subsequent generalization called the generalized ARCH (GARCH) by Bollerslev (1986), that most of the studies have measured inflation uncertainty as the conditional variance of unanticipated shocks to inflation process[8]. Engle (1983) and Bollerslev (1986) compared the graphs of conditional variance of inflation obtained from the estimated ARCH and GARCH models, respectively, to the average inflation rate for the US economy. They observed that during the period when inflation uncertainty is high, inflation is not particularly high, but when inflation uncertainty is low, average inflation rate is quite high. This led them to conclude that inflation and inflation uncertainty are related in a way which is contrary to the Friedman-Ball hypothesis. The evidence was also found to be the same in the study by Cosimano and Jansen (1988). Brunner and Hess (1993) have pointed out two reasons behind the failure of finding any support to the above hypothesis. According to them, for testing the Friedman-Ball hypothesis directly, conditional variance should be taken to be a function of lagged inflation, and an asymmetric behaviour should also be included in the conditional variance specification instead of a symmetric GARCH specification so as to allow for asymmetric news impact on inflation uncertainty. Subsequently, with the advancement of exponential GARCH (EGARCH) model (Nelson (1991)) and threshold GARCH (TGARCH) model (Glosten et al. (1993)), recent studies have used these two variants of the GARCH model to allow for asymmetric effects of past shocks in the conditional variance.

Both the Friedman-Ball and Cukierman-Meltzer hypotheses can be directly tested in a simultaneous approach where one uses the usual GARCH-in-mean (GARCH-M) model and the GARCH model is generalized to include lagged inflation rate in the conditional variance equation. In particular, Brunner and Hess (1993) allowed for asymmetric effects of inflation shocks on the conditional variance specification of inflation, and found a link between the US inflation and its uncertainty. Caporale and Mckierman (1997) also observed a positive relation between the US inflation and its uncertainty. Their findings are robust to some alternative inflation models as well. Joyce (1995) applied the EGARCH and TGARCH models to the UK inflation data and found that

---

[8] In his study, Hamilton (2010) has highlighted the importance of the GARCH modelling approach in macroeconomics.

inflation uncertainty is more responsive to positive inflation shocks than to negative shocks. Baillie et al. (1996) applied an autoregressive fractionally integrated moving average (ARFIMA) model to describe the long memory process of inflation dynamics for ten countries[9]. They found that for six low inflation countries *viz*., Canada, France, Germany, Italy, Japan and the USA, there is no apparent relationship between mean and variance of inflation. However, for the high inflation economics of Argentina, Brazil, Israel and the UK, there is strong support for the Friedman hypothesis.

Fountas et al. (2000) and Karanasos et al. (2004) have found strong evidence in favour of a positive bi-directional relationship between inflation and inflation uncertainty, by using the GARCH model that allows for simultaneous feedback between conditional mean and conditional variance of the US inflation series. With a similar model, Fountas (2001) found empirical support for the Friedman-Ball hypothesis for the UK inflation series. Hwang (2001) investigated the relationship for the US monthly inflation from 1926 to 1992 with various ARFIMA-GARCH type models and found that inflation affected its uncertainty weakly and negatively whereas inflation uncertainty affected inflation insignificantly. Kontonikas (2004) applied the TGARCH model to the UK inflation series to capture asymmetry in the conditional variance and the component GARCH (CGARCH) model to capture short-run and long-run inflation uncertainties in the model. His results support a positive effect of inflation on inflation uncertainty but not the reverse causation. Berument and Dincer (2005) have observed, using the full information maximum likelihood method, that inflation caused inflation uncertainty for all the G7 countries, while increased uncertainty lowered inflation for Canada, France, the UK and the US, and raised inflation only in case of Japan.

Some studies have examined the link between nominal uncertainty and the level of inflation by considering a two-step procedure where in the first step the conditional variance is estimated from a GARCH/GARCH-type model and in the second the Granger causality is applied to test for the existence of bi-directional effects. In particular, by using the GARCH and component-GARCH models, Grier and Perry (1998) have found that in all the G7 countries, inflation significantly raises

---

[9] 'Long memory' process of inflation typically refers to the persistence behaviour of inflation with an order of integration which differs significantly from 0 and 1. As argued by Baillie et al. (1996), and Baillie et al. (2002), the fractionally integrated models are sufficiently flexible to handle such characteristic of inflation.

inflation uncertainty, but the evidence is weaker in case of inflation uncertainty to cause inflation. For inflation series of six European Union countries, Fountas et al. (2004) have employed the EGARCH model of conditional variance to investigate the links between inflation and inflation uncertainty, and found that in five European countries inflation significantly raised its uncertainty. Conrad and Karanasos (2005) have used an ARFIMA-FIGARCH process to capture the high degree of persistence in inflation and nominal uncertainty for ten European countries, and found bi-directional causal relationship between inflation and inflation uncertainty. Thus, this evidence supports the Friedman-Ball hypothesis for all these countries but provides mixed results for Cuckierman and Meltzer hypothesis. The evidence is also similar for the three most industrialized countries *viz*., the UK, the US and Japan (see, Conrad and Karanasos (2005), for details). Daal et al. (2005) have examined the relationship for a large number of developed and emerging countries by using an asymmetric power GARCH (PGARCH) model, and found that their results show that inflation Granger causes inflation uncertainty for most of the countries while the evidence on causality in the reverse direction is mixed[10].

Business cycle fluctuations and economic growth have long been treated as independent issues in macroeconomics. Despite increasing attention to integrate growth and business cycle theories in recent decades (see, for example, Nelson and Plosser (1982), and Kyland and Prescott (1982) for details), empirical evidence on the interrelationship between output growth and economic fluctuations remains equivocal. The early empirical studies on the relationship between output variability and growth used cross-sectional as well as pooled data, and found mixed evidence (see, Kormendi and Meguire (1985), Zarnowitz and Moore (1986), Zarnowitz and Lambros (1987), Grier and Tullock (1989), Ramey and Ramey (1995), Martin and Rogers (2000), Dawson and Stephenson (1997), Dawson et al. (2001), and Chatterjee and Shukayev (2006), for details). It is rather recent that output uncertainty, as opposed to output variability, is being measured by the conditional variance of unanticipated shocks to output growth and estimated from the GARCH model. In particular, Caporale and Mackiernan (1996, 1998), using the GARCH-M model to the UK and the US data, have obtained positive relations between output growth and its

---

[10] The PGARCH process is nested in a general ARCH type model where a Box-Cox (1964) transformation of the conditional variances is used (see, for instance, Hentschel (1995) for details).

volatility, thus supporting the Black (1987) hypothesis. Speight (1999), on the other hand, found no relationship between output growth and its uncertainty for the post-war monthly UK data.

There is also the issue concerning the asymmetric effects of output volatility on output growth. Hamori (2000) used the GARCH, TGARCH and EGARCH models to examine the existence of asymmetry between the volatility and output growth in the US, the UK and Japan. His results show no evidence that volatility is high during recessions and low during the periods of expansions. Henry and Olekalns (2002), on the other hand, have found that output volatility is high when the US economy is contracting. Using a sample of 24 OECD countries, Kneller and Young (2001) observed a negative relationship between output volatility and output growth. Fountas et al. (2004) have employed the EGARCH-M model to examine this relationship using quarterly data on Japanese GDP. They have found that output uncertainty does not affect output growth. Further, they have not found any asymmetric impact of past shocks on output growth volatility. By applying the power-GARCH-M model with lagged output growth being included in the variance equation, Karanasos and Schurer (2005) have obtained a strong negative bi-directional feedback between output growth and its uncertainty in case of Italian data[11].

Fountas and Karanasos (2006) have applied the GARCH-M model augmented with a lag output growth term in the conditional variance specification to verify the growth and uncertainty linkages in the USA, Germany and Japan. Their findings support that output growth uncertainty leads to higher output growth in two of the three countries *viz*., Germany and Japan, while output growth negatively causes its uncertainty in case of Germany and the USA. Beamont et al. (2008) have employed several GARCH-M models to investigate the above relationship in 20 OECD countries and found hardly any evidence of this link. In a two-step procedure, Jiranyakul (2011) has tested the hypothesis proposed by Black (1987) for the five Asian countries *viz*., India, Japan, Malaysia, South Korea and Japan, and found that output volatility positively Granger causes output growth only for Japan and the South Korea. Thus the available empirical evidence shows a mixed outcome regarding the relationship between output growth uncertainty and output growth.

We have so far discussed those empirical studies that have considered the relationship between either inflation and inflation uncertainty or output growth and output growth uncertainty.

---

[11] See, Apergis (2004), for an excellent study on the relation between inflation and inflation uncertainty using panel data.

With the introduction of multivariate GARCH model (MGARCH) by Bollerslev (1990)[12], more recent studies use this model, mostly in bivariate case, where the relationship involving inflation, output growth and their respective uncertainties can be analyzed together, and hence a greater number of hypotheses, as predicted by theories, can be tested directly. The two most commonly used bivariate GARCH specifications are the diagonal (constant conditional correlation) CCC model[13] and the BEKK model[14].

In this case of studying the relationship in a multivariate framework, the approach is, as before, simultaneous or two-step. Some studies have relied on the procedure where the relevant hypotheses can be tested simultaneously, while others have used the two-step approach, where inflation and output growth uncertainties are estimated first from a multivariate model and then the Granger causality test is applied to detect the nature of the relationships. In particular, Grier and Perry (2000), using a bivariate CCC-GARCH-M model, have found that higher inflation uncertainty significantly lowers output growth in the US. Applying a bivariate model to the Japanese data, Fountas et al. (2002) have tested the causal relationships in a two-step procedure, and found that inflation reduces output growth both directly and indirectly *via* the inflation uncertainty channel. Additionally, their results support Holland's (1995) stabilization hypothesis that higher inflation uncertainty reduces inflation rate. Grier et al. (2004) and Shields et al. (2005) have used the BEKK-threshold GARCH (TGARCH)-M model to the US data to establish relationships between inflation, output growth, nominal (inflation) and real (output growth) uncertainties. Both studies have found that inflation uncertainty reduces output growth and inflation, while higher output uncertainty increases growth but reduces inflation significantly. It has also been found that both inflation and output growth display evidence of significant asymmetric response to positive and negative shocks of equal magnitude. Further, Elder (2004) has observed that inflation uncertainty significantly reduces real economic activity in the US. To test for the impact of real and nominal uncertainties on inflation and output growth, Bredin and Fountas (2005) have employed the BEKK-TGARCH-M model, similar to that of Grier et al.

---

[12] See, Bauwens et al. (2006), for an excellent survey on multivariate GARCH models.

[13] Bollerslev (1990) first introduced a class of constant conditional correlation (CCC) model in which conditional correlation matrix is assumed to be constant, and thus the conditional covariances are proportional to the product of the corresponding conditional standard deviations.

[14] Engle and Kroner (1995) proposed the BEKK model (an acronym used for the synthesized work on multivariate model of Baba, Engle, Kraft and Kroner). The model has the good property, *viz*., that the conditional variance-covariance matrix is positive definite by construction.

(2004), to the G7 countries covering the period 1957 to 2003. Their results suggest that in most of the seven countries output growth uncertainty is a positive determinant of the output growth, and that the evidence on the effect of inflation uncertainty on inflation and output growth is mixed. In another paper, by applying similar methodology to the 14 European Union countries, Bredin and Fountas (2009) have found that in majority of these countries output uncertainty significantly reduces output growth, while inflation uncertainty in most cases increases output growth. Finally, inflation and output growth uncertainty have been found to have mixed effects on inflation. Wilson (2006) has constructed a bivariate EGARCH-M model with Japanese inflation data spanning from 1957 to 2002 in order to examine the links between inflation, inflation uncertainty, output growth and output growth uncertainty. He has found that increased uncertainty is associated with higher average inflation and lower average growth in Japan. Fountas et al. (2006) and Fountas and Karanasos (2007) have explored the dynamic relationships for the G7 countries in a two-step procedure. They have applied the CCC-GARCH model as well as the CCC-component GARCH model, and found similar results. Bhar and Mallik (2010) have observed, based on the CCC-EGARCH-M model and the Granger causality test, that inflation uncertainty increases inflation significantly in the US covering the period from1957 to 2007. Conrad and Karanasos (2010) have applied an augmented version of the CCC-GARCH model which allows for lagged-in-mean effects, level effects as well as asymmetries in the conditional variances to the US data. Their results support that high inflation as well as high inflation uncertainty inhibit output growth, but output growth increases inflation in an indirect way through a reduction in real uncertainty. Similar studies with data on Mexican economy and some Central and Eastern European countries have been carried out by Grier and Grier (2006) and Omay and Hasanov (2010), respectively.

In the following table i.e., Table 1.2, we have mentioned the major empirical studies on the relationship involving inflation, output growth and their uncertainties. Brief descriptions of these works have already been given in the preceding section.

Table 1.2 Summarization of the empirical literature

Univariate studies on the relationship between inflation and inflation uncertainty	***Methodology used in the study***
Brunner and Hess (1997), Caporale and Mckierman (1997), Joyce (1995), Baillie et al. (1996), Fountas et al. (2000), Fountas (2001), Hwang (2001), Karanasos et al. (2004), Kontonikas (2004), and Berument and Dincer (2005).	Simultaneous estimation procedure
Grier and Perry (1998), Fountas et al. (2004), Conrad and Karanasos (2005), and Daal et al. (2005).	Two-step estimation technique
Univariate studies on the relationship between output growth and output growth uncertainty	
Hamori (2000), Henry and Olekalns (2002), Kneller and Young (2001), Fountas et al. (2004), Karanasos and Schurer (2005), and Beamont et al. (2008).	Simultaneous estimation procedure
Fountas et al. (2006), and Jiranyakul (2011)	Two-step estimation technique
Multivariate studies on the relationship between inflation, output growth, inflation uncertainty and output growth uncertainty	
Grier and Perry (2000), Elder (2004), Grier et al. (2004), Shields et al. (2005), Bredin and Fountas (2005), Wilson (2006), Bredin and Fountas (2009), Bhar and Mallik (2010), and Conrad and Karanasos (2010).	Simultaneous estimation procedure
Fountas et al. (2002), Fountas et al. (2006), and Fountas and Karanasos (2007).	Two-step estimation technique

Since 1960s most of the industrialized countries have experienced long-term swings in the level of inflation. Inflation had progressively risen in the 1960s and 1970s before it declined in the 1980s. Inflation further declined in the early to mid-1990s and since then remained low and stable. These observations have led many researchers to analyze the statistical properties of inflation persistence over the last two decades. However, the findings on whether inflation is persistence in nature or not are mixed in nature[15]. For instance, Taylor (2000) found that the US inflation persistence has declined in the 1980s. Considering a possible structural break, Levin and Piger (2003) have argued that persistence in inflation varies with the monetary policy regime. By applying a Bayesian VAR model, Cogley and Sargent (2001, 2005) have claimed that the US inflation persistence has experienced a significant decline. Kumar and Okimoto (2007) have investigated the dynamics of inflation persistence using long memory approach and found that there has been a marked decrease in the US inflation persistence over the past two decades. By employing an ARMA model with time varying autoregressive parameters, Beechey and Osterholm (2009) have shown that inflation persistence has fallen remarkably in a number of European countries after 1999. On the contrary, measuring persistence as the largest autoregressive root in the inflation, Stock (2001) and Stock and Watson (2007) have concluded that the US inflation persistence has remained unchanged for many decades. Pivetta and Reis (2007) have also drawn similar conclusion for the US economy. Employing the rolling regression on split samples, Batini (2006) has found that European inflation has varied only marginally over the past 30 years. Similar results are presented in O’Reilly and Whelan (2005) as well, where the estimates of the parameters indicating persistence have been found to be, in general close to one and essentially constant over time for Euro area.

Another important stylized fact during 1980s is the significant decline in the volatility of output growth in most of the industrialized countries. Economist dubbed this phenomenon as the ‘Great Moderation’. Among several studies, some have presented evidence in favor of structural breaks from a high to low volatility state while others have estimated regime switching models. For example, by applying Markov switching regression models, Hamilton (1988, 1989) showed

---

[15] See, among others, Kim (1993), Evans and Wachtel (1993), Pippenger and Goering (1993), Garcia and Perron (1996), Gonzalez and Gonzalo (1997), Crowder and Hoffman (1996), Burdekin and Siklos (1999), Bainard and Perry (2000), Camarero et al. (2000), Nelson (2001), Benati (2002), Kim et al. (2003), Murray et al. (2009), Tsong and Lee (2010, 2011), in this context.

that the output fluctuation is generated from a recurrent shift between high and low growth states. Hamilton and Susmel (1994) and Kim et al. (1998) suggested that the long-run variance dynamics may include regime shifts. Kim and Nelson (1999), Mills and Wang (2003), Bhar and Hamori (2003) have applied the Markov switching heteroskedasticity model to examine the volatility in the US output growth series. McConnell and Perez-Quiros (2000), Blanchard and Simon (2001), Ahmed et al. (2004), Fang and Miller (2007), and Burren and Neusser (2010) have identified a significant reduction in the volatility of the US output growth. Considering the G7 countries, Summers (2005), and Stock and Watson (2005) have found a structural break in the series on volatility of output growth. The breaks, however, occur at different times in different countries. Kent et al. (2005) has examined a sample of 20 OECD countries and demonstrated a considerable decline in the volatility of output growth around the developed world.

Most of the studies discussed above mainly deal with the persistence behavior of inflation and output growth. However, there are also a few studies that address the non-linearity aspect of the relationship between inflation and output growth. In fact, recently it is being argued that the relationship between output growth and inflation, far from being linear, is influenced by the level of inflation. While investigating the non-linearity of the relationship between inflation and growth, Fischer (1993) emphasized on the existence of a threshold level above and below of which the growth effects of inflation differ. More specifically, he showed that the relationship is positive for low levels of inflation, but negative or insignificant for high levels of inflation. Bruno and Easterly (1995) studied the inflation-growth relationship for 26 countries over the 1961-1992 period. They found negative relations between inflation and growth when inflation level exceeded a threshold. At the same time they showed that impact of low inflation on growth is quite ambiguous. Sarel (1995) found the evidence of structural breaks in interaction between inflation and growth. Barro (1997) used a panel data for 100 countries over the period 1960-1990 and obtained clear evidence that a negative relationship exists at high inflation level. But there is not enough information to argue that the same conclusion holds for low inflation rates. Khan and Senhadji (2001) investigated the inflation-growth relationship for both developed and developing countries over the period of 1960-1998. The authors applied the method of non-linear least squares to deal with nonlinearity in the relationship. The existence of such non-linear patterns has also been confirmed by other researchers, such as Ghosh and Phillips (1998), Christoffersen and Doyle (1998), Judson and

Orphanides (2003), Burdekin et al. (2004), Gillman and Kejak (2005), and Lopez-Villavicencio and Mignon (2011).

1.4 Motivation

It is quite evident from the presentation in the preceding section that one of the most important research topics in macroeconomics has been the study of the relationship between inflation and output growth and the consequent links between these two important macro variables. Obviously such studies have profound implications in deciding on the economic policies involving, *inter alia*, these two variables. Given the importance of this relationship, the early studies focused on the levels of the two series. But, subsequently, the focus shifted to both the levels of these two variables and the uncertainties associated with them. Most of the empirical studies have applied basically two procedures to investigate the relationships between the levels and the volatilities. Some studies have used what is called the ‘simultaneous procedure’ (see, among others, Brunner and Hess (1993), Fountas (2001), and Kontonikas (2004)), while others have relied on a ‘two-step procedure’ (see, for example, Grier and Perry (1998), Fountas et al. (2004), for details). However, the findings on the nature of the relationship and the empirical support for the link involving these variables has been found to be varied, offering a mixed outcome. Consequently, the different hypotheses proposed in this literature have found empirical support in varying degrees. While reasons for mixed results could partly be attributed to the differences in the sample periods and frequencies of the data sets used, but more importantly, it is the methodology or modelling approach applied that would explain the varied findings. *This is the first motivation behind this research work.*

A very recent development in this literature on the nature of relationship between the levels of inflation and output growth and their uncertainties is that these relations are assumed to be neither linear nor stable over the entire time series. According to several studies, including Evans (1991), Evans and Wachtel (1993), Fischer (1993), Caglayan and Filiztekin (2003), Arghyrou et al. (2005) and Lanne (2006), social, economic and political changes can be expected to make the relationship with constant parameter linear models particularly difficult, especially when the length of the time series is long enough. While there are a number of modelling procedures through which the constant parameter assumption can be relaxed, two most important ones are: regime switching models and models with due consideration to structural breaks. In case of inflation, regime switching model is quite relevant and appropriate since by its very nature as a macro variable, inflation may change for a period of time before reverting back to its original behaviour or switching to yet another style of behaviour, often due to intervention by government and/ or regularity authorities. Similar arguments also hold for output growth. Naturally, this would mean that certain properties of the time series, such as its mean, variance and/ or autocorrelations are different in different regimes, and hence models corresponding to different regimes ought to be specified with different sets of parameters. It is also worth noting that the overall model can also be categorized as a nonlinear model over the entire sample even when regime-wise models are linear in specification.

The issue of regime switching behaviour of inflation while dealing with inflation uncertainty was first raised by Evans and Wachtel (1993). They claimed that the resultant model will seriously underestimate both the degree of uncertainty and its impact if one neglects this regime switching feature of inflation. Evans and Wachtel developed a Markov switching model of inflation that decomposes inflation uncertainty into two components, which allowed them to examine Friedman's hypothesis in the light of uncertainties with the regime changes. Ball and Cecchetti (1990) found a positive relationship between inflation and inflation uncertainty at long horizons. Kim (1993) and Kim and Nelson (1999) extended Ball and Cecchetti's study in an unobserved component model. Following Kim (1993), Bhar and Hamori (2004) adopted a Markov switching heteroskedasticity model to examine the interaction between inflation and its uncertainty in the G7 countries over both the short and long horizons. Thus, there exist some studies based on regime switching consideration, where the underlying models are mostly Markov regime switching models. In this class of models, regimes are not completely deterministic and can be determined by an underlying unobservable stochastic process depending upon the probabilities assigned to the occurrence of the different regimes.

Now, there is another class of regime switching models, where regimes can be characterized by observable variables (see, Tong (1978, 1990), Tong and Lim (1980), Chan and Tong (1986), Granger and Terasvirta (1993), Terasvirta (1998), Hagerud (1997), Gonzalez-Rivera (1998), Fornari and Mele (1996, 1997), Anderson et al. (1999), Li and Li (1996), and Brooks (2001), for details on such models). In the context of the relationship between the levels of inflation and output growth and their volatilities, there are only very few studies where observed regime based models have been used. For instance, Baillie et al. (1996) have pointed out that the relationship between inflation and inflation uncertainty is significant mostly in the periods of high inflation, and not in the periods of relatively low inflation. In a recent study, Chen et al. (2008) have observed that the effect of inflation on inflation uncertainty is asymmetric. To be more specific, they have found a U-shaped pattern for four dragon economies of East Asia, based on a nonlinear flexible regression model of Hamilton (2001), suggesting that inflation uncertainty is more sensitive to inflation in an inflationary period than in a deflationary period.

Recent works also deal with the nonlinear impact of real uncertainty on output growth[16]. In a GARCH-M set up, Henry and Olekalns (2002) have examined the effect of recessions on the relationship between output uncertainty and growth for the US economy. It is evident from their study that recessions lead to a higher output uncertainty and thus reduces subsequent output growth, while the relationship would no longer exist as the economy expands. Garcia-Herrero and Vilarrubia (2007) have shown that an asymmetric relationship exist between real uncertainty and growth. Their key findings are that a moderate degree of uncertainty improves growth while a situation of high volatility dampens it. Neanidis and Savva (2013) have examined the asymmetric effects of macroeconomic uncertainties on inflation and output growth for G7 countries in a multivariate framework. Their study supports that real uncertainty increases growth in the low regime, while it has mixed effects on inflation. On the other hand, nominal uncertainty increases inflation and reduces output at a high inflation regime. It is thus evident that such models for studying the relationships between inflation and inflation uncertainty are very few in number. In case of such models for capturing the other links involving these two as well as output growth and output growth uncertainty, the number is even fewer. Further, there are hardly any studies with GARCH-type model with special features or GARCH-M-type model involving the levels of inflation and output growth and their uncertainties where regimes are also duly incorporated. *This prevailing state of modelling in regime switching framework involving these four variables has given the second motivation for undertaking this study.*

---

[16] The nonlinear effect of output volatility on output growth is also evident from some cross country studies (see, among others, Kroft and Lloyd-Ellis (2002), Hnatkovska and Loayza (2004), Aizenman and Pinto (2005), and Kose et al. (2006).

The other approach, mentioned earlier, is to incorporate structural breaks in the relationship between the levels and the volatilities of inflation and output growth. In this approach, the links involving these variables are studied by establishing the (causal) effects obtained from the estimated relations. Very few studies (see, Kontonikas (2004), Caporale and Kontonikas (2009), and Balcilar et al. (2011)) following this approach are available, that too only with inflation and inflation uncertainty. But, to our knowledge, there is no such study involving inflation, output growth, inflation uncertainty and output growth uncertainty.

In this context, it may be mentioned that researchers working with other economic and financial variables have noted that the results from Granger causality test, which is used to study the links, tend to be sensitive with respect to changes in the sample period. For instance, Thoma (1994) and Swanson (1998) suggested that changes taking place over the sample under consideration may have substantial influence over the causal relationships. Psaradakis et al. (2005) have pointed out that the information available to understand the causality relation may not be explanatory or sufficient enough in an economic sense due to the time varying nature of the causality pattern. Based on this notion, Balcilar et al. (2011) have examined the dynamic relationship between inflation and inflation uncertainty for Japan, the US and the UK by employing linear and nonlinear Granger causality tests. Their results support the existence of a nonlinear relationship between inflation and inflation uncertainty for those countries. Since the different causal effects or links involving inflation, output growth, inflation uncertainty and output growth uncertainty may not be 'permanent' in nature and they may vary both in nature and direction not only across different sub-periods which are found based on the presence of structural breaks in the relations, but also from the one obtained based on full sample, there is scope for looking into this aspect more carefully using modern time-series based methodologies. *The third motivation for this work stems from this important issue of lack of stability in the links between the levels of inflation and output growth and their uncertainties*.

Finally, be it the regime switching approach or the 'multiple structural breaks approach', appropriate models which would also incorporate the other important characteristic of the data, need to be considered. Since managing inflation and output growth in an economy is a challenging task, policy measures to be undertaken would be more effective the more detailed and insightful the results of the empirical analysis are. *This is the final motivation for this thesis work.*

1.5 Format of the thesis

The thesis, on the whole, has attempted at studying the relationship as well as the links between inflation, output growth, inflation uncertainty and output growth uncertainty, by considering two modelling approaches i.e., regime switching model and 'sub-period based model' where sub-periods are identified by applying tests for multiple structural breaks in the system of equations involved. For this purpose, some models which are extensions and/ or generalization of some existing models with appropriate modelling considerations, have been proposed. The performances of these models and the nature of the links have been studied for the G7 countries using time series data for the period from January 1970 to June 2013. The other chapters of the thesis are organized as follows:

Chapter 2: Data and Some Important Characteristics

In this chapter, we primarily discuss about the data sets on inflation and output growth for all the G7 countries. Apart from the usual summary statistics, important characteristics like stationarity, structural breaks, and dependences in these time series, have been studied using standard statistical tests and some recently developed tests due to Perron ad Yabu (2009), and Kim and Perron (2009). The organization of the chapter is as follows. It begins with an introduction in Section 2.1. In the next section, the reasons for the choice of the G7 countries are stated. In Section 2.3, plots, summary statistics like the mean, standard deviation, and coefficients of skewness and kurtosis for all the time series are presented. In Section 2.4, important characteristics of the time series *viz*., stationarity, structural breaks, and volatility are discussed. This chapter concludes with some remarks in Section 2.5.

Chapter 3: The Effect of Inflation on Inflation Uncertainty: A Double Threshold GARCH Model

The effect of inflation on inflation uncertainty is studied in this chapter in terms of a double threshold GARCH model, where the specifications for the conditional mean and conditional variance of inflation are based on consideration of two regimes, high and low, for inflation. Further, the conditional variance model for each regime is given by the GARCH specification with an additional lag inflation term. These two latter coefficients for the two regimes depict the regime varying effects of inflation on inflation uncertainty. The format of this chapter is as follows: Section 3.1 presents the introduction to this chapter. The proposed model is described in Section 3.2. Empirical findings are discussed in Section 3.3. This chapter ends with some concluding remarks in Section 3.4.

Chapter 4: Inflation and Inflation Uncertainty: A Bivariate Model with Multiple Structural Breaks

In this chapter, we study the stability of the bi-directional relationship between inflation and inflation uncertainty for the G7 countries. The analysis is based on a two-step procedure of estimation, where, in the first step, we employ a threshold GARCH model to estimate the conditional variance of inflation, which is taken as measure of inflation uncertainty. In the second step, a VAR model involving inflation and inflation uncertainty is used with due consideration to multiple structural breaks. In this context, we apply a recently developed test by Qu and Perron (2007) to test for multiple structural breaks in a system of equations consisting of inflation and inflation uncertainty, which can be used to validate the macroeconomic hypotheses regarding the relationship between these two variables. This chapter is organized as follows. Introduction is given in Section 4.1. In Section 4.2, we briefly describe the model and methodology, especially the Qu and Perron (2007) test for multiple structural breaks in a system of equations. In Section 4.3, the empirical results are discussed. This chapter concludes with some remarks in Section 4.4.

Chapter 5: The Effects of Inflation and Output Growth Uncertainty on Inflation and Output Growth: A TBVAR-BAGARCH-M Model

In this chapter, we propose a model to analyze the regime dependent effects of inflation uncertainty and output growth uncertainty on inflation and output growth. This model allows for regime switching behavior of inflation and output growth in conditional mean, and asymmetric effects of past shocks in conditional variance. The consideration of 'in-mean' component enables us to examine different macroeconomic hypotheses on the effects of inflation and output growth uncertainty on inflation and output growth. The organization of this chapter is as follows. In Section 5.1, the introduction to this chapter is presented. The proposed model along with a benchmark model is presented in the next section. In Section 5.3, the empirical results on estimation of the models and tests of hypotheses are discussed. This chapter ends with some concluding remarks in Section 5.4.

Chapter 6: Inflation, Output Growth, Inflation Uncertainty and Output Growth Uncertainty: A Two-Step Approach with Structural Breaks

This chapter contains the analysis of the stability of the relationships involving the four variables of inflation, output growth, inflation uncertainty and output growth uncertainty. The analytical procedure is basically the same as in Chapter 4. However, the main difference is that, we now extend this study by bringing in output growth and output growth uncertainty and consequently the number of links involving these four variables also increases. The format of the chapter is as follows. Introduction is given in Section 6.1. In the next section, we describe the methodology used in this chapter. The empirical results are discussed in Section 6.3. This chapter ends with some concluding observations in Section 6.4.

Chapter 7: Summary and Future Ideas

The last chapter of this thesis begins with a brief introduction of the problem studied in this thesis. In the next section i.e., in Section 7.2, a summary of the major findings of the entire work is presented. The concluding section contains a few ideas for further work on this topic.

Chapter 2

Data and Some Important Characteristics

2.1 Introduction

The empirical study done in this thesis involves time series of inflation and output growth for the G7, a group of seven industrialized nations of the world, formed by Canada, France, Germany, Italy, Japan, the UK and the USA.

In this chapter, we first state, in the following section, why the G7 countries have been chosen to be the group of countries for this multi-country study. Thereafter, in Section 2.3, plots of these series, summary statistics like the mean, standard deviation, and coefficients of skewness and kurtosis for all the time series are presented. In Section 2.4, important characteristics of the time series *viz*., stationarity, structural breaks, and volatility are discussed. This chapter concludes with some remarks in Section 2.5.

2.2 Why the G7 Countries?

One of the most remarkable features of the macroeconomic landscape during the last five decades is the phenomenon of 'great inflation' observed in most of the industrialized countries. This phenomenon refers to the high and volatile inflation that occurred in the mid-1960s and lasted almost twenty years. In the literature, several explanations have been given as to why this phenomenon took place and lasted for almost two decades (see, for details, Blinder (1982), Braun (1984), DeLong (1997), Hetzel (1998), Orphanides (2003), Lansing (2000), Clarida et al. (2000), Meltzer (2005), and Nelson (2005)). Among all explanations, the potential responsibility of monetary policy has been in the centre of attention. Cogley and Sargent (2005) and Sargent et al. (2006) have postulated that the 'great inflation' reflected policymakers' belief that a permanent gain in output (or unemployment) relative to its potential trend could be obtained by accepting permanently higher inflation rate. This argument goes as follows: After the observation by

Samuelson and Solow in 1960 that the US data exhibit the Phillips curve, policymakers attempted to exploit the long term relationship between inflation and unemployment, allowing inflation to increase in order to reduce unemployment. Subsequently, Friedman (1968) and Phelps (1968) argued that any such trade-off was bound to be short lived: once people came to expect the higher inflation, monetary policy could not keep unemployment below its long-run equilibrium rate. Their claim was later borne out by the experience of the 1970s when rising US inflation did not bring about lower unemployment rate as prescribed by the Phillips curve. Recently, Romer (2005) has pointed out that together with the US economy, the countries in the G7 had a similar pattern in their inflation behaviours and thus implying a common monetary policy behavior. Romer (2005), Nelson (2005) and Suda and Zervou (2012) have further explained that because of this, the monetary authorities of the G7 countries followed accommodating inflation policies, as in case of the USA, during the 1970s. At the beginning of 1980, however, the monetary authorities of these countries changed their policies in a similar way so as to stabilize inflation.

During the 1980s there was another striking feature of the world macro-economy, known as the ‘great moderation’, when there was the significant decline in volatility of output growth across various developed countries. For example, Kim and Nelson (1999), McConnel and Perez-Quiros (2000), and Blanchard and Simon (2001) have identified a rather dramatic reduction in the US output growth volatility in the early 1980s. Mills and Wang (2003), Summers (2005), Stock and Watson (2005) have considered the G7 countries and Australia, and observed a structural break in the volatility of the output growth. Macroeconomic literature (see, among others, Stock and Watson (2003, 2005), Ahmed et al. (2004), Clarida et al. (2000), Bernanke (2004), and Summers (2005)) suggests that the most important explanation for the ‘great moderation’ is good monetary policy, which indirectly affects the volatility of output growth by providing more stable economic environment with lower inflation and lower inflation volatility.

It is clear from the above two points that both inflation, output growth and their volatilities of most of the developed nations including the G7 countries declined significantly in period of 1980s as compared to 1970s. While this decline has been widely confirmed by several empirical studies, there are only few empirical evidence regarding the linkages between inflation, output growth and their volatilities through appropriate models with due consideration to structural breaks as well as regime changes, which is the primary focus of this thesis. Since the transition from more volatile period of the 1970s to an era of less volatile period of 1980s and 1990s has been documented in the literature mostly for the developed nations including the G7, it was decided that this study would be carried out for the G7 countries covering the period beginning with early 1970s till recently.

2.3 Data, Plots and Summary Statistics

Like most of the empirical studies on the relationships between inflation, output growth, inflation uncertainty and output growth uncertainty, monthly data (see, for instance, Grier and Perry (1998), Fountas et al. (2002), Fountas et al. (2004), Bredin and Fountas (2005)) have been used for this study. In doing so, we have taken monthly time series of consumer price index (CPI) and industrial production index (IPI) as measures of the monthly price level and output, respectively. The time series on CPI and IPI at monthly frequency of all the G7 countries have been downloaded from the official website of Federal Reserve Bank of St. Louis (http://research.stlouisfed.org/). The available time series on CPI is not adjusted of seasonality while the IPI series is given as seasonally adjusted for. Hence, the monthly CPI series has been adjusted for seasonality by applying the X12-ARIMA filtering method. The time period considered is from January 1970 to June 2013. The total number of observations for all the series is 522. The time series on inflation, $\tilde{\pi}_t$, has been obtained as the monthly differences of the logarithm values of the consumer price index in percentage i.e., $\tilde{\pi}_t = \log(\mathrm{CPI}_t/\mathrm{CPI}_{t-1}) * 100$. Likewise, the output growth series denoted as y_t, has been obtained as $y_t = \log(\mathrm{IPI}_t/\mathrm{IPI}_{t-1}) * 100$. All the computations required in this thesis have been done with Eviews 7 and GAUSS.

The time series of inflation and output growth for all the G7 countries are plotted in Figures 2.1 and 2.2, respectively. It is visually evident that all the inflation series have trend - although segmented in nature, especially in case of Canada, France, Italy, Japan and the USA - while no such clear trend is exhibited in the output growth plots of the seven countries. Further, it appears from the plots in Figure 2.1 that there may be at least one structural break in each of the seven time series on inflation. It is also evident that both the inflation and output growth series exhibit volatility for all the seven countries – although sometimes with episodes of low volatility for some countries.

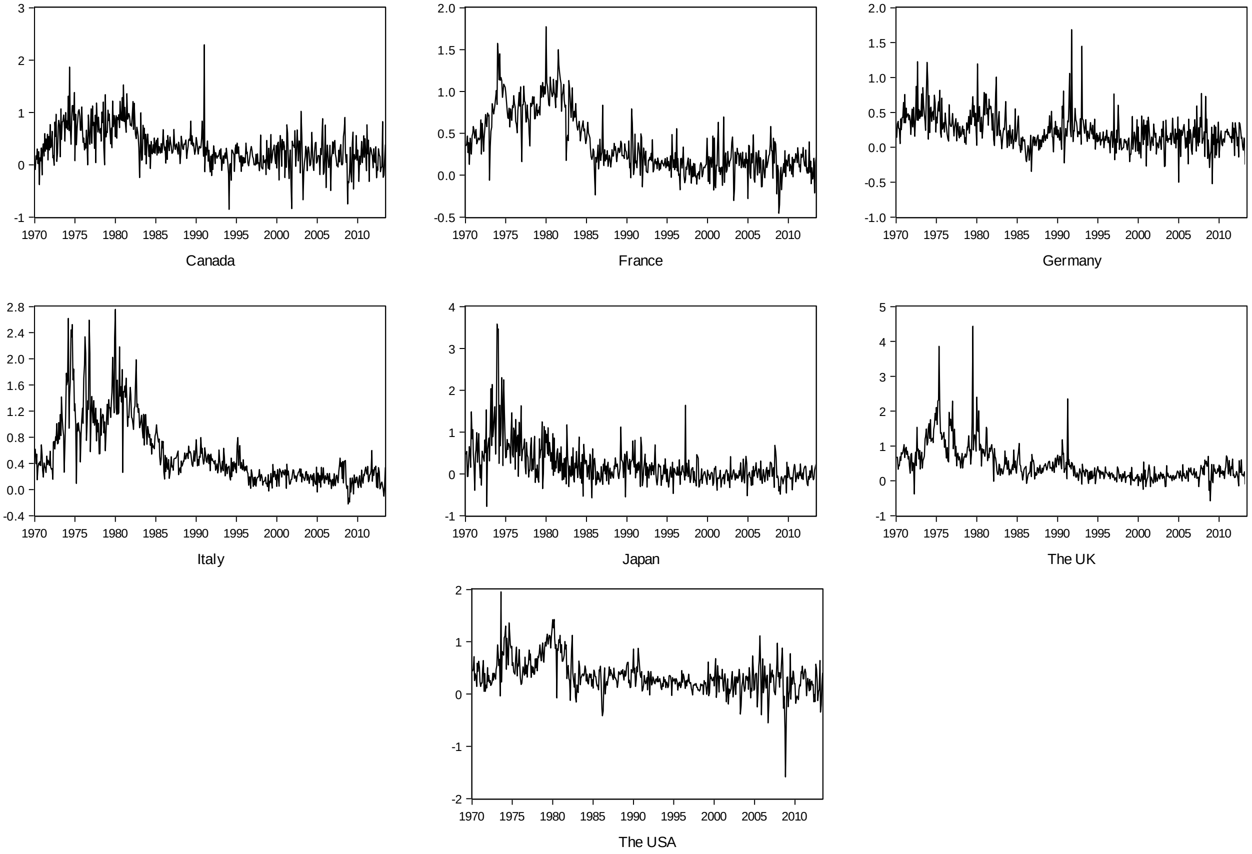

Figure 2.1: Time series plots of inflation of the G7 countries

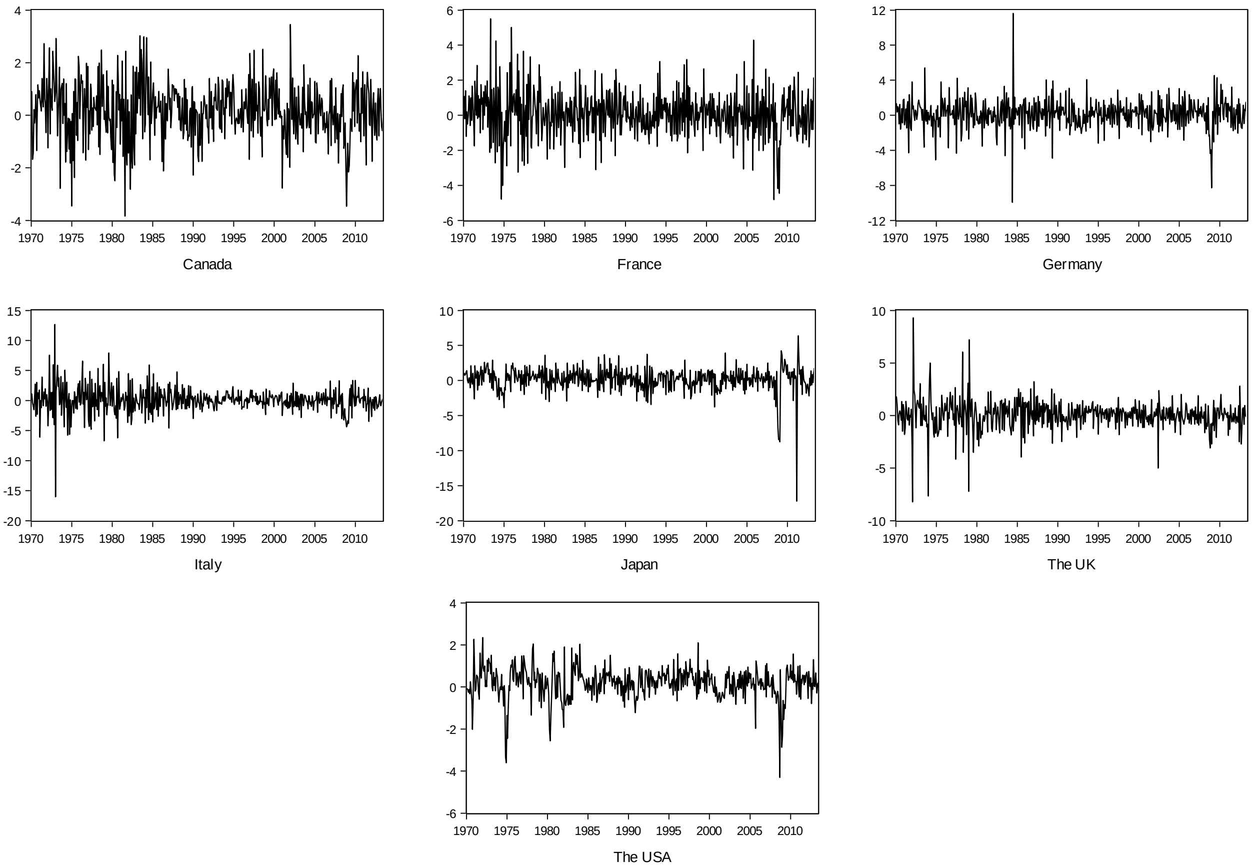

Figure 2.2: Time series plots of output growth of the G7 countries

We now represent the summary statistics on inflation and output growth of all the seven countries in Table 2.1.

Table 2.1 Descriptive statistics on inflation and output growth

Country	*Canada*	*France*	*Germany*	*Italy*	*Japan*	*The UK*	*The USA*
				Inflation			
Mean	0.346	0.372	0.233	0.555	0.218	0.472	0.349
Std. dev.	0.379	0.359	0.251	0.508	0.498	0.513	0.331
Skewness	0.613	0.849	1.172	1.572	2.620	2.514	0.329
Kurtosis	4.765	3.245	7.066	5.594	14.544	14.298	6.650
Jarque-Bera	100.33*	63.92*	478.22*	360.62*	3489.17*	3319.76*	298.62*
				Output growth			
Mean	0.162	0.075	0.133	0.073	0.145	0.056	0.185
Std. dev.	1.093	1.357	1.699	2.135	1.729	1.413	0.752
Skewness	-0.231	-0.004	-0155	-0.284	-2.678	-0.182	-1.169
Kurtosis	3.512	4.439	10.085	11.914	25.210	12.815	8.189
Jarque-Bera	10.31*	44.98*	1091.83*	1731.91*	11330.71*	2094.05*	703.17*

[indicates significance at 1% level of significance.]*

From this table it is evident that among the seven countries, Italy exhibits the highest average inflation of 0.555 per cent with the standard deviation of 0.508 per cent. The three countries *viz*., Italy, Japan and the UK have larger standard deviations than the remaining four countries. The entries of this table also indicate that all the seven inflation series are positively skewed and have leptokurtic distributions. It may, in particular, be noted that the value of skewness is the highest, 2.620, for Japan, while for the UK it is slightly below this. As for the kurtosis, the highest value of 14.544 is found for Japan and it is followed by the UK with a value of 14.298. The kurtosis values for Germany and Italy are also moderately high. Therefore, as expectedly, results of the Jarque-Bera normality test clearly indicate that the null hypothesis of normality is rejected for all the inflation series with the test statistic value being, in particular, very high for countries like Japan and the UK.

Similarly, the descriptive statistics for output growth indicate that among these seven countries, the USA shows the highest average output growth of 0.185 per cent, while Italy exhibits the highest standard deviation of 2.135 per cent. The skewness measure indicates that all the output growth series are negatively skewed with Japan having the highest value i.e., -2.678. The kurtosis measure shows that all the output growth series are leptokurtic. In fact, in most of these countries, the kurtosis values are quite high, with Japan having the highest value of 25.210. The deviation from normality is also confirmed by the reported Jarque-Bera statistic values. The null hypothesis of normality is found to be rejected at 1% level of significance for all the seven series.

2.4 Important Characteristics of the Time Series

In order to find the important characteristics of all the data sets, we have carried out some tests, the results of which are presented in Tables 2.2 and 2.3. The properties of time series that we are basically interested in studying are stationarity, structural break(s) and volatility. It is worth mentioning that we have used two recent tests to test for unit roots in presence of one unknown structural break in the time series.

2.4.1 Stationarity and structural break

We first report and discuss on the stationarity/ nostationarity status of all the time series on inflation and output growth. This statistical issue has special relevance for inflation since in the earlier studies on developed economies, especially those on the UK and the USA, the unit root status of the time series were found to be mixed (see Kontonikas (2004), Bhar and Hamori (2004), Fountas et al. (2004), Daal et al. (2005), Conrad and Karanasos (2006), and Fountas et al. (2006), for details). It may be noted, in this context, that the span of the data sets used in these studies is quite large. Hence, structural breaks in the trend function of these series are likely to occur, and as Perron (1989) first pointed out, disregarding this could mislead the conclusion on the presence of unit roots in the series.

To test for stationarity of a time series, most often the augmented Dicky-Fuller (ADF) (1979) test is used[17], where the null hypothesis of nonstationarity in the sense of having unit roots i.e., the underlying trend being stochastic in nature, is tested against the alternative of stationarity. However, due to the influential work by Perron (1989), the commonly used ADF test has been criticised because of its bias towards non-rejection of the null hypothesis of a unit root against the alternative of trend stationarity in the presence of a structural break in the deterministic trend, and also for its low power for near integrated process. Subsequently, Perron (1989, 1990) proposed an alternative unit root test which allows for the possibility of a structural break in the trend function under both the null and alternative hypotheses. This means that if a break/ change in the series is present, it is allowed under both the null and the alternative hypotheses, and thus it is likely to lead to improvement in the power of the test as against the standard ADF test. However, one serious limitation to this test is that it is based on the assumption of a known break date. Subsequently, Zivot and Andrews (1992), Perron (1997), and Vogelsang and Perron (1998), among others, have treated the break date to be unknown, which is endogenously determined from the model.

However, recently Kim and Perron (2009) have pointed out that in all these tests with an endogenous break point, i.e., those by Zivot and Andrews (1992), Perron (1997), and Vogelsang and Perron (1998), a trend break is not allowed under the null hypothesis. These tests consider a break in the time series under the alternative only. Hence, tests of this kind are likely to be affected

---

[17] Phillips-Perron test (1988) is also quite common and often used.

in terms of size and power. To overcome this limitation, Kim and Perron (2009) have developed a new test procedure on the line of Perron's (1989) original formulation of trend break being allowed under both the null and alternative hypotheses, but the break date is now assumed to be unknown. Since the existence of a structural break in the trend function is an important problem with long-horizon data and the horizon of the time series considered in this thesis is quite long- from January 1970 to June 2013 – we have applied this unit root test proposed by Kim and Perron because of its distinct advantage, as already mentioned, in case there is a break in the deterministic trend of the series.

Now, prior to applying this unit root test, it is most important to have the information on whether or not a structural break is present in a given time series, especially when the break date is assumed to be unknown as in the case with the Kim-Perron (2009) test. Further, it may be noted in this context that in the absence of a trend break, the well-known ADF test has the highest power than any other alternative test, and it is the most appropriate test for testing the presence of unit roots in a time series. It is, therefore, all the more important that the knowledge on presence or absence of a break in the trend function is available before deciding on the appropriate unit root test. However, as pointed out by Perron and Yabu (2009), testing for structural break in the trend function depends on whether the noise component is stationary or nonstationary having unit roots. Thus there is some sort of a circular problem in testing for these twin issues. To deal with this, recently Perron and Yabu (2009) have proposed a test for structural change in the trend function of a univariate time series, which can be performed without any prior knowledge on whether the noise component is stationary or nonstationary containing unit roots[18]. Since this test is very general in its approach insofar as the assumption on noise is concerned, we have performed this test to detect the presence of structural break, if any, in the trend function of a time series. Thus, in case the Perron-Yabu test suggests that there is no break in the deterministic trend, we apply the usual ADF test; otherwise, we use the Kim-Perron test to test the null hypothesis of unit roots

---

[18] Perron and Yabu (2009) have considered a quasi-feasible generalized least squares technique that uses a super-efficient estimate of the sum of autoregressive parameters, which governs the stationary or integrated behaviour of a time series.

against the alternative of stationarity with a break in the deterministic trend function under both the hypotheses[19].

It may be noted that three models - *Model I*, *Model II* and *Model III* - representing a single change in intercept only, a one-time change in the slope of linear trend function without a change in level, and a simultaneous change in the intercept and the slope coefficients, respectively, are considered for the Perron-Yabu test. For this test, we have chosen the trimming parameter to be 0.15. Since the relevant test statistic for *Model III* has the highest power against the three alternatives, we have considered this model only. The test statistic values are reported in Table 2.2. We first discuss about the findings on inflation.

Table 2.2 Results of tests for structural break and unit roots in inflation and output growth series

Country	*Perron-Yabu structural break test*	*Kim-Perron unit root test*	*Estimated break date*	*ADF unit root test*
Inflation				
Canada	53.029*	-21.615*[0.29]	June 1982	
France	48.350*	-8.000*[0.31]	September 1983	
Germany	8.741*	-12.948*[0.29]	October 1982	
Italy	12.557*	-5.034*[0.30]	December 1982	
Japan	21.985*	-12.279*[0.16]	December 1976	
The UK	41.028*	-7.767*[0.27]	December 1981	
The USA	27.492*	-15.488*[0.27]	September 1981	
Output growth				
Canada	1.829			-9.167*
France	0.251			-11.680*
Germany	-0.128			29.977*
Italy	0.246			32.121*
Japan	-0.159			13.702*
The UK	0.471			27.351*
The USA	0.839			-8.207*

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively. The fractions in parentheses denote the estimated break fraction.]*

---

[19] A GAUSS program code for Perron and Yabu (2009) structural break test and a MATLAB code for Kim and Perron (2009) unit root test in presence of a structural break have been taken from the official website of Pierre Perron.

The Perron-Yabu test statistic values are found to be significant for all the inflation series, which clearly establish that either or both of intercept and slope of the trend function have undergone structural change. The presence of one significant change in the deterministic trend of inflation is thus confirmed for each of the G7 countries.

With this empirical finding on the presence of a structural break in the trend function of inflation, we have applied the third variant of additive outlier model[20], *Model* A3 in Kim and Perron's study, to each of the seven inflation series for testing the null hypothesis of unit root with a deterministic trend break against the alternative of stationarity with a break in the deterministic trend. Following Kim and Perron, the test statistic values are reported in the 3rd column of Table 2.2. The computed values of t-statistic are compared with the appropriate critical values available in Perron (1989) and Perron and Vogelsang (1993). The findings clearly suggest that the inflation series of each of these countries is stationary when the presence of one structural break is taken into account. In each case, the null hypothesis of a unit root with a trend break against the alternative of a stationary process with a break is rejected. We thus conclude that the underlying data generating process for each of the seven inflation series is a trend stationary process (TSP) having a structural break in the respective deterministic trend function[21]. Thus, stationary time series on inflation for each country, denoted by π_t, has been obtained after removal of the segmented deterministic trend from $\tilde{\pi}_t$. Specifically, this has been obtained by regressing $\tilde{\pi}_t$ on an intercept, an intercept dummy, a linear trend term and a trend (linear) dummy, and then collecting the detrended series, π_t, which is now stationary. The stationary time series on inflation thus obtained has been used for all subsequent analyses.

The estimated break dates are reported in the 4th column of this table. It is evident that all the estimated break dates refer to the period of 1970s and 1980s, and thus it provides empirical support to the general world-wide observation that the high phase of inflation during the 1960s-1970s started reducing substantially towards stabilization in the 1980s. There are quite a few

---

[20] Kim and Perron (2009) have considered three types of additive outlier models *viz*., A1, A2 and A3, representing the occurrence of a structural break only in the intercept, only in the slope, and both in the intercept and slope coefficients of a time series, respectively.

[21] We also carried out the usual ADF test i.e., the ADF test without any consideration to break, for inflation, and found all the seven series to be trend stationary processes, which mean that these series have no stochastic trend, but only deterministic trend without any break. Thus, while the overall conclusions on unit roots are the same as those obtained with the Kim-Perron test, the point to be noted is that the null and the alternative hypotheses for these two tests are different, which have implications in further analysis with the inflation data.

studies to this observation as well. For instance, in their study, Cecchetti and Krause (2001) have reported that the inflation in most of the developed and developing countries remained at a very high level during the period of ‘great inflation’ in 1960s, which was coupled with the oil price shock in 1973. The volatility appear to be more pronounced during that period while it remained low and stable at the latter half of 1980s due to marked improvement in macroeconomic performances in those countries. This finding has also been supported by Stock and Watson (2002). They pointed out that during the period of 1990s, not only the volatility of inflation decreased sharply but the average inflation also got a downward trend. Further, Krause (2003) has reported that in a cross-section of 63 countries, mean inflation has fallen from approximately 83 per cent in the pre-1990 period to approximately 9 per cent in the latter half of 1990s. Given such empirical findings, it is expected that there would be at least one structural break in the time series on inflation, and this is what we have, in fact, found (see also Ozdemir (2010), and Balcilar et al. (2011), in this context)[22].

Now we discuss the results of the unit root and structural break test for the output growth series, which are presented in the lower panel of Table 2.2. It is clear that there is no structural break in the deterministic trend of each of the seven output growth series by the Perron-Yabu test. All the test statistic values are very low and the null of ‘no break’ in deterministic trend function cannot be rejected even at 10% level of significance. Hence we conclude that there is no structural break in trend of output growth in all the G7 countries. As mentioned earlier, the well-known ADF unit root test is the most appropriate test if there is no structural break, and hence we applied this test for all the output growth series. In the ADF test applied, the estimating equation includes both the intercept and deterministic linear trend as exogenous regressors. The optimum number of lags for the ADF test has been chosen using Schwarz’s (1978) information criterion (SIC). The computed values of the ADF test statistic for the time series of output growth of each of the seven countries were compared with the critical value of -3.976 at 1% level of significance. Accordingly, we conclude that the unit root assumption is rejected for all the countries, i.e., output growth of all the countries is stationary. Further, we have found that the trend coefficient in the ADF estimating

---

[22] Clark (2006) and Levin and Piger (2003) have allowed the possibility of structural breaks while examining the persistence of inflation. Rapach and Wohar (2005) have also tested for breaks and found evidence of shift in the level of inflation in a wide range of European countries.

equation is insignificant for all the output growth series. Thus we conclude that the time series of output growth is free from both stochastic and deterministic trend in all the G7 countries.

2.4.2 Autocorrelation and volatility

Finally, we report the findings on (linear) autocorrelation and volatility in all these series. We have applied the Ljung-Box test, $Q(.)$, to examine the presence of linear and squared autocorrelations in all the stationary series of inflation and output growth. We have also performed the Lagrange Multiplier (LM) test for the presence of ARCH effect in each of the time series. The values of these test statistics are reported in Table 2.3 below.

Table 2.3 Results of the Ljung-Box test for linear and squared autocorrelations and the LM test for ARCH effect

	Inflation					*Output growth*				
Country	$Q(5)$	$Q(10)$	$Q^2(5)$	$Q^2(10)$	*LM test*	$Q(5)$	$Q(10)$	$Q^2(5)$	$Q^2(10)$	*LM test*
Canada	23.68*	38.53*	10.02***	13.49	5.55**	55.97*	70.39*	24.87*	35.48*	5.23**
France	254.09*	349.76*	99.95*	102.48*	4.63**	67.16*	105.09*	23.46*	71.71*	21.38*
Germany	45.00*	102.69*	9.96**	10.35	11.60*	49.45*	52.66*	83.74*	84.28*	99.10*
Italy	393.08*	552.03*	221.21*	353.79*	32.06*	63.67*	100.08*	102.76*	123.42*	88.83*
Japan	69.15*	127.02*	227.30*	303.53*	92.94*	16.17*	20.57**	31.86*	32.03*	36.95*
The UK	279.64*	370.24*	15.62*	22.95*	15.08*	20.23*	33.23*	92.07*	100.07*	77.14*
The USA	93.25*	114.33*	56.95*	68.92*	30.09*	190.14*	209.03*	124.61*	125.08*	48.29*

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively. $Q(.)$ and $Q^2(.)$ are the Ljung-Box test statistic values for linear and squared autocorrelations, respectively.]*

The results of the Ljung-Box test clearly establish that both inflation and output growth series of the G7 countries are autocorrelated – linearly as well as in their squared values**.** Further, the LM statistic values for both inflation and output growth are found to be significant. This provides evidence for the presence of ARCH effect in both the series for all the G7 countries.

2.5 Conclusions

In this chapter, we have presented the plots, the summary statistics, and some important characteristic of the time series on inflation and output growth for all the G7 countries. We have also applied two most recent tests, as developed by Perron and Yabu (2009) and Kim and Perron (2009), to test for stationarity in presence of a structural break in the deterministic trend function of a time series. By applying these two tests, we have found that the time series on inflation for all the seven countries are trend stationary processes having a structural break each in their respective deterministic trend functions. Accordingly, we have adjusted for the deterministic trend component so as to obtain the stationary series of inflation for each of the member countries of G7.

On the other hand, the Perron-Yabu test concludes that there is no structural break in the deterministic trend component in the output growth series of any of the seven countries. Subsequently, the usual ADF test suggests presence of no unit roots. Accordingly, the conclusion is that the output growth series of all the seven countries are free from both stochastic trend and deterministic tend i.e., these series are stationary. Finally, the Ljung-Box test indicates that there are significant linear and squared dependences in both inflation and output growth series of all the G7 countries.

Chapter 3

The Effect of Inflation on Inflation Uncertainty: A Double Threshold GARCH Model

3.1 Introduction

In a seminal paper in 1977, Friedman made a profound observation on the effect of inflation on inflation uncertainty which, in turn, affects output growth. His view on this, which is well-known as the Friedman hypothesis, has two parts. In the first part, he argues that an increase in inflation may induce an erratic policy response by monetary authority, and therefore lead to more uncertainty about the future inflation. In the second part of his hypothesis, Friedman advocates that increasing uncertainty about inflation distorts the effectiveness of the price mechanism in allocating resources efficiently, thus leading to negative output growth effects. Ball (1992) formalized the first part of Friedman's argument in the context of an asymmetric information game between the public and the policy maker. Ball's formalization of Friedman hypothesis, known as the Friedman-Ball hypothesis thus states that inflation affects inflation uncertainty positively. On the contrary, Pourgerami and Maskus (1987) and Ungar and Zilberfarb (1993) argued that the effect of inflation on its uncertainty is negative. When inflation occurs, the nominal income and nominal wealth are eroded, which, in turn, reduces the real income and real wealth. In order to retard the speed of erosion, economic agents pay more attention to inflation forecast. This leads to a reduction in the forecast error, which, in turn, reduces inflation uncertainty. Thus, from theoretical consideration, there exists an impact of inflation on inflation uncertainty, which could be either positive or negative. The empirical results also provide mixed findings with some studies showing a positive relationship[23], while some others indicating a negative relationship[24].

---

[23] See, for evidence of positive effect of inflation on inflation uncertainty, Evans (1991), Holland (1995), Caporale and Mckierman (1997), Grier and Perry (1998), Fountas (2001), Fountas et al. (2002), Kontonikas (2004), Daal et al. (2005), and Fountas and Karanasos (2007).

[24] See, Engle (1983), Bollerslev (1986), Cosimano and Jansen (1988), Hwang (2001), and Wilson (2006), for studies showing negative effect.

Such mixed empirical evidence, sometimes even for the same country but obviously in different studies, may arise due to different modelling approaches used to capture the intrinsic nature of the relationship involving inflation and its uncertainty. Different time periods for different studies may also partly explain this. However, that regime shifts in the time series could as well be one of the reasons has been noted only recently. Evans and Wachtel (1993) first raised the issue of regime switching behaviour of inflation while dealing with inflation uncertainty. The authors concluded that serious attention needs to be paid on the consequences of regime switches, otherwise existing models without any consideration to regime changes would seriously underestimate both the degree of uncertainty of inflation and its impact. Following their lead, some researchers including Kim (1993), Kim and Nelson (1999), Bhar and Hamori (2004), Chang and He (2010), and Chang (2012) have studied the relationship between inflation and its uncertainty where the regime specific behaviours have been duly incorporated in the model. A point worth noting is that all these studies have used the concept of unobserved regime and accordingly applied the Markov switching regression model. However, the purpose in this work is to study the effect of inflation on inflation uncertainty based on their underlying relationship, and hence regimes are now assumed to be observed and determined by the level of inflation. This is indeed the basis of the first work in this thesis. This approach is consistent with the theoretical studies of Ball (1992), Ungar and Zilberfarb (1993) and Azariadis and Smith (1996). Some empirical studies like those by Baillie et al. (1996), Chen et al. (2008) and Neanidis and Savva (2013), have also studied essentially such relationships between inflation and its uncertainty with inflation being in high or low level.

To be specific, the model proposed in this chapter is a double-threshold GARCH (DTGARCH) model, originally due to Li and Li (1996), where, apart from consideration of regimes for both the conditional mean and conditional variance (GARCH) specifications, the usual GARCH specification is extended by explicitly incorporating a lagged inflation term in the conditional variance specification, the coefficient of which depicts the impact of inflation on inflation uncertainty. One important advantage of this model is that it allows for different behaviours of inflation uncertainty in different regimes, including the one captured through the lagged inflation term. The regimes in both the conditional mean and variance are determined by the past level of inflation. We have applied this model to the time series covering the period from January 1970 to December 2013 for all the members of the G7 countries. The estimates of the parameters obtained from this model have been used to verify the Friedman-Ball hypothesis which states that inflation has a positive impact on inflation uncertainty. Given the nature of inflation prevailing in the G7 countries during the period under study, as mentioned in Section 2.2, it is relevant as well as important to examine whether the transition from the high inflation prevailing during 1960s and 1970s to an era of low inflation during 1980s and 1990s affected the dynamic interaction between inflation and inflation uncertainty.

The organization of this chapter is as follows. The proposed model is described in Section 3.2. Empirical findings are discussed in Section 3.3. The chapter ends with some concluding remarks in Section 3.4.

3.2 The Proposed Model and Methodology

After the introduction of the autoregressive conditional heteroskedasticty (ARCH) and the generalised ARCH (GARCH) model by Engle (1982) and Bollerslev (1986), respectively, innumerable studies on inflation have used the GARCH or GARCH-type models as a measure of inflation uncertainty that underpin the dynamic nexus between inflation and inflation uncertainty. As discussed in Chapter 1, among these, some studies *viz*., Brunner and Hess (1993), Baillie et al. (1996), Fountas et al. (2000), Hwang (2001), have used a simultaneous estimation technique to detect this link, while others like Grier and Perry (1998), Fountas et al. (2004), and Conrad and Karanasos (2006) have relied on a method where the conditional variance is first estimated from a GARCH/GARCH-type model, and then the Granger causality test is applied to test for the existence of causal links. In this chapter, we consider the first approach i.e., we consider a model for inflation wherein the effect of inflation on inflation uncertainty is incorporated in the specification of conditional variance, and then the model is studied in a simultaneous framework.

Following Fountas et al. (2000), the conditional variance specification for inflation is assumed to explicitly include a lag inflation term. Thus with the conditional mean specification being an AR(*k*) model, the model, designated as AR(*k*)-GARCH(1,1)[25]L(1)[26] for describing inflation, consists of the following specifications for the conditional mean and conditional variance:

$$\pi_t = \phi_0 + \phi_1 \pi_{t-1} + \phi_2 \pi_{t-2} + \cdots + \phi_k \pi_{t-k} + \varepsilon_t, \qquad \varepsilon_t | \Psi_{t-1} \sim N(0, h_{\pi,t}) \tag{3.1}$$

$$h_{\pi,t} = \omega + \alpha \varepsilon_{t-1}^2 + \beta h_{t-1} + \theta \pi_{t-1} \tag{3.2}$$

where $\Psi_{t-1} = \{\pi_{t-1}, \pi_{t-2}, \dots\}$ is the information set at $t-1$, π_t stands for inflation at time 't', $h_{\pi,t}$ is the conditional variance of π_t at 't', and k the optimal lag order in the conditional mean specification. Here the coefficient θ depicts the impact of inflation on inflation uncertainty. Obviously, significant positive value of θ establishes the Friedman-Ball hypothesis for a given time series on inflation. All roots of the polynomial $(1 - \phi_1 B - \cdots - \phi_k B^k) = 0$ are assumed to lie outside the unit circle for stationarity of π_t, and the usual restrictions on the parameter in $h_{\pi,t}$ are assumed to ensure positivity. This model is being taken as a benchmark model with a view to concluding the extent to which introduction of regimes in both inflation and inflation uncertainty leads to better understanding and modelling involving these two variables.

In describing the proposed model which is a regime-dependent model, we state that here we allow the effect of inflation on its uncertainty to be different in different regimes. As already stated in the preceding section, we implicitly assume that the threshold variable which defines the regime that occurs at any given point in time, is known, and take, as in self-exiting threshold autoregressive model (SETAR), the preceding value of inflation i.e., π_{t-1} to be the threshold variable. We define two regimes according as $\pi_{t-1} > 0$ and $\pi_{t-1} \leq 0$. It may be noted that in our case, as mentioned in Section 2.4.1, the time series on inflation i.e., $\tilde{\pi}_t$ has been found to be trend stationary process for each of the G7 countries. Accordingly, all the inflation series have been detrended appropriately so as to reduce these to stationarity with zero mean, which is denoted as

---

[25] In most empirical works with GARCH(*p*,*q*) specification for volatility, the orders *p*=*q*=1 have been found to be adequate, and the same has been the case in this study as well. Hence, GARCH(1,1) model has been considered for this study.

[26] 'L(1)' stands for the fact that the specification for $h_{\pi,t}$ includes the first lag of inflation as a separate term.

π_t. It may be noted that the estimated deterministic trend values for all the seven inflation series ($\tilde{\pi}_t$) have been found to be positive for all time points except some in case of Japan. Thus, the two regimes defined by $\pi_{t-1} > 0$ and $\pi_{t-1} \leq 0$ essentially refer to the actual inflation i.e., $\tilde{\pi}_t$ being, in general, above or below a certain positive value for the country concerned. Thus, we would henceforth refer $\pi_{t-1} > 0$ to be a high inflation regime and $\pi_{t-1} \leq 0$ to be a low inflation regime.

The proposed model can be considered to be a generalization of the model in Fountas et al. (2000) in that here regime is introduced in the specifications of the conditional mean and conditional variance. The proposed model thus far is indeed the double-threshold GARCH (DTGARCH) model, originally due to Li and Li (1996) and Chen (1998)[27]. In our proposed model, we have extended this DTGARCH model to allow for the inclusion of a lag inflation term in the conditional variance specification. This model, therefore, has the advantage of incorporating the effects of high and low inflation in both the conditional mean and conditional variance of inflation. The resultant model, denoted as DTGARCH(1,1)L(1), is thus specified as follows:

$$\pi_t = \left(\phi_0^l + \phi_1^l \pi_{t-1} + \phi_2^l \pi_{t-2} + \cdots + \phi_k^l \pi_{t-k}\right) I[\pi_{t-1} \leq 0] + \left(\phi_0^h + \phi_1^h \pi_{t-1} + \phi_2^h \pi_{t-2} + \ldots + \phi_k^h \pi_{t-k}\right)(1 - I[\pi_{t-1} \leq 0]) + \varepsilon_t, \qquad \varepsilon_t | \Psi_{t-1} \sim N(0, h_{\pi,t}) \tag{3.3}$$

$$h_{\pi,t} = [\omega^l + \alpha^l \varepsilon_{t-1}^2 + \beta^l h_{t-1} + \theta^l \pi_{t-1}] I[\pi_{t-1} \leq 0] + [\omega^h + \alpha^h \varepsilon_{t-1}^2 + \beta^h h_{t-1} + \theta^h \pi_{t-1}](1 - I[\pi_{t-1} \leq 0]) \tag{3.4}$$

where $I[.]$ is the indicator function which takes the value 1 if $\pi_{t-1} \leq 0$ and 0 otherwise. In this model $\xi^l = (\phi_0^l,\ \phi_1^l, \ldots, \phi_k^l, \omega^l, \alpha^l, \beta^l, \theta^l\ )'$ is the coefficient vector comprising the coefficients in both conditional mean and conditional variance specifications for the low inflation regime and similarly $\xi^h = (\phi_0^h, \phi_1^h, \ldots, \phi_k^h, \omega^h, \alpha^h, \beta^h, \theta^h)'$ for the high inflation regime. Apart from the usual GARCH coefficients, θ^l and θ^h capture the link between inflation uncertainty and inflation in the two regimes, respectively.

The parameters of each of the benchmark and the proposed models i.e., AR(*k*)-GARCH(1,1)L(1) and DTGARCH(1,1)L(1) models have been estimated by the maximum likelihood (ML) method of estimation under the assumption of normality for the conditional

---

[27] See also, Brooks (2001), Chen et al. (2003), Chen and So (2006), Chen et al. (2006), and Yang and Chang (2008) for applications of the DTGARCH model.

distribution of ε_t. For the iterative optimization procedure involved in the estimation process, the well-known BHHH algorithm has been used. The necessary computations were done in GAUSS.

3.3 Empirical Analysis

In this study, we have taken monthly stationary time series on inflation, π_t, for the G7 countries *viz.*, Canada, France, Germany, Italy, Japan, the UK and the USA. In this section we first present the estimates of the benchmark AR(k)-GARCH(1,1)L(1) model. The results of estimation and testing of hypotheses of interests involving the parameters of the two regimes of the proposed model are discussed next.

3.3.1 AR(k)-GARCH(1,1)L(1) model

The results of estimation of the benchmark AR(k)-GARCH(1,1)L(1) model specified in equations (3.1) and (3.2) are reported Table 3.1[28]. The optimal lag orders of the autoregressive terms for the seven inflation series have been obtained by using the Akaike information criterion (AIC).

Table 3.1 Estimates of the parameters of AR(k)-GARCH(1,1)L(1) model

Country *Parameter*	*Canada*	*France*	*Germany*	*Italy*	*Japan*	*The UK*	*The USA*
Conditional mean							
ϕ_0	0.007	0.006	0.003	-0.004	0.003	-0.012	-0.004
ϕ_1	-0.012	0.305*	0.078	0.266*	0.082***	0.208*	0.351*
ϕ_2	0.141*	0.026	0.184*	0.199*	0.037	0.298*	0.016
ϕ_3	0.094**	0.114**	0.110**	0.150*	0.021	0.124**	-0.008
ϕ_4	0.049	0.020	0.058	0.032	0.043	-0.096**	0.099**

(Continued on next page)

---

[28] The estimation procedure is based on the assumption of normality. However, given the fact that the assumption of normality, strictly speaking, does not apply and hence the estimates are quasi-ML estimates, one can use the standard errors of the estimates following the procedure suggested by Bollerslev and Wooldridge (1992). In our study, we have obtained such standard errors for the benchmark AR(k)-GARCH(1,1)L(1) model. The results are almost similar to those presented in Table 3.1 except that the coefficient θ for Canada is now found to be insignificant. Further, in case of Japan, the coefficients ϕ_1 and ϕ_7 which were found to be significant only at 10% level of significance in the earlier results, have now turned out to be insignificant.

Table 3.1 (continued from previous page)

Country *Parameter*	*Canada*	*France*	*Germany*	*Italy*	*Japan*	*The UK*	*The USA*
ϕ_5	0.113**	-0.018	0.015	-0.016	0.114**	0.057	-0.029
ϕ_6	0.016	0.052	0.117*	0.119**	0.029	0.114*	0.019
ϕ_7	0.035	0.080***	0.038	0.091***	0.082***		0.067***
ϕ_8		0.045	0.067***	0.032	0.025		-0.058
ϕ_9		-0.003		0.027	0.150*		0.062
ϕ_{10}		0.057***		0.026	0.044		0.055
ϕ_{11}				-0.046	0.051		
ϕ_{12}				-0.125*	-0.133*		
Conditional variance							
ω	0.011*	0.009**	0.013*	0.001***	0.002***	0.008*	0.004*
α	0.237*	0.181*	0.464*	0.160*	0.080**	0.675*	0.271*
β	0.662*	0.553*	0.347*	0.830*	0.896*	0.437*	0.692*
θ	0.025**	0.007	0.023	0.002	-0.007	-0.007	0.024*
MLLV	-75.64	161.00	97.86	182.77	-121.21	-6.78	75.66

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively. MLLV is the maximized log-likelihood value.]*

It is observed from this table that the autoregressive coefficients are significant in varying numbers across the seven countries. While ϕ_1, ϕ_2, and ϕ_3 are significant in most of the countries, some of the distant lags, barring 7th lag, are significant only for few countries. The usual GARCH parameters *viz.*, ω, α and β are statistically significant for all the inflation series. Additionally, in agreement with the Friedman-Ball hypothesis, the estimate of the lagged inflation coefficient θ, is found to be positive and statistically significant only for two countries *viz.*, Canada and the USA, while for the remaining countries the relationship is not found to be significant. It is quite possible that this finding of no such significant effect of inflation on its uncertainty for most i.e., five, of the G7 countries may be due to the fact that this model has no consideration to regime-specific inflation behaviour, which might have masked potentially different realizations due to probable regime shift in inflation series, especially because the span of the data set is quite large.

3.3.2 DTGARCH(1,1)L(1) model

The DTGARCH(1,1)L(1) model as specified in equations (3.3) and (3.4), incorporates differential behaviour in both inflation and inflation uncertainty from consideration of regime switching and also allows for the coefficient attached to the lagged inflation term in inflation uncertainty model specified in equation (3.4) to be different in the two regimes. This model is locally i.e., regime-wise linear but overall nonlinear in nature, and its estimation involved substantial volume of computations[29]. The estimates of the parameters of this model are presented in Table 3.3.

Before we discuss about the findings based on the estimates of the proposed model, we make a comparison between the benchmark AR(*k*)-GARCH(1,1)L(1) model and the proposed DTGARCH(1,1)L(1) model by the likelihood ratio (LR) test to find if introduction of regimes based on low and high inflation in both conditional mean and conditional variance has led to any statistical gain in understanding on the effect of inflation on inflation uncertainty. We report the LR test statistic values in Table 3.2.

Table 3.2 LR test statistic values

Country	AR(*k*)-GARCH(1,1)L(1) *versus* DTGARCH(1,1)L(1)
Canada	24.26**
France	22.92***
Germany	13.36
Italy	32.24**
Japan	9.90
The U.K.	46.34*
The U.S.A.	25.48**

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively.]*

---

[29] For writing the GAUSS codes of DTGARCH(1,1)L(1) model, we have made use of codes from the GAUSS programs developed by Philip Hans Franses and Dick Van Dijk on different volatility models, which were downloaded from http://www.few.eur.nl/few/few/people/frances.

We observe from this table that the LR test statistic values are significant for five countries *viz*., Canada, France, Italy, the UK and the USA, and hence we can conclude that the proposed model is a better model than the benchmark model. In other words, introduction of two regimes for inflation in both the conditional mean and conditional variance models yields a substantially better model for inflation, where the impact of inflation on inflation uncertainty is duly incorporated in the modelling framework.

We now discuss on the estimated DTGARCH(1,1)L(1) model in detail to understand the role of the inflation regimes in this inflation model and also the effect of inflation on inflation uncertainty.

Table 3.3 Estimates of the parameters of the DTGARCH(1,1)L(1) model

Country *Parameter*	*Canada*	*France*	*Germany*	*Italy*	*Japan*	*The UK*	*The USA*
Conditional mean for the low regime							
ϕ_0^l	0.007	0.005	0.010	-0.011	-0.022	-0.053*	-0.001
ϕ_1^l	0.069	0.326*	0.141	0.261*	-0.020	-0.050	0.394*
ϕ_2^l	0.087	-0.033	0.134**	0.283*	0.014	0.328*	0.025
ϕ_3^l	0.153**	0.029	0.163**	0.046	0.022	0.215*	-0.079
ϕ_4^l	0.078	0.171**	0.109***	-0.026	0.013	-0.084	0.155**
ϕ_5^l	0.160**	-0.092	-0.011	0.018	0.109***	-0.055	-0.031
ϕ_6^l	-0.073	-0.031	0.120**	0.113**	-0.009	0.178*	0.121***
ϕ_7^l	0.000	0.116	0.052	0.186*	0.100***		-0.021
ϕ_8^l		0.057	0.089***	-0.035	0.009		-0.106
ϕ_9^l		0.041		-0.043	0.112**		0.130**
ϕ_{10}^l		0.075		0.049	0.094		0.086
ϕ_{11}^l				-0.029	0.013		
ϕ_{12}^l				-0.152*	-0.084		

(continued on next page)

Table 3.3 (continued from the previous page)

Country *Parameter*	*Canada*	*France*	*Germany*	*Italy*	*Japan*	*The UK*	*The USA*
Conditional mean for the high regime							
ϕ_0^h	0.018	-0.015	0.014	-0.006	-0.003	-0.018	-0.006
ϕ_1^h	-0.044	0.401*	0.034	0.221**	0.121	0.425*	0.325*
ϕ_2^h	0.276*	0.141***	0.208*	0.217*	0.094	0.263*	0.020
ϕ_3^h	0.032	0.169**	0.047	0.043	0.097	0.029	0.019
ϕ_4^h	-0.004	-0.072	-0.003	0.157*	0.099	-0.031	0.040
ϕ_5^h	0.055	0.023	0.030	0.089***	0.129***	0.147*	-0.013
ϕ_6^h	0.020	0.125	0.114**	0.256*	0.001	0.138*	-0.012
ϕ_7^h	0.089	0.021	0.005	-0.020	0.076		0.146**
ϕ_8^h		0.042	0.072	-0.034	-0.030		-0.001
ϕ_9^h		-0.047		0.137*	0.144**		-0.040
ϕ_{10}^h		-0.007		0.139**	0.062		0.027
ϕ_{11}^h				-0.157*	0.060		
ϕ_{12}^h				-0.251*	-0.195*		
Conditional variance for the low regime							
ω^l	0.027**	0.004**	0.011***	0.002	0.006	0.002	0.004***
α^l	0.605*	0.363**	0.604*	0.255***	0.000	0.640*	0.304*
β^l	0.468*	0.710*	0.492*	0.323*	0.555*	0.529*	0.619*
θ^l	0.111**	0.034***	0.046	-0.055*	-0.154**	-0.017	0.010
Conditional variance for the high regime							
ω^h	0.002	0.033*	0.008	0.000	0.000	0.009**	0.000
α^h	0.000	0.120	0.000	0.948*	0.222**	0.513*	0.001
β^h	0.658*	0.001	0.280*	0.020	0.837*	0.000	0.655*
θ^h	0.119*	-0.039	0.154*	0.153*	-0.003	0.198*	0.124*
MLLV	-63.51	172.46	104.54	198.89	-116.26	16.39	88.40
Wald test for $H_0: \theta^l = \theta^h$	0.02	2.69	5.42**	33.89*	3.51***	13.40*	11.19*

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively. MLLV is the maximized log-likelihood value.]*

Several findings from the estimation results are worth mentioning. First, the estimates of the parameters in conditional mean clearly establish regime switching behaviour in inflation for all the seven series since some of the own lags in both regimes are statistically significant. In case of Canada, the number of significant parameters in conditional mean is least *viz*., 2 in the low inflation regime and 1 in the high inflation regime while these numbers are highest, 5 and 9 respectively, for Italy. Second, looking at the parameters of the model for the conditional variance in the two inflation regimes, we note that either or both of α^l and α^h, the coefficients of ε_{t-1}^2 in the two regimes, are significant for all the G7 countries. Further, this is same for β^l and β^h as well. It is thus found that consideration of two regimes based on a threshold level of inflation for the conditional variance which measures inflation uncertainty, is found to be relevant and statistically meaningful. Turning to the coefficient of interest from consideration of finding the effect of inflation on inflation uncertainty, i.e., θ^l and θ^h, we note that both these coefficients are significant in two countries only, namely, Canada and Italy, while for the remaining 5 countries, at least one of θ^l and θ^h is significant. This establishes the fact that the effect of inflation on inflation uncertainty is also regime specific. Hence, on the whole, any policy measure on inflation should be based, *inter alia*, on regime consideration of inflation.

Finally, the most important hypothesis for the proposed model is whether inflation affects inflation uncertainty differently in the two inflation regimes. In terms of the parameters, the null and alternative hypotheses are $H_0: \theta^l = \theta^h$ and $H_1: \theta^l \neq \theta^h$, respectively. This null hypothesis has been tested by using the Wald test, and the test statistic values for the seven series are reported in the last row of Table 3.3. The results of the Wald test show that the null hypothesis is rejected for all countries barring Canada and France. As regards the latter two countries, we can conclude that in case of Canada, inflation has a positive impact on inflation uncertainty and it is invariant with the regime change while for France, the only conclusion that can be drawn is that the coefficients do not change significantly between the two regimes. The Wald test results thus suggest that a significant difference exists insofar the effect of inflation on inflation uncertainty is concerned, in case of five members of the G7 countries. These countries are Germany, Italy, Japan, the UK and the USA.

The positive and significant values of θ^h in four of these countries *viz*., Germany, Italy, the UK and the USA indicate that inflation increases inflation uncertainty at the high inflation regime in each of these countries, while the effect is found to be insignificant for Germany, the UK and the USA at the low inflation regime and negative for Italy. This evidence for Germany, the UK and the USA thus support the findings of Ungar and Zilberfarb (1993) *viz*., that inflation affects inflation uncertainty only in the high inflation regime but not in the low one. The finding that $\widehat{\theta^{l}}$ is negative and significant for Italy and Japan is, however, somewhat unusual although not exceptional. This means that at the low regime inflation has a negative effect on inflation uncertainty or in other words, a reduction in inflation in the low regime increases inflation uncertainty, and thus the Friedman-Ball hypothesis fails to hold for these two countries. Such evidence has been found by a few other studies as well – although with different volatility specifications. For instance, based on a study on 12 European Monetary Union countries, Caporale and Kontonikas (2009) have found that during the post-1999 period when average inflation was low, a further reduction in inflation led to increase rather than decrease in inflation uncertainty for a number of countries in Euro Zone. In a recent study based on monthly data on US inflation over the period from 1926 to 1992, Hwang (2001) has found that inflation affects its uncertainty weakly negatively during the periods of both high and low inflation. In a recent study, Chang (2012) has incorporated the regime switching aspect of inflation in studying the relationship inflation and inflation uncertainty for the USA. However, his study is based on the methodology where the regime is assumed to be unobserved. The main findings of this paper are that the inflation uncertainty has no impact on inflation regardless of the inflation regimes, and that inflation affects inflation uncertainty negatively in high inflation regime. Contrary to these results, our findings based on an observed regime switching model, show that inflation significantly raised inflation uncertainty for most of the G7 countries including the USA during the high inflation regime.

Finally, we report on the Ljung-Box test statistic values based on residuals of this model for all the G7 countries in Table 3.4.

Table 3.4 Results of the Ljung-Box test with standardized residuals and squared standardized residuals

Country	*Q(1)*	*Q(5)*	*Q(10)*	*$Q^2(1)$*	*$Q^2(5)$*	*$Q^2(10)$*
Canada	0.007	3.746	7.027	0.670	1.386	4.238
France	0.107	1.975	4.710	0.014	4.348	5.481
Germany	0.369	2.123	4.823	0.638	3.656	7.972
Italy	0.024	2.434	11.420	2.281	5.418	12.963
Japan	0.027	0372	1.480	0.002	2.112	8.114
The UK	0.001	2.676	6.196	0.003	2.303	11.887
The USA	0.014	2.604	5.050	1.501	7.512	9.926

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively. Q(.) and Q^2(.) denote the Ljung-Box test for autocorrelation in standardized residuals and squared standardized residuals, respectively.]*

The test statistic has been computed for both the standardized and squared standardized residuals. It is evident from Table 3.4 that none of these are significant, and hence it can be concluded that the proposed models for both the conditional mean and conditional variance of inflation along with the chosen lag values are adequate for all the G7 countries.

3.4 Conclusions

The effect of inflation on inflation uncertainty has been studied in this chapter in terms of a model called the DTGARCH(1,1)L(1), where the conditional mean as well as the conditional variance of inflation are based on consideration of two regimes for inflation, and the regimes are determined by the level of inflation of the preceding time point being negative or positive, which in terms of the original inflation data means being below or above a certain level of inflation. Further, the conditional variance specification for each regime is GARCH with an additional term of inflation of lag 1. The empirical findings clearly show that the impact of inflation on inflation uncertainty is different in the two regimes for five countries *viz*., Germany, Italy, Japan, the UK and the USA. For Canada, a positive effect of inflation on its uncertainty holds, but this effect is invariant to the two regimes. On the other hand, the Friedman-Ball hypothesis holds only in the high inflation regime for Germany, Italy, the UK and the USA. Further, the relationship is negative in the low inflation regime for Italy and Japan, which suggests that in the low regime a decline in inflation has led to increase in inflation uncertainty in these two countries, and this obviously goes counter to the Friedman-Ball hypothesis. Thus, we can conclude by stating that the model for inflation wherein effect of inflation on inflation uncertainty is incorporated in the framework of regime switching, has been found to be not stable over time in all the G7 countries barring Canada and France, thus clearly establishing the importance of consideration of regime-specific behaviour in studying the impact of inflation on inflation uncertainty. Further, the effect of inflation on its uncertainty is evident in each of the two regimes – although in varying number of countries, thus giving empirical support to the Friedman-Ball hypothesis regime-wise to most of the G7 countries.

Chapter 4

Inflation and Inflation Uncertainty: A Bivariate Model with Multiple Structural Breaks

4.1 Introduction

An extensive body of theoretical literature analyzes the relationship between inflation and inflation uncertainty. Different theories emphasize different channels - some pointing to positive relationships and some to negative ones. According to Friedman-Ball hypothesis, as stated in Chapter 3, an increase in inflation may induce erratic policy responses to counter it, with consequent unanticipated inflation movements and this leads to increase in inflation uncertainty. In contrast, Pourgerami and Maskus (1987), and Ungar and Zilberfarb (1993) pointed out that a negative effect may exist. The opposite direction in this relationship i.e., inflation uncertainty affecting inflation, has also been discussed in the theoretical literature. In particular, Cukierman and Meltzer (1986) contended that inflation uncertainty produces greater inflation due to opportunistic central bank behaviour, whereas Holland (1995), based on the 'stabilization' motive of central bank, showed that a higher inflation uncertainty leads to lower rates of inflation. Given such theoretical findings, a number of empirical works have been done with the aim at finding the effect of inflation on its uncertainty as well as the impact of inflation uncertainty on inflation.

Variance or standard deviation of inflation was used in early studies to measure inflation uncertainty[30]. Following the development of autoregressive conditional heteroskedasticity (ARCH) model by Engle (1982), most of the recent studies have used the conditional variance of inflation to measure the inflation uncertainty. As mentioned in Chapter 1, to analyze the relationship between inflation and inflation uncertainty, some studies have adopted a simultaneous procedure (see, among others, Brunner and Hess (1993), Baillie et al. (1996), and Fountas et al. (2000)) while others a two-step procedure (see, among others, Grier and Perry (1998), and Fountas et al.

---

[30] Golob (1993) have compiled many of these earlier studies and their findings related to the relationship between inflation and inflation uncertainty.

(2004)). In the preceding chapter, we have analyzed the unidirectional effect of inflation on inflation uncertainty by adopting the simultaneous procedure. In this chapter we apply the two-step procedure to study this relationship. Apart from the methodological differences which are mentioned in the following paragraphs, this chapter unlike the preceding chapter, studies the bi-directional relationship between inflation and inflation uncertainty.

The two-step method, in this context, essentially proposes that in the first step a GARCH/ GARCH-type model is used to estimate the conditional volatility (of inflation). Considering this estimated volatility of inflation as a measure of inflation uncertainty, in the second step, a vector autoregressive (VAR) model of inflation and inflation uncertainty is used to examine the relationship between these two variables. This second step thus enables us to study the direction of causality and hence the validity of the aforesaid hypotheses. The two-step approach has been employed, among others, by Grier and Perry (1998), who have noted that inflation significantly raises inflation uncertainty as predicted by Friedman-Ball hypothesis, but the evidence is weaker for inflation uncertainty to cause inflation. For inflation series of six European Union countries, Fountas et al. (2004) have obtained that in five of these countries inflation significantly raises its uncertainty. Conrad and Karanasos (2005) have also obtained strong evidence regarding the positive causal effect of inflation on its uncertainty, but the evidence is mixed in case of causality in the reverse direction. Daal et al. (2005) have examined the relationship for a large number of developed and emerging countries, where the results support that inflation causes inflation uncertainty for most of the countries while the evidence to support Cukierman-Meltzer hypothesis is rather weak. One common feature in all these studies is that the relationship between inflation and inflation uncertainty is assumed to be stable although the span of data is long in most studies. But, it is now well understood that in such cases of data with long periods, structural breaks or changes in the time series occur, and consequently in subsequent analysis including studying the relationship involving inflation and inflation uncertainty, consideration of structural break(s) becomes very important and relevant.

In this chapter, as already stated, we apply the two-step approach in a VAR modeling framework such that both directions of causality involving inflation and its uncertainty can be examined. An important aspect of this study is that here in the second step we consider VAR with due consideration to structural breaks in the relationship between these two variables. Thus, the first step, in the proposed approach, is meant for the purpose of obtaining the time series of estimated inflation uncertainty, while the second step essentially considers a VAR model with inflation and measure of inflation uncertainty as obtained in the first step where due consideration has been given to structural breaks in the two relations. After obtaining the two estimated models with structural breaks, we study how the bi-directional relationship involving inflation and inflation uncertainty varies across the different sub-periods.

Thus, a focal point of this study is not to assume a permanent relationship between inflation and inflation uncertainty, but rather adopt a notion of ‘temporary’ causality, that is, causality that may hold during some sub-periods of the entire sample period but may not in other sub-periods. It has been noted in a few recent studies on this issue (see, Kontonikas (2004), Caporale and Kontonikas (2009), for details) that results from the causality tests tend to be sensitive with respect to changes in the sample period. They have also noted that direction of causality is sensitive to the choice of the sample period. Furthermore, there are periods with no causality being found along with periods having causal effects between inflation and inflation uncertainty. For instance, using a break point test, Kontonikas (2004) has noted that the effect of inflation on its uncertainty has a break around 1992, which can be attributed to the introduction of ‘inflation targeting’ in the UK. Caporale and Kontonikas (2009) have applied the procedure for detecting multiple structural breaks, as developed by Bai and Perron (1998, 2003), to study the stability of the relationship in twelve Economic and Monetary Union (EMU) countries. In the same line, our objective in this chapter is to study the relationship between inflation and inflation uncertainty with due consideration to structural breaks, and its consequent effect on causality across the different sub-periods and hence on the validity or otherwise of the Friedman-Ball hypothesis and the Cukierman-Meltzer hypothesis for these sub-periods. In this exercise, we have adopted the recently developed technique of Qu and Perron (2007) to study the multiple structural changes in a system of equations. One important advantage of this approach is that unlike Kontonikas (2004) and Caporale and Kontonikas (2009), who have applied structural break tests only to study the unidirectional effect of inflation on its uncertainty, we can now test for structural stability in both the relationships involving inflation and its uncertainty and hence their bi-directional causality since we have considered a VAR model involving these two variables.

The format of this chapter is as follows. In Section 4.2, we briefly describe the model and the methodology applied, especially the Qu and Perron (2007) test for multiple structural breaks in a system of equations. In Section 4.3, the empirical results are discussed. This chapter ends with some remarks in Section 4.4.

4.2 The Models and Methodology

In this section, we state the models and also briefly describe the methodology applied in this work including the Qu-Perron test for multiple structural breaks in the system of equations.

4.2.1 Measuring inflation uncertainty

The econometric methodology used in this chapter, as stated in the preceding section, entails a two-step procedure. In the first step, a model is used to generate a time-varying conditional variance of inflation. With this conditional variance as a measure of inflation uncertainty, the VAR set-up is used in the second stage to detect the bi-directional nature of the relationship between these two variables and hence the nature of influence of one on the other. To this end, therefore, we need to specify the conditional variance for inflation. The GARCH model of Bollerslev (1986) is generally used as the specification for the conditional variance of inflation. However, it has been argued that the behaviour of inflation uncertainty is often asymmetric rather than symmetric. Brunner and Hess (1993), Joyce (1995), Grier et al. (2004), Shields et al. (2005), and Fountas et al. (2006) are of the view that positive inflation shocks or the ‘bad news’ of inflation increases inflation uncertainty more than the negative inflation shock or the ‘good news’ of inflation of equal magnitude. In this context it is worth mentioning that the TGARCH (Glosten et al. (1993)) and EGARCH (Nelson (1991)) models are two well-known alternative models to capture volatility of a time series in presence of leverage effect. While either or both of these two can be used, in terms of the News Impact Curve (NIC)[31], as introduced by Pagan and Schwert (1990), both are rather similar. Since the two models are non-nested in nature, the choice is primarily made by the researcher/ analyst simplicity and computational ease. Accordingly, we have used the TGARCH model for our study[32].

---

[31] The NIC measures how new information is incorporated into volatility.

[32] These two asymmetric GARCH models are widely used in studying stock returns (see, among others, Cao and Tsay (1992), Heynen and Kat (1994), Brailsford and Faff (1996), and Taylor (2004)).

Hence, in this chapter, we have considered both the standard GARCH specification as well as the threshold GARCH (TGARCH) model of Glosten et al. (1993)[33] for inflation. With the conditional mean specification being taken as an AR(*k*) model and that of conditional variance as GARCH(1,1), which are given in equations (4.1) and (4.2) below, the model is denoted as the AR(*k*)-GARCH(1,1) model. With the TGARCH(1,1) specification, given in equation (4.3), as the model for conditional variance, the overall model is designated as the AR(*k*)-TGARCH(1,1) model[34].

$$\pi_t = \phi_0 + \phi_1 \pi_{t-1} + \phi_2 \pi_{t-2} + \cdots + \phi_k \pi_{t-k} + \varepsilon_t, \qquad \varepsilon_t | \Psi_{t-1} \sim N(0, h_{\pi,t}), \qquad (4.1)$$

$$h_{\pi,t} = \omega + \alpha \varepsilon_{t-1}^2 + \beta h_{t-1}, \qquad (4.2)$$

$$h_{\pi,t} = \omega + \alpha \varepsilon_{t-1}^2 (1 - I[\varepsilon_{t-1} > 0]) + \gamma \varepsilon_{t-1}^2 I[\varepsilon_{t-1} > 0] + \beta h_{t-1}, \qquad (4.3)$$

where π_t is inflation at time 't', $\Psi_{t-1} = \{\pi_{t-1}, \pi_{t-2}, \ldots\}$ is the information set at $t-1$ and k is the optimal lag order in the conditional mean specification. $h_{\pi,t}$ is the conditional variance of inflation at 't'. As stated in Chapter 3, the standard consideration for stationarity of π_t is assumed to hold along with the usual restrictions on the parameters for positivity of $h_{\pi,t}$ in equation (4.2). In the TGARCH(1,1) specification, *I*[.] is the indicator function which takes the value 1 if $\varepsilon_{t-1} > 0$ and 0 otherwise. In this model, 'bad news' on inflation at $t-1$ i.e., $\varepsilon_{t-1} > 0$ and 'good news' on inflation at $t-1$ i.e., $\varepsilon_{t-1} \leq 0$, have differential effects on the conditional variance. Bad news has an impact of γ, while good news has an impact of α. The conditions for positivity of $h_{\pi,t}$ in this case are $\omega > 0$, $\beta > 0$ and $\frac{\alpha+\gamma}{2} \geq 0$.

4.2.2 Qu-Perron methodology with multiple structural breaks in a system of equations

In econometrics there exists a vast literature on tests for structural changes with unknown break dates. A major part of this is specifically meant for the case of a single change.[35] The problem

---

[33] See, Wu (2010), for an extensive survey on the threshold GARCH models.

[34] In the empirical study, we have thus estimated both the AR(*k*)-GARCH(1,1) and AR(*k*)-TGARCH(1,1) in the first step. Subsequent analyses have been done with the TGARCH(1,1) specification since this model performed better than the symmetric GARCH model for conditional heteroskedasticity in most of the seven series.

[35] See, Perron (2006), for an extensive review.

of testing for multiple structural changes/breaks has received attention only recently, that too mostly in the context of a single equation model (see, Bai and Perron (1998, 2003)). Research work on structural changes in the context of a system of equations is indeed very recent. Naturally, there are only very few studies on this, and the important ones are Bai et al. (1998), Hansen (2003), and Qu and Perron (2007).

The distinct advantage of the test procedure proposed by Qu and Perron (2007) is that it provides a comprehensive treatment of issues related to estimation, inference, and computation with multiple structural changes that occur at unknown points in multiple linear regression models which include vector autoregressive (VAR) model, some linear panel data models, and also seemingly unrelated regression (SUR) model. Changes can occur in the parameters of the conditional mean and the covariance matrix of errors, or both, and the distribution of the regressors can be allowed to change across regimes. Additionally, it is not a requirement that the regressors are independent of the errors at all leads and lags in the presence of heteroskedasticity and/or autocorrelation.

The general model considered by Qu and Perron (2007) is

$$Y_t = (I \otimes z_t')S\beta_j + u_t \tag{4.4}$$

where the vector $Y_t = (Y_{1,t}\ Y_{2,t} \ldots Y_{n,t})'$ refers to observations for n dependent variables at t$^{\text{th}}$ time point. The total number of structural changes in the system is assumed to be m and the break dates are denoted by an $m \times 1$ vector $\tilde{T} = (T_1, T_2, \ldots, T_m)$, taking into account that $T_0 = 1$ and $T_{m+1} = T$. The first subscript say, j, indexes a sub-period $(j = 1, 2, \ldots, m+1)$, the subscript t indexes the temporal observation $(t = 1, 2, \ldots, T)$, and the subscript i indexes the equation $i = (1, 2, \ldots, n)$ to which the scalar dependent variable $Y_{i,t}$ is associated. q is the number of regressors and z_t is the set which includes the regressors from all the equations i.e., $z_t = (z_{1,t}\ z_{2,t} \ldots z_{q,t})'$ and β_j is the set of parameters in the j^{th} sub-period. Furthermore, the error u_t is assumed to have mean 0 and covariance matrix Σ_j for $T_{j-1} + 1 \leq t \leq T_j$. The selection matrix is denoted by S in the above equation and it is of dimension $nq \times p$, which involves elements that take the values 0 and 1, and thus, indicate which regressors appear in each equation. When we use a VAR model, z_t is then $z_t = \left(Y_{t-1}\ Y_{t-2} \ldots Y_{t-q}\right)'$, which simply contains the lagged dependent variables, and hence S will be an identity matrix. The set of basic parameters in regime j consists of p vector of β_j and Σ_j. A set of r restrictions of the form $g\big(\beta, \mathrm{vec}(\Sigma)\big) = 0$, is used where $\beta = (\beta_1', \beta_2', \dots, \beta_{m+1}')'$, $\Sigma = (\Sigma_1, \Sigma_2, \dots, \Sigma_{m+1})$, and $g(.)$ is a r-dimensional vector.

The method of estimation considered in their study is called the restricted quasi-maximum likelihood (RQML) that assumes serially uncorrelated Gaussian distribution for the errors u_t. Conditional on a given partition of the sample $\tilde{T} = (T_1,\ T_2, \dots, T_m)$, the Gaussian quasi-likelihood function is

$$L_T\big(\tilde{T}, \beta, \Sigma\big) = \prod_{j=1}^{m+1} \prod_{t=T_{j-1}+1}^{T_j} f(Y_t | x_t;\ \beta_j, \Sigma_j)$$

where $x_t' = (I \otimes z_t')S$ and

$f\big(Y_t \big| x_t;\ \beta_j, \Sigma_j\big) = \frac{1}{(2\pi)^{n/2}\left|\Sigma_j\right|^{1/2}} \exp\left\{-\frac{1}{2}\left[Y_t - x_t'\beta_j\right]'\Sigma_j^{-1}\left[Y_t - x_t'\beta_j\right]\right\}$, and the quasi-likelihood ratio is

$$LR_T = \frac{\prod_{j=1}^{m+1} \prod_{t=T_{j-1}+1}^{T_j} f(Y_t | x_t;\ \beta_j, \Sigma_j)}{\prod_{j=1}^{m+1} \prod_{t=T_{j-1}^0+1}^{T_j^0} f(Y_t | x_t; \beta_j^0, \Sigma_j^0)}$$

where the true values of the parameters are denoted with a superscript 0.

The aim is to obtain values of $(T_1, T_2, \dots, T_m, \beta, \Sigma)$ that maximize LR_T subject to the restriction $g\big(\beta, \mathrm{vec}(\Sigma)\big) = 0$. Let $lr_T(.)$ denote the log-likelihood ratio and let $rlr_T(.)$ denote the restricted log-likelihood ratio. Then the objective function is $rlr_T\big(\tilde{T}, \beta, \Sigma\big) = lr_T\big(\tilde{T}, \beta, \Sigma\big) + \lambda' g\big(\beta, \mathrm{vec}(\Sigma)\big)$, where λ is the break fraction. The estimates are obtained as

$$\left(\hat{\tilde{T}}, \hat{\beta}, \hat{\Sigma}\right) = \arg \quad \max_{(T_1, T_2, \dots, T_m, \beta, \Sigma)} rlr_T\big(\tilde{T}, \beta, \Sigma\big).$$

Under certain assumptions, Qu and Perron (2007) have obtained that for $j = 1, 2, \dots, m$, $v_T^2\big(\widehat{T_j} - T_j^0\big) = O_p(1)$, and for $j = 1, 2, \dots, m+1$, $\sqrt{T}\big(\widehat{\beta_j} - \beta_j^0\big) = O_p(1)$ and $\sqrt{T}\big(\widehat{\Sigma_j} - \Sigma_j^0\big) = O_p(1)$, where v_T is either a positive number independent of T or a sequence of positive numbers that satisfy $v_T \longrightarrow 0$ and $T^{1/2} v_T/(\log T)^2 \longrightarrow \infty$. They have also showed that the limiting distributions of the conditional mean and the covariance matrix of the errors are the same with estimated break dates those when the break dates are known.

Qu and Perron (2007) have proposed a number of test statistics for testing and then identified the multiple break points in the system of n equations. In all these tests, all time points except some at the beginning as well as at the end of the time series, are considered to be probable break dates. The proportion of time points to be left out so that the first and the last sub-periods could be statistically distinguished is called the trimming parameter, and its value is often taken to be 0.15. The tests proposed by Qu and Perron are the following.

(i) The $UDmax$ test and the $WDmax$ test from consideration of having equal weighting scheme and unequal weighting scheme, respectively, where weights depend on the number of regressors and the significance level of the tests. For these two tests, the alternative hypothesis is that the number of breaks is unknown, but up to some specified maximum[36].

(ii) The $sup\, F_T(l+1|l)$ test i.e., a sequential test for the null hypothesis of l breaks versus the alternative of $(l+1)$ breaks.

It should be quite obvious that the size and power of these tests are important issues for the purpose of final inference. Similar to Bai and Perron (1998, 2003), Qu and Perron have suggested the following useful strategy. First, either or both of the double maximum tests i.e., the $UDmax$ test and the $WDmax$ test, is (are) used to see if at least one break is present. If these tests indicate the presence of at least one break, then the number of breaks can be decided based on the sequential examination of the $sup\, F_T(l+1|l)$ statistics constructed using global minimizers for the break dates.

For our study in this chapter, Y_t in equation (4.4) now consists of two variables, inflation and inflation uncertainty[37], i.e., $Y_t = \left(\pi_t \quad h_{\pi,t}\right)'$. In case of two variables, the general model represented in equation (4.4) is nothing but a VAR model, which is being specified for lag 1 in the

---

[36] The basic testing methodologies of these two tests are the same as those in Bai and Perron (1998).

[37] $h_{\pi,t}$ in the second step refers to the estimated value of the conditional variance of inflation based on the TGARCH model, as obtained in the first step.

equations (4.5) and (4.6) below[38]. The coefficients in these two equations are being given different notations for the sake of meaningful easy understanding.

$$\pi_t = \beta_{\pi,j} + \beta_{\pi\pi,j}\pi_{t-1} + \beta_{\pi h_\pi,j}h_{\pi,t-1} + u_\pi \tag{4.5}$$

and $$h_{\pi,t} = \beta_{h_\pi,j} + \beta_{h_\pi\pi,j}\pi_{t-1} + \beta_{h_\pi h_\pi,j}h_{\pi,t-1} + u_{h_\pi} \tag{4.6}$$

where the coefficients $\beta_{\pi\pi,j}$ and $\beta_{h_\pi h_\pi,j}$ denote the own lag effects at the j^{th} sub-periods. The main parameters of interest are $\beta_{\pi h_\pi,j}$ and $\beta_{h_\pi\pi,j}$, where the first one indicates the effect of inflation uncertainty on inflation in the j^{th} sub-period and the latter depicts the impact of inflation on inflation uncertainty in the j^{th} sub-period.

We have also estimated the usual VAR model involving inflation and inflation uncertainty without any consideration to structural break and having the parameters same for the entire sample. The model is written as follows.

$$\pi_t = \beta_\pi + \beta_{\pi\pi}\pi_{t-1} + \beta_{\pi h_\pi}h_{\pi,t-1} + u_\pi \tag{4.7}$$

and $$h_{\pi,t} = \beta_{h_\pi} + \beta_{h_\pi\pi}\pi_{t-1} + \beta_{h_\pi h_\pi}h_{\pi,t-1} + u_{h_\pi} \tag{4.8}$$

where the parameters stands for the same as before but now without any consideration to structural break. The estimated parameters are then compared with previous ones to find how the nature of the causal relationship between inflation and its uncertainty varies across sub-periods i.e., whether inflation affects inflation uncertainty as well as the inflation uncertainty affects inflation and if so, whether these are positive or negative.

4.3 Empirical Analysis

4.3.1 AR(*k*)-GARCH(1,1) and AR(*k*)-TGARCH(1,1) models

We first estimate both the AR(*k*)-GARCH(1,1) and AR(*k*)-TGARCH(1,1) models of inflation for all the G7 countries, and then carry out the likelihood ratio (LR) test in order to find

---

[38] Lag order 1 has been found to be adequate for our study.

if TGARCH(1,1) is a better model for capturing volatility in the time series of inflation. The results of estimation of the AR(k)-GARCH(1,1) and AR(k)-TGARCH(1,1) model are reported in Tables 4.1 and 4.2, respectively. And the Ljung-Box test statistic values based on the standardized residuals and their squared values for both the models are presented in Table 4.3 along with the LR test statistic values.

Table 4.1 Estimates of the parameters of the AR(k)-GARCH(1,1) model

Country *Parameter*	*Canada*	*France*	*Germany*	*Italy*	*Japan*	*The UK*	*The USA*
Conditional mean							
ϕ_0	0.003	0.001	-0.001	-0.006	0.004	-0.011	-0.018
ϕ_1	-0.020	0.297*	0.070	0.267*	0.077***	0.208*	0.327*
ϕ_2	0.141*	0.026	0.194*	0.198*	0.036	0.300*	0.004
ϕ_3	0.093**	0.110**	0.106**	0.147*	0.025	0.124**	0.003
ϕ_4	0.035	0.019	0.053	0.033	0.044	-0.099**	0.062**
ϕ_5	0.098**	-0.007	0.013	-0.018	0.116**	0.049	-0.034
ϕ_6	0.016	0.034	0.113*	0.127**	0.029	0.117*	0.024
ϕ_7	0.029	0.084***	0.035	0.087***	0.082***		0.048***
ϕ_8	-0.024	0.054	0.064***	0.028	0.024		-0.042
ϕ_9	0.016	0.012		0.029	0.148*		0.071
ϕ_{10}	0.066***	0.061***		0.028	0.044		0.031
ϕ_{11}				-0.045	0.051		0.121
ϕ_{12}				-0.127*	-0.132*		-0.218*
Conditional variance							
ω	0.010*	0.011**	0.013*	0.001***	0.003***	0.008*	0.002*
α	0.288*	0.163*	0.494*	0.164*	0.080**	0.566*	0.205*
β	0.636*	0.490*	0.333*	0.828*	0.893*	0.394*	0.723*
MLLV	-73.60	167.54	96.90	182.13	-121.83	-7.11	84.71

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively. MLLV is the maximized log likelihood value.]*

Table 4.2 Estimates of the parameters of the AR(k)-TGARCH(1,1) model

Country *Parameter*	*Canada*	*France*	*Germany*	*Italy*	*Japan*	*The UK*	*The USA*
Conditional mean							
ϕ_0	0.007	0.001	-0.001	0.000	0.003	-0.015	-0.011
ϕ_1	-0.035	0.296*	0.072	0.268*	0.085	0.210*	0.326*
ϕ_2	0.108**	0.025	0.195*	0.202*	0.033	0.295*	0.008
ϕ_3	0.080***	0.110**	0.106**	0.142*	0.024	0.111**	-0.003
ϕ_4	0.037	0.019	0.052	0.013	0.043	-0.090***	0.071**
ϕ_5	0.104**	-0.007	0.013	-0.007	0.117**	0.050*	-0.024
ϕ_6	0.019	0.034	0.113*	0.101**	0.029	0.116*	0.035
ϕ_7	0.025	0.08***	0.035	0.115**	0.077**		0.047***
ϕ_8	-0.017	0.055	0.064***	0.030	0.022		-0.040
ϕ_9	0.017	0.013		0.037	0.144*		0.073
ϕ_{10}	0.062***	0.062**		0.030	0.053		0.034
ϕ_{11}				-0.032	0.045		0.117*
ϕ_{12}				-0.122*	-0.138*		-0.207*
Conditional variance							
ω	0.009*	0.011**	0.013*	0.001**	0.002	0.008*	0.002**
α	0.185**	0.161**	0.518*	0.039	0.092**	0770*	0.219*
γ	0.337*	0.169***	0.330*	0.200*	0.067	0.570*	0.387*
β	0.667*	0.493**	0.330*	0.863*	0.899*	0.347*	0.715*
MLLV	-72.05	167.90	99.93	186.84	-121.70	-6.38	86.63

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively. MLLV is the maximized log likelihood value.]*

Table 4.3 Ljung-Box test statistic values with standardized residuals and squared standardized residuals for both the models

AR(k)-GARCH(1,1) model							
Autocorrelation in standardized residuals							
Q(1)	0.524	0.289	0.072	0.605	0.283	1.002	0.417
Q(5)	1.004	4.245	1.572	1.004	0.616	2.752	2.873
Q(10)	2.245	5.238	4.604	1.789	1.371	8.006	9.417
Autocorrelation in squared standardized residuals							
$Q^2(1)$	0.651	0.018	0.600	1.001	0.519	0.139	0.678
$Q^2(5)$	2.363	1.474	2.251	2.816	2.566	2.465	3.331
$Q^2(10)$	4.451	3.102	5.081	10.184	5.189	6.353	6.985
AR(k)-TGARCH(1,1) model							
Autocorrelation in standardized residuals							
Q(1)	1.204	0.311	0.087	0.641	0.358	0.990	0.432
Q(5)	1.261	4.461	1.652	1.374	0.690	2.558	2.693
Q(10)	2.536	5.454	4.664	1.995	1.794	7.850	7.630
Autocorrelation in squared standardized residuals							
$Q^2(1)$	0.332	0.018	0.622	1.295	0.758	0.151	0.637
$Q^2(5)$	2.007	1.461	2.279	4.346	2.770	2.583	4.630
$Q^2(10)$	4.169	3.133	5.154	10.862	5.293	6.800	8.243
LR test	3.10***	0.72	6.06**	9.42*	0.26	1.46	3.84**

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively.]*

The lag order of the AR process for conditional mean was determined by using the Akaike Information Criterion (AIC). It is observed from Table 4.1 that all the three GARCH parameters, ω, α and β, are positive and significant for all the seven countries, suggesting that GARCH is an appropriate model for measuring inflation uncertainty for all the G7 countries. The conclusion on the TGARCH model is also similar. Except the parameters ω and γ for Japan and α for Italy, all other parameters in TGARCH are statistically significant for all the countries. This means TGARCH is also an appropriate model for capturing uncertainty in inflation for all the G7 countries. The Ljung-Box test also confirms that for both the models, the standardized residuals show that there are no significant linear as well as squared dependences.

Finally, we note from the entries on the LR test in the last row of Table 4.3 that for four countries *viz*., Canada, Germany, Italy and the USA the symmetric GARCH model is rejected in favour of the TGARCH model. For the remaining three i.e., France, Japan and the UK, the maximized log likelihood values are very close and hence the LR test statistic values are found to be insignificant. It is further noted from Table 4.2 that among these four countries the estimated value of the coefficient γ is higher than that of α for Canada, Italy and the USA. For instance, in case of Canada, $\hat{\gamma}$ and $\hat{\alpha}$ are 0.337 and 0.185, respectively. Thus for these three countries, 'bad news' of inflation affects volatility more than the 'good news'. However, in Germany, the 'good news' increases volatility more than that of 'bad news' since the estimated value of α, i.e., 0.518, is more than that of $\hat{\gamma}$ which is 0.330. Since TGARCH performs significantly better than GARCH in four of the G7 countries and in the remaining three, TGARCH and GARCH explain the conditional volatility of inflation equally well, in subsequent analyses we have taken the estimated values of conditional volatility as obtained from the AR(k)-TGARCH(1,1) model, to be the measure of inflation uncertainty for all the G7 countries.

4.3.2 Findings on structural breaks

Once the inflation uncertainty has been measured in the first step, in the second step, the methodology proposed by Qu and Perron (2007) is applied for finding the presence of multiple structural breaks in the two models specified in equations (4.5) and (4.6) involving inflation and inflation uncertainty[39]. The results on structural breaks along with the estimated break dates are reported in Table 4.4.

---

[39] The GAUSS code for this test was obtained from the official website of Pierre Perron.

Table 4.4 Results on the Qu-Perron structural break test

Country	*Canada*	*France*	*Germany*	*Italy*	*Japan*	*The UK*	*The USA*
WDmax test							
Up to one break	74.64*	40.24*	101.55*	114.39*	92.94*	70.32*	142.56*
Sequential test							
Sup$F_T(2\|1)$	255.51*	28.02*	152.53*	8.53	25.05	66.36*	16.36
Sup$F_T(3\|2)$	21.40	9.93	18.93			65.48*	
Sup$F_T(4\|3)$						22.30	
Estimated break dates							
$\hat{T}_1$	**1991M01** [1990M09 -1991M05]	**1992M01** [1990M09-1993M05]	**1990M09** [1990M05-1991M01]	**1983M08** [1983M04-1983M12]	**1976M10** [1976M06-1977M02]	**1979M08** [1978M07-1980M09]	**1977M06** [1976M12-1977M12]
$\hat{T}_2$	**1997M06** [1997M02-1997M10]	**1999M11** [1998M06-2001M04]	**1997M02** [1996M11-1997M05]			**1991M06** [1991M02-1991M10]	
$\hat{T}_3$						**2000M06** [2000M03-2000M11]	

[indicates significance at 1% level of significance. $\hat{T}_1$, $\hat{T}_2$ and $\hat{T}_3$ give the estimates of the first, second and third break dates, respectively. Figures in parentheses are the 95% confidence intervals of the estimated break dates.]*

It is evident from the above table that all the tests results indicate the presence of at least one structural break in the relationship involving inflation and inflation uncertainty for each of the G7 countries. For instance, in case of Canada, the test statistic value for the *WDmax* test is found to be 74.64, which is significant at 1% level of significance, and hence the null hypothesis of 'no break' is rejected in favour of the alternative of 'up to one break' in the above system of two equations. To detect further if there is more than one structural break, the sequential break test is now carried out. By looking at the relevant entries of Table 4.4, we note that the test statistic $Sup\ F_T(2|1)$ has the value 255.51 for Canada, which is highly significant. So the test rejects the null hypothesis of 'one break' in favour of 'two breaks'. However, the sequential test for detecting more than two breaks i.e., $Sup\ F_T(3|2)$ cannot be rejected for Canada. The value of this test statistic is found to be 21.40, which is insignificant at 1% level of significance and hence no further test is required for Canada. Finally, the two break points for Canada have been estimated following the procedure of Qu-Perron, and these are found to be January 1991 and June 1997. Similarly, we have obtained two breaks for France and Germany, one break for each of Italy, Japan and the USA, and three breaks for the UK. The estimated break dates are January 1992 and November 1999 for France, October 1990 and February 1997 for Germany, August 1983 for Italy, October 1976 for Japan, August 1979, June 1991 and June 2000 for the UK, and June 1977 for the USA.

In what follows we attempt at providing some plausible economic explanations for the findings on the break dates for each country. For Canada, the first break has been found in the early 1990s when, in fact, decrease in both the inflation level and its volatility were observed and this coincided with the introduction of an inflation target by the Bank of Canada. In February 1991, the Bank of Canada and the Government of Canada issued a joint statement setting out a target path for inflation reduction. The initial inflation target was further revised in the middle and at the end of 1990s[40]. Post 1999 was the period when higher fluctuation in the Canadian inflation series as compared to the 'targeting' period was observed. One probable reason for this inflation fluctuation could be attributed to sharp movements in the oil prices that occurred in the 2000s. Gomez-Loscos (2012) have pointed out that oil price shock on inflation was the highest in the 1970s and progressively disappeared in 1980s and 1990s. The effect reappeared in the 2000s, causing a fluctuation in the inflation series in most of the industrialized economies.

Concerning the structural break in the relationship between inflation and inflation uncertainty in some G7 countries in the Euro area, specifically France, Germany and Italy, our findings on the break dates are very similar to that obtained by Caporale and Kontonikas (2009). The most important policy event taking place in the then called European Community around the time the breaks have been detected was the adoption by the Committee of Central Bank Governors of some changes in the operation of the European Monetary System (EMS) and in the rules governing the activities of the European Monetary Cooperation Fund (EMCF). These rules came into force on 1st July 1985. In France, Germany and Italy, the first break dates have been obtained as January 1992, October 1990 and August 1983, respectively, which were the first stages of progress towards the Economic and Monetary Union (EMU). Finally, for France and Germany, the second break has been estimated during the late 1990s, the period when the third and final stage of EMU started with the adoption of a common currency and monetary policy.

---

[40] A publication *viz*., *Renewal of the Inflation-Control Target: Background Information* by the Bank of Canada, November 2006, give these explanations.

The break date found in Japan coincides exactly with the period when the Bank of Japan adopted an explicit monetary tightening policy to combat the high inflationary situation of 1960s and 1970s. In case of the UK, the first break date has been estimated to be in the late 1970s i.e., the period with which is associated not only the various changes in monetary policy, but it is also the period of wage price controls in the UK (see, Nelson (2005)). In October 1992, following a 2-year European Exchange Rate Mechanism membership, the UK government adopted an explicit inflation targeting policy with the aim at reducing inflation to 2.5% within five years (see, among others, Martin and Milas (2004) and Benati (2006)). Again, May 1997 marked a further notable change. By May 1997, the UK Central Bank was awarded operational independence in setting short term interest rates to meet the government's stated target of inflation of 2.5%. The estimated break dates obtained is thus found to coincide with these periods in the UK. To reduce the chronic inflation of 1960s and 1970s in the USA, the Federal Reserve under the chairmanship of Paul Volcker adopted an extremely contractionary monetary policy. This significant change in policy regime in the case of the USA is supported by the finding of the observed break date in this study.

4.3.3 Relationship between inflation and its uncertainty

We now report, in Table 4.5, the estimation results regarding the relationship between inflation and inflation uncertainty in different sub-periods, as specified in the system of equations in (4.5) and (4.6). As stated earlier, we have also estimated the model specified in equations (4.7) and (4.8) which are based on the entire sample with no consideration to structural breaks in the system of equations. Both these full-sample and sub-period based estimation results for the relevant parameters have been used to find the existence of bi-directional nature of the relationship between inflation and inflation uncertainty. These findings are also indicated in the same table.

Table 4.5 Results on the relationship between inflation and inflation uncertainty

	Effect of inflation on inflation uncertainty					*Effect of inflation uncertainty on inflation*				
	Full sample	*Sub-period I*	*Sub-period II*	*Sub-period III*	*Sub-period IV*	*Full sample*	*Sub-period I*	*Sub-period II*	*Sub-period III*	*Sub-period IV*
Country	$\beta_{h_\pi \pi}$	$\beta_{h_\pi \pi,1}$	$\beta_{h_\pi \pi,2}$	$\beta_{h_\pi \pi,3}$	$\beta_{h_\pi \pi,4}$	$\beta_{\pi h_\pi}$	$\beta_{\pi h_\pi,1}$	$\beta_{\pi h_\pi,2}$	$\beta_{\pi h_\pi,3}$	$\beta_{\pi h_\pi,4}$
Canada	0.087*	0.051*	0.337*	0.028*		0.064	0.544***	0.136	-0.419	
France	0.005**	0.007***	0.007***	-0.004		0.610	0.562	0.263	-2.354***	
Germany	0.133*	0.079*	0.392*	-0.018		0.169	0.240	0.061	-0.013	
Italy	0.054*	0.072*	0.012*			0.378*	0.489***	2.740*		
Japan	0.023*	0.040*	0.010*			0.214***	0.290	0.611**		
The UK	0.495*	0.699*	0.328*	-0.034*	-0.019	0.046	0.047	0.018	0.191*	-0.171
The USA	0.048*	0.220*	0.002			0.273*	0.624*	-0.007		

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively. $\beta_{h_\pi \pi,j}$ and $\beta_{\pi h_\pi,j}$ capture the effect of inflation on inflation uncertainty and the effect of inflation uncertainty on inflation, respectively, in the j^{th} sub-period.]*

The empirical findings based on the full sample indicate that the coefficient $\beta_{h_\pi \pi}$ is highly significant for all the G7 countries. For instance, in case of Canada, $\hat{\beta}_{h_\pi \pi}$ is 0.087 and this is significant at 1% level of significance. Additionally, this coefficient is positive for all the countries, thus supporting the Friedman-Ball hypothesis for positive effect of inflation on inflation uncertainty. This empirical observation is similar to most of the previous studies on this problem which support the Friedman-Ball hypothesis for many industrialized economies. On the other hand, as regards the reverse causation from inflation uncertainty to inflation, as denoted by the coefficient $\beta_{\pi h_\pi}$, we note that it is significant in three countries only *viz.*, Italy, Japan and the USA. Again, for all these three countries, we find evidence in favour of positive effect of inflation uncertainty on inflation as predicted by Cukierman-Meltzer hypothesis. However, no significant impact of inflation uncertainty on inflation has been obtained for Canada, France, Germany and the UK.

Now, we discuss the results sub-period-wise for each country[41]. In case of Canada, the above results indicate that inflation is a positive determinant of inflation uncertainty in all the sub-periods. The estimated values of the relevant coefficient i.e., $\beta_{h_\pi \pi, j}$ are 0.051, 0.337 and 0.028 for the three sub-periods, respectively, and all these are highly significant. Thus it is found that the positive causal effect of inflation on its uncertainty is invariant to states of high and low volatile periods of inflation in Canada – with the former referring to the volatile periods of 1970s and 2000s and latter to the less volatile period i.e., the period after 'inflation targeting'. In this context, it is important to note that even if both inflation and inflation uncertainty move in the same direction, differences in the size of the coefficients may be observed in different sub-periods, implying thereby that the effects are also economically significant. The results show that the size of the effect is substantially greater in the second sub-period, the coefficient being six times higher in magnitude as compared to the first sub-period. However, the magnitude of the effect reduces in the third sub-period as the estimate of the coefficient $\beta_{h_\pi \pi}$ is just 0.028 which is much smaller than 0.337 for the second sub-period. On the other hand, somewhat contrary to full sample results, we get marginal evidence in favour of the Cukierman-Meltzer hypothesis that states about a positive impact of inflation uncertainty on inflation, in case of Canada. The effect is found to be significant, although not very strong, only in the first sub-period as the value of estimated coefficient of $\beta_{\pi h_\pi, 1}$, 0.544, is significant at 10% level of significance whereas the effect is not significant at all for the second and third sub-periods.

For France, we have obtained a positive and significant impact of inflation on inflation uncertainty in the first and second sub-periods. However, the effect is not so strong in these two sub-periods as $\beta_{h_\pi \pi, 1}$ and $\beta_{h_\pi \pi, 2}$ are significant only at 10% level. It can also be noted that the effect is similar in magnitude for both the first and second sub-periods. Again, this impact is found to be insignificant in the third sub-period. In other words, the positive effect of inflation on inflation uncertainty that is significant, although not so strongly, in the first and second regimes does not hold after the formation of European Monetary Union (EMU). Now, contrary to the full sample results, the reverse causation from inflation uncertainty to inflation is highly significant in the third

---

[41] For example, in case of Canada where we have found two breaks, we consider, based on the break dates estimated, three sub-periods of which the first sub-period covers the time period from December 1970 to January 1991. The second sub-period includes observations from February 1991 to June 1997, and obviously the third sub-period, refers to the remaining period *viz*., from July 1997 to June 2013.

sub-period. A negative sign indicates that inflation uncertainty reduces future inflation, and thus it gives empirical support to Holland's hypothesis of stabilization of inflation in France.

We did not find any significant result on the effect of inflation uncertainty on inflation for Germany either in full sample or in the different sub-periods. All the values of the coefficient – 0.169 for the full sample and 0.240, 0.061 and -0.013 for the three consecutive sub-periods - are found to be insignificant. Now, regarding the impact of inflation on inflation uncertainty in Germany, we have found that a significant positive effect exists in full sample as well as in the first two sub-periods. However, similar to France, the Friedman-Ball hypothesis that holds in the first two sub-periods is not found to be so for the third sub-period where the coefficient $\beta_{h_\pi \pi,3}$ turns out to be insignificant. In case of Germany, the effect of inflation on its uncertainty has increased substantially in the second sub-period from that of the first sub-period as the estimate of the coefficient has increased from 0.079 to 0.392 in the second sub-period. It is thus important to note that for these two countries i.e., Germany and France, the effect of inflation on inflation uncertainty in fact does not hold during the Euro period in the sample, i.e., the period after the introduction of the Euro and a common monetary policy in 1999.

Sub-samples results for Italy and Japan indicate that the Friedman-Ball hypothesis holds in both the sub-periods. While it is interesting to note that in both of these countries the positive effect of inflation uncertainty on inflation, as predicted by Cukierman and Meltzer (1986), is highly significant only in the second sub-period. However, during the period of 'great inflation' of 1970s, this effect is found to be weak for Italy since the coefficient $\beta_{\pi h_\pi,1}$ is significant only at 10% level of significance, and insignificant in case of Japan. It is also evident that for Italy and Japan, the effect of inflation on inflation uncertainty are rather equal in size in both the sub-periods. However, the size of the reverse effect i.e., from inflation uncertainty to inflation has increased substantially in the second sub-period for these two countries.

It is worthwhile to note that in case of the UK the positive causal effect of inflation on inflation uncertainty holds only for the first two sub-periods, whereas it is found to be negative in the third sub-period i.e., in the period after 'inflation targeting' in the UK. This finding is in sharp contrast to the Friedman-Ball hypothesis that in the post-targeting period, a further reduction of inflation would tend to increase inflation uncertainty instead of reducing it. These findings are similar to those found in Kontonikas (2004) where he found that the Friedman-Ball hypothesis was valid for the UK only before 1992 i.e., the pre-targeting period, but not so in the post-targeting period. Again, the significant effect of inflation uncertainty on inflation is obtained only in the third sub-period, i.e., just after the targeting period. The estimated value of the coefficient $\beta_{\pi h_{\pi},3}$ i.e., 0.191, is significant at 1% level of significance. Further, the positive sign of this effect is in sharp contrast to 'no significant effect' obtained in full sample.

Finally, the estimated value of the coefficient $\beta_{h_{\pi}\pi,1}$ for the USA clearly shows that inflation significantly caused an increase in its uncertainty only during 1970s. It is also true that a reverse causation *viz*., a positive and significant effect of inflation uncertainty on inflation exists only in the first sub-period i.e., during the period of 'great inflation'. No causality, however, in either direction is found to be significant in the second sub-period in case of the USA. In case of the UK and the USA, the size and magnitude of the inflationary effect on inflation uncertainty has reduced significantly in the latter sub-period(s) as compared to the first sub-period.

4.4 Conclusions

In this chapter, we studied the links between inflation and inflation uncertainty for each of the G7 countries using a framework which allows for multiple structural breaks in the underlying system of equations. The study which is based on time series data covering the period from January 1970 to June 2013 uses a two-step procedure. In the first step, the threshold GARCH (TGARCH) model has been used to estimate the conditional variance of inflation, which has been taken to be a measure for inflation uncertainty. In the second step, the Qu-Perron (2007) methodology has been applied. This essentially means using a VAR model with inflation and inflation uncertainty along with consideration to testing for and then incorporating multiple structural breaks in the two equations. It can, therefore, be analyze as to how the relationship varies across different sub-periods, which, in turn, validates or otherwise the macroeconomic theories/hypotheses concerning inflation and inflation uncertainty.

In our analysis, we have found at least one structural break in the relationship for each of the G7 countries. The estimated break date(s) thus obtained for each country seems to broadly give empirical support to the policy changes of the respective country during those time periods. As regards the nature of the relationship, the empirical evidence, in general supports that the relationship varies significantly in different sub-periods.

As for the effect of inflation on inflation uncertainty, we note that the Friedman-Ball hypothesis for positive causal effect of inflation holds for all the seven countries in the full sample period. However, evidence based on different sub-periods show that this hypothesis holds mostly during the first half of the sample period in most of the countries, whereas the effect is, in general, not significant in the latter half of the sample period. More specifically, for France and Germany, the positive impact of inflation on inflation uncertainty that is observed in the pre-Euro period, is not found to be significant in the post-Euro period, i.e., after the introduction of the Euro and of a common monetary policy in 1999. Similarly, in the UK, in contrast to the Friedman-Ball hypothesis, the impact is found to be negative in the period from 1992 to 2000, but the same does not hold during the recent period. The evidence is also similar for the USA, since the positive impact has been obtained only for the period of high inflation during 1970s.

Finally, the findings regarding the reverse impact, i.e., the incidence of inflation uncertainty affecting inflation is found to be rather scant both in the full sample as well as in different sub-periods. The relevant coefficient is found to be positive and highly significant only for Italy and the USA, while for the remaining five countries the evidence is either weak or insignificant. In their respective first sub-periods, only Canada, Italy and the USA provide support to the Cukierman-Meltzer hypothesis even though the evidence is weak for Canada and Italy. Only in case of Italy and Japan, significant positive effect of inflation uncertainty on inflation has been found in their respective second sub-periods. Finally, the study provides support to the Cukierman-Meltzer hypothesis only in the third sub-period of the UK while weak evidence in favour of Holland’s stabilization hypothesis is found for France in the third sub-period only.

Chapter 5

The Effects of Inflation and Output Growth Uncertainty on Inflation and Output Growth: A TBVAR-BAGARCH-M Model

5.1 Introduction

One of the most important and debatable issues in macroeconomics that drew serious attention of researchers in recent years is the impacts of inflation uncertainty and output growth uncertainty on inflation and output growth. Friedman (1977) argued that a rise in average inflation creates uncertainty about future monetary policy to counter it, leading to wide variations in actual and anticipated inflation, and thus resulting in economic inefficiency and lower output growth[42]. The negative effect of inflation uncertainty on output growth has also been supported by Pindyck (1991) and Huizinga (1993). On the other hand, some researchers like Abel (1983), and Dotsey and Sarte (2000) have found the existence of a positive relationship between inflation uncertainty and output growth. Likewise, the influence of nominal (inflation) uncertainty on the rate of inflation has been found to be positive (see, for instance, Cukierman and Meltzer (1986) and Cukierman (1992)), or negative (Holland (1995)). Theoretical ambiguity also surrounds the effect of real (output growth) uncertainty on inflation. The positive effect is supported by Devereux (1989), Cukierman and Gerlach (2003), while Taylor (1979) and Cukierman and Meltzer (1986) posit for a negative relation. Finally, as noted by Mirman (1971), Black (1987) and Blackburn (1999), the effect of real uncertainty on output growth could be positive while Bernanke (1983) and Pindyck (1991) argued that this effect is negative.

---

[42] To be precise, the Friedman (1977) hypothesis is comprised of two coherent relationships that articulate a positive effect of inflation on inflation uncertainty together with a negative effect of inflation uncertainty on output growth. In the previous two chapters, we have dealt with the first part of this hypothesis. In this as well as in the next chapter, we make an assessment of the importance of inflation uncertainty channel i.e., how inflation uncertainty affects output growth.

All these theoretical contributions assume that the influence of nominal and real uncertainty on inflation and output growth is linear, or constant. An implication of this is that when the theories are brought into the test, between each pair of suggestive explanations, one theory should prevail as being correct. However, one cannot dismiss the possibility that the impact of uncertainty on inflation and output growth may vary so that all theories are relevant to some extent. This possibility is, in fact, corroborated by the mixed and often contradictory findings in the empirical literature.

There exists a sizable literature investigating the above relationships with the use of GARCH or GARCH-type models. Although, as discussed in the previous two chapters, univariate study on the relationship between inflation and inflation uncertainty is quite voluminous, studies in bivariate framework involving inflation and output growth along with the models for their conditional variances which represent their respective uncertainties, are rather recent and few in number. Notable among these are Grier and Perry (2000), Fountas et al. (2002), Grier et al. (2004), Bredin and Fountas (2005, 2009), Wilson (2006), Fountas and Karanasos (2007). The findings of these studies that utilize bivarite GARCH-M models, in particular, are found to vary considerably. For example, in the case of the USA, three of the most well-known studies in the literature agree only on the negative impact of inflation uncertainty on output growth (see, for details, Grier and Perry (2000), Grier et al. (2004) and Bredin and Fountas (2005)). The significance of the remaining three effects i.e., effect of inflation uncertainty on inflation, output growth uncertainty on inflation and output growth uncertainty on output growth, have been found to vary across studies. For Japan, Bredin and Fountas (2005), and Wilson (2006) have agreement on the sign and significance of the impact of real uncertainty on inflation only. The same has been found to hold for the UK also. No agreement across studies on the other effects has been found (see, Bredin and Fountas (2005) and Bredin et al. (2009)). It may therefore, be concluded that the empirical evidence is mixed, even for studies that use similar estimation techniques[43].

A very recent development in this literature is that the relationship between inflation and

---

[43] The variations in results could be explained partly by the fact that different studies have used different measures of output growth (GDP and industrial production index) and inflation (CPI and PPI), as also due to the different time periods considered.

inflation uncertainty is assumed to be not stable over time, especially when the span of the series is large enough. So is the case with output growth and output growth uncertainty. In this chapter we deal with this issue by considering regime shifts in examining the effects of real and nominal uncertainties on inflation and output growth. In Chapter 3, we have considered inflation and inflation uncertainty only, and allowed for regime switching behaviour in specifying the model for inflation. Two regimes have been considered based on inflation at lag 1 being negative or positive. As mentioned there, these two regimes essentially refer to low and high regimes, respectively. In this chapter, we extend this work by considering regimes for output growth also based on similar criterion i.e., by taking output growth at lag 1 as the threshold variable and 0 as the threshold value, the two regimes are defined as output growth at lag 1 being negative or positive.

The notion of taking lag values of inflation and output growth as the threshold variables has been influenced by a few recent studies. While we have cited those studies concerning inflation and inflation uncertainty where such a threshold variable has been considered, in Chapter 3, we mention below the findings of a few studies on output growth and its uncertainty based on such regime consideration. Using a GARCH-M set up, Henry and Olekalns (2002) have examined the effect of recession on the relationship between output growth uncertainty and output growth for the US economy. It is evident from their study that recession leads to a higher output uncertainty and thus it reduces subsequent output growth, while the relationship is found not to exist as the economy expands. Further, Garcia-Herrero and Vilarrubia (2005) have shown that different relationship exists between output growth uncertainty and output growth in the two regimes based on output growth. Their key findings are that a moderate degree of uncertainty improves growth while a situation of high volatility dampens it. A very recent study by Neanidis and Savva (2013) have examined the differential effect of macroeconomic uncertainties on inflation and output growth for the G7 countries in a bivariate framework. By defining the regimes on the basis of inflation rate and the economy’s position along the business cycle, this study finds that real uncertainty increases growth in the low output growth regime, while it has mixed effects on inflation. On the other hand, nominal uncertainty increases inflation and reduces output at a high inflation regime.

In line with the recent literature, in this chapter we propose a model to analyze the regime dependent effects of inflation and output growth uncertainty on inflation and output growth where the regimes are based on the past level of inflation and output growth. The model is called the threshold bivariate AR–bivariate asymmetric GARCH-in-mean (TBVAR(*p*)-BAGARCH(1,1)-M) model of inflation and output growth. The conditional mean model is threshold BVAR and hence it captures interdependences between inflation and output growth through the two mean equations which are now assumed to vary in the two regimes. The consideration of 'in-mean' in the model is intended to further generalize this by allowing for explicit inclusion of uncertainties associated with inflation and output growth in the mean model so that the effects of inflation uncertainty and output growth uncertainty on inflation and output growth could be obtained. It is to be noted that based on our findings in the preceding chapter on the presence of asymmetric effect of past shocks in the volatility specification of inflation, we have assumed an asymmetric GARCH (BAGARCH) model in bivariate set-up in this context, which captures the interdependences between the uncertainties associated with inflation and output growth. Thus, this model explicitly incorporates, apart from own volatility, both direct and indirect cross volatilities. The main innovation in the proposed model is that here we generalize the conditional mean to allow for the possibility of directly capturing the effects of inflation uncertainty and output growth uncertainty on inflation and output growth, and this too at two different regimes for each inflation and output growth.

The format of this chapter is as follows. The proposed model along with a benchmark model is presented in the next section. In Section 5.3, the empirical results on estimation of the two models along with some hypothesis testing are discussed. This paper ends with some concluding remarks in Section 5.4.

5.2 Econometric Methodology

In this section, we introduce the proposed threshold bivariate AR(*p*)-bivarite asymmetric GARCH(1,1)-in-mean (TBVAR(*p*)-BAGARCH(1,1)-M) model which allows for testing for the effects of inflation and output growth uncertainties on the levels of inflation and output growth in two different regimes. Before doing that we first state a single regime bivariate VAR(*p*)-bivariate GARCH(1,1)-in-mean (BVAR(*p*)-BGARCH(1,1)-M) model which is taken as a benchmark model for this study since our proposed model is a generalization of this model where regimes have been introduced for the conditional mean model and asymmetry reactions in the model for conditional variance. We also describe the method of estimation briefly. Finally, we specify some hypotheses of interest concerning the proposed model.

5.2.1 BVAR(*p*)-BGARCH(1,1)-M model

In equations (5.1) and (5.2) below, we present, the BVAR(p)-BGARCH(1,1)-M model involving inflation (π_t) and output growth (y_t).

$$Z_t = \mu + \sum_{i=1}^{p} \Phi_i Z_{t-i} + \delta \text{vech}(H_t) + \varepsilon_t, \qquad \varepsilon_t | \psi_{t-1} \sim N(0, H_t) \tag{5.1}$$

$$H_t = CC' + A\varepsilon_{t-1}\varepsilon'_{t-1}A' + BH_{t-1}B' \tag{5.2}$$

where $Z_t = \begin{bmatrix} \pi_t \\ y_t \end{bmatrix}$, $\mu = \begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix}$, $\Phi_i = \begin{bmatrix} \phi_{i,11} & \phi_{i,12} \\ \phi_{i,21} & \phi_{i,22} \end{bmatrix}$, $\delta = \begin{bmatrix} \delta_{11} & \delta_{12} & \delta_{13} \\ \delta_{21} & \delta_{22} & \delta_{23} \end{bmatrix}$, $H_t = \begin{bmatrix} h_{\pi,t} & h_{\pi y,t} \\ h_{\pi y,t} & h_{y,t} \end{bmatrix}$,

$\text{vech}(H_t) = \begin{bmatrix} h_{\pi,t} \\ h_{\pi y,t} \\ h_{y,t} \end{bmatrix}$, $\varepsilon_t = \begin{bmatrix} \varepsilon_{\pi,t} \\ \varepsilon_{y,t} \end{bmatrix}$, $C = \begin{bmatrix} c_{11} & c_{12} \\ 0 & c_{22} \end{bmatrix}$, $A = \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \end{bmatrix}$, $B = \begin{bmatrix} \beta_{11} & \beta_{12} \\ \beta_{21} & \beta_{22} \end{bmatrix}$, and ψ_{t-1} represents the information set at time point *t*.

In equation (5.1), the coefficients $\phi_{i,11}$ and $\phi_{i,22}$ for $i = 1,2, \dots, p$, capture the effects of own lags in the conditional mean equations for inflation and output growth, respectively. Similarly, the coefficients $\phi_{i,12}$ and $\phi_{i,21}$ depict the effects of output growth on inflation and inflation on output growth, respectively. The main parameters of interest are δ_{11}, δ_{13}, δ_{21} and δ_{23}. The coefficients, δ_{11} and δ_{21} denote the impacts of inflation uncertainty on inflation and output growth, respectively, while δ_{13} and δ_{23} reflect the impacts of output growth uncertainty on inflation and output growth, respectively[44]. This model also allows, through δ_{12} and δ_{22}, capturing the effect of the covariance (called the indirect effect) on inflation and output growth, respectively.

The form of H_t is an important issue in this model, as noted by Bollerslev et al. (1988) who first introduced the multivariate GARCH model, called the VEC model, which involved a large number of parameters and ensuring the positive definiteness of H_t was difficult. Thereafter they

---

[44] Similar to the existing studies (see, for example, Grier and Perry (2000), Elder (2004), Grier et al. (2004), Shields et al. (2005), Bredin and Fountas (2005), Wilson (2006), and Bredin and Fountas (2009)), the in-mean coefficient in our proposed model indicates only the contemporaneous effect of macroeconomic uncertainty on inflation and output growth. However, at the same time one can very well consider the lag values of in-mean term to capture the lagged effects of uncertainty on inflation and output growth. These effects are more likely to be present with data at monthly frequency.

introduced a simplified version of the VEC model which is the diagonal VEC model. This model reduces the number of parameters greatly and it is easier to derive the conditions on the parameters to guarantee the positive definiteness property of H_t. Later in 1995, Engle and Kroner proposed the BEKK model (an acronym used for the synthesized work on multivariate model of Baba, Engle, Kraft and Kroner (1989)), as specified in equation (5.2), which can be viewed as a restricted version of the VEC model. Though the number of parameters to be estimated is still quite large, the BEKK model has the good property that the conditional variance-covariance matrix is positive definite by construction. Keeping this in mind, we have considered the BEKK model for incorporating volatility dependences between inflation and output growth in the benchmark model[45].

5.2.2 The proposed TBVAR(*p*)-BAGARCH(1,1)-M model

In this section, we present the proposed threshold bivariate AR(*p*)-bivariate asymmetric GARCH(1,1)-in-mean (TBVAR(*p*)-BAGARCH(1,1)-M) model. As stated in the previous section, our main objective is to find the effects of inflation and output growth uncertainties on the levels of inflation and output growth in two different regimes. This gives the links involving inflation and output growth with their uncertainties in the two regimes. To that end, we have assumed that the two threshold variables, which define the regimes, are known. The transition variables are considered as the first lagged values of inflation and output growth i.e., π_{t-1} and y_{t-1}, where the threshold value has been taken to be zero for both inflation and output growth series. The use of output growth as a transition variable with a zero threshold value is consistent with the literature that distinguishes between periods of positive and negative growth, or more commonly to the expansions and contractions of an economy (see, Terasvirta and Anderson (1992), Terasvirta (1994), Tiao and Tsay (1994), Potter (1994), Van Dijk et al. (2002)). Similarly, as already

---

[45] Another important direction in which the multivariate GARCH model has grown involves modeling the correlations between the series indirectly instead of modeling the conditional variance-covariance matrix directly as in the case of BEKK. Bollerslev (1990) first introduced a class of constant conditional correlation (CCC) model in which the conditional covariance matrix is time-varying but the conditional correlations across equations are assumed to be constant. The assumptions of a constant correlation matrix represents a major reduction in terms of computational complexity, and thus it is commonly used in the literature that examines the effect of inflation and output growth uncertainties on inflation and output growth (see, Grier and Perry (2000), Fountas et al. (2002), Fountas and Karaasos (2006), Wilson (2006), Neanidis and Savva (2013), for details).

discussed in Chapter 3, we use zero inflation rate at stationary level as the threshold value in defining low (≤ 0) and high (> 0) inflation regimes. In this context, we may state that on reason of parity of description with inflation, we could identify these two regimes of output growth as low and high, respectively. Thus our proposed model has the advantage that it can capture the effect of the state of the economy, denoted by two levels each of inflation and output growth, for examining the impacts of real and nominal uncertainty on inflation and output growth.

Thus the conditional mean model as specified in equation (5.1) for a single regime, has now two specifications for the two regimes, denoted as 'l' and 'h' for low and high, respectively. The notations are accordingly changed with adding super scripts l and h in case of coefficient parameters. The two models for inflation and output growth can thus be explicitly written as

$$\pi_t = \left(\mu_1^l + \sum_{i=1}^{p} \phi_{i,11}^l \pi_{t-1} + \sum_{i=1}^{p} \phi_{i,12}^l y_{t-1} + \delta_{11}^l h_{\pi,t} + \delta_{12}^l h_{\pi y,t} + \delta_{13}^l h_{y,t}\right)[I(\pi_{t-1}) \leq 0] + \left(\mu_1^h + \sum_{i=1}^{p} \phi_{i,11}^h \pi_{t-1} + \sum_{i=1}^{p} \phi_{i,12}^h y_{t-1} + \delta_{11}^h h_{\pi,t} + \delta_{12}^h h_{\pi y,t} + \delta_{13}^h h_{y,t}\right)[1 - (I(\pi_{t-1}) \leq 0)] + \varepsilon_{\pi,t} \tag{5.3}$$

and

$$y_t = \left(\mu_2^l + \sum_{i=1}^{p} \phi_{i,21}^l \pi_{t-1} + \sum_{i=1}^{p} \phi_{i,22}^l y_{t-1} + \delta_{21}^l h_{\pi,t} + \delta_{22}^l h_{\pi y,t} + \delta_{23}^l h_{y,t}\right)[I(y_{t-1}) \leq 0] + \left(\mu_2^h + \sum_{i=1}^{p} \phi_{i,21}^h \pi_{t-1} + \sum_{i=1}^{p} \phi_{i,22}^h y_{t-1} + \delta_{21}^h h_{\pi,t} + \delta_{22}^h h_{\pi y,t} + \delta_{23}^h h_{y,t}\right)[1 - (I(y_{t-1}) \leq 0)] + \varepsilon_{y,t} \tag{5.4}$$

In equation (5.3), p denotes the lag order of the VAR process. The coefficients $\phi_{i,11}^l$ and $\phi_{i,11}^h$ for $i = 1, 2, .., p$, capture the effects of own lags in the conditional mean of inflation for the low and high inflation regimes, while $\phi_{i,12}^l$ and $\phi_{i,12}^h$, $i = 1, 2, .., p$, depict the effects of lagged output growth on inflation for the two regimes. Similar are the interpretations for $\phi_{i,22}^l$, $\phi_{i,22}^h$, $\phi_{i,21}^l$ and $\phi_{i,21}^h$, $i = 1, 2, .., p$ in the conditional mean model of output growth given in equation (5.4). The coefficients, δ_{11}^l and δ_{11}^h, capture the effects of inflation uncertainty on inflation in low and high inflation regimes, respectively, and δ_{21}^l and δ_{21}^h denote the effects of inflation uncertainty on output growth in low and high output growth regimes, respectively. Likewise, the effects of output uncertainty on inflation in the two inflation regimes and also of output growth uncertainty on output growth in the two output growth regimes are captured by δ_{13}^l and δ_{13}^h, and δ_{23}^l and δ_{23}^h, respectively.

It is also to be noted that like the usual GARCH model in the univariate case, the BEKK model (*cf*. equation (5.2)) is symmetric in nature in that it does not capture the asymmetric effects of positive and negative shocks on the volatility of inflation and output growth. Hence, in the proposed model we have taken the asymmetric version of the BEKK representation, due to Grier et al. (2004), which is given by

$$H_t = CC' + A\varepsilon_{t-1}\varepsilon_{t-1}'A' + Du_{t-1}u_{t-1}'D' + BH_{t-1}B' \qquad (5.5)$$

where $D = \begin{bmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{bmatrix}$ is a 2×2 matrix of coefficients associated with u_{t-1} where $u_{t-1} = \begin{bmatrix} u_{\pi,t-1} \\ u_{y,t-1} \end{bmatrix}$ and $u_{\pi,t-1} = \varepsilon_{\pi,t-1} I(\varepsilon_{\pi,t-1} \leq 0)$, $u_{y,t-1} = \varepsilon_{y,t-1} I(\varepsilon_{y,t-1} \leq 0)$, where $I(.)$ is an indicator function which takes the value 1 if $\varepsilon_{\pi,t-1} \leq 0$ and 0 otherwise for inflation. The same holds for output growth i.e., $I(.)$ takes the value 1 if $\varepsilon_{y,t-1} \leq 0$ and 0 otherwise. The concepts of 'good' and 'bad news' can be easily captured by the above specification of H_t. Specifically, if inflation is lower than the expected, we take that to be 'good' news. By contrast, if output growth is lower than the expected, we consider that to be 'bad' news. The form of H_t specified in equation (5.5) is called the (bivariate) asymmetric GARCH (BAGARCH) model[46]. Obviously, the symmetric BEKK model is a special case of the BAGARCH model where $d_{ij} = 0$ for $i, j = 1, 2$. Equations (5.3) and (5.4) along with equation (5.5) constitute our proposed model TBVAR(*p*)-BAGARCH(1,1)-M model[47].

5.2.3 Estimation and testing of hypothesis

Given a sample of T observations and under the assumption of bivariate normality of $\varepsilon_t|\psi_{t-1}$, the log-likelihood function (ignoring the constant term) is given by

---

[46] To capture the asymmetric effects of past shocks in the multivariate set-up, two popular model has been used in the literature *viz*., multivariate generalization of the TGARCH model (see, Grier et al. (2004)) and multivariate generalization of the EGARCH model (see, Koutmos and Booth (1995)). Since in Chapter 4, we have considered TGARCH model of Glosten et al. (1993) to capture the conditional volatility of inflation, in the next two chapters we have applied the multivariate extension of the TGARCH model to capture the effect of asymmetry of shocks on the volatilities of inflation and output growth.

[47] Conditions for stationarity, as obtained by Chan and Tong (1985) and Chan et al. (1985) for the univariate TAR model, are assumed to hold for both inflation and output growth series.

$$L(\theta) = -\frac{1}{2}\sum_{t=1}^{T}(\ln|H_t|) + \varepsilon_t' H_t^{-1}\varepsilon_t) \quad (5.6)$$

where θ is the vector of all parameters involved in the proposed model. Obtaining the ML estimates of the parameters require optimization of a highly nonlinear objective function (conditional on some starting values of H_t and other relevant parameters). To that end, we have used the standard gradient search algorithm, which is known as the Broyden-Fletcher-Goldfarb-Shanno (BFGS) algorithm[48]. All the programs required for doing the computations of the parameters have been written in GAUSS.

Given the proposed model, it is of interest and relevance to carry out some statistical tests to find if some of the effects/ links in the model are statistically significant and/or some restrictions on the parameters of H_t suggesting restricted variance-covariance matrix being adequate for a given data set. To that end, we first test for the presence of overall 'in-mean' effect in the proposed model. The next set of hypotheses refers to the effects of nominal and real uncertainty on inflation and output growth. Tests for hypotheses concerning parameters in the conditional variance model given in equation (5.5) are also done so as to conclude if H_t indeed the symmetric bivariate GARCH and diagonal bivariate GARCH. These tests have been done using the Wald test. The standard Wald test statistic, in terms of general linear restrictions i.e., under the null hypothesis $R\theta = \xi$, is given as:

$$W = \left[R\hat{\theta} - \xi\right]' \left[R\hat{V}(\hat{\theta})R'\right]^{-1} \left[R\hat{\theta} - \xi\right] \quad (5.7)$$

where R is a $q \times k$ matrix of known constants with $q < k$, q is the number of restrictions, k is the number of parameters i.e., number of elements in θ, ξ is a $q \times 1$ vector of known constants, $\hat{\theta}$ is the $k \times 1$ vector of the estimated parameters under the unrestricted model, and $\hat{V}(\hat{\theta})$ is the estimated variance-covariance matrix of the estimated parameters. $W \sim \chi_q^2$ asymptotically, under the null hypothesis. The null hypotheses for the different tests of interests are stated below. The alternative hypotheses can be specified appropriately.

(i) Test for overall significance of 'in-mean' effect.

---

[48] The estimation of our proposed model is based on the assumption that inflation and output growth follow a bivariate normal distribution. However, given that normality assumption does not, strictly speaking, hold, one should use the method proposed by Bollerslev and Wooldridge (1992) to obtain the robust standard errors of the estimates.

H_{01}: $\delta_{mn}^{s} = 0$ for all $m = 1, 2$; $n = 1,2,3$ and $s = l, h$. More specifically, this null hypothesis is written as

$$H_{01}: \delta_{11}^{l} = \delta_{12}^{l} = \delta_{13}^{l} = \delta_{21}^{l} = \delta_{22}^{l} = \delta_{23}^{l} = \delta_{11}^{h} = \delta_{12}^{h} = \delta_{13}^{h} = \delta_{21}^{h} = \delta_{22}^{h} = \delta_{23}^{h} = 0.$$

(ii) Test for the differential effects of inflation uncertainty on inflation in low and high inflation regimes. In this case the null hypothesis is H_{02}: $\delta_{11}^{l} = \delta_{11}^{h}$.

(iii) Test for the differential effects of output growth uncertainty on inflation in low and high inflation regimes. Here the null hypothesis is H_{03}: $\delta_{13}^{l} = \delta_{13}^{h}$.

(iv) Test for the differential effects of inflation uncertainty on output growth in low and high output growth regimes. The underlying null hypothesis is H_{04}: $\delta_{21}^{l} = \delta_{21}^{h}$.

(v) Test for the differential effects of output growth uncertainty on output growth in low and high output growth regimes. The null hypothesis is H_{05}: $\delta_{23}^{l} = \delta_{23}^{h}$.

(vi) Test for diagonal bivariate GARCH.

$$H_{06}: \alpha_{12} = \alpha_{21} = \beta_{12} = \beta_{21} = d_{12} = d_{21} = 0.$$

(vii) Test for symmetric bivariate GARCH.

$$H_{07}: d_{11} = d_{12} = d_{21} = d_{22} = 0.$$

5.3 Empirical Analysis

In this section we first discuss the findings on the benchmark BVAR(*p*)-BGARCH(1,1)-M model, and then report on the results of estimation of the proposed TBVAR(*p*)-BAGARCH(1,1)-M model. We recall, in this context, that, as noted in Section 2.4.1, the time series of inflation has been found to be a trend stationary process and it has then been appropriately reduced to a stationary series, while the time series of output growth turned out to be a stationary series for all the G7 countries.

5.3.1 Results of estimation of the BVAR(p)-BGARCH(1,1)-M model

In this model, the mean is specified as BVAR(p) and the conditional variance has the symmetric BEKK representation (*cf*. equations (5.1) and (5.2), respectively). Here we have applied the Schwarz Information Criterion (SIC) to determine the lag structure of the BVAR(p) process. The optimal lag has been found to be 2 for all the countries except Germany and Italy where the lag is found to be 1.

Table 5.1 Estimates of the parameters of the BVAR(p)-BGARCH(1,1)-M model

Country *Parameter*	*Canada*	*France*	*Germany*	*Italy*	*Japan*	*The UK*	*The USA*
VAR model							
μ_1	-0.047	-0.125	0.006	-0.030*	0.008	-0.042*	-0.010
$\phi_{1,11}$	0.019	0.348*	0.100***	0.506*	0.097**	0.191*	0.317*
$\phi_{1,12}$	-0.008	0.004	-0.004	0.000	-0.003	-0.010	-0.005
$\phi_{2,11}$	0.161*	0.132*			0.081**	0.276*	0.029
$\phi_{2,12}$	0.018	0.012***			0.016**	-0.002	-0.002
μ_2	0.030	0.401***	0.303***	0.092	0.314*	0.130***	0.111
$\phi_{1,21}$	-0.094	0.161	0.134	-0.075	-0.014	-0.193	-0.074
$\phi_{1,22}$	-0.039	-0.390*	-0.267*	-0.230*	-0.226*	-0.339*	0.267*
$\phi_{2,21}$	-0.018	-0.024			-0.466*	0.073	-0.310*
$\phi_{2,22}$	0.063	-0.044			0.066	-0.092**	0.139*
'in-mean' component							
δ_{11}	0.175	0.642	0.374	-0.131	0.016	0.228	0.262
δ_{12}	-0.204	-1.326***	0.168	-0.085	0.266***	0.002	0.120
δ_{13}	0.015	0.077**	-0.012**	0.009**	-0.003	-0.002	-0.035
δ_{21}	-0.032	-1.412**	-2.371	-2.389**	-0.103	-0.590	0.545
δ_{22}	-0.881	-5.063**	-2.591*	-0.562	3.899*	-0.254	3.210*
δ_{23}	0.016	-0.189	0.008	0.012	-0.095***	-0.006	-0.137
BGARCH model							
c_{11}	-0.106*	0.162*	-0.059	0.029*	-0.044*	-0.041**	-0.008
c_{21}	0.102	-0.178	-0.694	-0.173*	0.222*	-0.739*	0.525*

(continued on next page)

Table 5.1 (continued from the previous page)

Country Parameter	*Canada*	*France*	*Germany*	*Italy*	*Japan*	*The UK*	*The USA*
c_{22}	0.000	0.000	1.142***	0.000	0.000	0.426	0.000
α_{11}	0.482*	0.348*	-0.553*	0.340*	0.248*	0.291*	0.494*
α_{12}	-0.006	0.005	0.001	0.009**	0.000	-0.014	-0.024
α_{21}	0.626*	0.579***	0.566	0.755**	0.145**	0.644**	-0.303**
α_{22}	-0.219*	0.193*	0.488*	0.286*	0.293*	0.796*	-0.458*
β_{11}	-0.717*	-0.083	0.731*	-0.903*	0.951*	-0.907*	-0.884*
β_{12}	-0.108*	0.032**	0.057*	-0.022	-0.026	0.044*	-0.056*
β_{21}	-1.582*	2.934*	-0.405	-1.650	-0.570	0.422	0.216**
β_{22}	0.858*	0.845*	-0.202	0.933*	-0.942*	-0.231***	-0.375*
MLLV	-836.52	-666.70	-880.16	-855.98	-1077.66	-851.67	-423.99

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively. MLLV is the maximized log likelihood value.]*

It is noted from the above table that at least one of the own lagged coefficients for both inflation and output growth is significant. To be specific, at least one of the two coefficients in each of inflation and output growth models i.e., at least one of $\phi_{1,11}$ and $\phi_{2,11}$ and one of $\phi_{1,22}$ and $\phi_{2,22}$ in equation (5.1) are statistically significant for all countries except Canada where no past lag of output growth is significant. Next, we find the direct effect of output growth on inflation through the coefficients $\phi_{1,12}$ and $\phi_{2,12}$. Similarly, the coefficients $\phi_{1,21}$ and $\phi_{2,21}$ indicate the direct impact of inflation on output growth. It is evident from the results that for France and Japan, there exists a positive and significant impact of output growth on inflation since the coefficient $\phi_{2,12}$ is positive and significant in these two countries. The estimated values of the coefficient $\phi_{2,12}$ are 0.012 and 0.016 for these two countries, respectively. While for the remaining countries none of $\phi_{1,12}$ and $\phi_{2,12}$ is significant, suggesting no direct impact of output growth on inflation for these countries. On the other hand, while studying the reverse link i.e., from inflation to output growth, we note that the effect is negative and significant only for two countries *viz*., Japan and the USA. The estimates of the relevant parameter i.e., $\hat{\phi}_{2,21}$ are -0.466 and -0.310, respectively, for these two countries, and these are to be significant at 1% level of significance.

Now, to test for the hypotheses concerning the impact of nominal (inflation) and real (output growth) uncertainty on inflation and output growth, we focus on the statistical significance and signs of the coefficients δ_{11}, δ_{13}, δ_{21} and δ_{23}, respectively. It is evident from above table that the effect of inflation uncertainty on inflation, as depicted by δ_{11}, is statistically insignificant for all the G7 countries, thus offering no empirical support to either the Cukierman and Meltzer (1986) hypothesis of positive impact or the Holland (1995) hypothesis of negative impact of inflation uncertainty on inflation. On the other hand, output growth uncertainty exhibits a mixed effect on inflation as denoted by the coefficient δ_{13}. The positive effect found in case of France and Italy lends support to the Deveraux (1989) hypothesis, while the negative effect in Germany provides empirical evidence in favour of Taylor (1979) effect combined with the Cukierman-Meltzer hypothesis. For the remaining four countries i.e., Canada, Japan, the UK and the USA, there is no significant impact of output growth uncertainty on inflation. On the other hand, the impact of inflation uncertainty on output growth, captured by δ_{21}, is negative for five countries, but only two of them *viz*., France and Italy, are statistically significant, supporting the argument given by Friedman (1977). Finally, the estimated coefficient of δ_{23} offers some support to the irreversible investment hypothesis of Bernanke (1983) and Pindyck (1991), as output growth uncertainty is found to reduce output growth for Japan. For the remaining countries, the effect is not significantly different from zero, and hence this supports the theory that real uncertainty has no impact on output growth[49].

In general, absence of any significant relationship between inflation, output growth and macroeconomic uncertainties for most of the G7 countries may be due to the consideration of single regime in the modeling framework which may mask potentially different realizations due to regime shifts in inflation and output growth series, especially because the span of the data set is quite large (see, Bredin and Fountas (2009), Neanidis and Savva (2013), in this context). The benchmark model is also restricted as it uses the symmetric BEKK specification for the conditional variance-covariance matrix H_t, and thus it is unable to capture the asymmetric effects of past shocks of inflation and output growth on the conditional variances (see, Grier et al. (2004)). To

---

[49] Estimated coefficients of the benchmark model are mostly in line with the existing literature and the policies of the respective central banks. In the particular case of Germany, finding of a positive effect of inflation uncertainty on inflation may appear to be somewhat surprising, but a careful look at the anti-inflationary measures taken by the German central bank during the relevant period, suggests that the finding is in tune with the policies pursued.

deal with these issues we have proposed the TBVAR(p)-BAGACRH(1,1)-M model, as specified in the equations (5.3), (5.4) and (5.5), which allow for incorporation of regime switching behavior in the conditional mean model of both inflation and output growth as also of asymmetric reactions to positive and negative shocks on the conditional variance.

Before proceeding with the estimation of the proposed model, a preliminary data analysis was carried out to test for the presence of asymmetry in conditional variance of output growth. However, the results of testing for asymmetry in conditional variance in a bivariate framework of inflation and output growth is reported in Table 5.5. It is already observed from the results of the likelihood ratio (LR) test done in Chapter 4 (see, Table 4.1) that the conditional variance of inflation exhibits asymmetry for four countries, *viz*., Canada, Germany, Italy and the USA. In the present context i.e., for output growth series, we have estimated both AR(k)-GARCH(1,1) and AR(k)-TGARCH(1,1) models as specified in equations (4.1), (4.2) and (4.3) in Chapter 4, for the output growth series and then performed the LR test. The results of this test are reported in Table 5.2.

Table 5.2 LR test statistic value for testing the AR(*k*)-GARCH(1,1) model against the AR(*k*)-TGARCH(1,1) model

Country	AR(k)-GARCH(1,1) *versus* AR(k)-TGARCH(1,1)
Canada	3.80***
France	2.86***
Germany	6.06**
Italy	1.04
Japan	19.66*
The U.K.	5.18**
The U.S.A.	35.20*

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively.]*

It is noted from the above table that four all the seven countries except Italy the symmetric GARCH model is rejected in favour of the TGARCH model. Thus we have strong empirical evidence that both the time series of inflation and output growth have significant asymmetry in their respective conditional variances for most of the G7 countries, This has, in fact, led us to consider the asymmetric form of bivariate GARCH model, due to Grier et al. (2004), for the proposed model.

5.3.2 Results of estimation of the TBVAR(*p*)-BAGARCH(1,1)-M model

In this section, we discuss the empirical findings of the TBVAR(*p*)-BAGARCH(1,1)-M model. The relevant computational figures of this model are reported in Table 5.3.

Table 5.3 Estimates of the parameters of TBVAR(*p*)-BAGARCH(1,1)-M model

Country Parameter	*Canada*	*France*	*Germany*	*Italy*	*Japan*	*The UK*	*The USA*
Low regime							
TBVAR model							
μ_1^l	-0.069	-0.124	-0.062**	-0.013	-0.014	-0.177*	0.032***
$\phi_{1,11}^l$	0.428**	0.426*	0.614*	0.534*	-0.208**	-0.043	0.539*
$\phi_{1,12}^l$	-0.003	0.004	0.003	0.003	0.009	0.015***	-0.037
$\phi_{2,11}^l$	0.037	0.034			0.064	0.375*	-0.028
$\phi_{2,12}^l$	0.034***	0.006			0.009	0.002	-0.013
μ_2^l	-0.059	1.032*	0.317***	-0.049	0.510*	0.565*	0.324*
$\phi_{1,21}^l$	-0.182	0.195	-1.011**	0.020	0.074	-0.520*	0.092
$\phi_{1,22}^l$	-0.796*	-0.438*	-0.368**	-0.235*	-0.443*	-0.438*	-0.222
$\phi_{2,21}^l$	-0.135	-0.155			-0.276**	0.364	-0.649*
$\phi_{2,22}^l$	-0.131**	-0.041			0.056	-0.189*	0.368*
'in-mean' component							
δ_{11}^l	1.816**	2.162	3.006*	-0.141	-0.630*	-0.626*	0.970*
δ_{12}^l	-1.818*	-1.535	0.306	0.109	0.027	0.590*	-0.004
δ_{13}^l	-0.013	0.047	-0.007	0.004	0.002	0.112*	-0.149*
δ_{21}^l	-6.792*	-3.283**	-0.628	-0.642*	-2.994*	0.297	-1.878**
δ_{22}^l	-4.089*	1.425*	-0.672	-0.068	-1.071	-1.713*	-2.731*
δ_{23}^l	0.272	-0.648**	-0.026	0.033	-0.148*	-0.447*	-0.852*
High regime							
TBVAR model							
μ_1^h	-0.116**	0.266**	-0.006	-0.067*	-0.028	0.041***	-0.022
$\phi_{1,11}^h$	-0.105	0.726*	0.072	0.553*	0.197*	0.384*	0.310*
$\phi_{1,12}^h$	0.017	-0.003	0.011	-0.012	-0.001	-0.003	-0.007
$\phi_{2,11}^h$	0.200*	0.091			0.100***	0.227*	-0.027

(continued on next page)

Table 5.3 (continued from the previous page)

Country *Parameter*	*Canada*	*France*	*Germany*	*Italy*	*Japan*	*The UK*	*The USA*
$\phi_{2,12}^{h}$	-0.008	0.010			0.034*	-0.008	0.036***
μ_{2}^{h}	-0.080	-0.241	-0.947	0.267**	-0.042	-0.306*	0.030
$\phi_{1,21}^{h}$	0.018	0.511	0.647	-0.796*	0.091	0.084	-0.183
$\phi_{1,22}^{h}$	-0.083	-0.364*	-0.233*	-0.480*	-0.327*	-0.630*	0.190*
$\phi_{2,21}^{h}$	-0.285	-0.049			-0.512*	-0.115	0.010
$\phi_{2,22}^{h}$	0.028	-0.100			0.013	-0.078***	0.051
'in-mean' component							
δ_{11}^{h}	-1.108***	-10.181*	1.711	-0.876*	0.089	-0.219**	-0.434*
δ_{12}^{h}	0.629	3.071*	2.525*	-0.586*	0.062	-0.430*	0.413
δ_{13}^{h}	0.217*	-0.038	-0.010	0.031*	-0.000	-0.028**	0.049
δ_{21}^{h}	-2.671*	-2.770*	0.097	-0.117*	0.931	-0.887***	0.518
δ_{22}^{h}	-5.105*	-4.785**	3.273	0.212*	0.385	0.837*	-0.248
δ_{23}^{h}	0.265	0.235	0.520***	0.017	0.043	0.455*	-0.037
BAGARCH model							
c_{11}	-0.118*	-0.153*	-0.145*	-0.026*	-0.039*	-0.104*	0.038*
c_{21}	-0.303*	0.205	-0.133	0.118**	0.215*	-0.522*	-0.454*
c_{22}	-0.172**	-0.310	1.156*	-0.086	-0.018	-0.010	0.002
α_{11}	0.249*	0.376*	0.678*	0.345*	0.217*	0.910*	0.581*
α_{12}	0.038*	0.017**	0.012***	0.010***	-0.000	0.020**	0.004
α_{21}	0.221**	0.450	-0.822***	0.757*	-0.133	0.293***	-0.893*
α_{22}	-0.202*	0.152*	-0.120*	0.216*	-0.007	0.222*	-0.423*
d_{11}	0.326*	-0.316**	0.313***	-0.254*	0.201*	0.147	0.005
d_{12}	0.119*	0.034*	0.003	0.037*	-0.002	0.078*	-0.018
d_{21}	-0.537*	0.125	-0.187	0.712*	0.103	-0.920*	0.106
d_{22}	0.260*	0.225*	0.533*	0.087***	0.319*	-0.586*	0.636*
β_{11}	-0.642*	-0.068	0.242*	0.878*	0.959*	-0.400*	0.795*
β_{12}	-0.108*	0.026	-0.033**	0.023*	-0.010	0.051*	0.107*
β_{21}	-1.291*	2.180**	1.848**	1.087*	0.001	-0.207***	0.521*
β_{22}	0.836*	0.855*	0.433*	-0.953*	-0.961*	-0.778*	0.241**
MLLV	-806.39	-649.30	-849.95	-842.41	-1049.38	-805.74	-379.06

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively. MLLV is the maximized log-likelihood value.]*

Before discussing about the results presented in Table 5.3 and their implications, we first check if introduction of regime has led to any significant improvement in the modeling sense as compared to the benchmark model. In other words, we compare the proposed model with the BVAR(*p*)-BGARCH(1,1)-M model where no regime in conditional mean and no asymmetry in conditional variance have been considered. To that end, we have carried out the LR test and the results are given in Table 5.4.

Table 5.4 LR test statistic value for testing the BVAR(*p*)-BGARCH(1,1)-M model against the TBVAR(*p*)-BAGARCH(1,1)-M model

Country	BVAR(*p*)-BGARCH(1,1)-M *versus* TBVAR(*p*)-BAGARCH(1,1)-M
Canada	60.26*
France	34.80**
Germany	60.42*
Italy	27.14**
Japan	56.56*
The UK	91.86*
The USA	89.86*

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively.]*

It is clearly seen that for all the seven countries, the proposed model is statistically better than the benchmark model, thus strongly establishing the importance and relevance of the two regimes in conditional mean and also of asymmetry in the conditional variance in modelling inflation and output growth with due consideration to their uncertainties.

Now coming back to Table 5.3, we now discuss about the sign and significance of the parameters based on their estimated values and the implications thereof. It is evident from Table 5.3 that the parameters signifying own dependences in the two different regimes, i.e., $\phi_{i,11}^{l}$and $\phi_{i,11}^{h}$ in the low and high inflation regimes and $\phi_{i,22}^{l}$ and $\phi_{i,22}^{h}$ in the low and high output growth regimes, are statistically significant for all the seven countries. For instance, Canada shows a significant lag effect both in the conditional mean of inflation and output growth, which was not found in case of the (single regime) BVAR(*p)*-BGARCH(1,1)-M model.

As specified in the proposed model, $\phi_{i,12}^{l}$ and $\phi_{i,12}^{h}$ denote the effect of output growth on inflation in low and high inflation regimes, respectively. From the estimated values of these parameters, we note that for four countries *viz*., Canada, Japan, the UK and the USA, output growth significantly increases inflation. The positive effect of output growth on inflation has been observed for Canada and the UK in the low inflation regime since the estimated values of the coefficient $\phi_{2,12}^{l}$ for Canada and $\phi_{1,12}^{l}$ for the UK are found to be positive and significant. For Japan and the USA, the positive effect is observed in the high inflation regime as the coefficient $\phi_{2,12}^{h}$ is positive and significant for both of these two countries. In case of Canada and the UK, the effect of output growth on inflation is greater in size during the period of low inflation regime whereas, the size effect is greater in magnitude for Japan and the USA in the high inflation regime. On the other hand, no significant relationship has been observed for France, Germany and Italy in any of the two regimes.

In studying the impact of inflation on output growth, we obtain that the effect in the low output growth regime, as captured by $\phi_{i,21}^{l}$, is negative and significant for Germany, Japan, the UK and the USA. It is observed that for Germany and the UK, the coefficient $\phi_{1,21}^{l}$ is significant. The estimated values are -1.011 and -0.520 for these two countries, respectively. For Japan and the USA, we find that $\phi_{2,21}^{l}$ is negative and significant, the estimated values being -0.276 and -0.649 for these two countries, respectively. Similarly, the negative and significant values of $\phi_{1,21}^{h}$ for Italy and $\phi_{2,21}^{h}$ for Japan suggest that inflation reduces output growth in the high output growth regime. In case of Japan, the effect of inflation on output growth has increased by two folds in the high output growth regime whereas, the effect is found to be insignificant in Germany, the UK and the USA in the high growth regime.

While discussing the main parameters of interest depicting the effects of inflation and output growth uncertainties on the levels of inflation and output growth, we first test whether the 'in-mean' coefficients are jointly significant or not. In terms of parameters, the null hypothesis, as specified in Section 5.2.3, is $H_{01}\colon \delta_{mn}^{s} = 0$ for all $m = 1, 2;$ $n = 1, 2, 3$ and $s =$

l (low regime), h (high regime) . The Wald test statistic values for this test as well as for the others mentioned in Section 5.2.3 are reported in Table 5.5.

Table 5.5 Results of the Wald test

Null hypothesis	*Canada*	*France*	*Germany*	*Italy*	*Japan*	*The UK*	*The USA*
No 'in-mean' effect							
$H_{01}: \delta^{s}_{mn} = 0$ For all $m = 1, 2$; $n = 1,2,3$, and $s = l, h$	327.10 (0.00)	192.09 (0.00)	298.55 (0.00)	406.00 (0.00)	1059.71 (0.00)	325.47 (0.00)	238.15 (0.00)
$H_{02}: \delta^{l}_{11} = \delta^{h}_{11}$	5.08 (0.02)	11.11 (0.00)	1.10 (0.29)	4.05 (0.04)	12.20 (0.00)	2.25 (0.13)	10,14 (0.00)
$H_{03}: \delta^{l}_{13} = \delta^{h}_{13}$	4.57 (0.03)	0.69 (0.41)	0.003 (0.96)	5.19 (0.02)	0.200 (0.65)	19.65 (0.00)	13.78 (0.00)
$H_{04}: \delta^{l}_{21} = \delta^{h}_{21}$	3.79 (0.05)	2.23 (0.14)	0.147 (0.70)	5.79 (0.02)	106.00 (0.00)	1.59 (0.21)	11.21 (0.00)
$H_{05}: \delta^{l}_{23} = \delta^{h}_{23}$	0.001 (0.98)	5.09 (0.02)	2.97 (0.08)	0.103 (0.75)	7.34 (0.00)	40.74 (0.00)	27.46 (0.00)
Diagonal bivariate GARCH							
$H_{06}: \alpha_{12} = \alpha_{21} = \beta_{12} = \beta_{21} = d_{12} = d_{21} = 0$	215.78 (0.00)	54.71 (0.00)	12.34 (0.05)	59.11 (0.00)	4.49 (0.69)	168.47 (0.00)	99.28 (0.00)
No asymmetric bivariate GARCH							
$H_{07}: d_{ij} = 0$ for all $i, j = 1, 2$	129.02 (0.00)	21.01 (0.00)	55.43 (0.00)	64.88 (0.00)	137.54 (0.00)	168.92 (0.00)	77.94 (0.00)

[p-values are given in parentheses.]

It is clear from the entries in the second row of the above table that the null hypothesis of no 'in-mean' effects is rejected for all the seven countries. For instance, in case of Canada, the test statistic value is 327.10 and this is significant at 1% level of significance. In what follows we discuss the different links involving inflation, output growth and their uncertainties, that can be concluded based on the Wald test results.

The effect of inflation uncertainty on inflation

This link is captured through the parameters δ_{11}^{l} and δ_{11}^{h} for the low and high inflation regimes, respectively. It is worth noting from Table 5.3 that unlike the single regime results, each country now exhibits a significant impact of inflation uncertainty on inflation in at least one of the regimes. In the low inflation regime, a positive effect exists for each of Canada, Germany and the USA, whereas a negative effect of inflation uncertainty on inflation is observed for Japan and the UK. Likewise, the estimate of δ_{11}^{h} shows that inflation uncertainty significantly reduces inflation for Canada, France, Italy, the UK and the USA in the high inflation regime. It is clear from the estimation results that barring Germany all others G7 countries exhibit negative δ_{11} value in at least one of the two regimes with the UK showing it in both the regimes.

Now, one important hypothesis of interest is whether this own 'in-mean' effect is statistically different in the two different inflation regimes. In other words, we test the null hypothesis H_{02}: $\delta_{11}^{l} = \delta_{11}^{h}$, as specified in Section 5.2.3. The reported Wald test results in Table 5.5 indicate that between low and high inflation regimes, there are five countries *viz.*, Canada, France, Italy, Japan and the USA where the impacts of inflation uncertainty on inflation are different, while in case of Germany and the UK, the effect is invariant with the regimes. Looking at the parameter estimates of δ_{11}^{l} and δ_{11}^{h}, we again note that for Canada and the USA, the effect is positive in the low inflation regime while it is negative in the high regime. In the case of France and Italy, there is 'no significant' impact of inflation uncertainty on inflation in the low regime but it is negative in the high inflation regime. This suggests that while there is mixed findings on the impact of inflation uncertainty on inflation in the low inflation regime, this link is observed to be mostly (5 out of 7 countries) negative in the high inflation regime, the latter giving support to Holland (1995) stabilization hypothesis that higher inflation uncertainty affects negatively on inflation. It is thus found that this hypothesis has empirical support from the G7 group of countries, and this finding could very well be attributed to the consideration of two inflation regimes in this model.

The effect of output growth uncertainty on inflation

Looking at the estimated coefficients of δ_{13}^{l} and δ_{13}^{h}, we observe a mixed evidence on the impact of real uncertainty on inflation in low and high inflation regimes. Significant impact is observed only for four countries, *viz*., the UK, the USA, Canada and Italy, where the two coefficients are significant in at least one of the two regimes. The Wald test results of the null hypothesis H_{03}: $\delta_{13}^{l} = \delta_{13}^{h}$ also corroborate these findings. It shows that for these four countries, there is significant asymmetry in the relationship between output growth uncertainty and inflation. Further, we note that out of the four countries where there are significant regime effects, the link is negative in nature for the USA in the low inflation regime and for the UK in the high inflation regime, whereas the effect is positive for the UK in the low regime and for Canada and Italy in the high inflation regime. Therefore, the Devereux (1989) hypothesis for positive causal relationship is confirmed for Canada and Italy only during the period of high inflation, and for the UK during the period of low inflation. While, on the other hand, the evidence for a negative effect of output uncertainty on inflation is observed for the USA during low inflation regime and for the UK over the high inflation period, and hence this gives support to the Taylor (1979) effect in conjunction with the Cukierman and Meltzer (1986) hypothesis.

The effect of inflation uncertainty on output growth

It may be recalled that the influence of inflation uncertainty on output growth has been found to be insignificant in the single regime specification in five of the G7 countries. Only two countries *viz*., France and Italy provided support to the Friedman (1977) hypothesis of negative effect of inflation uncertainty on output growth. With the consideration of two regimes in the proposed model, we now find significant evidence of this impact. Turning to the estimates of the relevant coefficients i.e., δ_{21}^{l} and δ_{21}^{h}, we observe that there are six countries where at least one of these two coefficients is statistically significant. Moreover, the results indicate a strong negative relationship between inflation uncertainty and output growth. In particular, in the low output growth regime, the negative effect on growth *via* inflation uncertainty channel is highly significant for five countries *viz*., Canada, France, Italy, Japan and the USA. On the other hand, the negative effect holds for four countries *viz*., Canada, France, Italy and the UK in the high output growth regime. It is only for Germany that the coefficient is insignificant in both the regimes. The results of Wald test of the null hypothesis H_{04}: $\delta_{21}^{l} = \delta_{21}^{h}$ show that the parameter δ_{21} differs significantly between the two output growth regimes for four countries *viz*., Canada, Italy, Japan and the USA.

The above findings thus strongly support the Friedman hypothesis that increasing inflation uncertainty inhibits output growth. Thus, in case of this link as well, we find that the introduction of regime yields results which are somewhat different from the one without regimes, and that the empirical support for Friedman hypothesis is substantially strong now.

The effect of output growth uncertainty on output growth

The issue of the effect of output uncertainty on output growth has received considerable attention both in the theoretical and empirical macroeconomic literature. However, there is no consensus among macroeconomists on the direction of this effect. On the empirical ground, a positive relation has been found in the studies of Grier and Tullock (1989), Caporale and McKiernan (1998), and Fountas and Karanasos (2006). In other words, these studies have provided empirical evidence in support to the Black (1987) hypothesis. On the other hand, the existence of a negative effect, as argued by Pindyck (1991), and Blackburn and Pelloni (2005), has been found to be empirically supported by Ramey and Ramey (1995), and Martin and Rogers (2000). Finally, in line with the business cycle theory, several studies including Speight (1999), and Grier and Perry (2000) have reported no significant relation between real uncertainty and output growth. However, most of the above studies assume that the relationship between real uncertainty and growth is same across different output growth regimes. However, there is no *a priori* reason to believe that the sign and size of the output uncertainty and output growth relation is same whether the economy is in contraction or expansion. In our model, we have allowed for differential effects of output growth uncertainty on output growth through two regimes for output growth. The Wald test results for testing the null hypothesis H_{05}: $\delta_{23}^{l} = \delta_{23}^{h}$ suggest that with the exception of France and Italy, in the other five countries significantly different effects of output growth uncertainty on output growth in two different output growth regimes have been observed. From the estimated values of δ_{23}^{l} and δ_{23}^{h}, as reported in Table 5.3, we note that the relationship appears mainly negative in the low growth regime. The effect of real uncertainty on output growth is statistically significant for France, Japan, the UK and the USA in the low growth regime. However, for all the G7 countries barring Germany and the UK, this effect is found to be insignificant in the high growth regime. The estimated values of δ_{23}^{h} are 0.520 and 0.455 for Germany and the UK, respectively. The positive sign indicates that real uncertainty boosts output growth in the high growth regime for these two countries.

Finally, we report the findings on the hypotheses of interest involving the parameters of H_t. Similar in line with Grier et al. (2004), and Bredin and Fountas (2005, 2009), we have considered tests for different kinds of specifications of the conditional covariance matrix H_t. As stated in Section 5.2.3, we test the null hypotheses of 'diagonal bivariate GARCH' and 'no asymmetric bivariate GARCH' by applying the Wald test. The test statistic values are reported in the third panel from below of Table 5.5. On the basis of these test statistic values we can conclude the following. First, the hypothesis of a diagonal covariance matrix requires the off-diagonal elements of A, D and B coefficient matrices to be jointly insignificant i.e., $H_{06}: \alpha_{12} = \alpha_{21} = \beta_{12} = \beta_{21} = d_{12} = d_{21} = 0$. However, the results suggest that the null hypothesis is rejected for all the G7 countries except Japan. For Japan, the test statistic value is 4.49 which is insignificant even at 10% level of significance. These empirical results thus indicate that lagged conditional variances and lagged squared innovations in inflation (output growth) affect the conditional variances of output growth (inflation) in the remaining six of the seven countries i.e., Canada, France, Germany, Italy, the UK and the USA. Finally, the finding of joint significance of the elements of the D matrix i.e., the Wald test statistic value for testing the null hypothesis $H_{07}: d_{ij} = 0$ for all $i, j = 1, 2$ exceeding the critical value at 1% level of significance leads us to conclude that the covariance process is asymmetric for all countries. We can, therefore, conclude that consideration of regimes that depends on the levels of inflation and output growth in specifying the conditional mean model along with asymmetry in volatility are very important in proper understanding of the effects of nominal and real uncertainty on inflation and output growth. The effectiveness of the proposed TBVAR(p)-BAGARCH(1,1)-M model, which explicitly incorporates these two aspects, has thus been empirically established.

Finally, we report the Ljung-Box test statistic values, based on residuals of the proposed model, for all the G7 countries in Table 5.6.

Table 5.6 Results of the Ljung-Box test with standardized and squared standardized residuals of the proposed model

	Inflation				*Output growth*			
Country	$Q(1)$	$Q(5)$	$Q^2(1)$	$Q^2(5)$	$Q(1)$	$Q(5)$	$Q^2(1)$	$Q^2(5)$
Canada	0.283	7.999	3.689	6.752	0.009	4.186	1.829	6.827
France	0.001	1.552	1.608	2.856	0.604	4.447	0.857	9.188
Germany	0.706	6.423	4.997	7.741	0.367	18.975*	0.070	1.271
Italy	8.911*	39.073*	4.185**	7.912	0.023	6.602	17.872*	23.011*
Japan	0.095	6.134	0.383	0.834	0.814	33.317*	0.494	8.463
The UK	0.314	1.747	2.491	7.809	0.722	3.136	4.316**	5.474
The USA	0.393	2.072	0.663	1.530	0.750	10.762	3.332	5.779

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively. $Q(.)$ and $Q^2(.)$ are the Ljung-Box test statistic values for linear and squared autocorrelations, respectively.]*

It is observed from the above table that the choice of lag *p* for the proposed TBVAR(*p*)-BAGARCH(1,1)-M model has been found to be adequate in most cases by the Ljung-Box test with standardized residuals. It is only for the inflation series of Italy where the values of the test statistic have been found to be significant for both the lag values of 1 and 5. Further, the test statistic is found to be significant for the output growth series of Germany and the UK in case of lag 5. In our proposed model, the orders of asymmetric GARCH has been taken to be (1,1). The results on Ljung-Box test statistic on the squared standardized residuals indicate that the choice of orders for the asymmetric GARCH model is adequate.

5.4 Conclusions

In this chapter, we have introduced a TBVAR(*p*)-BAGARCH(1,1)-M model for inflation, output growth and their uncertainties. This model allows for regime switching behavior of inflation and output growth in the conditional mean and asymmetric effects of past shocks in the conditional variance. The consideration of ‘in-mean’ component enables us to examine the regime dependent effects of inflation uncertainty and output growth uncertainty on the levels of inflation and output growth. The major findings of this study are summarized below.

We have found that inflation uncertainty reduces inflation with the effect being mainly observed in the high inflation regime. Out of the seven countries, five countries *viz*., Canada, France, Italy, the UK and the USA, lend empirical support to negative effect of inflation uncertainty on inflation in the high inflation regime, and hence to Holland (1995) hypothesis, whereas in the low inflation regime we observe mixed evidence for this impact. About the effect of output growth uncertainty on inflation, we find that only for four countries *viz*., Canada, Italy, the UK and the USA, a significant relationship is present. Again among these four countries, we find mixed evidence regarding the sign of the effect in each of the two different inflation regimes. The uncertainty associated with the inflation seems to have a negative effect on output growth. The negative effect is found to be significant in five countries *viz*., Canada, France, Italy, Japan and the USA in the low output growth regime and in four countries *viz*., Canada, France, Italy and the UK in the high growth regime. In other words, Friedman's assertion that inflation uncertainty can be detrimental to the output growth has received a strong support in our study. We can mention here that our finding regarding the impact of inflation uncertainty on output growth is very similar to that of Neanidis and Savva (2013), who have also used a bivariate regime switching model to study the impacts of macroeconomic uncertainties on inflation and output growth. However, contrary to their findings of positive effect of inflation uncertainty on inflation, our results assert that inflation uncertainty significantly reduces inflation in the high inflation regime. Lastly, we observe that in four countries *viz*., France, Japan, the UK and the USA, output growth uncertainty has negative effect on output growth in the low output growth regime, while the effect is found to be insignificant in most of the countries in the high growth regime barring Germany and the UK where a positive effect, as predicted by Black (1987), has been observed.

For each of the G7 countries, we have tested various null hypotheses which include 'homoskedastic conditional variance', 'diagonal GARCH specification', 'no asymmetry in the conditional variances' and also 'no in-mean effect'. According to the results obtained in this study, all the four hypotheses are rejected for all countries except only the 'diagonal GARCH specification' for Japan.

Chapter 6

Inflation, Output Growth, Inflation Uncertainty and Output Growth Uncertainty: A Two-Step Approach with Structural Breaks

6.1 Introduction

In Chapter 4, we have discussed the relationship involving inflation and inflation uncertainty following the ‘two-step’ procedure in order to understand the links between these two in presence of multiple structural breaks in the system of equations involved. We now extend this study by bringing in output growth and output growth uncertainty. It is worth noting that the relationship between inflation, output growth, inflation uncertainty and output growth uncertainty has attracted a fair amount of interest in both theoretical and empirical works over the last three decades. As stated in the preceding chapter, the empirical literature studying the relationship involving these four variables is not very few. Prominent among these are Grier and Perry (1998), Henry and Olekalns (2002), Fountas et al. (2004), Conrad and Karanasos (2005), Karanasos and Kim (2005), Fountas and Karanasos (2006), and Fountas et al. (2006). The conclusions drawn from these studies, however, have changed a number of times since researchers have modified their models in the light of developments both in economic theory and econometric techniques. It is worth mentioning that in many practical applications, a standard auxiliary assumption typically made is that the parameters depicting the relationship are assumed to be constant over the entire sample period. This corresponds to an assumption that the causal links are stable over time. But, this assumption is far from innocuous and may often not hold in practice. Furthermore, there is considerable evidence supporting the view that the economic time series are best thought of as being generated by processes with time dependent parameters (see, e.g., Stock and Watson (1996)).

As mentioned by Stock and Watson (2007), inflation was much less volatile in 1980s and 1990s than it was in the 1960s and 1970s in the G7 and many other industrialized nations. Since the 1970s and early 1980s, which saw historically high levels of inflation, there have been renewed interests amongst macroeconomists in terms of theory and policy. Arguably, the most noteworthy achievement of macroeconomic policy has been the reduction of inflation in industrialized countries during the periods of 1980s and 1990s. For example, inflation in G7 economies declined from 10% during 1970-1983 to levels below 4% in 1990s (see, Henry and Shields (2004)). Cecchetti and Krause (2001) and Krause (2003) also documented a reduction in both the level and volatility of inflation for large number of industrialized and developing economies. Again, quite a few studies including those by McConnell and Perez-Quiros (2000), Blanchard and Simon (2001), Kim et al. (2004), Ahmed et al. (2004), Doyle and Faust (2005) and Fang and Miller (2007) have documented significant reduction in the volatility of output growth that became more stable in 1980s. A number of studies have examined the extent to which a decline in the level of inflation and output growth and their volatilities may reflect improved monetary policy design and implementation, increasing globalization, and enhanced role of informational technology (see Kumar and Okimoto (2007), for more details). Furthermore, the global macroeconomic imbalances in trade and capital flows that occurred in the early 2000s (see, Bernanke (2009) and Obstfeld and Rogoff (2009)) and the subsequent global financial crisis in 2007-2008 (see, in this context, Cooper (2007), Mendoza et al. (2007), and Caballero et al. (2008)) affected most of the industrialized economies by creating more distortion in the levels and volatilities of inflation and output growth.

Keeping the above findings in mind, we raise a question: Have the relations involving inflation, output growth and their respective uncertainty remained stable or have these changed over time? To address this issue, we have applied the statistical methodology, as in Chapter 4, proposed by Qu and Perron (2007), for detecting multiple structural breaks in the system of equations involving these four variables. One distinct advantage of the Qu and Perron methodology is that it tests for multiple structural breaks in a system of equations, where the location of break dates are assumed to be unknown and these are determined endogenously from the model. To draw conclusion on the stability of the relationship, we first need to measure the uncertainties of inflation and output growth. In so doing, we rely on a two-step estimation procedure which is widely used in this literature (see, among others, Grier and Perry (1998), Fountas et al. (2006) and Fountas and Karanasos (2006)). Under this two-step approach, we first estimate the conditional variances of inflation and output growth from a bivariate GARCH-type model, and then in the second step these estimates are used in the framework of VAR model with due consideration to multiple structural breaks in the relationship involving inflation, output growth, inflation uncertainty and output growth uncertainty. With this approach, our objective, in this chapter, is to examine all possible links concerning these four variables that have been advanced by several economic theories. These theories include the relationships between (i) inflation and output growth (see, in this context, Tobin (1965), Sidrauski (1967), Briault (1995), Bruno and Easterly (1996), and Gillman and Kejak (2005)), (ii) inflation and inflation uncertainty (see, for details, Friedman (1977), Ball (1992), Pourgerami and Maskus (1987), Cukierman and Meltzer (1986), and Holland (1995)), (iii) inflation uncertainty and output growth (see, for instance, Friedman (1977), Huizinga (1993), Dotsey and Sarte (2000), and Blackburn and Pelloni (2004)), (iv) output growth and output growth uncertainty (Devereux (1989), Black (1987), Bernanke (1983), and Ramey and Ramey (1991)), and finally, (v) inflation uncertainty and output growth uncertainty (see, for details, Taylor (1979), Fuhrer (1997), and Logue and Sweeney (198))[50].

The organization of this chapter is as follows. In the next section, we discuss the methodology used in this chapter. The empirical results are discussed in Section 6.3. This chapter ends with some concluding remarks in Section 6.4.

6.2 Econometric Methodology

6.2.1 The Model

The methodology applied for this work, as stated in the preceding section, entails a two-step procedure. The first step considers a model to generate time-varying conditional variances of inflation and output growth. To that end, we consider a bivariate asymmetric GARCH (BAGARCH) model to estimate the conditional variances of inflation and output growth. Let π_t

---

[50] Some details on the theoretical literature have already been discussed in Chapter 1.

and y_t denote the inflation rate and output growth, respectively. Taking these two variables together in a bivariate AR(p) framework, we have the models for π_t and y_t as

$$Z_t = \mu + \sum_{i=1}^{p} \Phi_i Z_{t-i} + \varepsilon_t, \qquad \varepsilon_t | \psi_{t-1} \sim N(0, H_t) \tag{6.1}$$

where $Z_t = \begin{bmatrix} \pi_t \\ y_t \end{bmatrix}$, $\mu = \begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix}$, $\Phi_i = \begin{bmatrix} \phi_{i,11} & \phi_{i,12} \\ \phi_{i,21} & \phi_{i,22} \end{bmatrix}$, $\varepsilon_t = \begin{bmatrix} \varepsilon_{\pi,t} \\ \varepsilon_{y,t} \end{bmatrix}$, and $H_t = \begin{bmatrix} h_{\pi,t} & h_{\pi y,t} \\ h_{\pi y,t} & h_{y,t} \end{bmatrix}$.

In equation (6.1), the coefficients $\phi_{i,11}$ and $\phi_{i,22}$ for $i = 1,2, \dots, p$, capture the effects of own lag in the conditional mean models for inflation and output growth, respectively. Similarly, the coefficients $\phi_{i,12}$ and $\phi_{i,21}$ depict the effects of output growth on inflation, and of inflation on output growth, respectively. Finally, $h_{\pi,t}$ and $h_{y,t}$ represent the conditional variances of inflation and output growth, respectively.

Insofar as the uncertainty of inflation and uncertainty of output growth are concerned, we consider a bivariate GARCH set-up so that the spillover effects – both direct and indirect – of inflation uncertainty on output growth uncertainty and vice versa could be simultaneously captured in the analysis. However, as noted in Chapter 4 and 5, the empirical evidence, in most of the G7 countries, is in favour of asymmetric effects of positive and negative shocks on the volatility of inflation and output growth. Hence, as in the preceding chapter, we have taken the asymmetric version of the BEKK representation, due to Grier et al. (2004), to define H_t as in equation (5.5) i.e.,

$$H_t = CC' + A\varepsilon_{t-1}\varepsilon_{t-1}'A' + Du_{t-1}u_{t-1}'D' + BH_{t-1}B' \tag{6.2}$$

where all the notations are as defined in equation (5.5).

The model specified in equations (6.1) and (6.2) is designated as the BVAR(p)-BAGARCH(1,1) model. We use the maximum likelihood method of estimation for estimating this model.

Estimation

Under the assumption of bivariate normality of $\varepsilon_t | \psi_{t-1}$, the log-likelihood function (ignoring the constant term) is given by

$$L(\theta) = -\frac{1}{2}\sum_{t=1}^{T}(\ln|H_t|) + \varepsilon_t' H_t^{-1} \varepsilon_t) \tag{6.3}$$

where θ is the vector of all parameters involved in the model. In order to obtain the ML estimates of the parameters, we have used the standard gradient search algorithm, called the Broyden-Fletcher-Goldfarb-Shanno (BFGS) algorithm. All the programs required for obtaining the estimates have been written in GAUSS.

6.2.2 Qu-Perron methodology

We first estimate the BVAR(p)-BAGARCH(1,1) model and then generate the series of conditional variances for inflation and output growth. By taking these estimated values of the respective conditional variance as measures of inflation uncertainty and output growth uncertainty, in the second step we apply the procedure of estimation and testing proposed by Qu and Perron (2007) for detecting multiple structural breaks in the system of equations involving inflation, output growth, inflation uncertainty and output growth uncertainty. A brief description of this test procedure including the procedure of estimation of the underlying system of equations has already been given in Chapter 4. The general model thus considered in this chapter is the same as that in equation (4.4), i.e.,

$$Y_t = (I \otimes z_t')S\beta_j + u_t \tag{6.4}$$

where the notations are similar to those mentioned in Chapter 4. The only difference is that the dependent variable now consists of inflation, output growth, inflation uncertainty and output growth uncertainty i.e., $Y_t = (\pi_t \ \ y_t \ \ h_{\pi,t} \ \ h_{y,t})'$ instead of just $Y_t = (\pi_t \ \ h_{\pi,t})'$. In this case also, we choose the VAR set-up to test for the presence multiple structural breaks in the equations with z_t comprising the lag values of Y_t only. In this case, the model in equation (6.4) reduces to the following system of four equations involving the afore-mentioned four variables corresponding to a sub-period, say jth sub-period.

$$\pi_t = \beta_{\pi,j} + \beta_{\pi\pi,j}\pi_{t-1} + \beta_{\pi y,j}y_{t-1} + \beta_{\pi h_\pi,j}h_{\pi,t-1} + \beta_{\pi h_y,j}h_{y,t-1} + u_\pi \tag{6.5}$$

$$y_t = \beta_{y,j} + \beta_{y\pi,j}\pi_{t-1} + \beta_{yy,j}y_{t-1} + \beta_{yh_\pi,j}h_{\pi,t-1} + \beta_{yh_y,j}h_{y,t-1} + u_y \tag{6.6}$$

$$h_{\pi,t} = \beta_{h_\pi,j} + \beta_{h_\pi\pi,j}\pi_{t-1} + \beta_{h_\pi y,j}y_{t-1} + \beta_{h_\pi h_\pi,j}h_{\pi,t-1} + \beta_{h_\pi h_y,j}h_{y,t-1} + u_{h_\pi} \tag{6.7}$$

$$h_{y,t} = \beta_{h_y,j} + \beta_{h_y\pi,j}\pi_{t-1} + \beta_{h_y y,j}y_{t-1} + \beta_{h_y h_\pi,j}h_{\pi,t-1} + \beta_{h_y h_y,j}h_{y,t-1} + u_{h_y} \tag{6.8}$$

where the parameters have the following descriptions. $\beta_{\pi,j}$, $\beta_{y,j}$, $\beta_{h_\pi,j}$ and $\beta_{h_y,j}$ are the constants terms in inflation, output growth, inflation uncertainty and output growth uncertainty models for the j^{th} sub-period, respectively. The coefficients $\beta_{\pi\pi,j}$, $\beta_{yy,j}$, $\beta_{h_\pi h_\pi,j}$ and $\beta_{h_y h_y,j}$ denote the own lag effects in the j^{th} sub-period. $\beta_{\pi y,j}$ and $\beta_{y\pi,j}$ denote the effects of output growth on inflation, and inflation on output growth, respectively, in the j^{th} sub-period. Similarly, the effect of inflation on inflation uncertainty is denoted by the coefficient $\beta_{h_\pi\pi,j}$, and that of inflation uncertainty on inflation by $\beta_{\pi h_\pi,j}$. The impact of output growth uncertainty on inflation in the j^{th} sub-period as well as the impact in reverse order are depicted by the coefficients $\beta_{\pi h_y,j}$ and $\beta_{h_y\pi,j}$, respectively. The effect of inflation uncertainty on output growth is represented by the coefficient $\beta_{yh_\pi,j}$ while that of output growth on inflation uncertainty by $\beta_{h_\pi y,j}$. $\beta_{h_y y,j}$, $\beta_{yh_y,j}$ indicate the effects of output growth on output growth uncertainty, and output growth uncertainty on output growth, respectively, in the j^{th} sub-period. Finally, the impacts of inflation uncertainty on output growth uncertainty, and output growth uncertainty on inflation uncertainty are denoted by the coefficients $\beta_{h_y h_\pi,j}$, $\beta_{h_\pi h_y,j}$, respectively.

We have also estimated the usual VAR model with these four variables without any consideration to structural breaks. The system of equations for the four variables is written as follows.

$$\pi_t = \beta_\pi + \beta_{\pi\pi}\pi_{t-1} + \beta_{\pi y}y_{t-1} + \beta_{\pi h_\pi}h_{\pi,t-1} + \beta_{\pi h_y}h_{y,t-1} + \tilde{u}_\pi \tag{6.9}$$

$$y_t = \beta_y + \beta_{y\pi}\pi_{t-1} + \beta_{yy}y_{t-1} + \beta_{yh_\pi}h_{\pi,t-1} + \beta_{yh_y}h_{y,t-1} + \tilde{u}_y \tag{6.10}$$

$$h_{\pi,t} = \beta_{h_\pi} + \beta_{h_\pi\pi}\pi_{t-1} + \beta_{h_\pi y}y_{t-1} + \beta_{h_\pi h_\pi}h_{\pi,t-1} + \beta_{h_\pi h_y}h_{y,t-1} + \tilde{u}_{h_\pi} \tag{6.11}$$

$$h_{y,t} = \beta_{h_y} + \beta_{h_y\pi}\pi_{t-1} + \beta_{h_yy}y_{t-1} + \beta_{h_yh_\pi}h_{\pi,t-1} + \beta_{h_yh_y}h_{y,t-1} + \tilde{u}_{h_y} \qquad (6.12)$$

where the parameters have similar interpretations as in case equations (6.5) through (6.8), but without any consideration to structural break. The estimated parameters of this model are compared with the ones from the models with structural breaks to study how the relations vary between the total sample and sub-periods.

6.3 Empirical Analysis

6.3.1 First-step estimation results

In this section, we first report the estimated BVAR(*p*)-BAGARCH(1,1) model which yields measure of inflation uncertainty and output growth uncertainty for all the G7 countries. Schwarz information criterion (SIC) has been used to determine the value of *p* for the BVAR(*p*) model. The estimation results are reported in Table 6.1.

Table 6.1 Estimates of the parameters of BVAR(*p*)-BAGARCH(1,1) model

Country *Parameter*	*Canada*	*France*	*Germany*	*Italy*	*Japan*	*The UK*	*The USA*
Conditional mean							
μ_1	-0.004	-0.001	-0.006	-0.013***	-0.002	-0.020**	-0.016**
$\phi_{1,11}$	0.050	0.382*	0.151**	0.527*	0.118*	0.258*	0.306*
$\phi_{1,12}$	-0.012	0.003	-0.003	-0.003	-0.001	-0.005	0.010
$\phi_{2,11}$	0.187*	0.131*			0.058**	0.230*	0.037
$\phi_{2,12}$	0.013	0.005			0.018*	-0.006	-0.001
μ_2	0.033	0.026	0.156**	0.055	-0.030	0.049	0.053***
$\phi_{1,21}$	-0.030	0.291	-0.136	-0.145	0.009	-0.247	-0.030
$\phi_{1,22}$	-0.054	-0.352*	-0.281*	-0.280*	-0.122*	-0.326*	0.165*
$\phi_{2,21}$	0.088	-0.420			-0.499*	-0.108	-0.255**
$\phi_{2,22}$	0.070	-0.030			0.162*	-0.110**	0.147*

(continued on next page)

Table 6.1 (continued from the previous page)

Country *Parameter*	*Canada*	*France*	*Germany*	*Italy*	*Japan*	*The UK*	*The USA*
Conditional variance							
c_{11}	-0.102*	-0.162*	-0.085*	0.025*	0.024***	0.083**	-0.035
c_{21}	0.058	-0.083	-0.317	-0.191*	-0.044	0.338*	-0.008
c_{22}	0.214	0.000	1.265*	0.000	0.716*	0.000	0.325*
α_{11}	0.406*	0.229**	0.606*	0.341*	0.164*	0.722*	0.502*
α_{12}	0.017	0.016	0.002	0.002	-0.001	0.047*	-0.047**
α_{21}	0.682*	0.600	-1.176**	0.748***	0.054	-0.447***	-0.076
α_{22}	-0.185*	0.287*	-0.050	0.266*	-0.054	0.329*	-0.084
d_{11}	0.249**	-0.413*	0.235	0.207**	0.262*	-0.059	0.251**
d_{12}	0.070***	0.050*	-0.006	-0.026*	-0.015*	0.099*	-0.037
d_{21}	-0.236	0.274	-0.480	-1.334**	0.369*	-1.937*	-0.076
d_{22}	0.325*	0.148	0.624*	-0.139**	-0.484*	-0.314*	0.724*
β_{11}	-0.706*	0.126	0.664*	0.889*	0.969*	0.465*	-0.664*
β_{12}	-0.106***	-0.013	-0.044***	0.025	-0.003	-0.089*	0.167*
β_{21}	-1.395**	-1.648**	0.545	1.791	0.011	2.365*	1.410*
β_{22}	0.841*	0.917*	0.298	-0.918*	0.833*	0.700*	0.542*
MLLV	-829.52	-675.18	-874.85	-853.17	-1096.49	-833.11	-399.47

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively. MLLV is the maximized log likelihood value.]*

It is first noted from the above table that at least one of the own lagged coefficients for both inflation and output growth is significant. To be specific, at least one of the two coefficients $\phi_{1,11}$ and $\phi_{2,11}$ in case of inflation and $\phi_{1,22}$ and $\phi_{2,22}$ for output growth, are statistically significant for all countries except Canada where lag 1 of inflation is significant but no lag of output growth is significant. If we consider the case of France, the estimated values 0.382 and 0.131 of the coefficients $\phi_{1,11}$ and $\phi_{2,11}$, respectively, in the inflation equation, are statistically significant at 1% level, whereas in the output growth equation, only $\phi_{1,22}$ is significant. Next, we can find the effect of output growth on inflation through the coefficients $\phi_{1,12}$ and $\phi_{2,12}$, and that of inflation to output growth in terms of $\phi_{1,21}$ and $\phi_{2,21}$, respectively. By carrying out tests of significance for these coefficients, we find that only the coefficient $\phi_{2,12}$ is significant for Japan, while for the remaining countries neither of $\phi_{1,12}$ and $\phi_{2,12}$ is significant. On the other hand, while studying the reverse impact i.e., from inflation to output growth, we note that the coefficient $\phi_{2,21}$ is negative and significant only for two countries *viz*., Japan and the USA. Thus we note that in most of the G7 countries the coefficients $\phi_{1,21}$, $\phi_{2,21}$ and $\phi_{1,12}$, $\phi_{2,12}$ are found to be insignificant, and hence it provides support to the fact that there is no direct effect of output growth on inflation and vice versa.

For the conditional variance specification, it is noted that most of the parameters in BAGARCH specification are statistically significant for all the seven countries indicating, as before and also as expectedly, the relevance of asymmetry in volatility for both inflation and output growth uncertainty.

The Ljung-Box $Q(.)$ statistic values based on the standardized residuals and squared standardized residuals of the BVAR(p)-BAGARCH(1,1) model are reported in the following table. We find from this table that the choices of the lag orders for the BVAR process and for the asymmetric GARCH (BAGARCH(1,1)) model are adequate in most of the countries, and hence the model is well specified from this consideration.

Table 6.2 Results of the Ljung-Box test with standardized and squared standardized residuals of the BVAR(*p*)-BAGARCH(1,1) model

	Inflation				*Output growth*			
Country	$Q(1)$	$Q(5)$	$Q^2(1)$	$Q^2(5)$	$Q(1)$	$Q(5)$	$Q^2(1)$	$Q^2(5)$
Canada	0.996	8.291	1.935	4.808	0.541	4.173	0.264	1.901
France	0.538	5.567	0.643	2.124	2.915	11.617**	0.066	6.193
Germany	1.277	5.843	4.024	7.857	0.074	10.103	0.235	1.786
Italy	2.172	16.886*	2.090	5.446	0.265	9.350	9.867*	10.503*
Japan	0.003	5.822	5.114**	5.799	5.386**	20.992*	0.047	0.511
The UK	0.040	11.975**	3.449	7.169	0.362	4.812	0.001	4.495
The USA	1.226	1.809	0.157	0.984	0.175	17.611*	2.643	4.379

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively. $Q(.)$ and $Q^2(.)$ represent the Ljung-Box test statistic values for linear and squared autocorrelations, respectively.]*

6.3.2 Results on structural break tests in system of equations

After estimating the inflation uncertainty and output growth uncertainty from the above BVAR(p)-BAGARCH(1,1) model, we now apply the testing procedure proposed by Qu and Perron (2007) for finding the presence of multiple structural breaks in the relations involving inflation, output growth, inflation uncertainty and output growth uncertainty. The test results along with the estimated break date(s) are reported in Table 6.3 below.

Table 6.3 Results of Qu-Perron structural break test

	Canada	*France*	*Germany*	*Italy*	*Japan*	*The UK*	*The USA*
The WDmax test							
Up to 1 break	102.22*	53.26*	123.03*	113.86*	86.04*	69.43*	182.70*
Sequential test							
Sup$F_T(2\|1)$	228.41*	213.41	228.61*	172.26*	46.01	54.83	138.16*
Sup$F_T(3\|2)$	64.00	68.13	104.49	73.28			53.14
Estimated break dates							
$\hat{T}_1$	**1985M03** [1985M01 -1985M05]	**1982M11** [1982M02-1983M08]	**1989M06** [1989M02-1991M02]	**1985M04** [1984M08-1985M11]	**1976M11** [1976M04-1977M06]	**1991M10** [1991M05-1992M04]	**1982M06** [1982M01-1983M01]
$\hat{T}_2$	**1991M09** [1991M07-1991M11]	**2006M11** [2006M07-2007M03]	**1995M01** [1994M11-1995M03]	**2006M12** [2006M02-2007M02]			**2005M04** [2004M12-2005M08]

[indicates significance at 1% level of significance. $\hat{T}_1$and $\hat{T}_2$ indicate the first and second break dates, respectively. Figures in parentheses are the 95% confidence intervals of the estimated break dates.]*

It is observed from the *WDmax* test statistic values that there exists at least one structural break in the VAR set-up with four variables *viz*., inflation, output growth, inflation uncertainty and output growth uncertainty for each of the G7 countries. For example, in case of the USA, the test statistic value for the *WDmax* test for 0 *versus* 1 break is 182.70, and it is significant at 1% level of significance. Thus the null hypothesis of 'no structural break' is rejected in favour of the alternative of 'one structural break' for the USA. Now, as prescribed in Qu and Perron, to detect the presence of more than one structural break, we have carried out the sequential testing procedure. It is obtained from the relevant entries of Table 6.3 that the value of $Sup\ F_T(2|1)$ test i.e., 138.16, is significant at 1% level, and accordingly we reject the null hypothesis of one break in favour of two breaks in case of the USA. However, it is evident from the next test i.e., $Sup\ F_T(3|2)$ that the null hypothesis of two breaks cannot be rejected in favour of three breaks.

Thus we can conclude that for the USA, the sequential testing procedure has identified two breaks in the system of equations involving the above four variables. Finally, the two estimated break dates are found to be June 1982 and April 2005. Similarly, we have found two structural breaks in the system of equations for Canada, France, Germany and Italy and one break for Japan and the UK. The estimated break dates are March 1985 and September 1991 for Canada, November 1982 and November 2006 for France, June 1989 and January 1995 for Germany, April 1985 and December 2006 for Italy, November 1976 for Japan and October 1991 for the UK.

It is worthwhile to note that the estimated break dates obtained above are, by and large, the same to those obtained in Chapter 4. Of course, the estimates of the break dates are not exactly the same as obtained earlier. For example, in case of Germany, the two estimated break dates were found in Chapter 4 to be October 1990 and February 1997 are slightly different from the present case. These are now June 1989 and January 1995. The occurrences of the first break date for Germany, Italy, Japan and the USA are close to those found in Chapter 4. Thus, the plausible explanations given in Chapter 4 also hold, in general, for the current model. However, the differences in this regard are the following. For example, in case of the UK, we find only one break here as compared to three breaks earlier. For this country, the above estimated break date obtained in case of this model is very close to the second break obtained in Chapter 4, which indeed refer to the year of 'inflation targeting' in the UK. Again, the break dates observed for France are not at all close to those obtained previously. In this context it is worth mentioning that in Chapter 4 the model is based on two variables *viz.*, inflation and inflation uncertainty, but in this chapter, we are analyzing the presence of multiple structural breaks in a system of equations with four variables, and thus it provides some explanations for these differences in the estimates of the break dates.

Additionally, we have obtained break dates that are found to have occurred in the latter half of 2000 for France, Germany and the USA. It is a common fact that the level of inflation in most of the industrialized economies was much lower in the periods of 1980s and 1990s than in 1960s and 1970s. It is also a fact that the volatility of output growth declined significantly in 1980s. Of course, a lower volatility of external surprises (such as oil-price changes) and improved private sector behaviour resulting from the employment of new technology played leading roles to these changes. It appears, however, that better monetary policy has contributed significantly to this decline. Thus the periods of 1980s and 1990s recognized as the periods of strong economic performances. During this period, inflation was generally low, output growth was more stable, international trade and especially financial flows expanded, and the industrialized economics experienced widespread progress.

However, this favourable phenomenon was hit by the global imbalances at the starting of 2000[51]. Slowdown of output growth, escalation of commodity prices that were caused by the combination of several shocks like negative supply and demand shocks, the increase oil prices in 1999, and restrictive monetary policy in 2000, produced an unfavourable situation in many of the industrialized countries at the starting of this millennium (see, Peersman (2005)). There are some trends that appeared increasingly unsustainable as time went by, the real estate values were rising at a high rate in many countries, including the world's largest economy, the USA again, and a number of countries were simultaneously running with high and rising current account deficit. Since 2004 global imbalances widened under the pressure of continuing increase in housing and equity prices which was then followed by the global financial crisis in 2007-2008. Following the collapse of the sub-prime mortgage market in the USA[52], the global financial system has undergone a period of unprecedented turmoil. The confidence in financial markets has been severely eroded and it still remains fragile. The collapse or near collapse of high profile, and in some cases systematically important financial institutions along with unprecedented government intervention in the banking system, has served to completely transform the landscape of global finance and thus ultimately creates severe distortion in the macroeconomic variables.

6.3.3 Findings on the different links

In this section, we discuss the findings on the relationship involving different bivariate combinations of the four variables considered in the VAR system of equation. We first begin with reporting on the estimation results concerning the links between inflation and output growth.

---

[51] See, for details on global imbalances, Bernanke (2005, 2009).

[52] In the USA, credit market distortions, Fed's monetary policy and financial innovation created the conditions that made the US the epicenter of the global financial crisis (Obstfeld and Rogoff (2009)).

Inflation and output growth

Table 6.4 Results on the relationship between inflation and output growth

	Effect of inflation on output growth				*Effect of output growth on inflation*			
	Full sample	*Sub-period I*	*Sub-period II*	*Sub-period III*	*Full sample*	*Sub-period I*	*Sub-period II*	*Sub-period III*
Country	$\beta_{y\pi}$	$\beta_{y\pi,1}$	$\beta_{y\pi,2}$	$\beta_{y\pi,3}$	$\beta_{\pi y}$	$\beta_{\pi y,1}$	$\beta_{\pi y,2}$	$\beta_{\pi y,3}$
Canada	-0.111	-0.070	-0.797**	-0.026	-0.010	-0.013	-0.022	0.007
France	0.171	-0.353	0.414	1.325	0.001	-0.018***	0.008	0.023***
Germany	-0.015	-1.126**	-0.039	3.504*	0.003	-0.001	-0.010	0.007
Italy	0.394	0.454	-0.380	2.898**	0.006	0.008	-0.002	0.001
Japan	-0.038	-0.312	0.351		-0.003	-0.034	0.001	
The UK	-0.195	-0.167	-0.237		-0.005	-0.007	0.010	
The USA	-0.031	-0.273	-0.173	0.417***	-0.022	-0.058**	0.040**	-0.024

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively. $\beta_{y\pi,j}$ and $\beta_{\pi y,j}$ denote the effect of inflation on output growth and the effect of output growth on inflation, respectively, in the j^{th} sub-period.]*

As is evident from this table, we do not find any empirical support to any of the two links between inflation and output growth in case of full sample since the two coefficients describing the two links - $\beta_{y\pi}$ *and* $\beta_{\pi y}$ – are insignificant for all the G7 countries. These suggest that neither inflation has impact on output growth in any of these developed economics nor output growth on inflation. Thus these two links – inflation affecting output growth and output growth affecting inflation – are non-existent in the G7 countries.

Now, at the sub-period level, the findings are slightly encouraging. If we first consider the impact of inflation on output growth, we find no significant impact in most of countries in the first two sub-periods. Though the coefficients are mostly negative in these two sub-periods, it is only for Germany in the first sub-period and Canada in its second sub-period that the effect is found to be significant. In contrast to this, the coefficient values for sub-period III i.e., $\beta_{y\pi,3}$, clearly show that for each of Germany, Italy and the USA, a significant impact of inflation on output growth is observed. Interestingly, the impact is positive for all these three countries. Thus we can conclude that in their respective third sub-periods, which cover the latter half of 2000 for Italy and the USA and mid-1990s till 2013 for Germany, inflation is a positive determinant of output growth for these three countries. Finally, we note that for three countries *viz*., France, Japan and the UK, inflation does not have any impact on output growth either in full sample or in any of the sub-periods.

The empirical support for the reverse causation i.e., from output growth to inflation is also very limited. The relevant coefficient $\beta_{\pi y,j}$ is found to be significant only for France and the USA in different sub-periods. France supports a negative significant effect of output growth on inflation in its first sub-period i.e., during 1970 to 1982, while the impact is positive in the third sub-period which covers the sample from mid 2000 to 2013. For the USA, the effect is negative and significant during 1970s to early 1980s, whereas it is positive and significant in the period from 1983 to mid 2000. For both of these two countries, it is noted that output growth significantly reduces inflation in the periods of ‘great inflation’, whereas the impact becomes positive in the latter periods.

Inflation and inflation uncertainty

We next discuss the findings on the relationship between inflation and inflation uncertainty.

Table 6.5 Results on the relationship between inflation and inflation uncertainty

	Effect of inflation on inflation uncertainty				*Effect of inflation uncertainty on inflation*			
	Full sample	*Sub-period I*	*Sub-period II*	*Sub-period III*	*Full sample*	*Sub-period I*	*Sub-period II*	*Sub-period III*
Country	$\beta_{h_\pi \pi}$	$\beta_{h_\pi \pi,1}$	$\beta_{h_\pi \pi,2}$	$\beta_{h_\pi \pi,3}$	$\beta_{\pi h_\pi}$	$\beta_{\pi h_\pi,1}$	$\beta_{\pi h_\pi,2}$	$\beta_{\pi h_\pi,3}$
Canada	0.014**	0.013***	0.182*	0.020**	-0.003	1.198**	-0.581	-0.334
France	0.001	0.005	0.000	-0.005	0.377	0.654	-0.880	-1.225
Germany	0.118*	0.063*	0.196*	0.014	0.210	0.269	0.065	-0.105
Italy	0.018*	0.022*	-0.001	0.008**	0.227	0.267	-1.478	-0.492
Japan	0.010*	0.018*	0.001		0.118	0.206	0.458**	
The UK	0.361*	0.413*	-0.007		0.085***	0.067	0.323	
The USA	0.022*	0.083*	0.007	-0.040**	0.592*	0.624**	0.217	0.813**

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively. $\beta_{h_\pi \pi,j}$ and $\beta_{\pi h_\pi,j}$ denote the effect of inflation on inflation uncertainty and the effect of inflation uncertainty on inflation, respectively, in the j^{th} sub-period.]*

The empirical results for the relationship between inflation and inflation uncertainty are, by and large, similar to what we have reported in Chapter 4 where the study was done with these two variables only. Thus, in this case we find strong significant support for the Friedman-Ball hypothesis for positive causal effect of inflation on its uncertainty in full sample. Except France, the estimated values of $\beta_{h_\pi \pi}$ are positive and significant for all the other six countries. Similar to results in Chapter 4, we also obtain strong evidence regarding the positive impact of inflation on inflation uncertainty for the first sub-period i.e., the period when inflation was high and more volatile, for all the countries in G7 barring France. However, the impact turns out to be relatively weak in the latter sub-periods. In their respective third sub-period, we find a significant positive impact of inflation on its uncertainty for Canada and Italy. For the remaining countries, in their third sub-periods, the effect of inflation on its uncertainty is either found to be insignificant or negatively significant. For instance, in case of the USA, we observe a negative effect of inflation on its uncertainty for the period covering mid-2000s to 2013.

The evidence is not so much profound for the causal effect of inflation uncertainty on inflation as the coefficient $\beta_{\pi h_\pi}$ is found to be insignificant in most of the G7 countries for both in the full sample as well as in different sub-periods. In the full sample, $\beta_{\pi h_\pi}$ is significant only for the UK and the USA with the impact being positive in both of these two countries, while inflation uncertainty has no significant effect on inflation for the remaining five countries. The empirical evidence for any significant impact is also scant in different sub-periods for each of the G7 countries. In their respective first sub-periods, Canada and the USA show a positive and significant effect of inflation uncertainty on inflation. It is also noted from the above table that this impact is not found to be significant in any of the seven countries in the latter sub-periods with the exception of Japan and the USA in their last sub-periods.

Even though the results in this chapter are somewhat similar to those obtained in Chapter 4, we find that there are some differences as well. For example, in case of Italy, we have found in Chapter 4 that the significant positive impact of inflation on inflation uncertainty is invariant in different sub-periods. But, in the present model the result is different for Italy as the coefficient $\beta_{h_\pi \pi}$ is found to be insignificant in its second sub-period which covers the observations from mid-1980s to mid-2000s. Again, in case of the USA, this effect was not found to be significant during 1977 to 2013 in the previous model. But, in the present context, a negative and significant effect of inflation on inflation uncertainty has been found in the third sub-period covering mid-2000s to 2013 for the USA. Similarly, we have noted some differences in the impact in the reverse direction i.e., from inflation uncertainty to inflation. For instance, in the present model, the coefficient $\beta_{\pi h_\pi}$ is found to be positive and significant in the third-sub period for the USA, whereas this coefficient was not significant in the previous model during the period from 1977 to 2013.

We note from the results of the Qu-Perron structural break test that there are some differences in the estimates of the break dates in case of some countries in the two models of Chapters 4 and 6. As for instance, in case of Italy and the USA, in the present model with four variables we have found two breaks in the system of equations in each of these two countries, whereas in Chapter 4, only one break in the relationship between inflation and inflation uncertainty has been found for each of these two countries. The possible explanation for these differences in break point estimates lies basically on the fact that the model in this chapter is an enlarged model than the one in Chapter 4. And this, in turn, should explain the differential findings on the nature of the causal relationship as mentioned in the preceding paragraph.

Inflation and output growth uncertainty

Table 6.6 Results on the relationship between inflation and output growth uncertainty

	Effect of inflation on output growth uncertainty				*Effect of output growth uncertainty on inflation*			
	Full sample	*Sub-period I*	*Sub-period II*	*Sub-period III*	*Full sample*	*Sub-period I*	*Sub-period II*	*Sub-period III*
Country	$\beta_{h_y\pi}$	$\beta_{h_y\pi,1}$	$\beta_{h_y\pi,2}$	$\beta_{h_y\pi,3}$	$\beta_{\pi h_y}$	$\beta_{\pi h_y,1}$	$\beta_{\pi h_y,2}$	$\beta_{\pi h_y,3}$
Canada	0.073	-0.154***	0.928*	0.187*	0.041	-0.049	0.166	0.115
France	0.015	0.127	-0.007	-0.140	0.011	0.006	0.074**	-0.019
Germany	0.080	0.159	0.929*	-1.832	-0.008**	-0.003	0.042	-0.014*
Italy	-0.066	0.075	-0.205**	-1.509*	0.002	0.004	0.005	-0.011
Japan	0.040	-0.002	0.150		-0.000	-0.141	0.001	
The UK	0.336	0.280	-0.470		-0.009**	-0.010***	-0.011	
The USA	-0.148***	-0.116	-0.022	-0.301	-0.101*	-0.076**	-0.010	-0.144*

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively. $\beta_{h_y\pi,j}$ and $\beta_{\pi h_y,j}$ denote the effect of inflation on output growth uncertainty and the effect of output growth uncertainty on inflation, respectively, in the j$^{\text{th}}$ sub-period.]*

In case of inflation and output growth uncertainty, we first discuss the effect of inflation on output growth uncertainty. It is worth noting that this impact, as indicated by the coefficient $\beta_{h_y\pi}$ is found to be insignificant in case of full-sample analysis for all the G7 countries except the USA where $\hat{\beta}_{h_y\pi}$ is -0.148 which is significant only at 10% level. Moreover, the negative sign indicates that in the full sample, inflation reduces output growth uncertainty for the USA. It is also noted that this effect is not significant in the first sub-periods of each country. Only Canada yields a significant negative impact. In contrast to these findings, we obtain some significant results when we consider latter sub-periods. We observe that for three countries *viz*., Canada, Germany and Italy, inflation is found to have significant impact on output growth uncertainty in their respective second sub-period. For instance, in case of Canada, $\hat{\beta}_{h_y\pi,2}$ is 0.928 and is significant at 1% level of significance. In addition, we obtain mixed findings in this sub-period. A positive impact is found for Canada and Germany, while Italy supports a negative causal effect. It is also observed that the sign of the causal impact remains same for Canada and Italy in their respective third sub-periods, while for Germany $\beta_{h_y\pi,3}$ it is found to be insignificant. Thus in contrast to the full sample results, we find that inflation significantly increases output growth uncertainty for Canada during the period that includes observation from mid-1980s to 2013, whereas for Italy, inflation significantly reduces output growth uncertainty in the same time period.

On the other hand, the reverse causation from output growth uncertainty to inflation is found to be significant for three countries *viz*., Germany, the UK and the USA in the whole sample. For these three countries we find a negative causal effect as predicted by Cukierman-Meltzer hypothesis in conjunction with the Taylor (1979) effect. In case of Germany, the estimation results based on different sub-periods reveal that the negative effect of output growth uncertainty on inflation is observed only in the third sub-period since the estimated value of the coefficient $\beta_{\pi h_y,3}$ i.e., -0.014, is significant at 1% level. In case of the UK and the USA, the impact is negative for all the sub-periods, but it is significant only at the first sub-period i.e., in the pre 'inflation targeting' period of the UK and for the USA during the periods from 1970 to early 1980s and again from mid-2000s to 2013. For France, a positive effect is found only in its second sub-period. However, for the remaining three countries *viz*., Canada, Italy and Japan, we do not observe any significant causal effect from output growth uncertainty to inflation.

Output growth and inflation uncertainty

Table 6.7 Results on the relationship between output growth and inflation uncertainty

	Effect of output growth on inflation uncertainty				*Effect of inflation uncertainty on output growth*			
	Full sample	*Sub-period I*	*Sub-period II*	*Sub-period III*	*Full sample*	*Sub-period I*	*Sub-period II*	*Sub-period III*
Country	$\beta_{h_\pi y}$	$\beta_{h_\pi y,1}$	$\beta_{h_\pi y,2}$	$\beta_{h_\pi y,3}$	$\beta_{y h_\pi}$	$\beta_{y h_\pi,1}$	$\beta_{y h_\pi,2}$	$\beta_{y h_\pi,3}$
Canada	-0.008*	-0.008*	0.000	-0.011*	-2.378*	-5.090*	-0.365	-2.634*
France	-0.002*	-0.002**	-0.001**	-0.004*	-10.917*	-5.484	3.474	-6.977*
Germany	-0.001	-0.001	0.002	-0.001	0.020	-0.679	-0.306	4.572
Italy	-0.001	-0.001	-0.000	-0.002*	-6.145*	-6.479*	13.271	-62.962*
Japan	-0.000	-0.001	-0.001***		-1.025***	-2.207*	-0.216	
The UK	-0.030*	-0.032*	-0.013*		-0.337***	-0.253	-4.729*	
The USA	-0.005***	-0.006	-0.004**	-0.011	-1.148*	-0.553	-3.786*	-1.545***

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively. $\beta_{h_\pi y,j}$ and $\beta_{y h_\pi,j}$ denote the effect of output growth on inflation uncertainty and the effect of inflation uncertainty on output growth, respectively, in the j^{th} sub-period.]*

It is noted from the above table that the coefficient describing the impact of output growth on inflation uncertainty in the full sample i.e., $\beta_{h_\pi y}$ is negative for all the G7 countries. However, among them four countries *viz*., Canada, France, the UK and the USA, show a significant impact. The empirical evidence clearly indicates that an increase in output growth reduces inflation uncertainty in these four countries. Similarly, we get a strong support to the negative causal effect of inflation uncertainty on output growth. We find that the estimated values of the coefficient $\beta_{y h_\pi}$ are negative and significant for all the G7 countries barring Germany. For instance, $\hat{\beta}_{y h_\pi}$ for Canada is -2.378 and it is significant at 1% level of significance. Thus, we obtain overwhelming evidence in favour of the second part of the Friedman (1977) hypothesis i.e., increase in inflation reduces output growth *via* the uncertainty channel.

Sub-periods results also provide uniformity insofar as the sign of the relationship is concerned, but the findings are different in respect of direction of causality (unidirectional/bi-directional) as well as 'no causality' in the sub-period. For instance, in case of Canada, bidirectional causality holds only in its first and third sub-periods. Associated negative signs of the coefficients $\beta_{h_\pi y,1}$, $\beta_{h_\pi y,3}$ and $\beta_{y h_\pi,1}$ and $\beta_{y h_\pi,3}$ indicate that increase in output growth reduces inflation uncertainty while at the same time we find that inflation uncertainty reduces output growth in the two sub-periods in case of Canada. In case of France, the negative effect of output growth on inflation uncertainty is found to be invariant with different sub-periods since all the relevant coefficients i.e., $\beta_{h_\pi y,1}$, $\beta_{h_\pi y,2}$ and $\beta_{h_\pi y,3}$ are found to be negative and significant. On the other hand, the negative effect of inflation uncertainty on output growth is significant only in its third sub-period. Thus the Friedman (1977) hypothesis holds for France for the third sub-period i.e., the period that includes observations from mid-2000s to 2013.

Similarly, in case of both Italy and Japan, contrary to full sample results where no significant effect of output growth on inflation uncertainty is obtained for these two countries, it is now found to be statistically significant in their respective last sub-period. For the reverse causation i.e., from inflation uncertainty to output growth, the above result indicates that the Friedman hypothesis holds for Italy only in its first and third sub-periods. Again, for Japan we find that inflation uncertainty significantly reduces output growth only during the period of 'great inflation' of 1970s. Further, in case of the UK, the negative causal effect of output growth on inflation uncertainty is found to be invariant from consideration of different sub-periods. The reverse causation is significant only in the last sub-period for the UK i.e., in the post 'inflation targeting' period in the UK. Furthermore, the negative sign of the coefficient $\beta_{y h_\pi,3}$ indicates that the Friedman hypothesis holds for the UK for this period i.e., the third sub-period. The sub-period based results for the USA indicate that output growth has a negative impact on inflation uncertainty for all the sub-periods, but we observe that only the coefficient $\beta_{h_\pi y,2}$ is significant. Similar finding is obtained for the reverse impact. We find that inflation uncertainty negatively affects output growth in all the three sub-periods, but it is found to be significant only in the second and third sub-periods for the USA. It is only in case of Germany that no significant bi-directional relationship is found to exist either in full sample or in different sub-periods.

Output growth and output growth uncertainty

We now report the estimation results on the relationship between output growth and output growth uncertainty.

Table 6.8 Results on the relationship between output growth and output growth uncertainty

	Effect of output growth on output growth uncertainty				*Effect of output growth uncertainty on output growth*			
	Full sample	*Sub-period I*	*Sub-period II*	*Sub-period III*	*Full sample*	*Sub-period I*	*Sub-period II*	*Sub-period III*
Country	$\beta_{h_y y}$	$\beta_{h_y y,1}$	$\beta_{h_y y,2}$	$\beta_{h_y y,3}$	$\beta_{y h_y}$	$\beta_{y h_y,1}$	$\beta_{y h_y,2}$	$\beta_{y h_y,3}$
Canada	-0.104*	-0.141*	-0.101**	-0.049*	0.006	-0.125	0.068	0.350
France	-0.035*	-0.036**	-0.013**	-0.060*	-0.110***	-0.186	-0.292	0.245**
Germany	-0.979*	-1.112*	-0.325*	-1.337*	-0.026	0.148*	0.085	-0.073
Italy	-0.084*	-0.091**	-0.036*	-0.078**	0.099*	0.128**	0.002	0.428*
Japan	-1.213*	-0.233*	-1.315*		0.049*	-0.243	0.053*	
The UK	-1.585*	-1.764*	-0.844*		0.078*	0.085*	0.094**	
The USA	-0.528*	-0.542*	-0.162*	-0.961*	-0.087***	-0.010	-0.247	-0.057

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively. $\beta_{h_y y,j}$ and $\beta_{y h_y,j}$ denote the effect of output growth on output growth uncertainty and the effect of output growth uncertainty on output growth, respectively, in the j*th *sub-period.]*

We note from Table 6.8 that the coefficient $\beta_{h_y y}$ that depicts the impact of output growth on output growth uncertainty is highly significant for all the seven countries in case of full sample. As for instance, in case of the UK $\hat{\beta}_{h_y y}$ is -1.585 and this coefficient is found to be significant at 1% level. It is also worth noting that for all the G7 countries, output growth affects output growth uncertainty negatively and thus these provide empirical support to the Friedman-Ball hypothesis in conjunction with the Taylor (1979) effect. It is interesting to note that for all the countries in different sub-periods, we find a significant impact of output growth on output growth uncertainty. For instance, in case of Canada, $\hat{\beta}_{h_y y,1}$, $\hat{\beta}_{h_y y,2}$ and $\hat{\beta}_{h_y y,3}$ are -0.141, -0.101 and -0.049, respectively, and all these values are found to be significant at 5% level of significance. Additionally, we obtain a strong support for the negative causal effect of output growth on its uncertainty for all the seven countries in all their different sub-periods. Thus these findings lead us to conclude that the negative effect of output growth on its uncertainty does not change for the different sub-periods.

However, for the reverse causation from output growth uncertainty to output growth, the empirical evidence is found to be mixed. We find positive effect for Italy, Japan and the UK but negative effect for France and the USA. Thus in the full sample, Italy, Japan and the UK support Black (1987) hypothesis, while France and the USA support the theory of Pindyck (1991). However, for the remaining two countries *viz*., Canada and Germany, the effect is found to be insignificant.

The empirical results based on different sub-periods reveal that for three countries *viz*., Germany, Italy and the UK, in their first sub-periods, two countries *viz*., Japan and the UK, in their second sub-periods and two countries *viz*., France and Italy, in their respective last sub-periods, a significant impact of output growth uncertainty on output growth is found. During the first sub-period where most of the observations are for the period covering 1970 to mid-1980s with the exception of the UK where the first sub-period spans from 1970 to the end of 1990s, we find a positive effect of output growth uncertainty on output growth for Germany, Italy and the UK, while the coefficient $\beta_{yh_y,1}$ is found to be insignificant for the remaining four countries. The same positive effect of real uncertainty on output growth holds for France, Italy, Japan and the UK in their respective last sub-periods.

Inflation uncertainty and output growth uncertainty

Finally, we present the estimates of the parameters of the relations between inflation uncertainty and output growth uncertainty for the full sample as well as for the different sub-periods in Table 6.9.

Table 6.9 Results on the relationship between inflation uncertainty and output growth uncertainty

	Effect of inflation uncertainty on output growth uncertainty				*Effect of output growth uncertainty on inflation uncertainty*			
	Full sample	*Sub-period I*	*Sub-period II*	*Sub-period III*	*Full sample*	*Sub-period I*	*Sub-period II*	*Sub-period III*
Country	$\beta_{h_y h_\pi}$	$\beta_{h_y h_\pi,1}$	$\beta_{h_y h_\pi,2}$	$\beta_{h_y h_\pi,3}$	$\beta_{h_\pi h_y}$	$\beta_{h_\pi h_y,1}$	$\beta_{h_\pi h_y,2}$	$\beta_{h_\pi h_y,3}$
Canada	0.993*	1.975*	1.747*	0.586*	0.028*	0.031*	0.088*	0.058**
France	14.525*	14.162*	11.278*	26.556*	0.001**	0.000	0.001	0.001
Germany	-1.571	-4.970	-1.031**	0.858	0.004*	0.003*	0.015*	0.004*
Italy	-0.122	-1.212	2.303	21.001*	0.001*	0.001	0.001***	0.001***
Japan	-1.968**	-0.106	-2.624		-0.000	-0.009	-0.000	
The UK	-0.301	-0.673	6.480*		0.003	0.003	0.005**	
The USA	1.930*	0.963**	1.369*	1.992*	0.033*	0.017**	0.039*	0.047*

[, ** and *** indicate significance at 1%, 5% and 10% levels of significance, respectively.* $\beta_{h_y h_\pi,j}$ *and* $\beta_{h_\pi h_y,j}$ *denote the effect of inflation uncertainty on output growth uncertainty and the effect of output growth uncertainty on inflation uncertainty, respectively, in the* j^{th} *sub-period.]*

It is noted from the above table that inflation uncertainty has a significant impact on output growth uncertainty for Canada, France, Japan and the USA in the full sample period. However, among these four countries, Canada, France and the USA support a positive effect, whereas the impact is negative for Japan. For the remaining three countries, $\beta_{h_y h_\pi}$ is found to insignificant, suggesting no link from inflation uncertainty to output growth uncertainty. It is interesting to mention that for the aforesaid three countries, the sign of the causal effect does not vary in their respective sub-periods. As for instance, in case of Canada, $\hat{\beta}_{h_y h_\pi,1}$, $\hat{\beta}_{h_y h_\pi,2}$ and $\hat{\beta}_{h_y h_\pi,3}$ are 1.975, 1.747 and 0.586, respectively, and these estimated values are highly significant in all the three sub-periods. Thus we can conclude that the hypothesis due to Logue and Sweeney (1981) hypothesis which states that there is a positive impact of inflation uncertainty on real uncertainty holds for Canada, France and the USA and obviously, therefore, this finding of the impact being positive is not affected by the presence of structural breaks. For Germany and the UK, nominal uncertainty significantly affects real uncertainty only in their second sub-period. However, the coefficient $\beta_{h_y h_\pi,2}$ is found to be positive for the UK and negative for Japan.

On the other hand, the estimation results support the reverse causation from output growth uncertainty to inflation uncertainty that exists for five countries *viz*., Canada, France, Germany, Italy and the USA in the full sample period. Additionally, output growth uncertainty is found to cause increase in inflation uncertainty in all these countries. The findings are same for the different sub-periods for Canada, Germany and the USA where the positive effect of output growth uncertainty on inflation uncertainty is invariant at sub-period level analysis, since the coefficients $\beta_{h_\pi h_y,1}$, $\beta_{h_\pi h_y,2}$ and $\beta_{h_\pi h_y,3}$ are found to be positive and significant for all these three countries. We further note that no significant effect is observed in any of its sub-periods in case of France. In contrast to the full sample results, we find a significant positive impact of real uncertainty on nominal uncertainty in the post 'inflation targeting' period in the UK. Finally, no significant effect is found in the full sample as well as in different sub-periods in case of Japan.

6.4 Conclusions

In this chapter, we have analyzed the stability or otherwise of the relationships along with the direction and nature – positive or negative – of the different bivariate combinations of the four variables i.e., inflation, output growth, inflation uncertainty and output growth uncertainty. Our prime concern here is that we have not assumed fixed relationships involving these four variables over the long span of data considered in this study. Rather, we have used a notion of temporary relationship i.e., the relationship may vary between different sub-periods of the entire time series. The framework of analysis is based on a two-step procedure. In the first step, we have employed a bivariate model consisting inflation and output growth to estimate the conditional variances of inflation and output growth, and thus getting measures for inflation uncertainty and output growth uncertainty, respectively. The model we have adopted in the first step is the VAR(*p*)-BAGARCH(1,1) model for inflation and output growth. By estimating inflation uncertainty and output growth uncertainty through this model, we have followed the next step where a system of equations is used to study the relationship between inflation, output growth and their uncertainties after giving due consideration to structural breaks in the system of equations. In this second step, in order to study how the relationship varies between different sub-periods of the full sample, we have applied a recently developed test (Qu and Perron (2007)) for testing for multiple structural breaks in a system of equations consisting of these four variables.

By applying the Qu-Perron methodology, we have found that at least one structural break exists in the relationship for all the G7 countries. The empirical evidence clearly shows that the relationship varies significantly in different sub-periods. It has been also found that in some sub-periods only unidirectional relationship holds, while in some sub-periods the relationship is bi-directional in nature and in some sub-periods no such links exists between the variables concerned. The important conclusions on the nature and directions of the links in the pairs of these relationships are stated below. First, inflation increases inflation uncertainty in the full sample for all the G7 countries barring France, and thus the findings support the Friedman-Ball hypothesis. It is interesting to note that the sub-period-wise results clearly show that the Friedman-Ball hypothesis holds only for the sub-periods covering the first half of the sample for most of the G7 countries. While for the latter half of the sample period, the effect of inflation on its uncertainty is found to be insignificant for most of the countries. Second, inflation uncertainty is detrimental for output growth in the full sample for all countries barring Germany. The sub-period-wise results also lend support these findings, in general. Finally, it is important to note that increase in output growth significantly reduces output growth uncertainty for the full sample as well as for different sub-periods for all the G7 countries. We can thus conclude that the effect of output growth on its uncertainty is always negative.

Chapter 7

Summary and Future Ideas

7.1 Introduction

Even though a good deal of theoretical and empirical literature on the relationship between inflation, output growth, inflation uncertainty and output growth uncertainty exists, yet the exact nature of the relationship involving these four variables is not completely known, and, to that extent, the issue of determining the relationship appropriately remains open. The literature offers many competing theories and hypotheses on the relationship involving these variables. Over the last three decades several empirical studies have estimated these relations and also verified the validity of the hypotheses. Some studies have used a simultaneous estimation technique to study this relationship and found the links involving these variables while others have relied on a two-step estimation procedure. However, the empirical support to these theories is quite varied, offering mixed outcomes. Such mixed empirical evidence, sometimes even for the same country but obviously in different studies, can be attributed to different modelling approaches used to capture the intrinsic nature of the relationship involving these variables. Different time periods for different studies may also partly explain these varied outcomes.

However, one common aspect in most of these empirical studies is that the relations are assumed to be linear and stable over time. But this assumption is far from being true even for data of moderate span, not to talk about large time periods. Recently, some researchers have observed some kind of nonlinear behaviour in inflation and output growth series. Such findings have motivated us to study the relationship and the links involving the levels and volatilities of inflation and output growth using two modeling approaches which entail consideration of regime switching and existence of multiple structural breaks in the system of equations involved.

This thesis examines the linkages between inflation, output growth and their uncertainties and thus verifies different hypotheses prescribed in the theoretical literature. The contribution is empirical in nature. We have used both the simultaneous estimation procedure and the two-step method to examine this relationship. As there are some overlapping of the economic theories along with the econometric methods in different chapters, we first provide a brief overview of the chapters including the relationship(s) studied in each chapter along with the econometric methodology used in the corresponding one.

In Chapters 3 and 5 of this thesis, we have employed models that incorporate the regime switching behaviour of inflation and output growth. In fact, in Chapter 3, our objective has been to verify the impact of inflation on inflation uncertainty after giving due consideration to regime switching behaviour of inflation. The model proposed in this chapter is a double-threshold GARCH (DTGARCH) model where, apart from consideration of two regimes for both the conditional mean and conditional variance, the usual GARCH specification for conditional variance is extended by explicitly incorporating a lagged inflation term for each regime, the coefficient of which depicts the impact of inflation on inflation uncertainty. One significant advantage of this model is that it allows for different behaviours of inflation uncertainty in the two different regimes.

In Chapter 5, we have introduced a threshold bivariate autoregressive - bivariate asymmetric GARCH-in-mean (TBVAR-BAGARCH-M) model for inflation, output growth and their uncertainties. This model incorporates regime switching behavior of inflation and output growth in conditional mean and asymmetric effects of past shocks in conditional variance. The consideration of ‘in-mean’ component enables us to examine the regime dependent effects of inflation uncertainty and output growth uncertainty on the levels of inflation and output growth.

A point to take note of is that in Chapters 3 and 5 we have used a simultaneous estimation procedure to study the relationship and the links, whereas in Chapters 4 and 6, we have relied on a two-step procedure. In case of the latter, we have incorporated the notion of multiple structural breaks in the system of equations to study the stability of the relationship. Further, in Chapter 4, we have analyzed the relationship and nature of links between inflation and inflation uncertainty, while in Chapter 6, we have extended this by incorporating output growth and output growth uncertainty as well. Thus the stability of the relationship involving these four variables *viz*., inflation, output growth, inflation uncertainty and output growth uncertainty, has been examined together in chapter 6, and accordingly the subsequent analysis and validity of the well-known hypotheses have been done at the sub-period level.

The study has been carried out with the monthly time series of inflation and output growth for the G7 countries – Canada, France, Germany, Italy, Japan, the UK and the USA - covering the period from January 1970 to June 2013. This last chapter of the thesis is organized as follows. A summary of the major findings of the entire work is presented in Section 7.2. The last section i.e., Section 7.3, presents a few ideas for further work on this topic.

7.2 Major Findings

We have stated in the preceding section that in Chapters 3 and 5, there is a similarity in the two approaches followed since both incorporate regime switching behaviour in their respective models. Of course, the model in Chapter 3 involves inflation and inflation uncertainty, while the one in Chapter 5 has two more variables i.e., output growth and its uncertainty. We first discuss the findings of Chapter 3 and then of Chapter 5. The major findings of the other two chapters i.e., Chapters 4 and 6 are presented thereafter. However, we begin with Chapter 2.

Chapter 2 presents the plots, summary statistics, and some important characteristics of the time series on inflation and output growth for all the G7 countries. By applying two recent tests which are due to Perron and Yabu (2009) and Kim and Perron (2009) we have found that the time series on inflation for all the seven countries are trend stationary processes having a structural break each in their respective deterministic trend functions. Accordingly, we have adjusted for the deterministic trend component so as to obtain the stationary series of inflation for each of the member countries of G7.

On the other hand, the Perron-Yabu test concludes that there is no structural break in the deterministic trend component in the output growth series of any of the seven countries. Subsequently, the usual ADF test suggests presence of no unit roots. Accordingly, the conclusion is that the output growth series of all the seven countries are free from both stochastic trend and deterministic tend i.e., these series are stationary. Finally, the Ljung-Box test indicates that there are significant linear and squared dependences in both inflation and output growth series in all the G7 countries.

In Chapter 3, the empirical findings clearly show that the impact of inflation on inflation uncertainty is different in the two regimes – high and low - for five countries *viz*., Germany, Italy, Japan, the UK and the USA. For Canada, a significant positive effect of inflation on its uncertainty holds for both high and low inflation regimes. On the other hand, the positive impact of inflation on its uncertainty is observed for Germany, Italy, the UK and the USA in the high inflation regime only, whereas the effect is found to be insignificant in the low inflation regime. Thus, the Friedman hypothesis of positive effect of inflation on inflation uncertainty holds for these four countries in the high inflation regime only. Further, the relationship is negative in the low inflation regime for Italy and Japan, which suggests that in the low regime a decline in inflation has led to an increase in inflation uncertainty in these two countries, and this obviously goes counter to the Friedman-Ball hypothesis. Thus, we can conclude that the model for inflation, where effect of inflation on inflation uncertainty is incorporated in the framework of regime switching, is found to be not stable over time in all the G7 countries barring Canada and France. This clearly establishes the importance of consideration of regime-specific behaviour in studying the impact of inflation on inflation uncertainty.

In Chapter 5, the work in Chapter 3 has been extended by including output growth and output growth uncertainty. The modelling framework is somewhat different in the sense that here we can study the effects of inflation and output growth uncertainties on the levels of inflation and output growth. The model proposed is a threshold bivariate autoregressive – bivariate asymmetric GARCH-in-Mean (TBVAR-BAGARCH-M) model for inflation, output growth and their uncertainties. This model allows for examination of the regime dependent effects of inflation uncertainty and output growth uncertainty on inflation and output growth. The major findings of this chapter are as follows.

We have found that inflation uncertainty reduces inflation with the effect being mainly observed in the high inflation regime. Out of the seven countries, five countries *viz*., Canada, France, Italy, the UK and the USA, lend empirical support to negative effect of inflation uncertainty on inflation in the high inflation regime, and hence to the ‘stabilization hypothesis’ proposed by Holland (1995). Combining this finding with the one obtained in Chapter 3 that inflation increases inflation uncertainty for most of the G7 countries and that too in the high inflation regime, we can conclude that in the high inflation regime when inflation uncertainty increases due to increasing inflation, the monetary authority responds by lowering the money supply growth in order to eliminate uncertainty and the related welfare effect. Thus the observed negative causal effect of inflation uncertainty on inflation strongly supports the ‘stabilization’ motive of the central banks in most of the G7 countries. Again, for this model, uncertainty associated with inflation has been found to have a significant negative effect on output growth for each of Canada, France, Italy, Japan and the USA in the low output growth regime, and in four countries *viz*., Canada, France, Italy and the UK, in the high growth regime. In other words, it is found that Friedman’s assertion that inflation uncertainty can be detrimental to output growth has received strong support in our study.

About the effect of output growth uncertainty on inflation, we have obtained that only for four countries *viz*., Canada, Italy, the UK and the USA, a significant relationship is present. Again among these four countries, we have mixed evidence regarding the sign of the effect in each of the two different inflation regimes. Lastly, we have observed that in each of the four countries of France, Japan, the UK and the USA, output growth uncertainty has negative effect on output growth in the low output growth regime, while the effect is found to be insignificant in the high growth regime, in most of the G7 countries barring Germany and the UK where a positive effect, as predicted by Black (1987), has been observed.

Finally, it is also observed that the modelling of inflation and output growth through the introduction of regimes for both inflation and output growth yields statistically a better model since the (single regime) BVAR-BGARCH-M model, taken to be benchmark model, is found to be rejected by the likelihood ratio test in favour of the proposed TBVAR-BAGARCH-M model for all the G7 countries.

We now discuss the major findings of Chapter 4 and 6. As in case of Chapters 3 and 5, here also Chapter 6 is an extension of the work in Chapter 4 where output growth and output growth uncertainty have been included in the analysis. To be specific, in Chapter 4, we have studied the stability of the bi-directional relationship between inflation and inflation uncertainty for the G7 countries. The procedure of estimation is a two-step procedure in this chapter. In the first step, we have employed a threshold GARCH (TGARCH) model to estimate the conditional variance of inflation and this has been taken as a measure of inflation uncertainty. In the second step, a VAR process involving inflation and inflation uncertainty has been used with due consideration being given to testing for and then inclusion of structural breaks while estimating VAR. In this context, we have applied a recently developed test by Qu and Perron (2007) to test for multiple structural breaks in a system of equations. After estimation in the second step, we have studied the causal effects between inflation and inflation uncertainty, and accordingly concluded on the links involving these two variables. In Chapter 6, we have also followed the same steps, but here we have extended our analysis by including output growth and output growth uncertainty and thus, in this chapter, all types of bi-directional effects involving the four variables have been studied for inference on the possible links and hence of the empirical validity of the different hypotheses involving these variables.

Apart from the relationship, one common finding arising because of the approach used in these two chapters is that there are multiple structural breaks in the relationships under study for the G7 countries. Most of the estimated break dates appear to coincide broadly with the well-known and identifiable macroeconomic events like the introduction of inflation targeting in Canada and the UK, the introduction of Euro and a common monetary policy regime in case of France, Germany and Italy, and the Volcker disinflation in the USA.

The major findings of Chapter 4 on the concerned macroeconomic links in case of inflation and inflation uncertainty are stated below. The first finding is that inflation increases inflation uncertainty in case of full sample for all the G7 countries, and thus it provides empirical support to the Friedman-Ball hypothesis. It is interesting to note that the sub-period-wise results clearly show that the Friedman-Ball hypothesis holds only for the first half of the sample for most of the G7 countries, while for the latter half of the sample, the effect of inflation on its uncertainty is found to be insignificant for most of the countries. The effect in the reverse direction i.e., the effect of inflation uncertainty on inflation, is hardly present since the effect is found to be insignificant for most of the G7 countries for the full sample as well as the sub samples. In case of full sample, a positive and significant impact of inflation uncertainty on inflation is found to hold for Italy, Japan and the USA, even though the relevant coefficient is significant only at 10% level of significance for Japan. Similarly, a highly significant positive impact is obtained in case of the USA in its first sub-period, Italy and Japan in their respective second sub-periods and the UK in its third sub-period only.

In case of Chapter 6, one major finding is that the relationship involving different combinations of inflation, output growth, inflation uncertainty and output growth uncertainty vary significantly in different sub-periods. It has further been found that for some periods only unidirectional relationship holds, while in some others bi-directional relationship holds. But there are some sub-periods as well with no linkages between the underlying two variables. To be specific, we have found not much empirical support to the bi-directional causal links between inflation and output growth in both the full sample as well as in different sub-periods since most of the values of the coefficients describing these links are found to be insignificant. For example, in case of full sample, no bi-directional relationship between inflation and output growth has been found to hold for any of the G7 countries. Results are slightly encouraging since France and Canada support a negative impact of inflation on output growth in their respective first and second sub-periods. It is also worth mentioning that we have found a positive impact of inflation on output growth for Germany, Italy and the USA in their respective third sub-periods. On the reverse impact i.e., from output growth to inflation, we have obtained a negative effect in case of France and the USA in their first sub-periods covering the periods from 1970 to mid-1980s, while a positive impact is found to hold for France in its third sub-period and the USA in its second sub-period.

Regarding the relationship between inflation and inflation uncertainty, we have obtained, by and large, similar findings as those in Chapter 4. Specifically, we have found that inflation has a positive impact on inflation uncertainty, as predicted by the Friedman-Ball hypothesis in the full sample for all the G7 countries barring France. Similarly, sub-period-wise results suggest that the Friedman-Ball hypothesis is more pronounced in the first half of the sample when the inflation is high and more volatile. Notable among these is the positive effect that has been found to be invariant with different sub-periods for Canada. Again, as expectedly, the effect of inflation uncertainty on inflation has been found to have very little empirical support since most of the relevant test statistic values are insignificant. In case of full sample, only the UK and the USA support a positive and significant impact of inflation uncertainty on inflation. Moreover, a significant positive impact is found to hold for Canada and Japan in their first and second sub-periods respectively, and the USA in its first and third sub-periods.

The effect of output growth on inflation uncertainty is negative for most of the countries in the full sample. However, among them four countries *viz*., Canada, France, the UK and the USA, show a significant impact. It is worth mentioning that for two countries *viz*., France and the UK, this effect is invariant with different sub-periods. It is only for Germany that this impact is insignificant in both the full sample as well as in the different sub-periods. On the other hand, inflation uncertainty has been found to be detrimental for output growth in the full sample for all the seven countries barring Germany. The sub-period wise results also support these findings. Thus we find strong empirical support to the second part of the Friedman (1977) hypothesis *viz*., that increasing uncertainty about inflation distorts the effectiveness of the price mechanism in allocating resources efficiently, thus leading to negative output growth.

Another important finding is that output growth significantly reduces output growth uncertainty both for the full sample and in different sub-samples for all of the G7 countries. Thus we can conclude that the negative effect of output growth on its uncertainty is invariant at sub-period levels.

Finally, inflation uncertainty is found to have a significant impact on output growth uncertainty for Canada, France, Japan and the USA in full sample period. However, among these four countries, Canada, France and the USA support a positive causal effect, whereas the impact is negative for Japan. For the remaining three countries this impact is found to be insignificant, suggesting no causality from inflation uncertainty to output growth uncertainty. It is interesting to note that for the aforesaid three countries, the sign of the causal effect does not vary in their respective sub-periods. Further, as regards the reverse causation, we have found mainly positive impact of output growth uncertainty on inflation uncertainty. It is only for Japan where this effect is insignificant in both the full sample and sub-samples, while for three countries *viz*., Canada, Germany and the USA, the positive effect of output growth uncertainty on inflation uncertainty is found to be significant for all sub-periods.

7.3 A Few Ideas for Further Research

In the last section of the last chapter of this thesis, we briefly state a few ideas on the further research on this topic.

On other developing countries

The macroeconomic issues of inflation and output growth are extremely important and their consequences are often much serious when inflation is high and/or output growth is low in developing countries. Given the state of economic development of these countries, the relations and the links are very likely to be somewhat different from those found for the developed G7 countries, at least in some situations. Further, the roles of uncertainties associated with inflation and output growth may also have different kinds of effects as compared to those for the G7 countries. It would, therefore, be instructive to examine the links between inflation, output growth and their uncertainties for some developing countries. Important groups of countries in the developing economies like the BRICS group would be an interesting group for such a study. Lack of availability of time series data on inflation and output growth for a moderately long period of time may impede carrying out similar studies with poor developing countries. Yet, it should be useful to do so for countries where such data are available.

Unobserved regime switching model

In our thesis we have used the regime switching approach to study the relationship between macroeconomic performance and uncertainty where the regimes have been assumed to be observed and based on the past levels of inflation and output growth. It would be interesting as well as useful to study this relationship in a framework where the regimes cannot actually be observed but these are determined by an underlying unobservable stochastic process. Thus, in this approach, the regime that occurs at a particular time point cannot be observed; instead probabilities can be assigned to the occurrence of the different regimes. Very few studies (see, for instance, Kim (1993), Bhar and Hamori (2004), and Chang and He (2010)) have examined the relationship between inflation and inflation uncertainty by applying a Markov regime switching heteroskedasticity model. But, to the best of our knowledge, there is no study where an unobserved regime switching model has been applied to study such a relationship where in addition to inflation and inflation uncertainty, output growth and its uncertainty have also been included. Hence, it should be an exciting empirical research problem to work with since it would not only extend the horizon of such studies, but it would also be possible to find which of the two approaches – regimes determined by observed and unobserved variables – is capable of bringing out the true but unknown nature of the relationship more appropriately.

Impulse response function

The growing popularity of the class of multivariate GARCH models and their applications for study of inflation, output growth and their volatilities makes it imperative to study the dynamic responses of inflation and output growth following shocks. Grier et al. (2004) have used a generalized impulse response function to analyze the time profile of the effects of shocks on the future behaviour of output growth rate and inflation. It should be instructive to extend such works by taking into account the complex interactions between the levels and the volatilities.

References

Abel, A. B. (1983). Optimal investment under uncertainty. *The American Economic Review , 73* (1), 228-233.

Ahmed, S., Levin, A., & Wilson, B. A. (2004). Recent US macroeconomic stability: good policies, good practices, or good luck? *Review of economics and Statistics, 86 (3)* , 824-832.

Aizenman, J., & Pinto, B. (Eds.). (2005). *Managing Economic Volatility and Crises: A Practitioner's Guide.* Cambridge University Press.

Anderson, H. M., Nam, K., & Vahid, F. (1999). Asymmetric nonlinear smooth transition GARCH models. *Nonlinear time series analysis of economic and financial data , 1*, 191-207.

Apergis, N. (2004). Inflation, output growth, volatility and causality: evidence from panel data and the G7 countries. *Economics Letters, 83(2)*, 185-191.

Arghyrou, M., Martin, C., & Milas, C. (2005). Non-linear inflationary dynamics: evidence from the UK. *Oxford Economic Papers , 57* (1), 51-69.

Azariadis, C., & Smith, B. D. (1996). Private information, money, and growth: Indeterminacy, fluctuations, and the Mundell-Tobin effect. *Journal of Economic Growth , 1* (3), 309-332.

Baba, Y., Engle, R. F., Kraft, D., & Kroner, K. F. (1989). Multivariate simultaneous generalized ARCH. *UCSD, Department of Economics* .

Bai, J., & Perron, P. (2003). Computation and analysis of multiple structural change models. *Journal of Applied Econometrics, 18(1)* , 1-22.

Bai, J., & Perron, P. (1998). Estimating and testing linear models with multiple structural changes. *Econometrica, 66(1)* , 47-78.

Bai, J., Lumsdaine, R. L., & Stock, J. H. (1998). Testing for dating common breaks in multivariate time series. *The Review of Economic Studies, 65(3)* , 395-432.

Baillie, R. T., Chung, C. F., & Tieslau, M. A. (1996). Analysing inflation by the fractionally integrated ARFIMA-GARCH model. *Journal of applied Econometrics , 11* (1), 23-40.

Baillie, R. T., Wook, Y. H., & Kwon, T. G. (2002). Further long memory properties of inflationary shocks. *Southern Economic Journal , 68* (3), 496-510.

Balcilar, M., Ozdemir, Z. A., & Cakan, E. (2011). On the nonlinear causality between inflation and inflation uncertainty in the G3 countries. *Journal of Applied Economics 14(2)* , 269-296.

Ball, L. (1992). Why does high inflation raise inflation uncertainty? *Journal of Monetary Economics , 29* (3), 371-388.

Ball, L., & Cecchetti, S. (1990). Inflation uncertainty at short and long horizons. *Brooking Papers on Economic Activity 21(1)* , 215-254.

Ball, L., Mankiw, N. G., Romer, D., Akerlof, G. A., Rose, A., Yellen, J., et al. (1988). The new Keynesian economics and the output-inflation trade-off. *Brookings papers on economic activity* , 1-82.

Barro, ,. R. (1997). *Determinants of Economic Growth: A Cross-Country Empirical Study*. Cambridge, MA: MIT Press.

Barro, R. J., & Gordon, D. B. (1983). Rules, discretion and reputation in a model of monetary policy. *Journal of monetary economics , 12* (1), 101-121.

Batini, N. (2006). Euro area inflation persistence. *Empirical Economics , 31* (4), 977-1002.

Bauwens, L., Laurent, S., & Rombouts, J. V. (2006). Multivariate GARCH models: a survey. *Journal of applied econometrics , 21* (1), 79-109.

Beaumont, P. M., Norrbin, S. C., & Yigit, F. P. (2008). Time series evidence on the linkage between the volatility and growth of output. *Applied Economics Letters , 15* (1), 45-48.

Beechey, M., & Österholm, P. (2009). Time-varying inflation persistence in the Euro area. *Economic Modelling , 26* (2), 532-535.

Benati, L. (2002). Investigating Inflation Persistence Across Monetary Regimes. *Manuscript, Bank of England* .

Benati, L. (2006). UK monetary regimes and macroeconomic stylised facts. *Bank of England, Working Paper no. 290* .

Bernanke, B. S. (2009). Financial reform to address systemetic risk. *Speech at the Council on Foreign Relations, Washington, D.C. (March 10)* .

Bernanke, B. S. (1983). Nonmonetary Effects of the Financial Crisis in the Propagation of the Great Depression. *American Economic Review , 73*, 257-276.

Bernanke, B. S. (2005). Remarks by Governor Ben S. Bernanke: the global saving glut and the U.S. current account deficit. *The Sandridge Lecture, Virginia Association of Economists, Richmond, VA (March 10)* .

Bernanke, B. S. (2004, February). The great moderation. *20* . Washington, DC: The Federal Reserve Board.

Berument, H., & Dincer, N. (2005). Inflation and inflation uncertainty in the G-7 countries. *Physica A: Statistical Mechanics and its Applications 348(C)* , 371-379.

Bhar, R., & Hamori, S. (2003). Alternative characterization of the volatility in the growth rate of real GDP. *Japan and the World Economy , 15* (2), 223-231.

Bhar, R., & Hamori, S. (2004). The link between inflation and inflation uncertainty: evidence from G7 countries. *Empirical Economics , 29* (4), 825-853.

Bhar, R., & Mallik, G. (2010). Inflation, inflation uncertainty and output growth in the USA. *Physica A: Statistical Mechanics and its Applications , 389* (23), 5503-5510.

Black, F. (1987). *Business Cycles and Equilibrium.* New York: Basil Blackwell.

Blackburn, K. (1999). Can stabilisation policy reduce long-run growth? *The Economic Journal, 109(452)* , 67-77.

Blackburn, K., & Pelloni, A. (2005). Growth, cycles, and stabilization policy. *Oxford Economic Papers, 57(2)* , 262-282.

Blackburn, K., & Pelloni, A. (2004). On the relationship between growth and volatility. *Economics Letters , 83* (1), 123-127.

Blanchard, O., & Simon, J. (2001). The long and large decline in US output volatility. *Brookings papers on economic activity , 2001* (1), 135-174.

Blinder, A. S. (1982). The anatomy of double-digit inflation in the 1970s. In *NBER Chapters, in: Inflation: Causes and Effects* (pp. 261-382). National Bureau of Economic Research.

Bollerslev, T. (1986). Generalized autoregressive conditional heteroskedasticity. *Journal of econometrics , 31* (3), 307-327.

Bollerslev, T. (1990). Modelling the coherence in short-run nominal exchange rates: a multivariate generalized ARCH model. *The Review of Economics and Statistics , 72* (3), 498-505.

Bollerslev, T., Engle, R. F., & Wooldridge, J. M. (1988). A capital asset pricing model with time-varying covariances. *The Journal of Political Economy, 96(1)* , 116-131.

Bollerslev, T., & Wooldridge, J. M. (1992). Quasi-maximum likelihood estimation and inference in dynamic models with time-varying covariances. *Econometric Reviews, 11(2),* 143-172.

Box, G. E., & Cox, D. R. (1964). An analysis of transformations. *Journal of the Royal Statistical Society. Series B (Methodological) , 26* (2), 211-252.

Brailsford, T. J., & Faff, R. W. (1996). An evaluation of volatility forecasting techniques. *Journal of Banking & Finance, 20(3)* , 419-438.

Brainard, W. C., & Perry, G. L. (2000). Making Policy in a Changing World. In J. Tobin, & G. Perry (Eds.), *Economic Events, Ideas, and Policies: The 1960s and After*. The Brookings Institution.

Braun, S. (1984). Productivity and the NIIRU (and Other Phillips Curve Issues). *Board of Governors of the Federal Reserve System, Working Paper 34* .

Bredin, D., & Fountas, S. (2005). Macroeconomic uncertainty and macroeconomic performance: Are they related? *The Manchester School , 73* (s1), 58-76.

Bredin, D., Elder, J., & Fountas, S. (2009). Macroeconomic uncertainty and performance in Asian countries. *Review of Development Economics, 13(2)* , 215-229.

Bredin, D., Elder, J., & Fountas, S. (2009). Macroeconomic Uncertainty and Performance in Asian Countries. *Review of Development Economics , 13* (2), 215-229.

Briault, C. (1995). The costs of inflation. *Bank of England Quarterly Bulletin , 35* (1), 33-45.

Brooks, C. (2001). A double-threshold GARCH model for the French/Deutschmark exchange rate. *Journal of Forecasting, 20(2)* , 135-143.

Brunner, A. D. (1993). Comment on inflation regimes and the sources of inflation uncertainty. *Journal of Money, Credit, and Banking , 25* (3), 512–514.

Brunner, A. D., & Hess, G. D. (1993). Are higher levels of inflation less predictable? A state-dependent conditional heteroscedasticity approach. *Journal of Business & Economic Statistics , 11* (2), 187-197.

Bruno, M., & Easterly, W. (1996). Inflation crises and long-run growth. *Journal of Monetary Economics , 41* (1), 3-26.

Burdekin, R. C., & Siklos, P. L. (1999). Exchange rate regimes and shifts in inflation persistence: does nothing else matter? *Journal of Money, Credit, and Banking , 31* (2), 235-247.

Burdekin, R. C., Denzau, A. T., Keil, M. W., Sitthiyot, T., & Willett, T. D. (2004). When does inflation hurt economic growth? Different nonlinearities for different economies. *Journal of Macroeconomics , 26* (3), 519-532.

Burren, D., & Neusser, K. (2010). The decline in volatility of US GDP growth. *Applied Economics Letters , 17* (16), 1625-1631.

Caballero, R., Farhi, E., & Gourinchas, P.-O. (2008). Financial crash, commodity prices, and global imbalances. *Brooking Papers on Economic Activity* , 1-55.

Caglayan, M., & Filiztekin, A. (2003). Nonlinear impact of inflation on relative price variability. *Economics Letters , 79* (2), 213-218.

Camarero, M., Esteve, V., & Tamarit, C. (2000). Price convergence of peripheral European countries on the way to the EMU: A time series approach. *Empirical Economics , 25* (1), 149-168.

Cao, C. Q., & Tsay, R. S. (1992). Nonlinear time-series analysis of stock volatilities. *Journal of Applied Econometrics, 7(S1)* , S165-S185.

Caporale, G. M., & Kontonikas, A. (2009). The Euro and inflation uncertainty in the European Monetary Union. *Journal of International Money and Finance, 28(6)* , 954-971.

Caporale, T., & McKiernan, B. (1997). High and variable inflation: further evidence on the Friedman hypothesis. *Economics Letters , 54* (1), 65-68.

Caporale, T., & McKiernan, B. (1998). The Fischer Black hypothesis: some time-series evidence. *Southern Economic Journal , 64* (3), 765-771.

Caporale, T., & McKiernan, B. (1996). The relationship between output variability and growth: evidence from post war UK data. *Scottish Journal of Political Economy , 43* (2), 229-236.

Cecchetti, S. G., & Ehrmann, M. (1999). Does inflation targeting increase output volatility? An international comparison of policymakers' preferences and outcomes. *National bureau of economic research , No. w7426.*

Cecchetti, S. G., & Krause, S. (2001). Financial structure, macroeconomic stability and monetary policy. *Working Paper 8354, NBER* .

Chan, K. S., & Tong, H. (1986). On estimating thresholds in autoregressive models. *Journal of time series analysis , 7* (3), 179-190.

Chan, K. S., & Tong, H. (1985). On the use of the deterministic Lyapunov function for the ergodicity of stochastic difference equations. *Advances in Applied Probability, 17(3)* , 666-678.

Chan, K. S., Petruccelli, J. D., Tong, H., & Woolford, S. W. (1985). A multiple-threshold AR(1) model. *Journal of Applied Probability, 22(2)* , 267-279.

Chang, K. L. (2012). The impacts of regime-switching structures and fat-tailed characteristics on the relationship between inflation and inflation uncertainty. *Journal of Macroeconomics, 34 (2)* , 523-536.

Chang, K. -L., & He, C. -W. (2010). Does the magnitude of the effect of inflation uncertainty on output growth depend on the level of inflation? *Manchester School 78(2)* , 126-148.

Chatterjee, P., & Shukayev, M. (2006). *Are Average Growth Rate and Volatility Related?* Ottawa, Ontario: Bank of Canada.

Chen, C. W. (1998). A Bayesian analysis of generalized threshold autoregressive models. *Statistics & probability letters, 40 (1)* , 15-22.

Chen, C. W., & So, M. K. (2006). On a threshold heteroscedastic model. *International Journal of Forecasting, 22(1)* , 73-89.

Chen, C. W., Chiang, T. C., & So, M. K. (2003). Asymmetrical reaction to US stock-return news: evidence from major stock markets based on a double-threshold model. *Journal of Economics and Business, 55(5)* , 487-502.

Chen, C. W., Yang, M. J., Gerlach, R., & Jim Lo, H. (2006). The asymmetric ractions of mean and volatility of stock returns to domestic and international information based on a four-regime double-threshold GARCH model. *Physica A: Statistical Mechanics and its Applications, 366* , 401-418.

Chen, S. W., Shen, C. H., & Xie, Z. (2008). Evidence of a nonlinear relationship between inflation and inflation uncertainty: The case of the four little dragons. *Journal of Policy Modeling , 30* (2), 363-376.

Chew, L. C., Kim, D., & Suardi, S. (2011). Are empirical measures of macroeconomic uncertainty alike? *Journal of Economic Surveys, 25(4),* 801-827.

Christiano, L. J., Eichenbaum, M., & Evans, C. (2001). Nominal rigidities and the dynamic effects of a shock to monetary policy. *NBER Workin Papers 8403* .

Christoffersen, P., & Doyle, P. (2000). From inflation to growth. *Economics of Transition , 8* (2), 421-451.

Clarida, R., Gali, J., & Gertler, M. (2000). Monetary policy rules and macroeconomic stability: evidence and some theory . *Quarterly Journal of Economics, 115 (1)* , 147-180.

Clarida, R., Gali, J., & Gertler, M. (1999). The science of monetary policy: a new Keynesian perspective. *National bureau of economic research , No. w7147.*

Clark, T. E. (1997). CROSS-COUNTRY EVIDENCE ON LONG-RUN GROWTH AND INFLATION. *Economic Inquiry , 35* (1), 70-81.

Clark, T. E. (2006). Disaggregate evidence on the persistence of consumer price inflation. *Journal of Applied Econometrics 21(5)* , 563-587.

Cogley, T., & Sargent, T. J. (2001). Evolving post-world war II US inflation dynamics. In *NBER Macroeconomics Annual* (Vol. 16, pp. 331-388). MIT Press.

Cogley, T., & Sargent, T. (2005). The conquest of US inflation: Leaning and robustness to model uncertainty. *Review of Economic Dynamics, 8 (2)* , 528-563.

Conrad, C., & Karanasos, M. (2010). Negative volatility spillovers in the unrestricted ECCC-GARCH model. *Econometric Theory , 26* (3), 838-862.

Conrad, C., & Karanasos, M. (2005). On the inflation-uncertainty hypothesis in the USA, Japan and the UK: a dual long memory approach. *Japan and the World Economy , 17* (3), 327-343.

Cooper, R. N. (2007). Living with global imbalances. *Brookings Papers on Economic Activity, 2* , 91-107.

Cosimano, T. F., & Jansen, D. W. (1988). Estimates of the variance of US inflation based upon the ARCH model: comment. *Journal of Money, Credit and Banking , 20* (3), 409-421.

Crowder, W. J., & Hoffman, D. L. (1996). The long-run relationship between nominal interest rates and inflation: the Fisher equation revisited. *Journal of Money, Credit and Banking , 28* (1), 102-118.

Cukierman, A. (1992). *Central bank strategy, credibility, and independence: Theory and evidence.* MIT press.

Cukierman, A., & Gerlach, S. (2003). The inflation bias revisited: Theory and some international evidence. *The Manchester School , 71* (5), 541-565.

Cukierman, A., & Meltzer, A. H. (1986). A theory of ambiguity, credibility, and inflation under discretion and asymmetric information. *Econometrica* , 1099-1128.

Daal, E., Naka, A., & Sanchez, B. (2005). Re-examining inflation and inflation uncertainty in developed and emerging countries. *Economics letters , 89* (2), 180-186.

Davis, G. K., & Kanago, B. E. (2000). The level and uncertainty of inflation: results from OECD forecasts. *Economic Inquiry , 38* (1), 58-72.

Dawson, J. W., & Stephenson, E. F. (1997). The link between volatility and growth: Evidence from the States. *Economics Letters , 55* (3), 365-369.

Dawson, J. W., DeJuan, J. P., Seater, J. J., & Stephenson, E. F. (2001). Economic information versus quality variation in cross-country data. *Canadian Journal of Economics , 34* (4), 988-1009.

de Hek, P. A. (1999). On endogenous growth under uncertainty. *International Economic Review , 40* (3), 727-744.

DeLong, J. B. (1997). America's peacement inflation. In C. D. Romer, & D. H. Romer, *In Reducing Inflation: Motivation and Strategy* (pp. 247-280). University of Chicago Press.

Demetriades, P. (1988). Macroeconomic aspects of the correlation between the level and variability of inflation. *Economics Letters , 26* (2), 121-124.

Devereux, M. (1989). A positive theory of inflation and inflation variance. *Economic Inquiry , 27* (1), 105-116.

Dijk, D. V., Terasvirta, T., & Franses, P. H. (2002). Smooth transition autoregressive models - a survey of recent developments . *Econometric Reviews, 21(1)* , 1-47.

Dotsey, M., & Sarte, P. D. (2000). Inflation uncertainty and growth in a cash-in-advance economy. *Journal of Monetary Economics , 45* (3), 631-655.

Doyle, B. M., & Faust, J. (2005). Breaks in the variability and comovement of G7 economic growth. *The Review o Economics and Statistics, 87(4)* , 721-740.

Elder, J. (2004). Another perspective on the effects of inflation uncertainty. *Journal of Money, Credit and Banking , 36* (5), 911-928.

Engle, R. F. (1982). Autoregressive conditional heteroscedasticity with estimates of the variance of United Kingdom inflation. *Econometrica , 50*, 987-1007.

Engle, R. F. (1983). Estimates of the Variance of US Inflation Based upon the ARCH Model. *Journal of Money, Credit and Banking , 15* (3), 286-301.

Engle, R. F., & Kroner, K. F. (1995). Multivariate simultaneous generalized ARCH. *Econometric Theory, 11(01)* , 122-150.

Esanov, A., Merkl, C., & Vinhas de Souza, L. (2005). Monetary policy rules for Russia. *Journal of Comparative Economics 33(3)* , 484-499.

Evans, M. (1991). Discovering the link between inflation rates and inflation uncertainty. *Journal of Money, Credit and Banking 23(2)* , 169-184.

Evans, M., & Wachtel, P. (1993). Inflation regimes and the sources of inflation uncertainty. *Journal of Money, Credit and Banking , 25* (3), 475-511.

Fang, W. S., & Miller, S. M. (2008). he great moderation and the relationship between output growth and its volatility. *Southern Economic Journal , 74* (3), 819-838.

Fischer, S. (1993). The role of macroeconomic factors in growth. *Journal of monetary economics , 32* (3), 485-512.

Fornari, F., & Mele, A. (1996). Modeling the changing asymmetry of conditional variances. *Economics Letters , 50* (2), 197-203.

Fornari, F., & Mele, A. (1997). Weak convergence and distributional assumptions for a general class of nonliner arch models. *Econometric Reviews , 16* (2), 205-227.

Fountas, S. (2001). The relationship between inflation and inflation uncertainty in the UK: 1885–1998. *Economics Letters , 74* (1), 77-83.

Fountas, S., & Karanasos, M. (2007). Inflation, output growth, and nominal and real uncertainty: empirical evidence for the G7. *Journal of International Money and finance , 26* (2), 229-250.

Fountas, S., & Karanasos, M. (2006). The relationship between economic growth and real uncertainty in the G3. *Economic Modelling , 23* (4), 638-647.

Fountas, S., Ioannidis, A., & Karanasos, M. (2004). Inflation, inflation uncertainty, and a common European monetary policy. *The Manchester School , 72* (2), 221e242.

Fountas, S., Karanasos, M., & Karanassou, M. (2000). *A GARCH model of inflation and inflation uncertainty with simultaneous feedback.* Queen Mary and Westfield College, Department of Economics.

Fountas, S., Karanasos, M., & Kim, J. (2002). Inflation and output growth uncertainty and their relationship with inflation and output growth. *Economics Letters, 75 (3)* , 293-301.

Fountas, S., Karanasos, M., & Kim, J. (2006). Inflation uncertainty, output growth uncertainty and macroeconomic performance. *Oxford Bulletin of Economics and Statistics , 68* (3), 319-343.

Friedman, M. (1977). Nobel lecture: inflation and unemployment. *The Journal of Political Economy* , 451-472.

Friedman, M. (1968). The Role of Monetary Policy. *American Economic Review , 58*, 1-17.

Fuhrer, J. C. (1997). The (un)importance of forward-looking behavior in price specifications. *Journal of Money, Credit and Banking 29(3)* , 338-350.

Fuhrer, J., & Moore, G. (1995). Inflation persistence. *Quarterly Journal of Economics 110(1)* , 127-159.

Garcia, R., & Perron, P. (1996). An analysis of the real interest rate under regime shifts. *The Review of Economics and Statistics , 78* (1), 111-125.

García-Herrero, A., & Vilarrubia, J. (2007). The Laffer curve of macroeconomic volatility and growth: can it be explained by the different nature of crises? *MONEY , 44*.

Ghosh, A., & Phillips, S. (1998). Warning: inflation may be harmful to your growth. *Staff Papers-International Monetary Fund , 45* (4), 672-710.

Gillman, M., & Kejak, M. (2005). Contrasting models of the effect of inflation on growth. *Journal of Economic Surveys , 19* (1), 113-136.

Glosten, L. R., Jagannathan, R., & Runkle, D. E. (1993). On the relation between the expected value and the volatility of the nominal excess return on stocks. *The journal of finance , 48* (5), 1779-1801.

Golob, J. E. (1993). Inflation, inflation uncertainty, and relative price variability: a survey. *Federal Reserve Bank of Kansas City , Working paper* (No. 93-15).

Gomez-Loscos, A., Gadea, M. D., & Montanes, A. (2012). Economic growth, inflation and oil shocks: are the 1970s coming back? *Applied Economics, 44(35)* , 4575-4589.

Gomme, P. (1993). Money and growth revisited: Measuring the costs of inflation in an endogenous growth model. *Journal of Monetary economics , 32* (1), 51-77.

Gonzalez, M., & Gonzalo, J. (1997). *Threshold unit root models.* Working Paper, U. Carlos III de Madrid.

González-Rivera, G. (1998). Smooth-transition GARCH models. *Studies in Nonlinear Dynamics & Econometrics , 3* (2).

Goodriend, M., & King, R. (2009). The great inflation drift. *NBER Working Paper Series. N. 14862* .

Gordon, R. J. (1971). Steady anticipated inflation: Mirage or oasis? *Brookings Papers on Economic Activity , 1971* (2), 499-510.

Gordon, R. J., Brainard, W., & Juster, T. (1971). Inflation in recession and recovery. *Brookings Papers on Economic Activity , 1971* (1), 105-166.

Granger, C. W., & Terasvirta, T. (1993). Modelling non-linear economic relationships. *OUP Catalogue* .

Grier, K. B., & Perry, M. J. (1998). On inflation and inflation uncertainty in the G7 countries. *Journal of International Money and Finance , 17* (4), 671-689.

Grier, K. B., & Perry, M. J. (2000). The effects of real and nominal uncertainty on inflation and output growth: some GARCH-M evidence. *Journal of Applied Econometrics , 15* (1), 45-58.

Grier, K. B., & Tullock, G. (1989). An empirical analysis of cross-national economic growth, 1951–1980. *Journal of Monetary economics , 24* (2), 259-276.

Grier, K. B., Henry, Ó. T., Olekalns, N., & Shields, K. (2004). The asymmetric effects of uncertainty on inflation and output growth. *Journal of Applied Econometrics , 19* (5), 551-565.

Grier, K., & Ye, H. (2009). Twin sons of different mothers: the long and the short of the twin deficits debate. *Economic Inquiry , 47* (4), 625-638.

Grier, R., & Grier, K. B. (2006). On the real effects of inflation and inflation uncertainty in Mexico. *Journal of Development Economics , 80* (2), 478-500.

Hagerud, G. E. (1997). *A smooth transition ARCH model for asset returns.* Stockholm School of Economics, the Economic Research Inst.

Hamilton, B. W. (2001). Black–White Differences in Inflation: 1974–1991. *Journal of Urban Economics , 50* (1), 77-96.

Hamilton, J. D. (1989). A new approach to the economic analysis of nonstationary time series and the business cycle. *Econometrica , 57* (2), 357-384.

Hamilton, J. D. (2010). Macroeconomics and ARCH. In T. Bollerslev, J. R. Russell, & M. Watson, *Festschrift in Honor of Robert F. Engle* (pp. 79-96). Oxford University Press.

Hamilton, J. D. (1988). Rational-expectations econometric analysis of changes in regime: An investigation of the term structure of interest rates. *Journal of Economic Dynamics and Control , 12* (2), 385-423.

Hamilton, J. D., & Susmel, R. (1994). Autoregressive conditional heteroskedasticity and changes in regime. *Journal of Econometrics , 64* (1), 307-333.

Hamori, S. (2000). Volatility of real GDP: some evidence from the United States, the United Kingdom and Japan. *Japan and the World Economy , 12* (2), 143-152.

Hansen, P. R. (2003). Structural changes in the cointegrated vector autoregressive model. *Journal of Econometrics, 114(2)* , 261-295.

Haslag, J. H. (1997). Output, growth, welfare, and inflation: A survey. *Economic Review-Federal Reserve Bank of Dallas* , 11-21.

Henry, O. T., & Olekalns, N. (2002). The effect of recessions on the relationship between output variability and growth. *Southern Economic Journal , 68* (3), 683-692.

Henry, O. T., & Shields, K. (2004). Is there a unit root in inflation? *Journal of Macroeconomics, 26(3)* , 481-500.

Hentschel, L. (1995). All in the family nesting symmetric and asymmetric garch models. *Journal of Financial Economics , 39* (1), 71-104.

Hetzel, R. L. (1998). Arthur Burns and inflation. *FRB of Richmond Economic Quarterly* , 21-44.

Heynen, R. C., & Kat, H. M. (1994). Volatility prediction: a comparison of the stochastic volatility, Garch(1,1) and Egarch (1,1) models. *The Journal of Derivatives, 2(2)* , 50-65.

Hnatkovska, V. V., & Loayza, N. (2004). Volatility and growth. *World Bank Policy Research Working Paper 3184* .

Holland, A. S. (1995). Inflation and uncertainty: tests for temporal ordering. *Journal of Money, Credit and Banking* , 827-837.

Holland, A. S. (1993). Uncertain Effects of Money and the Link between the Inflation Rate and Inflation Uncertainy. *Economic Inquiry , 31* (1), 39-51.

Huizinga, J. (1993). Inflation uncertainty, relative price uncertainty, and investment in US manufacturing. *Journal of Money, Credit and Banking , 25* (3), 521-549.

Hwang, Y. (2001). Relationship between inflation rate and inflation uncertainty. *Economics Letters , 73* (2), 179-186.

Ireland, P. N. (1994). Money and growth: an alternative approach. *The American Economic Review , 84* (1), 47-65.

Jiranyakul, K. (2011). The Link between Output Growth and Output Volatility in Five Crisis-Affected Asian Countries. *Middle Eastern Finance and Economics , 12*, 101-108.

Johnson, H. G. (1967). *Essays in Monetary Economi.* Cambridge, Mass: Harvard University Pres.

Jones, L. E., & Manuelli, R. E. (1995). Growth and the effects of inflation. *Journal of Economic Dynamics and Control , 19* (8), 1405-1428.

Jones, L. E., Manuelli, R. E., Siu, H. E., & Stacchetti, E. (2005). Fluctuations in convex models of endogenous growth, I: Growth effects. *Review of Economic Dynamics , 8* (4), 780-804.

Joyce, M. (1995). Modelling UK inflation uncertainty: the impact of news and the relationship with inflation. *Bank of England , Working Paper 30* .

Judson, R., & Orphanides, A. (1999). Inflation, volatility and growth. *International Finance , 2* (1), 117-138.

Karanasos, M., & Kim, J. (2005). The inflation-output variability relationship in the G3: a bivariate GARCH (BEKK) approach. *Risk Letters, 1(2)* , 17-22.

Karanasos, M., Karanassou, M., & Fountas, S. (2004). Analyzing US inflation by a GARCH model with simultaneous feedback. *WSEAS Transactions on Information Science and Applications , 1* (2), 767-772.

Kent, C., Smith, K., & Holloway, J. (2005). Declining output volatility: what role for structural change? *Reserve Bank of Australia* .

Keynes, J. M. (1973). *1936. The General Theory of Employment, Interest and Money.* London: Macmillan.

Khan, M. S., & Senhadji, A. (2002). Inflation, financial deepening, and economic growth. *Banco de Mexico Conference on Macroeconomic Stability, Financial Markets and Economic Development*, (pp. 12-13). Mexico City.

Khan, M. S., & Ssnhadji, A. S. (2001). Threshold effects in the relationship between inflation and growth. *IMF Staff papers* , 1-21.

Kim, C. J. (1993). Unobserved-component time series models with Markov-switching heteroscedasticity: Changes in regime and the link between inflation rates and inflation uncertainty. *Journal of Business & Economic Statistics , 11* (3), 341-349.

Kim, C. J., & Nelson, C. R. (1999). Has the US economy become more stable? A Bayesian approach based on a Markov-switching model of the business cycle. *Review of Economics and Statistics , 81* (4), 608-616.

Kim, C. J., Nelson, C. R., & Piger, J. (2004). The less-volatile US economy: a Bayesian investigation of timing, breadth, and political explanations. *Journal of Business & Economic Statistics, 22(1)* , 80-93.

Kim, D., & Perron, P. (2009). Unit root tests allowing for a break in the trend function at an unknown time under both the null and alternative hypotheses. *Journal of Econometrics , 148* (1), 1-13.

Kim, S., Shephard, N., & Chib, S. (1998). Stochastic volatility: likelihood inference and comparison with ARCH models. *The Review of Economic Studies , 65* (3), 361-393.

Klump, R. (2003). Inflation, factor substitution and growth. *European Central Bank, Working Paper No. 280 .*

Kneller, R., & Young, G. (2001). Business Cycle Volatility, Uncertainty and Long-run Growth. *The Manchester School , 69* (5), 534-552.

Kontonikas, A. (2004). Inflation and inflation uncertainty in the United Kingdom, evidence from GARCH modelling. *Economic modelling , 21* (3), 525-543.

Kormendi, R. C., & Meguire, P. G. (1985). Macroeconomic determinants of growth: cross-country evidence. *Journal of Monetary economics , 16* (2), 141-163.

Kose, M. A., Prasad, E. S., & Terrones, M. E. (2006). How do trade and financial integration affect the relationship between growth and volatility? *Journal of international Economics , 69* (1), 176-202.

Koutmos, G., & Booth, G. G. (1995). Asymmetric volatility transission in international stock markets. *Journal of International Money and Finance, 14(6)*, 747-762.

Krause, S. (2003). Measuring monetary policy efficiency in European Union countries. *Department of Economics, Emory University, Working Paper No. 03-11* .

Kroft, K., & Lloyd-Ellis, H. (2002). Further cross-country evidence on the link between growth, volatility and business cycles. *Queens University, Department of Economic, Working Paper* .

Kumar, M. S., & Okimoto, T. (2007). Dynamics of persistence in international inflation rates. *Journal of Money, Credit and Banking , 39* (6), 1457-1479.

Kydland, F. E., & Prescott., E. C. (1982). Time to build and aggregate fluctuations. *Econometrica , 50* (6), 1345-1370.

Lanne, M. (2006). Nonlinear dynamics of interest rate and inflation. *Journal of Applied Econometrics , 21* (8), 1157-1168.

Lansing, K. J. (2000). Learning about a shift in trend output: Implications for monetary policy and inflation. *Unpublished manuscript. FRB San Francisco, <http://www.sf.frb.org/economic-research/workingp/2000/wpkl00-04.pdf>* .

Lee, J., & Nelson, C. R. (2007). Expectation horizon and the Phillips curve: the solution to an empirical puzzle. *Journal of Applied Econometrics 22(1)* , 161-178.

Levin, A. T., & Piger, J. (2003). s inflation persistence intrinsic in industrial economies? *Federal Reserve Bank of St. Louis Working Paper 2002-023E* .

Li, C. W., & Li, W. K. (1996). On a double-threshold autoregressive heteroscedastic time series model. *Journal of Applied Econometrics, 11 (3)* , 253-274.

Logue, D. E., & Sweeney, R. J. (1981). Inflation and real growth: Some empirical results: Note. *Journal of Money, Credit and Banking , 13* (4), 497-501.

Logue, D. E., & Willett, T. D. (1976). A Note on the Relation between the Rate and Variability of Inflation. *Economica , 43* (170), 151-158.

López-Villavicencio, A., & Mignon, V. (2011). On the impact of inflation on output growth: Does the level of inflation matter? *Journal of Macroeconomics , 33* (3), 455-464.

Luukkonen, R., Saikkonen, P., & Terasvirta, T. (1988). Testing linearity against smooth transition autoregressive models. *Biometrica 75(3)* , 491-499.

Martin, C., & Milas, C. (2004). Modelling monetary policy: inflation targeting in practice. *Economica, 71(282)* , 209-221.

Martin, P., & Rogers, C. A. (2000). Long-term growth and short-term economic instability. *European Economic Review , 44* (2), 359-381.

McConnell, M. M., & Perez-Quiros, G. (2000). Output fluctuations in the United States: What has changed since the early 1980's? *American Economic Review , 90* (5), 1464-1476.

Meltzer, A. H. (2005). Origins of the great inflation. *Federal Reserve Bank of St. Louis Review, 87 (2) (March/April 2005)* , 145-175.

Mendoza, E. G., Quadrini, V., & Rios-Rull, J. V. (2007). Financial integration, financial deepness and global imbalances. *National Bureau of Economic Research, (No. w12909)* .

Mills, T. C., & Wang, P. (2003). Have output growth rates stabilised? evidence from the g-7 economies. *Scottish Journal of Political Economy , 50* (3), 232-246.

Mirman, L. (1971). Uncertainty and optimal consumption decisions. *Econometrica , 39* (1), 179-185.

Murray, C., Nikolsko-Rzhevskyy, A., & Papell, D. (2009). Inflation persistence and the Taylor principle. *University of Houston, Working Paper* .

Nason, J. M., & Smith, G. W. (2008). Identifying the new Keynesan Phillips curve. *Journal of Applied Econometrics 23(5)* , 525-551.

Neanidis, K. C., & Savva, C. S. (2013). Macroeconomic uncertainty, inflation and growth: Regime-dependent effects in the G7. *Journal of Macroeconomics 35(C)* , 81-92.

Neiss, K., & Nelson, E. (2002). Infltion dynamics, marginal cost, and the output gap: evidence from three countries. *Proceedings, Federal Reserve Bank of San Francisco, issue Mar.*

Nelson, C. R., & Plosser, C. R. (1982). Trends and random walks in macroeconmic time series: some evidence and implications. *Journal of monetary economics , 10* (2), 139-162.

Nelson, C. R., Piger, J., & Zivot, E. (2001). Markov regime switching and unit-root tests. *Journal of Business & Economic Statistics , 19* (4), 404-415.

Nelson, D. B. (1991). Conditional heteroskedasticity in asset returns: A new approach. *Econometrica , 59,* 347-370.

Nelson, E. (2005). The great inflation of the seventies: what really happened? *The B.E. Journal of Macroeconomics, 5(1)* , 1-50.

Obstfeld, M., & Rogoff, K. S. (2009). Global imbalances and the financial crisis: products of common causes. *London: Centre for Economic Political Research* .

Okun, A. M. (1971). The mirage of steady inflation. *Brookings Papers on Economic Activity* , 485-498.

Omay, T., & Hasanov, M. (2010). The effects of inflation uncertainty on interest rates: a nonlinear approach. *Applied Economics* , *42* (23), 2941-2955.

O'Reilly, G., & Whelan, K. (2005). Has euro-area inflation persistence changed over time? *Review of Economics and Statistics* , *87* (4), 709-720.

Orphanides, A. (2003). The quest for prosperity without inflation. *Journal of Monetary Economics, 50 (3)* , 633-663.

Ozdemir, Z. A. (2010). Dynamics of inflation, output growth and their uncetainty in the UK: An empirical analysis. *The Manchester School 78(6)* , 511-537.

Pagan, A. R., & Schwert, G. W. (1990). Alternative models for conditional stock volatility. *Journal of Econometrics, 45(1)*, 267-290.

Peersman, G. (2005). What caused the early millennium slowdown? Evidence based on vector autoregressions. *Journal of Applied Econometrics, 20(2)* , 185-207.

Perron, P. (2006). Dealing with structural breaks. *Palgrave Handbook of Econometrics, 1* , 278-352.

Perron, P. (1997). Further evidence on breaking trend functions in macroeconomic variables. *Journal of Econometrics* , *80* (2), 355-385.

Perron, P. (1990). Testing for a unit root in a time series with a changing mean. *Journal of Business & Economic Statistics 8(2)* , 153-162.

Perron, P. (1990). Testing for a unit root in a time series with changing mean. *Journal of Business & Economic Statistics, 8 (2)* , 153-162.

Perron, P. (1989). The great crash, the oil price shock, and the unit root hypothesis. *Econometrica* , *57* (6), 1361-1401.

Perron, P., & Vogelsang, T. J. (1993). The great crash, the oil price shock and the unit root hypothesis: Erratum. *Econometrica* , *61* (1), 248-249.

Perron, P., & Yabu, T. (2009). Testing for shift in trend with and integrated or stationary noise component. *Journal of Business and Economic Statistics* , *27* (3), 369-396.

Phelps, E. S. (1968). Money-wage dynamics and labor-market equilibrium. *The Journal of Political Economy* , *76* (4), 678-711.

Pindyck, R. S. (1991). Irreversibility, Uncertainty, and Investment. *Journal of Economic Literature , 29* (3), 1110-1148.

Pippenger, M. K., & Goering, G. E. (1993). A Note on the Empirical Power of Unit Root Tests under Threshold Processes. *Oxford Bulletin of Economics and Statistics , 55* (4), 473-481.

Pivetta, F., & Reis, R. (2007). The persistence of inflation in the United States. *Journal of Economic dynamics and control , 31* (4), 1326-1358.

Potter, S. M. (1994). Asymmetric economic propagation mechanisms. In W. Semmler, *Business Cycles: Theory and Empirical Methods* (pp. 313-330). Boston: Kluwer.

Pourgerami, A., & Maskus, K. E. (1987). The effects of inflation on the predictability of price changes in Latin America: some estimates and policy implications. *World Development , 15* (2), 287-290.

Psaradakis, Z., Ravn, M. O., & Sola, M. (2005). Markov switching causality and the money–output relationship. *Journal of Applied Econometrics , 20* (5), 665-683.

Qu, Z., & Perron, P. (2007). Estimating and testing structural changes in multivariate regressions. *Econometrica, 75(2)* , 459-502.

Ramey, G., & Ramey, V. A. (1995). Cross-country evidence on the link between volatility and growth. *American Economic Review , 85*, 1138–1151.

Ramey, G., & Ramey, V. A. (1991). Technology commitment and the cost of economic fluctuations. *National Bureau of Economic Research (Cambridge, MA) , Working paper No. 3755*.

Rapach, D., & Wohar, M. (2005). Regime changes in international real interet rates: Are they a monetary phenomenon? *Journal of Money, Credit and Banking 37(5)* , 887-906.

Romer, C. D. (2005). Commentary. *Federal Reserve Bank of St. Louis Review, 87 (2), March/April* , 177-185.

Rotemberg, J., & Woodford, M. (1997). An optimization based econometric framework for the evaluation of monetary policy. *NBER Chapters 12* , 297-361.

Rudd, J., & Whelan, K. (2007). Modeling inflation dynamics: A critical review of recent reserch. *Jurnal of Money, Credit and Banking 39(s1)* , 155-170.

Samuelson, P. A., & Solow, R. M. (1960). Analytical aspects of anti-inflation policy. *The American Economic Review, 50 (2)* , 177-194.

Sandmo, A. (1970). The effect of uncertainty on saving. *Review of Economic Studies , 37*, 353-360.

Sarel, M. (1995). Nonlinear effects of inflation on economic growth. *IMF Working Paper* , 1-26.

Sargent, T. (1999). *The Conquest of American Inflation.* Princeton: Princeton Univ. Press.

Sargent, T., Williams, N., & Zha, T. (2006). Shocks and government beliefs: the rise and fall of American inflation. *American Economic Review, 96(4)* , 1193-1224.

Schwarz, G. (1978). Estimating the dimension of a model. *The Annals of Statistics, 6 (2)* , 461-464.

Shields, K., Olekalns, N., Henry, Ó. T., & Brooks, C. (2005). Measuring the response of macroeconomic uncertainty to shocks. *Review of Economics and Statistics , 87* (2), 362-370.

Sidrauski, M. (1967). Inflation and economic growth. *The Journal of Political Economy* , 796-810.

Smith, R. T. (1996). Cyclical uncertainty, precautionary saving and economic growth. *Economica , 63* (251), 477-494.

Speight, A. E. (1999). UK output variability and growth: some further evidence. *Scottish Journal of Political Economy , 46* (2), 175-184.

Stock, J. H. (2001). Discussion of Cogley and Sargent 'Evolving Post World War II U.S. Inflation Dynamics'. *NBER Macroeconomics Annual , 16,* 379-387.

Stock, J. H., & Watson, M. W. (2003). as the business cycle changed and why? *NBER Macroeconomics Annual 2002, MIT press , 17,* 159-230.

Stock, J. H., & Watson, M. W. (1996). Evidence on structural instability in macroeconomic time series relations. *Journal of Business & Economic Statistics, 14(1)* , 11-30.

Stock, J. H., & Watson, M. W. (2002). Has the business cycle changed and why? *NBER Macroeconomics Annual 2002, Volume 17* , 159-230.

Stock, J. H., & Watson, M. W. (2005). Understanding changes in international business cycle dynamics. *ournal of the European Economic Association , 3* (5), 968-1006.

Stock, J. H., & Watson, M. W. (2007). Why has US inflation become harder to forecast? *Journal of Money, Credit and banking , 37* (s1), 3-33.

Stock, J., & Watson, M. (2002). Has the busines cycle changed and why? *Working Paper 9127, NBER* .

Stockman, A. C. (1981). Anticipated inflation and the capital stock in a cash in-advance economy. *Journal of Monetary Economics , 8* (3), 387-393.

Suda, J., & Zervou, A. S. (2012). International great inflation and common monetary policy. *Available at SSRN 2207456* .

Summers, P. M. (2005). What caused the Great Moderation? Some cross-country evidence. *Economic Review-Federal Reserve Bank of Kansas City , 90* (3), 5-32.

Swanson, N. R. (1998). Money and output viewed through a rolling window. *Journal of monetary Economics , 41* (3), 455-474.

Taylor, J. B. (1979). Estimation and control of a macroeconomic model with rational expectations. *Econometrica* , 1267-1286.

Taylor, J. B. (2000). Low inflation, pass-through, and the pricing power of firms. *European economic review , 44* (7), 1389-1408.

Taylor, J. B. (1981). On the relation between the variability of inflation and the average inflation rate. *Carnegie-Rochester Conference Series on Public Policy*, *15,* pp. 57-85. North-Holland.

Taylor, J. B. (2000). Teaching modern macroeconomics at the principles level. *American Economic Review , 90* (2), 90-94.

Taylor, J. W. (2004). Volatility forecasting with smooth transition exponential smoothing. *International Journal of Forecasting, 20(2)* , 273-286.

Temple, J. (2000). Inflation and growth: stories short and tall. *Journal of economic surveys , 14* (4), 395-426.

Terasvirta, T. (1994). Specification, estimation, and evaluation of smooth transition autoregressive models. *Journal of the American Statistical Association, 89(425)* , 208-218.

Terasvirta, T., & Anderson, H. M. (1992). Characterizing nonlinearities in business cycles using smooth transition autoregressive models. *Journal of Applied Econometrics, 7(S1)* , S119-S136.

Teräsvirtra, T. (1998). Modelling economic relationships with smooth transition regressions. In A. Ullah, & D. E. Giles (Eds.), *Handbook of Applied Economic Statistics* (pp. 507-552). New York, Marcel Dekker.

Thoma, M. A. (1994). Subsample instability and asymmetries in money-income causality. *Journal of Econometrics , 61* (4), 279-306.

Tiao, G. C., & Tsay, R. S. (1994). Some advances in non-linear and adaptive modelling in time-series. *Journal of Forecasting, 13(2)* , 109-131.

Tobin, J. (1965). Money and economic growth. *Econometrica* , 671-684.

Tong, H. (1990). *Non-linear time series: a dynamical system approach.* Oxford University Press.

Tong, H. (1978). *On a threshold model* (Vol. 29). Sijthoff & Noordhoff.

Tong, H., & Lim, K. S. (1980). Threshold autoregression, limit cycles and cyclical data. *Journal of the Royal Statistical Society , Series B (Methodological)*, 245-292.

Tsong, ,. C., & Lee, C. f. (2010). Testing for stationarity of inflation rates with covariates. *South African Journal of Economics , 78* (4), 344-362.

Tsong, C. C., & Lee, C. F. (2011). Asymmetric inflation dynamics: evidence from quantile regression analysis. *Journal of Macroeconomics , 33* (4), 668-680.

Ungar, M., & Zilberfarb, B. Z. (1993). Inflation and Its Unpredictability--Theory and Empirical Evidence. *Journal of Money, Credit and Banking* , 709-720.

Van Djik, D., Osborn, D. R., & Sensier, M. (2002). Changes in variability of the business cycle in the G7 countries. *Centre for Growth and Business Cycle Research Discussion Paper Series 16, Economics, The University of Manchester* .

Vogelsang, T. J., & Perron, P. (1998). Additional tests for a unit root allowing for a break in the trend function at an unknown time. *International Economic Review , 39* (4), 1073-1100.

Wilson, B. K. (2006). The links between inflation, inflation uncertainty and output growth: New time series evidence from Japan. *Journal of Macroeconomics , 28* (3), 609-620.

Wu, J. (2010). Threshold GARCH model: theory and application. *Department of Economics, University of Western Ontario, London, Ontario* .

Yang, Y. L., & Chang, C. L. (2008). A double-threshold GARCH model of stock market and currency shocks on stock returns. *Mathematics and Computers in Simulation, 79(3)* , 458-474.

Zakoian, J. M. (1994). Threshold heteroskedastic models. *Journal of Economic Dynamics and control, 18(5)* , 931-955.

Zarnowitz, V., & Lambros, L. A. (1987). Consensus and Uncertainty in Economic Prediction. *Journal oJ Political Economy , 95*, 591 -621.

Zarnowitz, V., & Moore, G. H. (1986). Major changes in cyclical behavior. In R. J. Gordon (Ed.), *The American Business Cycle: Continuity and Change* (pp. 519-582). UMI.

Zivot, E., & Andrews, D. W. (1992). Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis. *10* (3), 251-270.