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Testing the relationship between Inflation, Inflation Uncertainty and Output Growth: Evidence from the G-20 Countries

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Abstract

This study examines the relationship between inflation, inflation uncertainty and output growth for the G-20 countries using several GARCH and GARCH-M models in order to generate a measure of inflation uncertainty. The test for the impact of inflation uncertainty on inflation and vice versa is adopted in two approaches. The first approach is based on the GARCH-M model that allows for simultaneous feedback between the conditional mean and variance of inflation and the second on a two-step procedure where Granger methods are employed using the conditional variance of a simple GARCH model. The results suggest significant positive relationship between inflation and inflation uncertainty in most countries, supporting the Cukierman-Meltzer and Friedman-Ball hypotheses. There is also some evidence for the Holland theory, that uncertainty lead to lower inflation. In addition, the examination of the effect of inflation uncertainty on output growth is approached with the two-step procedure, where the evidence that inflation uncertainty has negative real effects receives very little support.

Keywords: Inflation; inflation uncertainty; output growth; GARCH-M

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1 Introduction

Economists have long studied the relationship between inflation, inflation uncertainty and output growth because its central importance for policy analysis. Inflation uncertainty is often cited as a major source of the costs of inflation. Perfectly predicted inflation might induce some costs through institutional rigidities, governmental interference, and transaction costs, but in the long run, these should be rather minimal as these institutions adopts various forms of indexing. Nevertheless, uncertainty about future levels of inflation will distort saving and investment decisions since it causes the real value of future nominal payments to be unknown. These distortions are believed to have adverse effects on the efficiency of resource allocation and the level of real activity. Friedman (1977) lays out a framework for how inflation can cause inflation uncertainty, leading to inefficient decisions and decreases in economic growth. Cukierman and Meltzer (1986) show how, by providing an incentive for the monetary authority to create an inflation surprise in order to stimulate output growth, an increase in uncertainty on money growth and inflation will raise the optimal average inflation rate. In contrast, Holland (1995) claim that the central bank may act in a stabilizing manner reducing inflation in order to offset the increase in inflation uncertainty.

The random nature of shocks and imperfect knowledge of the structure of the economy means that some inflation uncertainty will exist under any policy regime. Although uncertainty cannot be eliminated, it may be that inflation uncertainty and therefore its costs could be minimized by adopting a particular policy regime. Since some theoretical models predict that inflation uncertainty increases with the level of inflation, the costs of inflation uncertainty might be minimized by pursuing a policy of price stability. This has led to numerous empirical studies since the ‘70s on the link between inflation and inflation uncertainty and on the real effects of uncertainty.

Despite the considerable volume of primarily empirical research to date, mainly with respect to the experience of the US and the G7 advanced economies, has supplied contradictory evidence regarding the impact of inflation on inflation uncertainty and of inflation uncertainty on inflation rate and growth. Early approaches did not distinguish between anticipated and unanticipated changes in inflation and they were proxying the inflation uncertainty by the moving standard deviation or variance of the inflation series. In more recent years, the development of Generalized Autoregressive Heteroskedasticity (GARCH) models allows researchers to measure inflation uncertainty by the conditional variance of the inflation rate. To test for the relationship between uncertainty and indicators of macroeconomic performance, such as inflation and output growth, one can use a simultaneous or a two-step approach. Following the simultaneous approach, a GARCH-in-mean (GARCH-M) model is estimated with the conditional variance equation incorporating lags of the series, thus allowing simultaneous estimation and testing the linkage between the uncertainty and the series. Under the two-step procedure, first, the conditional variance of inflation is estimated and then Granger causality tests are performed between this generated conditional variance measure of uncertainty, and inflation series.

In this study, we analyze empirically the theoretical issues concerning inflation and inflation uncertainty using both GARCH-M and two-step approach and we provide a comparison of the results. Furthermore, we test the real impact of inflation uncertainty on output growth adopting the two-step approach. It is noteworthy that, for two countries where there is no evidence for GARCH effect in series we proxy the inflation uncertainty from the moving standard deviation (MSD) of inflation series. There are a number of single or multi-country studies concerning the G7, developed, less developed, industrial, or European countries. However, in this work, we focus on the G-20 countries employing post-World War data and we attempt to test the theories for countries like Russia and Saudi Arabia that, to the best of our knowledge, no previous study on the inflation, inflation uncertainty and output growth use these economies or totally the G-20.

In general, three hypotheses are tested: 1) the effect of inflation on inflation uncertainty, where according to the Friedman-Ball (1977, 1992) argument higher inflation leads to more uncertainty, 2) the effect of inflation uncertainty on inflation, where a positive effect is in line of Cukierman-Meltzer (1986) hypothesis and a negative effect is in consistent with Holland (1995) theory, and 3) the impact of inflation uncertainty on output growth, where according the second part of the Friedman (1977) hypothesis inflation uncertainty causes adverse output effect, but according the Dotsey and Sarte (2000) theoretical model a higher inflation uncertainty leads to more output growth.

The rest of the study is organized as follows. In section 2 we consider the theories-hypotheses on inflation, inflation uncertainty and output growth in more detail. Section 3 discusses previous empirical studies in this area using GARCH-type models in order to measure the inflation uncertainty. Section 4 describes the econometric methodology used in the analysis. In section 5 we present our empirical approach and results. Conclusions are presented in section 6.

2 Theories on inflation, uncertainty and output growth

2.1 The impact of inflation on inflation uncertainty

Okun (1971) postulated first the hypothesis that there exists a positive relationship between the inflation rate and its variability. He argues that public policy by affecting individual's expectations and by being less stable at high inflation rates produces a stop-go pattern of economic time series and causes not only the average inflation rate to increase but its variability as well. Moreover, unexpected changes in the inflation rate do impose a welfare costs. Therefore, higher inflation rates are to be avoided not because they are high but rather because they are associated with increased inflation rate variability.

Gordon (1971) considered the welfare economics of inflation. In commenting on Okun, Gordon argues that Okun's most important point was the assertion of a positive correlation between the inflation rate and its variability. He concludes however, that this positive correlation is a result of the sample period chosen by Okun rather than any systematic relationship.

Friedman (1977) in his Nobel lecture emphasizes the positive link between inflation and inflation uncertainty because of the stop-go monetary policy that accompanies inflationary monetary periods. Because monetary policy is more difficult for the public to predict in high inflationary periods, higher average inflation results in greater uncertainty about future rate of inflation.
More analytically, according to Friedman, the most fundamental departure is that a high inflation rate is not likely to be steady during the transition decades. Rather, the higher the rate, the more variable it is likely to be. Friedman argues that governments have not produced high inflation as deliberate announced policy but as a consequence of other policies like policies of full employment and welfare state policies raising government spending. In high values of inflation policy goes from one direction to the other, encouraging wide variation in the actual and anticipated rate of inflation. Hence, the anticipations for inflation vary. Moreover, Friedman, points that the tendency for inflation that is high on the average to be highly variable, is reinforced by the effect of inflation on the political cohesiveness of a country in which institutional arrangements have been adjusted to a long-term price level.
Finally, in a second point of his argument, this uncertainty for inflation, distorts the effectiveness of the price mechanism in allocating resources efficiently, and thus it creates economic inefficiency, lower growth rate of output and increases unemployment.

Friedman’s intuitive result has also been subsequently derived formally by Ball (1992) in an asymmetric information game where the public knows that one type of policymaker is willing to bear the economic costs of the reducing inflation while the other type is not. In other words, the two types of policymaker differ in terms of their willingness to bear the economic costs of policy.

When inflation is low, both types of policymakers will keep it so. When inflation is high only the tough type will disinflate. Since the public does not know the tastes of future policymakers, it does not know whether disinflation will occur. A repeated game takes place between the public and the monetary authority as policy makers rotate in office. Ball assumes that the two types of policymakers alternate in office in a stochastic manner. Therefore, a higher current inflation rate creates more uncertainty about the level of future inflation since it is not known whether the tough type will gain power or and fight inflation. Thus, Ball’s work provides a formal justification of Friedman’s insight.

2.2 The impact of inflation uncertainty on inflation

Cukierman and Meltzer (1986) and Cukierman (1992) suggest the possibility that inflation uncertainty could cause higher inflation. Both studies build upon the Barro-Gordon model of Fed behavior.

According to this model, governments differ in the stability of their objectives, meaning that central bank faces a trade-off because it dislikes inflation but also seek to stimulate the economy with surprise inflation. The policymaker is free to determine the accuracy of monetary control and does not necessarily choose the most effective control variable. If monetary policy is discretionary and there is a lack of a commitment mechanism, Cukierman and Meltzer’s model predicts an inflationary bias in equilibrium during periods of increased uncertainty. Both the policy maker’s objective function and the money supply process as random variables. Thus, the public faces an inference problem (uncertainty) about the rate of money growth and therefore inflation.

Cukierman and Meltzer show that, in their model, an increase in inflation uncertainty raises the optimal average inflation rate because it provides an incentive to the policymaker to create inflation surprises in order to stimulate output growth. In other words, greater uncertainty about money growth and inflation causes a higher mean rate of inflation. If there are different policy regimes in a given country over time, their model can be applied to explain a positive relationship between the inflation rate and inflation uncertainty over time for a given country, at least slightly.

In contrast, Holland (1995) proposes that if inflation causes inflation uncertainty, there may be a negative feedback effect from inflation uncertainty to inflation as results of policymaker's stabilization efforts.

Holland argues that in the presence of a stabilization motive on the part of the policymaker, monetary authorities when faced with more inflation uncertainty in the economy will contract the growth rate of money supply and therefore lower the inflation and the uncertainty in order to minimize the negative welfare effects of inflation uncertainty on the economy. This is the so-called 'stabilizing Fed hypothesis'. The last is more likely to happen if policymakers could either have long-term stabilizing motives, be governed by some commitment mechanism which requires long-run price stability, or be under central bank independence (Grier and Perry, 1998). According to Holland and Grier and Perry, the most independent banks are in countries where inflation declines as the uncertainty of inflation rises, which is in contradiction to the Cukierman and Meltzer hypothesis. Therefore, Holland's argument supports the opposite sign in the causal relationship, that is, a negative causal effect of inflation uncertainty on inflation.

2.3 The impact of inflation uncertainty on output growth

Despite the Friedman's argument that higher inflation rate leads to more inflation uncertainty, Friedman (1977) also claim, that this uncertainty then lowers the economic efficiency and temporarily reduces the output growth. He points that the adverse output effect, is due to the distortion of the effectiveness of the price mechanism in allocating resources efficiently came from the uncertainty about future inflation.

More analytically, according Friedman, an increased variability of actual or anticipated inflation raise the nature rate of unemployment and affect negatively on economic efficiency in two rather different ways. First, increased volatility shortens the optimum length of unindexed commitments and leads index to be more advantageous. But even at best, indexing is an imperfect substitute for stability of inflation rate. Price indexes are imperfect. These developments lower economic efficiency. A second related effect of increased volatility of inflation which Friedman claims is that make market prices a less efficient system for coordinating economic activity. He argues that more noise in the price system again reduces the economic efficiency and raises unemployment, at least during some transitional period as firms adapt to the new environment.

Hence Friedman argues informally that by reducing economic efficiency, greater inflation uncertainty should at least temporarily increase the rate of unemployment and reduce economic growth.

The effect of inflation uncertainty on output growth has been addressed formally by Dotsey and Sarte (2000) in a model where money is introduced via a cash-in-advance constraint.

They find that inflation and growth are positively related in the short run, and that a rise in the volatility of inflation has a positive effect on growth. Furthermore, they argue that variability increases average growth through a precautionary savings motive and the assumption of risk-averse agents. According to the theoretical model of Dotsey and Sarte when agents receive a high money transfer today, next period's nominal balances will grow at a relatively fast pace. But at the same time, inflation is expected to be higher than average. Therefore, agents demand less real balances which leads to a rise in savings and hence investment and a decrease in consumption. As a consequence, Dotsey and Sarte, in contrast with Friedman, argue that a higher inflation uncertainty leads to more output growth.

Table 1: Summary of testable theories and expected signs

Testable theories	Sign
1. Inflation uncertainty affects inflation	
Cukierman-Meltzer (1986)	+
Holland (1995)	-
2. Inflation affects inflation uncertainty	
Friedman-Ball (1977,1992)	+
3.Inflation uncertainty affects output growth	
Friedman (1977)	-
Dotsey and Sarte (2000)	+

All the testable theories presented in this section are summarized in Table 1. Though these theories seem reasonable and persist in economic discussions, existing literature indicates only mixed support for them. In the next section we provide several empirical studies focused on the relationship between inflation, inflation uncertainty and output growth.

3 Related Empirical Research Review

The empirical examination of the relation between inflation, inflation uncertainty and output growth has received much attention over the last years. Despite the considerable volume of research, the evidence on the testable theories presented previously appears ambiguous.

A review of the many early studies provides usually two measures of inflation uncertainty; the cross-sectional dispersion of inflation forecasts from surveys of professional economists and the moving standard deviation of inflation rate.
For example Frohman et al. (1981) use the variance of Livingston survey inflation forecasts around the mean and find a significant positive relation with actual and expected inflation. Zarnowitz and Lambros (1987) use the standard deviation from the ASA-NBER survey GDP deflator forecasts where one standard deviation is based on probabilistic forecasts and another on point forecasts. They show a significant positive relation using the probabilistic, but not the point forecasts. Katsimpris and Miller (1982) compute six-year moving standard deviation around the mean for eighteen OECD countries and six-year moving standard deviation minus the six-year standard deviation of world inflation and find significant positive relationship between six-year moving average of inflation for nine countries for the first measure and significant positive relationship for five countries for the second measure. Ram (1985) computes a five-year moving standard deviation and five-year moving average of absolute change in the inflation rate for 117 countries and he finds a significant positive relation with the corresponding moving average for about 2/3 of the countries. Holland (1993) and Davis and Kanago (2000) provide an extensive overview of the studies and highlight the mixed results partly reflecting differences in the countries studied, sample periods and empirical methodologies, including the representation of inflation uncertainty.
Nevertheless, the main criticism to these measures is that they include both predictable and unpredictable variability even though the former does not imply any uncertainty. In other words, these studies measured inflation variability and not the uncertainty.

Ever since Engle's (1982) seminal paper on ARCH and the GARCH extension by Bollerslev (1986), inflation uncertainty, in recent years, is often proxied by the conditional variance from GARCH models of inflation. Such measure captures more accurate the type of uncertainty modeled by Ball or Cukierman and Meltzer.

Engle (1983) and Bollerslev (1986), making use of the ARCH, GARCH techniques, compare the estimated conditional variance of inflation series with the US average inflation rate over various time periods. However they do not find significant relation between the two series.

Also, Cosimano and Jansen (1988) using quarterly data over 1953-1979 for the US and applying ARCH model do not provide evidence for significant effect between inflation and its uncertainty. Jansen (1989) models the inflation over the 1959-1988 for the same country using quarterly data on real GNP and the GNP deflator in a bivariate ARCH-M model. His findings show that the variance of inflation had a positive but statistically insignificant effect on the rate of inflation. In contrast, Evans (1991) employs an ARCH model for US inflation in three sample periods, and finds a significant relation between inflation and inflation uncertainty providing a positive effect between the change in the variance of the steady state inflation and the change in inflation rate.

A review of the most recent literature, where GARCH process is adopted, reveals that in the majority of cases inflation has a positive effect on inflation uncertainty but the evidence on the reverse type of causality is rather mixed.

For example, Fountas (2001) tests the Friedman-Ball hypothesis, using a long series of UK inflation data and a GARCH model allowing to include the level of inflation rate into the conditional variance equation. The author provides strong evidence in favour of the hypothesis that inflationary periods are associated with high inflation uncertainty (Friedman-Ball hypothesis). Thornton (2006), following the same econometric model of Fountas (2001) and using monthly data for the South Africa CPI for the period 1957-2005 finds a positive relationship between the level and variability of inflation supporting the Friedman's-Ball argument. Moreover, on the same basis of analysis, Thornton (2008) using this time annual data for Argentine CPI for 1810-2005, confirms again the Friedman-Ball hypothesis.

Grier and Perry (1998) employ a two-step procedure to test not only the Friedman-Ball argument but also the Cukierman-Meltzer hypothesis. In particular, in the first step they use GARCH models to generate a measure of inflation uncertainty for the G7 countries from 1948 to 1993. Then they employ Granger methods to test the causality between average inflation and inflation uncertainty. They show that inflation raises uncertainty in all countries as predicted by Friedman-Ball hypothesis but increases in inflation uncertainty raises inflation in only two countries (Japan and France). They also find evidence for Holland hypothesis that uncertainty lowers inflation in three countries (US, UK and Germany).

Likewise, Nas and Perry (2000) construct a time series of monthly inflation uncertainty in Turkey from 1960-1980 using GARCH models and investigate the link between inflation and inflation uncertainty using Granger tests. The authors find strong evidence from Friedman-Ball hypothesis over the full sample periods and three subsamples but the effect of inflation uncertainty on average inflation is mixed. In the full period they provide evidence in favour of Holland hypothesis but in the subsamples the results depend on the lag lengths they use. Fountas et al. (2004) also employ Granger methods to test for causality between inflation and inflation uncertainty for six EU countries for the period 1960-99, but they use exponential GARCH models (EGARCH) to generate a measure of inflation uncertainty. They find that in all countries except Germany, inflation significantly raises inflation uncertainty as predicted by Friedman and Ball. However they show that in Germany and Netherlands, increased inflation uncertainty lowers inflation which is in consistent with Holland argument, while in Italy, Spain and to a lesser extent France, the effect is positive supporting the Cukierman-Meltzer hypothesis. Daal et al. (2005) propose an asymmetric power GARCH model (PGARCH) to examine the linkage between inflation-inflation uncertainty for both developed and emerging countries using monthly data from 1957 to 2004. They find that inflation Granger cause uncertainty for most countries but they provide mixed results of the opposite direction like the majority of literature. Fountas et al. (2006), examine the Friedman-Ball and Cukierman-Meltzer for the G7 countries using a bivariate GARCH model to construct the inflation uncertainty. Applying several bivariate causality tests, they find that inflation causes inflation uncertainty in all countries except UK and that inflation uncertainty in Canada, UK and probably in France and Italy raises the rate of inflation, while in Japan and US the opposite holds supporting the Holland argument. In the same framework of two-step procedure, Thornton (2007) examines the relationship for 12 emerging market economies. His results suggest that higher inflation rates increased inflation uncertainty in all the economies, providing strong support for Friedman-Ball hypothesis. He also find mixed evidence for the reverse type of causality, with increased uncertainty leading to lower average inflation in Colombia, Israel, Mexico and Turkey, consistent with the Holland Hypothesis, but to higher inflation in Hungary, Indonesia and Korea, consistent with the hypothesis of Cukierman and Meltzer. Jiranyakul and Opiela (2010) estimate the inflation uncertainty as a conditional variance in an EGARCH model using monthly data over the period 1970-2007 for the ASEAN-5 economies. The causality tests they imply show that rising inflation increases inflation uncertainty and that rising inflation uncertainty increases inflation in all five countries, providing strong evidence for both Friedman-Ball and Cukierman-Meltzer hypothesis.

Conrad and Karanasos (2005) construct a dual long memory fractionally integrated model (ARFIMA-FIGARCH) to test the relationship between inflation and inflation uncertainty using monthly data for US, Japan and UK for the period 1962-2000. They find that inflation significantly increases inflation uncertainty in all countries but regarding the direction of the impact of a change in uncertainty on inflation they find no effect for the US, whereas they obtain mixed evidence for the UK (evidence for Cukierman-Meltzer at eight lags and evidence for Holland at 12 lags) and positive relationship for Japan. These findings for US and Japan are in contrast with those of Baillie et al. (1996) who implement also the ARFIMA-FIGARCH process but they find no apparent relationship between inflation and inflation uncertainty to support Friedman-Ball hypothesis for the low-inflation countries. Nevertheless, they find positive evidence for the UK and also for Argentina, Brazil and Israel. Also, Hwang (2001) using ARFIMA-GARCH-type models for US inflation find results unlike Friedman-Ball's and Cukierman-Meltzer's view.

Other studies test the Cukierman-Meltzer (or Holland) and Friedman-Ball hypothesis in a simultaneous approach, where a GARCH-in-Mean (GARCH-M) model is estimated with the conditional variance equation incorporating lags of the inflation series. In line of this framework, Fountas et al. (2004) examine the relationship between inflation and inflation uncertainty in the US using a GARCH model that allows for simultaneous feedback between the conditional mean and the variance of inflation (GARCH-M-L). They show that there is a strong positive bidirectional relationship between the two variables which is in agreement with the predictions of economic theory expressed by the Friedman-Ball and Cukierman-Meltzer hypotheses. Likewise, Kontonikas (2004) tests simultaneously the two theories using UK data over the period 1972-2002. He proxies the uncertainty, using the estimated conditional volatility from symmetric, asymmetric and component GARCH-M models of inflation. The results indicate a positive relationship between past and inflation and uncertainty about future inflation, in line with the Friedman-Ball causal link, but in contrary to the Cukierman-Meltzer prediction, he finds that inflation uncertainty has no impact on average inflation in all cases. Moreover, in a recent study, Fountas (2010) uses an augmented GARCH-M model and a two step procedure to test the relationship between inflation and inflation uncertainty for 22 industrial countries using annual data spanning over one century. In most cases, author finds a significant positive effect of inflation uncertainty on inflation supporting the Cukierman-Meltzer hypothesis (in five cases the effect is negative as Holland predicts), but concerning the effect of inflation on inflation uncertainty, he finds only partial support to Friedman-Ball hypothesis.

The empirical studies concerning the impact of inflation uncertainty on output growth is more limited. In addition the evidence is rather mixed. Some authors provide a negative and significant effect supporting the second part of Friedman hypothesis that inflation uncertainty lowers the output growth while other authors provide some support to the Dotsey and Sarte prediction regarding the positive effect of inflation uncertainty on growth.

For example, of the GARCH studies we mentioned above, the second part of Friedman hypothesis is examined from Jansen (1989) who finds that the variance of inflation has a positive but statistically insignificant effect on the rate of output growth. Nevertheless, Fountas et al (2004), in their study for the six European countries, find that inflation uncertainty has a significant and negative effect for Italy and UK, but a significant and positive impact in Netherlands and Spain. Fountas (2010), in his study of the 22 industrial countries finds statistically significant effect only on eight countries, of which only in two countries there is negative effect, while for the rest six the results are in consistent with the Dotsey and Sarte theory.

Moreover, one can find evidence for the relationship between inflation uncertainty, output growth and not only, in a number of empirical studies where both output growth and inflation is modeled simultaneously. These studies, investigate usually the impact of real and nominal macroeconomic uncertainty on inflation and growth, but in this review we are limited to the case of the effect of the nominal (inflation) uncertainty on inflation and output growth.

For example, Grier and Perry (2000), use a bivariate GARCH-M model for both inflation and output growth to test the effects of inflation uncertainty on inflation and output growth in the US from 1948 to 1996 in a simultaneous approach. They find no evidence that higher inflation uncertainty raises or lowers inflation rate, but their key result is that in a variety of models and sample periods, inflation uncertainty significantly lowers real output growth which is in consistent with the second part of the Friedman hypothesis. Grier at al. (2004) tests the impact of inflation uncertainty on inflation rate and output growth for post-war US data using a vector autoregressive GARCH-M (VARMA-GARCH-M) model. Their results suggest also that higher inflation uncertainty is negatively correlated with lower output growth, as in the previous study of Grier and Perry, but they find that inflation uncertainty is associated with lower average inflation rates supporting Holland's claim. Likewise, Bredin and Fountas (2005) apply a VARMA-GARCH-M model for G7 countries, using monthly data covering the 1957-2003 period in order to test the Cukierman-Meltzer and the second part of Friedman hypotheses. They find mixed evidence regarding the effect of inflation uncertainty on inflation and output growth.

In particular, they show positive effects of inflation uncertainty on inflation for Canada, France and Italy and negative effect of uncertainty on output growth for US and UK, supporting the Friedman hypothesis that inflation uncertainty is detrimental to output growth. Grier and Grier (2006) estimate an augmented multivariate GARCH-M model of inflation and output growth for Mexico at business cycle frequencies. They find that inflation uncertainty has a significant and negative effect on growth as Friedman predicts and that higher inflation raises inflation uncertainty. Moreover, Bredin and Fountas (2009) and Brendin et al. (2009) test these two effects in the same framework of VARMA-GARCH-M model where one study considers the EU countries and the other some Asian countries. Regarding the EU countries, Bredin and Fountas find that in half of cases there is no significant relationship between inflation uncertainty and output growth performance. Nevertheless, they provide considerable evidence for Cukierman-Meltzer hypothesis. Regarding the Asian countries, Bredin et al. show that inflation uncertainty tends to enhance growth in S. Korea, Philippines, Singapore and Malaysia supporting Dotsey and Sarte theory. Moreover they find that Cukierman-Meltzer hypothesis is supported for S. Korea, while in India, Philippines and Singapore the results are in line of Holland's argument.

Chang and He (2010), employ a bivariate Markov switching model to investigate whether the relationship between inflation and inflation uncertainty, and their effects on output growth, would change across the inflation regimes for US, using quarterly data for the 1960-2003 period. Through investigation of the non-linear effects of inflation and inflation uncertainty on the real economy, the model can classify economic states endogenously and determine the regime-dependent nonlinear effects. They find that inflation and inflation uncertainty are positively correlated during periods of high inflation, but not during the low-inflation periods. Moreover, they show that the regime switching property of inflation is also a vital factor concerning uncertainty estimations. Finally, they find that inflation uncertainty can lower the output growth, and the degree of reduction can vary with the inflation regime. The negative influence in a high-inflation regime is around 2.664 times greater than that in a lower-inflation regime.

Tables 2 and 3 above, present in a summary the data, the methodologies and the results of the different empirical studies where the conditional variance from GARCH models is used to proxy the inflation uncertainty in order to examine the relationship of inflation and inflation uncertainty and the relationship between inflation uncertainty and output growth.

Table 2 : Empirical studies concerning the impact of inflation on inflation uncertainty and vice versa

Authors	Data	Methodology	Results
Engle (1983)	Sample: 1947Q4-1979Q4 Country: US Indexes: CPI, PPI, GNP deflator	ARCH model	Insignificant relationship between inflation uncertainty and inflation
Bollerslev (1986)	Sample: 1948Q2-1983Q4 Country: US Indexes: GNP deflator	GARCH model	No significant relationship
Cosimano and Jansen (1988)	Sample: 1947Q4-1979Q4 Country: US Indexes: CPI, GNP deflator	ARCH model	Insignificant relation between the two variables
Jansen (1989)	Sample: 1959Q1-1988Q2 Country: US Indexes: real GNP, GNP deflator	Bivariate ARCH-M model	Insignificant relationship
Evans (1991)	Sample: 1960M1-1988M2; 1960M1-1975M12; 1976M1-1988M2 Country: USA Indexes: CPI	ARCH model	Significant positive relationship between inlfation-uncertainty
Baillie and Chung (1996)	Sample: 1948M1-1990M(.) Country: 10 low and high inflation countries Indexes: CPI	ARFIMA-FIGARCH model	Strong positive evidence of joint feedback between inflation-uncertainty for UK, Argentina, Brazil and Israel
Grier and Perry (1998)	Sample: 1948M1-1993M12 Country: G7 Indexes: CPI	GARCH model and Granger causality tests	Friedman-Ball: in all countries Cukierman-Meltzer: Japan, France Holland: US, UK, Germany
Grier and Perry (2000)	Sample: 1948M7-1996M12 Country: US Indexes: PPI	Bivariate GARCH-M model	No evidence that higher inflation uncertainty raises or lowers inflation rate
Nas and Perry (2000)	Full sample: 1960M1-1998M3 Subsamples: 1980-98; 1986-98; 1990-98 Country: Turkey Indexes: CPI	GARCH model and Granger causality tests	Evidence for Friedman-Ball claim over the full sample and subsamples, evidence for Holland theory over the full sample and mixed results for subsamples

Fountas (2001)	Sample: 1885-1998 Country: UK Indexes: CPI	GARCH model enriched with inflation into the conditional variance eq.	Strong evidence in favour of Friedman-Ball hypothesis
Hwang (2001)	Sample: 1947M11-1992M12 Country: US Indexes: CPI	ARFIMA-GARCH-type models	No evidence for Friedman-Ball and Cukierman-Meltzer (or Holland) hypotheses
Fountas (2002)	Sample: 1961M1-1999M12 Country: Japan Indexes: PPI	Bivariate VAR-GARCH model and causality tests	Evidence that increased inflation raises uncertainty (Friedman-Ball) and that uncertainty lowers average inflation (Holland)
Fountas, Karanasos, and Karanassou (2004)	Sample: 1960M11-1999M2 Country: US Indexes: CPI	GARCH-M-L model	Strong positive bidirectional feedback between inflation and inflation uncertainty
Fountas, Ioannidis and Karanasos(2004)	Sample: 1960Q1-1992Q2 (UK) ; 1960Q1-1993Q3 (the rest five) Country: six EU countries Indexes: CPI	EGARCH model and Granger causality tests	Friedman-Ball: in all countries except Germany Cukierman-Meltzer: UK,Italy, Spain, France Holland:Netherlands, Germany
Grier, Henry, Olekalns, and Shields (2004)	Sample: 1947M4-2000M10 Country: US Indexes: PPI	VARMA-GARCH-M model	Evidence for Holland theory
Kontonikas (2004)	Sample: 1972M1-2002M12 Country: UK Indexes: CPI	Augmented GARCH-M model	Evidence for Friedman-Ball hypothesis but no evidence for Cukierman-Meltzer theory
Bredin and Fountas (2005)	Sample: 1967M1-2003M(.) Country: G7 Indexes: CPI, PPI	VARMA-GARCH-M model	Evidence for Cukierman-Meltzer hypothesis
Conrad and Karanasos (2005)	Sample: 1962M1-2000M12 Country: US, UK, Japan Indexes: CPI	ARFIMA-FIGARCH model	Evidence for Friedman-Ball in all countries while, Cukierman-Meltzer hypothesis in Japan. Mixed results for UK
Daal,Naka and Sanchez (2005)	Sample: 1957M2-2004M5 Country: 22 countries Indexes: CPI	PGARCH model and causality tests	Friedman-Ball: all countries except Germany Cukierman-Meltzer: mixed results

Fountas, Karanasos and Kim (2006)	Varying sample periods Country: G7 Indexes: PI	Bivariate GARCH model and Granger causality tests	Friedman-Ball: all countries except UK Cukierman-Meltzer: Canada, UK, France, Italy Holland: Japan, US
Grier and Grier (2006)	Sample: 1972M1-2001M12 Country: Mexico Indexes: CPI	Augmented multivariate GARCH-M model	Higher inflation raises inflation uncertainty
Thornton (2006)	Sample: 1957M1-2005M9 Country: South Africa Indexes: CPI	GARCH model enriched with inflation into the conditional variance eq.	Evidence for Friedman-Ball hypothesis
Thornton (2007)	Varying sample periods Country: 12 emerging economies Indexes: CPI	Enriched GARCH model and Granger causality tests	Strong evidence for Friedman-Ball hypothesis in all countries, mixed results for Cukierman-Meltzer hypothesis
Thornton (2008)	Sample: 1810-2005 Country: Argentina Indexes: CPI	Enriched GARCH model	Evidence for Friedman-Ball hypothesis
Bredin and Fountas (2009)	Sample: 1962M-2003M Country: 14 EU countries Indexes: CPI, PPI	VARMA-GARCH-M model	Considerable evidence for Cukierman-Meltzer theory for eight countries
Bredin, Elder, Fountas (2009)	Varying sample periods Country: five Asian countries Indexes: CPI	VARMA-GARCH-M model	Cukierman-Meltzer hypothesis is supported for S.Korea, while Holland theory for India, Philippines and Singapore
Fountas (2010)	Sample: annual data spanning the 19th and 20th centuries Country: 22 industrial countries Indexes: CPI	Enriched GARCH-M model and causality tests	Friedman-Ball: evidence for six countries, Cukierman-Meltzer: evidence in most cases Holland: evidence for five countries
Jiranyakul and Opiela (2010)	Sample: 1970M1-2007M12 Country: ASEAN-5 economies Indexes: CPI	EGARCH model and Granger causality tests	Strong evidence for both Cukierman-Meltzer and Friedman-Ball hypothesis
Chang and He (2010)	Sample: 1960Q1-2003Q3 Country: US Indexes: CPI	Bivariate Markov switching model	Inflation and inflation uncertainty are positively correlated during periods of high inflation , but not during the low-inflation periods

Table 3: Empirical studies concerning the impact of inflation uncertainty on growth

Authors	Data	Methodology	Results
Jansen (1989)	Sample: 1959Q1-1988Q2 Country: US Indexes: real GNP, GNP deflator	Bivariate ARCH-M model	No statistically significant evidence
Grier and Perry (2000)	Sample: 1948M7-1996M12 Country: US Indexes: PPI,IPI	Bivariate GARCH-M model	Inflation uncertainty lowers output growth (Friedman hypothesis)
Fountas (2002)	Sample: 1961M1-1999M12 Country: Japan Indexes: PPI, IPI	Bivariate VAR-GARCH model and causality tests	More inflation uncertainty lead to lower output growth
Fountas, Ioannidis and Karanasos(2004)	Sample: 1960Q1-1992Q2 (UK) ; 1960Q1-1993Q3 (the rest five) Country: six EU countries Indexes: CPI, IPI	EGARCH model and Granger causality tests	Inflation uncertainty cause negative output effects in UK and Italy and positive effects in Netherlands and Spain
Grier, Henry, Olekalns, and Shields (2004)	Sample: 1947M4-2000M10 Country: US Indexes: PPI,IPI	VARMA-GARCH-M model	Inflation uncertainty lowers the output growth
Bredin and Fountas (2005)	Sample: 1967M1-2003M(.) Country: G7 Indexes: CPI, PPI, IPI	VARMA-GARCH-M model	Evidence for the second part of Friedman's theory for US and UK
Fountas, Karanasos and Kim (2006)	Varying sample periods Country: G7 Indexes: PI , IPI	Bivariate GARCH model and Granger causality tests	Significant and negative effect between the two variables in all countries except France and Italy
Grier and Grier (2006)	Sample: 1972M1-2001M12 Country: Mexico Indexes: CPI, IPI	Augmented multivariate GARCH-M model	Evidence in favour of the second part of Friedman hypothesis
Bredin and Fountas (2009)	Sample: 1962M-2003M Country: 14 EU countries Indexes: CPI, PPI, IPI	VARMA-GARCH-M model	In half of cases there is no significant evidence
Bredin, Elder, Fountas (2009)	Varying sample periods Country: five Asian countries Indexes: CPI, IPI	VARMA-GARCH-M model	Inflation uncertainty enhance growth in S. Korea, Philippines, Singapore and Malaysia
Fountas (2010)	Sample: annual data spanning the 19th and 20th centuries Country: 22 industrial countries Indexes: CPI, real GDP	Enriched GARCH-M model and causality tests	Evidence for Friedman hypothesis in two countries and for Dotsey and Sarte theory in six countries
Chang and He (2010)	Sample: 1960Q1-2003Q3 Country: US Indexes: CPI, real GDP	Bivariate Markov switching model	Inflation uncertainty can lower the output growth, and the degree of reduction can vary with the inflation regime (non-linear negative effect)

4 Econometric Methodology and Modelling

Testing any of the above theories requires the construction of a specific measure for inflation uncertainty. As we discussed, two uncertainty measures that have been used in early literature are the cross-sectional dispersion of individual forecasts from surveys or a moving standard deviation of the variable under investigation.
However, according to the theories of Ball (1992) and Cukierman and Meltzer (1986), inflation uncertainty is the variance of the unpredictable component of an inflation forecast. That is, the conditional variance of inflation. Therefore, following the recent empirical literature, this study will derive the variable that will be used to measure inflation uncertainty from the volatility tests called Autoregressive Conditional Heteroskedasticity (ARCH) and Generalized Autoregressive Conditional Heteroskedasticity (GARCH). Only in a special case where the inflation series have no GARCH effect as we will see in empirical approach, moving standard deviation (MSD) of series is used for uncertainty. This measure (MSD) is commonly employed in studies that require a proxy for exchange rate uncertainty.
In recent years GARCH-type modeling of volatility are most popular since they estimate a time-varying residual variance that corresponds well to the notation of uncertainty in Cukierman and Meltzer, rather than simply calculating a variability measure from past outcomes like moving standard deviation.

On the basis of the above, in order to examine the relationship between inflation and inflation uncertainty, this paper adopts two approaches. The first is based on a GARCH-in-mean model enriched with a lagged inflation rate in the conditional variance equation. The second is based on a two-step approach where an estimate of the conditional variance is first obtained from a simple GARCH model without including the in-mean term and the lagged inflation. Then, using the conditional variance of inflation, causality tests are run, in order to test for the lagged impact of inflation uncertainty on inflation or vise versa.
On the one hand, the GARCH-in-mean model augmented by lagged inflation allows for the possibility of a simultaneous feedback relationship between inflation and uncertainty, but suffers from the drawback that does not allow us to capture the lagged causal effects of the conditional variances on the conditional means. On the other hand, the two-step procedure allows the use of lagged variables in Granger-causality equation and minimizes the number of the estimated parameters. Therefore, in the empirical approach in section 5 we use both of these approaches and we compare the results.
Additionally, the linkage between inflation uncertainty and output growth is explored by employing causality tests.

4.1 The ARCH (q) and GARCH (p, q) models

Many economic time series exhibit periods of unusually high volatility followed by more tranquil periods of low volatility. Therefore, in such cases it is clear that the assumption of homoskedasticity (or constant variance) is very limiting, and it is preferable to examine models that allow the variance of a regression to change over time.

In a series of papers, first Robert Engle (1982) developed a class of models that allow for explicit parameterization of the variance process for time series modeling, known as Autoregressive Conditional Heteroskedasticity (ARCH).

Such models permit a general form of heteroskedasticity that nests the homoskedasticity model as a special case. In particular, the variance is allowed to depend on realizations of past variables including past disturbances. The model explicitly recognizes the difference between the conditional and unconditional variance; the conditional variance may depend upon random variables in the conditioning set such as the past disturbances, while the unconditional variance would often be a constant as traditionally assumed.

The ARCH (q) model in general form is specified as:

$$h_t = \gamma_0 + \sum_{i=1}^{q} a_i \, \varepsilon_{t-i}^2 \tag{1}$$

where

$$\varepsilon_t = \nu_t \sqrt{h_t} \tag{2}$$

h_t is known as the conditional variance. ε_t is the error process where ν_t is normally distributed with zero mean and unit variance, so that ε_t will also be normally distributed with zero mean and variance h_t.

One of the drawbacks of the ARCH specification, according to Engle (1995), was that It looked more like a moving average specification than an autoregression. From this, a new idea was born which was to include the lagged conditional variance terms as autoregressive terms. This idea was worked out by Tim Bollerslev, who in 1986 developed the Generalized Autoregressive Conditional Heteroskedasticity models (GARCH).

The GARCH models allow the conditional variance to be dependent both on past values of the shocks and on previous own lags, so that the conditional variance equation in general form is now:

$$h_t = \gamma_0 + \sum_{i=1}^{q} a_i \, \varepsilon_{t-i}^2 + \sum_{j=1}^{p} \beta_j \, h_{t-j} \tag{3}$$

The extension of the ARCH process to the GARCH process bears much resemblance to the extension of the standard time series AR process to the general ARMA process and according Bollerslev (1986) permits a more parsimonious description in many situations with an error term which does not necessarily have a constant variance.

4.2 The GARCH-In-Mean (GARCH-M) model

An important extension of the GARCH model that will be employed in this analysis is the GARCH-in-mean (GARCH-M) model that allows for the conditional variance term h_t enters into the condition mean equation.

The GARCH-M (p, q) model states that

$$Y_t = a + \beta' X_t + \gamma h_t + \varepsilon_t \tag{4}$$

$$\varepsilon_t = \nu_t \sqrt{h_t} \tag{5}$$

$$h_t = \alpha_0 + \sum_{i=1}^{q} a_i \, \varepsilon_{t-i}^2 + \sum_{j=1}^{p} \beta_j \, h_{t-j} \tag{6}$$

Another variant of the GARCH-M type models is to using the standard deviation of the conditional variance having the eq. (4) the following specification:

$$Y_t = a + \beta' X_t + \gamma \sqrt{h_{\pi t}} + \varepsilon_t \tag{7}$$

Eq.(4) and (7) are the mean equations, where coefficient γ is the in-mean coefficient. Eq. (5) is the error process and Eq. (6) is the conditional variance equation.

4.3 Modelling of the relationship between inflation, inflation uncertainty and growth

Inflation – inflation uncertainty

Augmented GARCH-M approach

In order to test the relationship between inflation and inflation uncertainty, following Fountas et al. (2004), Fountas (2010), we will go one step further by using GARCH-M models extended to allow for the inclusion of a lagged inflation, as an exogenous regressor in the condition variance equation.
The system of equations we use to perform the test is described by eq. (8)-(9) below:

$$\pi_t = \Phi_0 + \sum_{i=1}^{n} \Phi_i \pi_{t-i} + \sum_{i=1}^{m} \Phi_{\varepsilon i} \varepsilon_{t-i} + \gamma \sqrt{h_{\pi t}} + \varepsilon_t \quad (8)$$

$$h_{\pi t} = \alpha_0 + \sum_{i=1}^{q} a_i\, \varepsilon_{t-i}^2 + \sum_{j=1}^{p} \beta_j\, h_{\pi t-j} + \delta \pi_{t-1} \quad (9)$$

Equation (8) is a standard, time series model of inflation, where the conditional mean of inflation, π_t , is assumed to follow an autoregressive, moving average process (ARMA). Inflation at time t is a function of past values of inflation, π_{t-i} , (AR terms) and past values of error term, ε_{t-i}, (MA terms). Equation (9) is the augmented with a lagged inflation conditional variance equation. $h_{\pi t}$, denotes the conditional variance of inflation as proxy for uncertainty [1] .

The advantage of this framework is that not only allows for simultaneously estimation of the mean and the condition variance equation but also allows for the examination of a possible simultaneous feedback between inflation and inflation uncertainty.

Coefficient γ represents the effect of inflation uncertainty on inflation. An estimated positive and significant γ is interpreted as evidence in favour of the Cukierman–Meltzer hypothesis (higher inflation uncertainty leads to more inflation). On the other hand, a negative sine for the coefficient γ is in consistent with Holland hypothesis (higher inflation uncertainty reduces inflation).

[1] The volatility measure used in the conditional mean equation (8) is Standard Deviation rather than variance. This approach to the in-mean modeling of inflation, was introduced by, Baillie et al. (1996).

Coefficient δ represents the effect of inflation on inflation uncertainty. Estimated positive and significant δ-coefficients are consistent with Friedman-Ball link (higher inflation leads to more inflation uncertainty).

Two step-approach

Following the alternative two step-approach, the above theories are also examined by employing Granger-causality tests, were an estimate of the conditional variance is first obtained from GARCH models. The equations we use to perform these tests are

$$\pi_t = a_0 + \sum_{i=1}^{k} a_i \, \pi_{t-i} + \sum_{i=1}^{k} \gamma_i \, h_{\pi t-i} + \varepsilon_{\pi t} \tag{10}$$

$$h_{\pi t} = \beta_0 + \sum_{i=1}^{k} \beta_i \, h_{\pi t-i} + \sum_{i=1}^{k} \delta_i \, \pi_{t-i} + \varepsilon_{ht} \tag{11}$$

where $h_{\pi t-i}$ is the lagged conditional variance of inflation estimated with GARCH models without the in mean term, and k is the number of lags specified.

Equation (10) is used to test whether inflation uncertainty causes inflation while, equation (11) is used to test whether inflation causes inflation uncertainty (lagged effect).

We test the statistical significance of overall (positive or negative) effects of the causality between π_t and $h_{\pi t}$.

The hypotheses of interest for eq. (10) are:

H_0: γ_1 = 0 and γ_2 = 0 … and γ_k = 0
H_1: at least one γ is different from zero ,

while for eq. (11) are:

H_0: δ_1 = 0 and δ_2 = 0 … and δ_k = 0
H_1: at least one δ is different from zero

Rejection of the null hypotheses implies that inflation uncertainty Granger-causes inflation and vice versa. Likewise, evidence that $\sum_{i=1}^{k} \gamma_i > 0$ is consistent with Cukierman–Meltzer hypothesis and evidence that $\sum_{i=1}^{k} \gamma_i < 0$ is consistent with Holland hypothesis. Similarly, a $\sum_{i=1}^{k} \delta_i > 0$ provides support for the Friedman-Ball argument.

Standard Grander-causality models are a test of temporal ordering between two variables and do not reveal the sign of the relationship. In particular, inflation uncertainty could be found to Granger-cause inflation, but whether uncertainty raises or lowers inflation would be obvious from a Granger equation estimated with OLS. Therefore, we will also calculate and report the sum of the coefficients from each Granger equation using OLS, to determine whether the Granger causality, when found, is positive or negative.

Inflation uncertainty - output growth

To test for the effect of inflation uncertainty on output growth, the following equation is estimated

$$Y_t = \varphi_o + \sum_{i=1}^{k} \varphi_i Y_{t-i} + \sum_{i=1}^{k} z_i h_{\pi t-i} + \varepsilon_{Yt} \tag{12}$$

Then performing Granger-causality test, we examine the null hypothesis:

H_0: $z_1 = 0$ and $z_2 = 0$ … and $z_k = 0$

Rejection of the null hypothesis indicates that inflation uncertainty causes output growth. Especially, an evidence that $\sum_{i=1}^{k} z_i > 0$ is consistent with the second Friedman argument that inflation uncertainty has negative real effects. In contrast, if $\sum_{i=1}^{k} z_i < 0$ there is support for the theoretical model of Dotsey and Sarte that inflation uncertainty raises output growth.

4.4 Restrictions for the Conditional Variance

In GARCH-type models, the parameters have to satisfy conditions that restrict the conditional variance to be positive. First, Bollerslev (1986) proposed the GARCH (p, q) model and imposed conditions which were sufficient to ensure the non-negativity of all the parameters in the conditional variance. Later, Nelson and Cao (1992) showed that the conditions of the coefficients given by Bollerslev can be relaxed by allowing some parameters in variance equation to be negative.

The most commonly used higher-order GARCH models are of order 2 because of the algebra becomes tedious for p, $q \geq 2$. Moreover, as He and Terasvirta (1999) have shown, GARCH (p, q) models with max $\{p, q\}$ =2 which allow some negative parameters, imply richer shapes of autocorrelation function of the squared residuals, than the constraints that restricting the parameters to be non-negative.

So, we will restricted to the case of p, q ≤ 2. Especially, the models that will be examined are GARCH (1, 0), GARCH (1, 1), GARCH (1, 2), GARCH (2, 1) and GARCH (2, 2). Considering the following GARCH (p, q) model, we are present these conditions:

$$h_t = \alpha_0 + \alpha_1\,\varepsilon_{t-1}^2 + \cdots + \alpha_q\,\varepsilon_{t-q}^2 + \beta_1\,h_{t-1} + \cdots + \beta_p\,h_{t-p}$$

Engle's Conditions: Assume that $\alpha_0 > 0$ and $0 < \alpha_i < 1$ for $i = 1$, $p = 0$.

Bollersev's Conditions: Assume that $\alpha_0 > 0$, $\alpha_i \geq 0$ with at least one $\alpha_i > 0$ and $\beta_i \geq 0$ for i = 1, 2. Also, the necessary and sufficient condition for the second order stationarity of model is $\sum_{i=1}^{q} \alpha_i + \sum_{i=1}^{p} \beta_i < 1$.

Nelson and Cao's Conditions: Allow some negative parameters. More precisely,

1. In the GARCH (1, 2) model, assume that $\alpha_0 > 0$, $\alpha_1 \geq 0$, $0 \leq \beta_1 < 1$, and $\beta_1\alpha_1 + \alpha_2 \geq 0$.

2. In the GARCH (2, 1) model, assume that $\alpha_0 > 0$, $\alpha_1 \geq 0$, $\beta_1 \geq 0$, $\beta_1 + \beta_2 < 1$ and $\beta_1^2 + 4\beta_2 \geq 0$.

3. In the GARCH (2, 2) model, assume that (a) $\alpha_1 \geq 0$, (b) $\beta_1\alpha_1 + \alpha_2 \geq 0$, (c) $\beta_1(\beta_1\alpha_1 + \alpha_2) + \beta_2\alpha_1 \geq 0$ (d) the roots of $1 - \sum_{i=1}^{2} \beta_i\, z^i$ lie outside the unit circle and the polynomials $1 - \sum_{i=1}^{2} \beta_i\, z^i$ and $\sum_{i=1}^{2} \alpha_i\, z^{i-1}$ have no common roots, (e) λ_1 and λ_2 are real numbers and $\lambda_1 > 0$, where λ_1 and λ_2 are the roots of $1 - \beta_1 z^{-1} - \beta_2 z^{-2}$, (f) $\alpha_0 / (1 - \lambda_1 - \lambda_2 + \lambda_1\,\lambda_2) > 0$, (g) $\alpha_1\,\lambda_1 + \alpha_2 > 0$.

5 Empirical Approach and Results

5.1 Description of the Data

We use monthly data on the Consumer Price Index (CPI) and a Production Index (PI), as proxies for inflation and output growth rates respectively. The data are obtained from the International Financial Statistics of the IMF database and refer to the G-20 countries, excluding Australia due to missing data in the monthly data file. In addition, Euro Area is used as the twentieth country of G-20 instead of European Union. Table 4 summarizes the G-20 countries, the data definition and sample size for all countries.

Table 4: Price and Output Data for G-20 countries

Countries	*Price Data*	*Output Data*	*Sample period*	*Number of observations*
Industrial Countries				
Canada	CPI	IPI	1969:01-2010:11	503
France	CPI	IPI	1969:01-2010:11	503
Germany	CPI	IPI	1991:01-2010:11	239
Italy	CPI	IPI	1969:01-2010:11	503
Japan	CPI	IPI	1969:01-2010:12	504
South Africa	CPI	MPI	1969:01-2010:11	503
Turkey	CPI	IPI	1989:01-2010:11	263
United Kingdom	CPI	IPI	1969:01-2010:11	503
United States	CPI	IPI	1969:01-2010:12	504
Euro Area	CPI	IPI	1998:01-2010:12	156
Middle East Countries				
Saudi Arabia	CPI	CPPI	1980:02-2010:12	372
Asia Countries				
China	CPI	-	1980:10-2010:12	353
India	CPI	IPI	1969:01-2010:10	502
Indonesia	CPI	CPPI	1971:07-2011:01	475
Korea	CPI	IPI	1970:01-2010:12	492
Russia	CPI	IPI	1995:01-2010:12	192
West Hemisphere				
Argentina	CPI	CPPI	1989:04-2010:11	260
Brazil	CPI	IPI	1992:07-2010:12	222
Mexico	CPI	IPI	1980:01-2010:11	371

Notes: Data are obtained from the International Financial Statistics of the IMF.

CPI: Consumer Price Index, IPI: Industrial Production Index, MPI: Manufactured Production Index, CPPI: Crude Petroleum Production Index.

For China there are no monthly data for Production Index. For CPPI in Argentina there are missing data during the period 1989:10-1993:1 and 2008:3-2008:5

The output data are seasonally adjusted with a few exceptions for India, Indonesia, Russia and S. Arabia, where these series were seasonally adjusted using the Tramo/Seats and Census X12 adjustments procedures provided in Eviews. Inflation is measured by the annualized monthly difference of the logarithm CPI:

$$\pi_t = log\left(\frac{CPI_t}{CPI_{t-1}}\right) * 1200 .$$

Real output growth is measured by the annualized monthly difference of the logarithm of the Production Index (PI):

$$y_t = log\left(\frac{PI_t}{PI_{t-1}}\right) * 1200 .$$

The inflation and output growth rates of the countries are plotted in Appendix. Summary statistics on both rates are presented in Tables 5 and 6. The reported

Table 5: Summary Statistics for Inflation

Countries	*Mean*	*Skewness*	*Kurtosis*	*J-B*
Industrial Countries				
Canada	4.322	0.421	4.407	56.301 (0.000)
France	4.676	0.657	3.441	40.197 (0.000)
Germany	1.915	0.930	5.574	100.112 (0.000)
Italy	6.883	1.475	5.370	299.623 (0.000)
Japan	2.919	1.669	8.013	760.3985 (0.000)
South Africa	9.284	1.187	4.476	163.642 (0.000)
Turkey	33.692	6.872	66.082	45504.15 (0.000)
United Kingdom	6.180	1.869	10.207	1378.982 (0.000)
Unites States	4.339	-0.177	6.381	242.325 (0.000)
Euro Area	1.987	-0.501	4.041	13.504 (0.000)
Middle East Countries				
Saudi Arabia	1.261	-0.687	30.570	11748.23 (0.000)
Asia Countries				
China	4.517	0.011	4.400	29.590 (0.000)
India	7.609	0.103	4.444	44.425 (0.000)
Indonesia	11.345	3.327	19.752	6417.295 (0.000)
Korea	7.276	1.649	7.103	567.214 (0.000)
Russia	20.178	7.340	75.012	42985.71 (0.000)
West Hemisphere				
Argentina	34.165	6.686	53.062	28977.22 (0.000)
Brazil	38.890	3.808	18.433	2727.702 (0.000)
Mexico	23.158	8.162	92.295	127037.4 (0.000)

statistics for inflation rate indicates that the distributions generally are nonnormal. In particular, the skewness measure indicates that all countries series are positively skewed except United States, Euro Area and Saudi Arabia and the kurtosis measure indicates that are highly leptokurtic (kurtosis > 3) relative to the normal distribution. The last column of Table 5 is the Jarque-Bera (J-B) normality test, where the large values of J-B statistics reject the null hypothesis of a normal distribution for all countries, confirming non-normality.

Similar are the results of statistics for output growth (Table 6). The growth rates are highly leptokurtic for all countries while for Canada, France, South Africa, India, Indonesia, Argentina and Brazil are positively skewed and for the rest of the countries are negatively skewed indicating nonnormality for all countries. The deviation from normality is also confirmed by the reported skewness and the J-B statistics.

Table 6: Summary Statistics for Output Growth

Countries	*Mean*	*Skewness*	*Kurtosis*	*J-B*	
Industrial Countries					
Canada	2.606	0.477	9.402	876.425	(0.000)
France	1.325	0.012	4.468	45.137	(0.000)
Germany	0.920	-0.629	5.591	82.331	(0.000)
Italy	1.234	-0.040	10.984	1333.548	(0.000)
Japan	2.279	-1.175	8.700	796.904	(0.000)
South Africa	2.306	0.219	4.043	26.795	(0.000)
Turkey	3.973	-0.305	4.288	22.211	(0.000)
United Kingdom	0.755	-0.142	13.059	2118.274	(0.000)
United States	2.123	-1.061	7.349	490.879	(0.000)
Euro Area	0.801	-1.183	6.165	100.884	(0.000)
Middle East Countries					
Saudi Arabia	-0.758	-0.208	10.663	908.692	(0.000)
Asia Countries					
India	6.082	0.335	16.425	3771.744	(0.000)
Indonesia	-0.218	0.024	13.240	2071.191	(0.000)
Korea	10.296	-0.517	7.759	485.345	(0.000)
Russia	4.048	-0.615	6.171	92.096	(0.000)
West Hemisphere					
Argentina	0.643	0.238	6.434	102.185	(0.000)
Brazil	3.001	-1.823	13.656	1168.068	(0.000)
Mexico	2.127	0.097	4.524	36.411	(0.000)

5.2 Unit Root Tests

Following the construction of annualized monthly inflation and real output growth series, in order to undertake this empirical analysis, the second step is to examine the time series properties of the variables. The presence of a unit root in the time series analysis has important implications for both the econometric method used and the economic interpretation of the model in which that variable appears.

A visual inspection of variables, especially of macroeconomic series, often suggests that they are trending, and therefore nonstationary. As economic theory shows, when variables are unit root non stationary, standard asymptotic distribution theory does not apply to the econometric system involving these variables and the standard ordinary least squares (OLS) model cannot be applied while there might be a spurious regression. Spurious regressions are normally characterized by having a high R^2 and statistical significant t-statistics.

In the present analysis we examine two of traditional and most popular unit root tests: the ADF and the PP test, and two of "second generation tests" such as DF-GLS and Ng-Perron.

5.2.1 The Augmented Dickey- Fuller (ADF) Test

Dickey and Fuller (1979, 1981) devised a procedure to formally test for non-stationarity. The key insight of their test is that testing for non-stationarity is equivalent to testing for the existence of a unit root. Thus, the basic objective of the test is to examine whether φ is equal to 1 (and hence 'unit root'), on a simple autoregressive AR (1) model of the form:

$$y_t=\varphi y_{t-1} + u_t \qquad (13)$$

$$u_t \sim WN\ (0, \sigma^2\ )$$

The null hypothesis is

$H_0:\ \varphi = 1\ \rightarrow\ y_t \sim I\ (1)$, which means that series contains a unit root

and the alternative hypothesis is

$H_1:\varphi < 1\ \rightarrow\ y_t \sim I\ (0)$, indicating that series are stationary.

However, the test above is valid only if u_t is white noise. As the error term is unlikely to be white noise, Dickey and Fuller extended their test procedure suggesting an augmented version of the test which includes extra lagged terms of the dependent variable in order to eliminate autocorrelation. The three possible forms of the Augmented Dickey Fuller (ADF) test are given by the following equations:

$$\Delta y_t = \psi y_{t-1} + \sum_{i=1}^{p} \beta_i \, \Delta y_{t-1} + u_t \qquad (14)$$

$$\Delta y_t = \alpha_0 + \psi y_{t-1} + \sum_{i=1}^{p} \beta_i \, \Delta y_{t-1} + u_t \qquad (15)$$

$$\Delta y_t = \alpha_0 + \psi y_{t-1} + \alpha_1 t + \sum_{i=1}^{p} \beta_i \, \Delta y_{t-1} + u_t \qquad (16)$$

where $\psi = \varphi - 1$

The difference between the three regressions is the presence of the deterministic elements α_0 and$\alpha_1 t$, where α_0 is a constant and t is the trend term. The lag length of these extra terms is either determined by the Akaike Information Criterion (AIC) or Schwartz Bayesian Criterion (SBC), or by the lag length necessary to whiten the error term. The residuals are also need to be homoskedastic.

The ADF test statistic (t-statistic) and normalized bias statistic are based on the least squares estimates of the above equations and are given by

$$ADF_t = t_\psi = \frac{\hat{\psi}}{se\,(\hat{\psi})}$$

$$ADF_n = \frac{T\hat{\psi}}{1 - \hat{\beta}_1 - \cdots - \hat{\beta}_p}$$

where $\hat{\psi}$ is the estimate of ψ , $\hat{\beta}$ the estimate of β and $se\,(\hat{\psi}\,)$ is the coefficient standard error.

Dickey and Fuller show that the test statistics do not follow the conventional Student's t-distributions under the null hypothesis and they derive asymptotic results and simulate critical values for various tests and sample sizes. Most recently, MacKinnon (1991, 1996) derive a much larger set of simulations than those of Dickey and Fuller. The null hypothesis of a unit root which implies that $\psi = \varphi - 1 = 0$, is rejected in favour of the stationarity alternative in each case if the test statistic is more negative than the critical value.

5.2.2 The Phillips-Perron (PP) Test

Phillips and Perron (1988) proposed an alternative method of controlling for serial correlation when testing for a unit root. The PP unit root tests differ from the ADF test mainly in how they deal with serial correlation and heteroskedasticity in the errors. More analytically, while the ADF test is based on the assumption that the error terms are statistically independent and have a constant variance, Phillips and Perron developed a generalization of the ADF procedure that allows for fairly mild assumptions concerning the distribution of errors. They use nonparametric statistical methods to take care of serial correlation in the error terms without adding lagged different terms.

To be more specific, the test regression for the Phillips-Perron is based on

$$\Delta y_t = \alpha_0 + \psi y_{t-1} + \alpha_1 t + u_t \tag{17}$$

where u_t is I (0) and may be heteroskedastic.

As mentioned before, while the ADF test corrects for higher order serial correlation by adding lagged differenced terms on the right-hand side, the PP test makes a correction (modify) to the statistics of the coefficient ψ from (17) regression to account for the serial correlation and heteroskedasticity in u_t . This modified statistics are given by

$$Z_t = \sqrt{\frac{\sigma^2}{f_0}}\; t_\psi - \frac{1}{2}\,(f_0 - \sigma^2)\,\frac{Tse(\hat{\psi})}{\sqrt{f_0 s^2}}$$

$$Z_\psi = T\hat{\psi} - \frac{1}{2}\,(f_0 - \sigma^2)\,\frac{T^2 se(\hat{\psi})}{s^2}$$

where $\hat{\psi}$ is the estimate of ψ , $se\,(\hat{\psi})$ is the coefficient standard error, s is the standard error of the test regression, σ^2 is a consistent estimate of the error variance in (17) , t_ψ is the t - ratio of ψ, and f_0 is an estimator of the residuals spectrum at frequency zero. The New-West (Bartlett) weights in the computation of f_0.

The PP unit root test is carried as in ADF test, by testing the null hypothesis $\psi = 0$, against the alternative $\psi < 0$. Also, the asymptotic distribution of the PP statistics is the same as the ADF statistics and similarly the test can be performed with the inclusion of a constant, of a linear trend, or a combination of the two. The same critical values from the MacKinnon tables are used us before.

One major advantage of the PP test over the ADF test is that PP tests are robust to general forms of heteroskedasticity in the error term, as another advantage is that users do not have to specify lag length for the test regression. In contrast, it requires a bandwidth parameter selection (as part of the New- West covariance estimator) which may be creates finite sample problems analogous to those associated with lag length selection in applying the ADF test. In principle, the PP tests tend to be more powerful than the ADF alternative but also subject to more severe size distortions if the moving average terms are large negative.

5.2.3 Modified ADF and PP Tests

Main criticism of ADF and PP tests is that the power of the tests is low if the process is stationary but with a root close to the non-stationary boundary. Schwert (1989) showed that these tests suffer from quite opposite problems. He demonstrated poor power properties for the ADF and poor size properties for PP tests.

In recent years, a variety of alternative procedures have been proposed that try to resolve these problems and improving the power features of the tests. Among these recent unit root tests described by Elliott, Rothenberg, and Stock (1996) and Ng and Perron (2001) which involve a step of detrending before constructing the test statistics. However, the selection a proper unit root test depends on the researcher while there is still no consensus on any one particular test as the 'most powerful' test.

5.2.3.1 The DF-GLS Unit Root Test

Elliott, Rothenberg, and Stock (1996) introduce a potentially more powerful unit root test in small samples: the Generalized Least Squares of the ADF test. They find that powers of ADF tests are lower than those of the limiting power functions when deterministic components (mean or trend) are included in the data generating process.

In terms of the size of the test, DF-GLS, is almost as the ADF t-test ADF_t and better than PP Z_t and Z_ψ test. In addition, the power of the DF-GLS is larger than ADF t-test especially when φ is close to unity.

ERS, to test for a unit root, estimate by least squares the following ADF test regression which omits the deterministic terms,

$$\Delta y_t{}^{d} = \psi y_{t-1}{}^{d} + \sum_{i=1}^{p} \beta_i \; \Delta y_{t-1}{}^{d} + u_t \tag{18}$$

where y_t^d is the detrended data defined as

$$y_t^d = y_t - x_t' D_t(\overline{c}) \tag{19}$$

D_t represents a vector of deterministic terms and $\overline{c}$ is the local-to-unity parameter which must be specified.

The hypotheses of interest are:

$H_0 : \psi = 0$

$H_1 : \psi < 0$

They called this detrending procedure GLS detrending. Typically D_t = 1 or $D_t = [1,\ t]$. When, D_t = 1 then $\overline{c} = -7$ and if $D_t = [1, t]$ then $\overline{c} = -13.5$. So, following ERS, the local-to-unity parameter is selected as:

$$\bar{c} = \begin{cases} 1 - \dfrac{7}{T} \ , \ if \ \ x_t = \{1\} \\ 1 - \dfrac{13.5}{T} \ , if \ \ x_t = \{1, t\} \end{cases}$$

Furthermore, when D_t = 1, ERS show that the asymptotic distribution of the DF-GLS test is the same as the ADF t-rest, but has higher asymptotic power.

5.2.3.2 The Ng-Perron (NP) Unit Root Test

Ng and Perron (2001) use the GLS detrending procedure of ERS to create efficient versions of the modified PP tests of Perron and Ng (1996). These tests do not exhibit the severe size distortions of the PP tests for errors with large negative MA or AR roots, and they can has substantially higher power in small samples than the PP test especially when φ is close to unity. However, a drawback of NP tests is that for non-local alternatives the power can be very small. In fact, for a given sample size T, the power can decrease as φ gets farther away from 1.

The Ng-Perron tests are defined as

$$MZ_a = \left(T^{-1}\,(y_T^d)^2 - f_0\right)/(\,2k\,)$$

$$MSB = (\,k/\,f_0\,)^{1/2}$$

$$MZ_t = MZ_a \times\ MSB$$

$$MP_t = \begin{cases} \bar{c}^2 k - \bar{c}\,T^{-1}\,(y_T^d)^2\,/\,f_0 & ,if\ \ x_t\ =\ \{1\} \\ \bar{c}^2 k + (1-\bar{c})\,T^{-1}\,(y_T^d)^2\,/\,f_0 & ,if\ \ x_t\ =\ \{1,t\} \end{cases}$$

where , $k = \sum_{t=2}^{T}(y_{t-1}^d)^2/T^2$ and $\bar{c} = \begin{cases} -7\ , & if\ \ x_t\ =\ \{1\} \\ -13.5 & ,if\ \ x_t\ =\ \{1,t\} \end{cases}$

The statistics MZ_a and MZ_t are efficient versions of the PP Z_a and Z_t tests that have much smaller size distortions in the presence of negative moving average errors. Ng and Perron derive the asymptotic distributions of these statistics under the local alternative $\varphi = 1 - c/T$ for D_t = 1 and $D_t\ =\ [1,t]$. In particular, they show that the asymptotic distribution of MZ_t is the same as the DF-GLS t-test.

Choosing Lag Lengths, p , to Achieve Good Size and Power

Ng and Perron also stress that good size and power properties of all the efficient unit root tests rely on the proper choice of the lag length p used for specifying the test regression (18). They suggest the modified information criteria (MIC) that selects p as

$$p_{MIC} = \arg min_{p \le p_{max}} MIC(p)$$

where

$$MIC(p) = \ln\left(\hat{\sigma}_p^2\right) + \frac{C_T\,(\tau_T(p) + p)}{T - p_{max}}$$

with $C_T > 0$ and $C_T/T \to 0$ as $T \to \infty$.

Estimating the frequency zero spectrum, f_0

Ng and Perron (2001) emphasize that the estimation of f_0 has important implications for the finite sample behavior of the efficient modified PP tests. They stress that an autoregressive estimate of f_0 should be used to achieve stable finite sample size. They recommend estimating f_0 from the ADF test regression (18) based on the GLS detrended data:

$$\widehat{\mathrm{f}}_{0_{AR}} = \frac{\hat{\sigma}_p^2}{(1-\hat{\beta}(1))^2}$$

where $\hat{\beta}(1) = \sum_{j=1}^{p} \hat{\beta}_j$ and $\hat{\sigma}_p^2 = (T-p)^{-1} \sum_{t=p+1}^{T} \hat{u}_t^2$ are obtained from (18) by least squares estimation.

5.2.4 Empirical Results of Unit Root Tests

The results of the two standard unit root tests used in most studies (ADF, PP) and of the two additional tests have recently developed (DF-GLS, NP) for the inflation series and output growth are reported in Tables 7 and 8, respectively. The null hypothesis is that there is a unit root in series. We reject the null hypothesis when the test statistic is less than the corresponding critical value. The regression models on which the unit root tests are based include only a constant, without a deterministic linear trend.

The ADF unit root test statistics for inflation rate (Table 7) indicate that is a stationary series for all countries, except Japan. Similar are the results of the PP test statistics which show the rejection of unit root for all countries implying the stationarity of inflation rate. The other test statistics are less clear cut; however the null of a unit root is not rejected for Canada, Germany, South Africa, Turkey, United Kingdom, China, India, Korea, and Russia in the case of the DF-GLS test implying that inflation is stationary for France, Italy, Japan, United states, Euro Area, Saudi Arabia, Indonesia, Argentina, Brazil and Mexico. In the case of Ng-Perron test, inflation series do not have unit root and so are stationary series only for France, Italy, United States, Saudi Arabia and Brazil.

Furthermore, the unit root tests for output growth are presented in Table (8). According the ADF and PP tests the series are integrated of order zero, meaning that each of the output growth series are stationary for all countries taking into consideration both tests. Applying the DF-GLS and NP tests the results show some ambiguity. More specifically, DF-GLS tests for each country, fail to reject the null hypothesis of unit root on output growth series for Turkey, India, Korea and Argentina. For the rest of countries DF-GLS tests indicate the stationarity of series. NP test statistics confirm these results of DF-GLS tests, adding evidence for non

Table 7: Unit Root Tests for Inflation

Countries	*ADF*	*P-P*	*DF-GLS*	*Ng-Perron test*	
	t-stat	*Adj. t-stat*	*t-stat*	*MZa*	*MZt*
Industrial Countries					
Canada	-7.215*	-20.138*	-1.376	-2.286	-1.067
France	-2.585***	-14.051*	-1.997**	-7.485***	-1.880***
Germany	-3.278**	-16.764*	-0.718	-0.485	-0.404
Italy	-2.947**	-13.740*	-2.087**	-7.357***	-1.917***
Japan	-2.202	-19.292*	-2.118**	-2.729	-1.146
South Africa	-10.005*	-24.587*	-1.248	-1.893	-0.970
Turkey	-15.674*	-15.689*	-1.529	-1.546	-0.878
United Kingdom	-2.579*	-17.329*	-1.348	-2.405	-1.040
United States	-11.843*	-12.735*	-2.044**	-6.170***	-1.700***
Euro Area	-3.083**	-11.987*	-2.458**	-1.470	-0.662
Middle East Countries					
Saudi Arabia	-16.276*	-17.441*	-2.120**	-7.360***	-1.876***
Asia Countries					
China	-3.073**	-18.728*	-1.534	-3.323	-1.267
India	-13.850*	-13.837*	-0.744	-0.664	-0.417
Indonesia	-8.098*	-13.869*	-2.570*	-11.318**	-2.348**
Korea	-11.456*	-11.596*	-1.065	-2.375	-1.031
Russia	-5.112*	-9.739*	-1.131	-3.002	-1.134
West Hemisphere					
Argentina	-11.903*	-7.970*	-11.954*	-0.196	-0.313
Brazil	-7.212*	-8.860*	-6.899*	-64.532*	-5.680*
Mexico	-2.765***	-19.317*	-2.145**	-3.240	-1.271

Notes: The tests include a constant. Lag length is chosen on the basis of Schwartz Bayesian Criterion with a maximum lag of 12 periods and on the New-West Bandwidth for PP test.
*, **, *** denotes significance at the 1% 5%and 10% level, respectively.
ADF test critical values: -3,464(1%), -2,876(5%), -2,569(10%), P-P test critical values: -3, 464(1%), -2,867(5%), -2, 569(10%), DG-GLS test critical values: -2, 569(1%), -1,942(5%), -1,615(10%), Ng-Perron critical values for MZa -13.8(1%), -8.1(5%), -5.7(10%), for MZt: -2.58(1%), -1.98(5%), -1.62(10%).

Table 8: Unit Root Tests for Output Growth

Countries	ADF	P-P	DF-GLS	Ng-Perron test	
	t-stat	Adj. t-stat	t-stat	MZa	Mzt
Industrial Countries					
Canada	-10.682*	-25.097*	-3.286*	-9.605**	-2.182**
France	-11.176*	-29.183*	-3.173*	-7.657***	-1.760***
Germany	-6.356*	-16.799*	-2.663*	-11.731**	-2.409**
Italy	-29.656*	-29.646*	-1.979**	-4.675	-1.444
Japan	-8.559*	-22.018*	-4.986*	-36.822*	-4.269*
South Africa	-13.653*	-37.969*	-1.781***	-1.299	-0.606
Turkey	-17.507*	-41.014*	-1.408	0.008	0.007
United Kingdom	-26.369*	-26.562*	-24.561*	-248.304*	-11.142*
United States	-8.141*	-17.177*	-7.137*	-78.852*	-6.269*
Euro Area	-3.512*	-11.863*	-3.410*	-14.034*	-2.643*
Middle East Countries					
Saudi Arabia	-16.224*	-16.058*	-15.269*	-175.220*	-9.359*
Asia Countries					
India	-23.406*	-44.349*	-0.571	0.638	0.648
Indonesia	-19.648*	-28.763*	-2.298**	-2.849	-1.187
Korea	-25.552*	-25.321*	-1.328	-2.938	-1.202
Russia	-16.575*	-16.491*	-8.817*	-70.799*	-5.936*
West Hemisphere					
Argentina	-17.008*	-37.672*	-0.269	0.164	0.243
Brazil	-15.455*	-15.455*	-13.974*	-109.638*	-7.403*
Mexico	-6.557*	-22.131*	-2.326**	-8.053***	-1.976***

Notes: The tests include a constant. Lag length is chosen on the basis of Schwartz Bayesian Criterion with a maximum lag of 12 periods and on the New-West Bandwidth for PP test.
*, **, *** denotes significance at the 1% 5%and 10% level, respectively.
ADF test critical values: -3,464(1%), -2,876(5%), -2,569(10%), P-P test critical values: -3, 464(1%), -2,867(5%), -2, 569(10%), DG-GLS test critical values: -2, 569(1%), -1,942(5%), -1,615(10%), Ng-Perron critical values for MZa -13.8(1%), -8.1(5%), -5.7(10%), for MZt: -2.58(1%), -1.98(5%), -1.62(10%).

stationary output growth series also for Italy, S. Africa, Indonesia and Korea.

The inferences about the stationarity of both inflation and output growth rates depend on the unit root tests we use each time. In present analysis taking into consideration the ADF and PP results and following the majority of bibliography we rely on these tests where inflation and output growth are stationary process.

5.3 Diagnostic Tests on Residuals

Before estimating a GARCH-type model, it is sensible first to examine the residuals of the mean equation (inflation) for time varying volatility so that make sure that this class of models is appropriate for the data.
Here, the test for ARCH or GARCH effects is approaching with two tests: (1) The ARCH LM test and (2) The Ljung-Box test of the squared residuals.

5.3.1 The ARCH LM Test

The ARCH test is a Lagrange Multiplier (LM) test for autoregressive conditional heteroskedasticity (ARCH) in the residuals developed by Engle (1982). The correlations with lagged values of the squares of the residuals provide evidence about ARCH or GARCH effect. An LM test of ARCH (q) against the hypothesis of no ARCH effects [ARCH (0)] can be carried by computing TR^2 statistic in the regression of ε_t^2 on a constant and q lagged values. Under the null hypothesis of no ARCH effects, values larger than the critical values, give evidence of ARCH/GARCH effects.

To be more specific, the first step involved in the ARCH test is to estimate a linear model so that the residuals can be tested for ARCH. So, considering a κ-variable linear regression model,

$$\mathrm{Y}_t = \beta_1 + \beta_2 \mathrm{X}_{2t} + \ldots + \beta_k \mathrm{X}_{kt} + \varepsilon_t \tag{20}$$

we can obtain the residuals, $\hat{\varepsilon}_t$.

In the next step, as Engle has shown, in order to test for ARCH effect is needed to regress the squared OLS residuals against a constant and on q own lags:

$$\hat{\varepsilon}_t^2 = \gamma_0 + \gamma_1 \hat{\varepsilon}_{t-1}^2 + \gamma_2 \hat{\varepsilon}_{t-2}^2 + \ldots + \gamma_q \hat{\varepsilon}_{t-q} + \upsilon_t \tag{21}$$

where υ_t is an error term.

The null hypothesis of no ARCH effects against the alternative hypothesis is:

H_0: $\gamma_1 = 0$ and $\gamma_2 = 0$ … and $\gamma_q = 0$
H_1: at least one of γ_1 , γ_2… γ_q is different from zero

The Engle's LM test statistic is defined as TR^2 (the number of observations multiplied by the coefficient of multiple correlation) from the last regression, which in large samples it approximately follows the x^2 (q) chi-squared distribution.
One can test the null hypothesis H_0 by the usual F test, or alternatively by LM= TR^2
If LM > x^2 (q) for a given level of significance the null hypothesis is rejected, concluding that ARCH effects are indeed present.

Bollerslev (1986) shows that the LM test for a qth order ARCH is equivalent to a test for GARCH (i , j) where $i + j = q$.

5.3.2 The Ljung - Box Test

The Ljung-Box test is a Q-test for serial correlation on the residuals and the squared residuals.

The hypotheses of interest are:

H_0: no serial correlation
H_1: serial correlation

In order to test the above hypotheses, the Q-statistic of Ljung-Box test is used, which is computed as:

$$Q_{LB} = T(T+2)\sum_{j=1}^{k}\frac{r_j^2}{T-j} \qquad (22)$$

where r_j is the j-th autocorrelation, k is the lag- length and T is the number of observations.

However, the Q-statistics of squared residuals (Q^2-statistic) can be used to check for ARCH effects. Under the null hypothesis that there is no serial correlation on squared residuals against the alternative of serial correlation of squared residuals, the rejection of null hypothesis implies that the residuals are significantly time varying indicating ARCH effect.

In large samples, it is approximately distributes as the chi-squared distribution. In an application, if the computed Q-statistic exceeds the critical value from the chi-square distribution at the chosen level of significance, one can reject the null hypothesis.

5.3.3 Empirical Results of Diagnostic Tests

Table 9 and 10 present the Ljung-Box statistics of the squared deviations of inflation from the sample means and the ARCH-LM statistics, respectively, for one, two, four and twelve lags. The large and significant Q^2 test statistics indicate that the inflation error variance is significantly time varying in the majority of countries at the 1% level or less, signifying the typical volatility clustering of an ARCH process. However there is no indication of ARCH effects in any lag for Saudi Arabia and Russia. These findings are also confirmed by the ARCH-LM test statistics (Table 10) where the null hypothesis of homoskedasticity or constant variance, is rejected for

Table 9: Ljung-Box Tests for Inflation

Countries	Q^2 [1]-stat	Q^2 [2]-stat	Q^2 [4]-stat	Q^2 [12]-stat
Industrial Countries				
Canada	3.104 (0.078)	6.985 (0.030)	10.256 (0.036)	24.116 (0.020)
France	31.070 (0.000)	60.998 (0.000)	159.82 (0.000)	364.97 (0.000)
Germany	4.247 (0.039)	4.850 (0.088)	6.495 (0.165)	17.837 (0.121)
Italy	105.770 (0.000)	134.600 (0.000)	186.160 (0.000)	365.12 (0.000)
Japan	81.767 (0.000)	96.108 (0.000)	136.12 (0.000)	237.19 (0.000)
South Africa	0.127 (0.721)	6.508 (0.039)	11.203 (0.024)	79.841 (0.000)
Turkey	0.017 (0.895)	0.026 (0.987)	0.052 (1.000)	21.052 (0.040)
United Kingdom	26.420 (0.000)	28.400 (0.000)	38.015 (0.000)	96.641 (0.000)
United States	122.670 (0.000)	142.700 (0.000)	150.240 (0.000)	177.65 (0.000)
Euro Area	1.079 (0.299)	12.338 (0.002)	12.977 (0.011)	90.724 (0.000)
Middle East Countries				
Saudi Arabia	0.172 (0.678)	0.182 (0.913)	0.236 (0.994)	0.647 (1.000)
Asia Countries				
China	4.578 (0.032)	4.587 (0.101)	4.787 (0.310)	18.616 (0.098)
India	52.205 (0.000)	82.435 (0.000)	97.792 (0.000)	174.860 (0.000)
Indonesia	52.409 (0.000)	58.499 (0.000)	67.414 (0.000)	110.340 (0.000)
Korea	165.500 (0.000)	215.010 (0.000)	231.22 (0.000)	338.670 (0.000)
Russia	0.034 (0.852)	0.077 (0.962)	1.643 (0.801)	1.736 (1.000)
West Hemisphere				
Argentina	58.938 (0.000)	62.872 (0.000)	62.968 (0.000)	116.690 (0.000)
Brazil	16.066 (0.000)	67.450 (0.000)	104.12 (0.000)	207.340 (0.000)
Mexico	0.014 (0.904)	0.029 (0.985)	0.775 (0.942)	38.631 (0.000)

Notes: Q^2 is the Ljung-Box test for serial correlation in the squared deviations of the inflation from its sample mean. Included lags are in brackets. P-values are in parenthesis.

Table 10: ARCH LM Tests for Inflation

Countries	*LM[1]*		*LM[2]*		*LM[4]*		*LM[12]*	
Industrial Countries								
Canada	3.080	(0.079)	6.408	(0.040)	8.394	(0.078)	16.874	(0.154)
France	30.846	(0.000)	48.353	(0.000)	105.995	(0.000)	134.999	(0.000)
Germany	4.180	(0.040)	5.239	(0.072)	7.566	(0.108)	18.766	(0.094)
Italy	104.929	(0.000)	105.261	(0.000)	127.227	(0.000)	155.715	(0.000)
Japan	81.139	(0.000)	81.059	(0.000)	93.594	(0.000)	113.140	(0.000)
South Africa	0.126	(0.722)	6.406	(0.040)	10.916	(0.027)	54.616	(0.000)
Turkey	0.017	(0.896)	0.026	(0.986)	0.053	(0.999)	19.190	(0.084)
United Kingdom	26.216	(0.000)	26.216	(0.000)	33.122	(0.000)	74.768	(0.000)
United States	121.753	(0.000)	123.546	(0.000)	124.894	(0.000)	130.491	(0.000)
Euro Area	1.057	(0.303)	11.560	(0.003)	12.830	(0.012)	65.564	(0.000)
Middle East Countries								
Saudi Arabia	0.170	(0.679)	0.179	(0.914)	0.230	(0.993)	0.599	(1.000)
Asia Countries								
China	4.531	(0.033)	4.535	(0.103)	4.404	(0.354)	15.247	(0.228)
India	52.217	(0.000)	63.699	(0.000)	65.920	(0.000)	93.800	(0.000)
Indonesia	11.345	(0.000)	51.910	(0.000)	54.711	(0.000)	71.353	(0.000)
Korea	164.225	(0.000)	164.302	(0.000)	163.601	(0.000)	178.311	(0.000)
Russia	0.034	(0.853)	0.062	(0.969)	1.464	(0.833)	1.478	(0.999)
West Hemisphere								
Argentina	58.043	(0.000)	170.834	(0.000)	91.879	(0.000)	235.405	(0.000)
Brazil	15.784	(0.000)	54.654	(0.000)	56.454	(0.000)	174.925	(0.000)
Mexico	0.014	(0.905)	0.029	(0.985)	0.752	(0.944)	36.065	(0.000)

Notes: The numbers in table are the Obs *R-squared (T R^2).
Included lags are in brackets.
P-values are in parenthesis.

all countries except for Saudi Arabia and Russia, while their P-values of LM - statistics are greater than any level of significant for all lags.

Thus, given the results of diagnostic tests on residuals of inflation, in the next section we proceed to estimation of GARCH-type models in order to capture the time-varying volatility of inflation for Canada, France, Germany, Italy, Japan, South Africa, Turkey, United Kingdom, Unites States, Euro Area, China, India, Indonesia, Korea, Argentina, Brazil and Mexico and test the theories for inflation-uncertainty-output growth as described in econometric methodology. In contrast, for Saudi Arabia and Russia where there is no evidence for GARCH effects we will obtain the inflation uncertainty by computing the moving standard deviation of inflation (see section 5.5) and we will test the theories employing causality tests.

5.4 Empirical Results of the Augmented GARCH-M estimation

As discussed, in our analysis we use the GARCH(1, 0), GARCH(1, 1), GARCH(1, 2), GARCH(2, 1) and GARCH(2, 2) models where the mean inflation equation follows an ARMA model. The use of monthly data in the estimation of the general model implies that the orders of AR and MA can be greater than one [2] . Therefore, following a general-to-specific-approach we estimate various ARMA-GARCH-M models for each country where the best fitted model is chosen according to the minimum values of Akaike (AIC) and Schwartz (SBC) Information Criteria.

Tables 11a-11c present the estimates of the best selected ARMA-GARCH-M model of inflation for each country [3] formed by Eqs. (8) and (9) and their diagnostic tests. The results of interest here thought are the effects of the inflation uncertainty and lagged inflation on inflation. That is, we are interesting on the statistical significance and on the signs of coefficients γ and δ in order to test the hypothesis of Cukierman-Meltzer (or Holland) and Friedman-Ball simultaneously.

The in-mean coefficient γ is statistically significant for France, Italy, South Africa, United Kingdom, Euro Area, China, India, Indonesia, and Korea. In the majority of those cases, the coefficient is positive, providing evidence for the Cukierman-Meltzer hypothesis. To be more specific the Cukierman-Meltzer hypothesis that a higher inflation uncertainty leads to more inflation is supported for France, Italy, United Kingdom, Euro Area, China, Indonesia, Korea. However, for South Africa and India, the effect is negative, a result which is consistent with Holland argument. For Canada, Germany, Japan, Turkey, United States and Mexico the relationship between the two variables is statistically insignificance.

Concerning the effect of inflation on inflation uncertainty the coefficient δ is significant for all countries, except Canada, France, Italy, Euro Area and China. But according to Friedman-Ball a higher inflation leads to more uncertainty so their argument is supported only for Japan, United States, United Kingdom, India, Indonesia and Korea where the coefficient δ is positive.
However, for Germany, South Africa, Turkey and Mexico, the estimated coefficient δ is negative, implying that a positive inflation shock leads to less uncertainty about inflation. This negative relationship is in line with Pourgerami and Maskus (1987) argument, who hold a different view than Friedman theory that, when the inflation

[2] The selection of the ARMA models is based on AIC-SBC criteria and the whiteness of the residuals.
[3] No GARCH model satisfying all theory-implied parameter restrictions could be estimated for Argentina and Brazil.

Table 11a: Estimates of GARCH-in-Mean models of inflation

Countries	Canada	France	Germany	Italy	Japan
Mean eq.					
Φ_0	0.847(0.379)		0.209(0.519)	0.070(0.764)	1.417(0.060)
Φ_1		0.210(0.000)		0.152(0.000)	
Φ_2		0.045(0.289)		0.128(0.004)	
Φ_3	0.171(0.000)	0.138(0.003)			
Φ_4	0.169(0.000)			0.054(0.196)	
Φ_5					0.121(0.003)
Φ_6		0.243(0.000)		0.040(0.353)	
Φ_7					0.152(0.001)
Φ_8					
Φ_9					0.055(0.173)
Φ_{10}	0.146(0.000)				
Φ_{11}				0.098(0.013)	0.100(0.007)
Φ_{12}	0.267(0.000)	0.252(0.000)	0.495(0.000)	0.281(0.000)	0.520(0.000)
$\Phi\varepsilon_1$	0.097(0.050)		-0.142(0.058)		0.115(0.023)
$\Phi\varepsilon_2$	0.149(0.003)				
γ	0.041(0.877)	**0.133(0.077)**	0.168(0.136)	**0.331(0.030)**	-0.288(0.137)
D				10.510(0.000)	
Variance eq.					
α_0	1.244(0.137)	0.611(0.093)	3.503(0.000)	0.026(0.438)	0.998(0.002)
α_1	0.098(0.003)	0.030(0.558)	0.198(0.006)	0.191(0.033)	0.007(0.752)
α_2		0.039(0.506)		-0.141(0.105)	
β_1	0.807(0.000)	0.835(0.000)	0.621(0.000)	0.935(0.000)	0.912(0.000)
β_2					
δ	0.127(0.210)	0.056(0.297)	**-0.863(0.000)**	0.010(0.633)	**0.588(0.000)**
Diagnostics					
Q (8)	3.011(0.807)	1.913(0.984)	5.367(0.615)	10.619(0.224)	4.075(0.771)
Q (12)	14.496(0.152)	9.111(0.693)	12.036(0.361)	15.051(0.239)	15.843(0.147)
Q^2(8)	2.988(0.810)	3.585(0.892)	8.581(0.284)	6.681(0.571)	3.714(0.812)
Q^2(12)	4.159(0.940)	9.414(0.667)	9.725(0.555)	12.411(0.413)	10.957(0.447)
LM (8)	2.996(0.934)	3.432(0.904)	7.157(0.519)	6.290(0.614)	3.475(0.901)
LM (12)	4.163(0.980)	8.682(0.729)	8.857(0.715)	11.486(0.487)	10.531(0.569)
AIC	5.730	5.094	5.153	5.195	6.101
SBC	5.833	5.188	5.275	5.315	6.203

Notes: Q and Q^2 denote the Ljung-Box test statistic of the residuals and squared residuals, respectively.
LM denotes the test statistic of chi-square for ARCH.
AIC is the Akaike Information Criterion and SBC is the Schwarz Bayesian Criterion.
D denotes the dummy used for Italy. D=1 for 3/74-11/74, 9/76 and 2/80.
P-values are in parenthesis.

Table 11b: Estimates of GARCH-in-Mean models of inflation

Countries	S.Africa	Turkey	U.K	U.S	Euro Area
Mean eq.					
Φ_0	13.809(0.000)			0.387(0.257)	
Φ_1	-0.126(0.016)	0.882(0.000)	0.162(0.000)	0.352(0.000)	
Φ_2			0.113(0.003)		
Φ_3	0.072(0.122)				
Φ_4					
Φ_5					
Φ_6	0.130(0.007)		0.147(0.000)		0.155(0.066)
Φ_7	0.087(0.038)			0.149(0.000)	
Φ_8			-0.055(0.107)		
Φ_9	0.079(0.059)	0.185(0.002)			
Φ_{10}					
Φ_{11}		0.008(0.917)		0.152(0.000)	
Φ_{12}		-0.077(0.410)	0.459(0.000)	0.137(0.001)	0.663(0.000)
$\Phi\varepsilon_1$		-0.952(0.000)			0.148(0.071)
$\Phi\varepsilon_2$					
$\boldsymbol{\gamma}$	**-0.750(0.000)**	-0.004(0.113)	**0.410(0.000)**	0.142(0.276)	**0.210(0.066)**
D	17.722(0.000)		17.752(0.000)		
Variance eq.					
α_0	38.712(0.005)	47.538(0.000)	9.915(0.000)	0.052(0.825)	0.151(0.781)
α_1	0.116(0.000)	0.562(0.000)	0.402(0.000)	0.216(0.000)	0.052(0.105)
α_2					
β_1	0.612(0.000)			0.738(0.000)	0.905(0.000)
β_2					
$\boldsymbol{\delta}$	**-1.774(0.000)**	**-53.653(0.000)**	**2.278(0.000)**	**0.170(0.026)**	0.097(0.599)
Diagnostics					
Q (8)	4.768(0.782)	6.614(0.470)	8.573(0.380)	6.280(0.616)	4.180(0.759)
Q (12)	15.327(0.224)	10.200(0.512)	15.315(0.225)	9.811(0.632)	10.885(0.453)
Q^2(8)	6.382(0.605)	0.163(1.000)	6.693(0.570)	5.938(0.654)	8.075(0.326)
Q^2(12)	19.201(0.084)	0.296(1.000)	18.116(0.112)	7.861(0.796)	12.493(0.328)
LM (8)	6.301(0.613)	0.165(1.000)	6.902(0.547)	5.694(0.681)	6.385(0.604)
LM (12)	18.180(0.110)	0.287(1.000)	15.283(0.107)	6.941(0.861)	9.639(0.647)
AIC	7.186	10.980	6.188	5.185	4.923
SBC	7.288	11.107	6.283	5.270	5.088

Notes: Q and Q^2 denote the Ljung-Box test statistic of the residuals and squared residuals, respectively.
LM denotes the test statistic of chi-square for ARCH.
AIC is the Akaike Information Criterion and SBC is the Schwarz Bayesian Criterion.
D denotes the dummies used for S. Africa (D=1 for 3/77-4/77) and United Kingdom (D=1 for 4/75-5/75 and 4/81).
P-values are in parenthesis.

Table 11c: Estimates of GARCH-in-Mean models of inflation

Countries	China	India	Indonesia	Korea	Mexico
Mean eq.					
Φ_0		9.444(0.000)	3.815(0.008)	-1.132(0.375)	2.632(0.952)
Φ_1	0.873(0.000)	0.385(0.000)	0.001(0.987)		
Φ_2	-0.547(0.000)		-0.049(0.226)	0.007(0.930)	-0.185(0.479)
Φ_3		0.117(0.011)	0.106(0.000)	-0.022(0.639)	
Φ_4	0.148(0.000)				0.213(0.017)
Φ_5					
Φ_6				0.174(0.000)	
Φ_7	0.175(0.000)	-0.140(0.000)	-0.013(0.671)		
Φ_8					
Φ_9		0.118(0.004)			
Φ_{10}					0.456(0.000)
Φ_{11}	0.223(0.000)	0.210(0.000)			
Φ_{12}			0.177(0.000)	0.275(0.000)	$-7.72*10^{-5}$(0.99)
$\Phi\varepsilon_1$	-0.958(0.000)		0.221(0.005)	0.262(0.000)	
$\Phi\varepsilon_2$	0.582(0.000)			0.073(0.443)	0.392(0.109)
γ	**0.080(0.054)**	**-0.737(0.012)**	**0.393(0.056)**	**0.752(0.000)**	0.279(0.747)
D			92.933(0.000)		
Variance eq.					
α_0	39.398(0.000)	0.269(0.958)	19.539(0.034)	20.387(0.001)	28.543(0.134)
α_1	0.226(0.013)	0.065(0.019)	0.122(0.136)	0.459(0.000)	0.191(0.06)
α_2		0.046(0.051)	0.308(0.021)		
β_1		-0.053(0.231)	0.081(0.527)		
β_2		0.841(0.000)			
δ	-0.792(0.258)	**1.215(0.001)**	**4.488(0.002)**	**2.141(0.003)**	**-9.869(0.091)**
Diagnostics					
Q (8)	5.369(0.497)	5.831(0.667)	7.600(0.369)	8.536(0.201)	9.229(0.237)
Q (12)	15.386(0.119)	13.321(0.346)	13.542(0.259)	13.478(0.198)	10.981(0.445)
$Q^2(8)$	2.953(0.815)	3.406(0.906)	1.635(0.977)	7.370(0.288)	0.520(0.999)
$Q^2(12)$	8.156(0.613)	6.612(0.882)	16.794(0.114)	12.038(0.283)	0.579(1.000)
LM (8)	3.090(0.928)	3.558(0.894)	1.558(0.991)	6.809(0.557)	0.487(0.999)
LM (12)	8.006(0.784)	6.530(0.887)	16.559(0.166)	12.295(0.422)	0.535(1.000)
AIC	6.680	7.381	7.478	6.745	10.831
SBC	6.801	7.493	7.603	6.841	10.940

Notes: Q and Q^2 denote the Ljung-Box test statistic of the residuals and squared residuals, respectively.
LM denotes the test statistic of chi-square for ARCH.
AIC is the Akaike Information Criterion and SBC is the Schwarz Bayesian Criterion.
D denotes the dummy used for Indonesia. D=1 for 11/71, 1/74, 7/98 and 10/2005.
P-values are in parenthesis.

rate increases, individuals may invest more resources in forecasting inflation, thus reducing uncertainty about inflation. Moreover, this empirical result for Germany coincides with Fountas et al. (2004) finding, who claim that this negative relationship can be attributed to the strong commitment of the monetary authorities towards anti-inflationary policies.

Finally, the coefficients in the conditional variance equation for all countries are in consistent with the restrictions of the nonnegativity of the variance as they described in section 4.4. Finally, the Ljung-Box statistics on the squared standardize residuals and ARCH-LM statistics reported in the bottom of tables 11a-11c are all insignificant confirming the proper model specification.

5.5 Empirical Results of Granger-Causality Tests

In this section we perform the Granger-causality tests as specified in Eqs. 10, 11 and 12 in order to provide some statistical evidence on the nature of the relationship among inflation, inflation uncertainty and output growth. We test for three lag structures: four, eight and twelve lags. Moreover, the signs of the sums of the lagged coefficients in case of statistical significance are calculated by estimating the Granger equations with OLS.

Tables 12a-12c report the results of the causality tests regarding the linkage between inflation and inflation uncertainty. The proxies of uncertainty (the estimated conditional variances of inflation) are obtained by estimating the GARCH models without the in-mean term. For the majority of countries (Canada, France, South Africa, United Kingdom, United States, Euro Area, India, Indonesia and Korea) we obtained the conditional variance series from a GARCH(1,1) model while for Germany we used GARCH(1,2) variances series, for Italy and Japan GARCH(2,1) and for Turkey, China and Mexico GARH(1,0) variance series. These orders of GARCH models for each country are chosen again in terms of AIC and SBC information criteria.

Panel (A) provides results of tests of causality running from inflation uncertainty to inflation. The null hypothesis that inflation uncertainty does not Granger-cause inflation is rejected for all countries, except Canada. To be more specific, the aggregated effects are positive for France, Italy, South Africa, United Kingdom Indonesia and Korea, at each lag, and for Germany at a lag length of four, for United States at four and eight lags and for China at eight and twelve lags. Overall, our findings are consistent with Cukierman-Meltzer hypothesis. We also observe statistically significant effects for Japan but here the results are mixed; inflation uncertainty affect positively inflation at four and eight lags (Cukierman-Meltzer) but negatively at twelve lags which is an evidence in favour of Holland argument. In addition, evidence for Holland theory is provided for Turkey at twelve lags and for Euro Area, India, and Mexico at each lag.

Panel (B) reports results where causality runs from inflation to inflation uncertainty. The effect is statistically significance for all countries, except for Euro Area and China. Furthermore, the sign of the sum of the coefficients on lagged inflation is positive for these countries at each lag. Thus, given the results, we find strong evidence of Friedman-Ball argument.

Next, the results of the relationship between inflation uncertainty and output growth performing the causality tests are shown in Table 13 [4]. The estimated conditional variances of inflation are the same used previously. The effect of uncertainty on output growth is significant in only four cases. In fact, mixed results are obtained regarding the sign of the effect. We find that the inflation uncertainty has negative real effects only for France (at eight and twelve lags) and USA (at all lags) implying limited support for Friedman's argument. In contrast, the effect is positive for Italy (at eight and twelve lags) and South Africa (at four lags). Such a result is consistent with the theory of Dotsey and Sarte who claim that the inflation uncertainty raises growth.

Finally, Table 14 reports the results for the two countries (Saudi Arabia and Russia) where there was no evidence for GARCH effects. In order to proxy the inflation uncertainty we used the moving standard deviation (MSD) of inflation for each country calculated as:

$$MSD_t = \left[\frac{1}{n} \sum_{j=0}^{n-1} (\overline{\pi}_t^i - \pi_{t-j}^i)^2 \right]^{1/2}$$

where $\overline{\pi}_t^i$ denotes the moving average of inflation.

We calculate the MSD series with two alternative lags (6-month MSD and 12-month MSD) for both Saudi Arabia and Russia to check for the robustness of our results. Next, in order to test for the theories, we run the causality tests specified in Eqs. 10, 11 and 12, for four, eight and twelve lags, using the MSD series in equations, instead of the GARCH variance series ($h_{\pi t-i}$).

[4] We exclude China since there are no monthly data for Production Index.

Regarding the impact of inflation uncertainty on inflation, Panel (A), Table 14, shows significant effect for Russia at all lags both with 6-month and 12-month MSD series. In addition, the sign of the effect is positive, indicating strong evidence in favour of Cukierman-Meltzer hypothesis.

Considering the Panel (B) in the same table, the results for Saudi Arabia indicate lack of any significant effect of inflation on inflation uncertainty. There is only a significant effect at eight lags of 6-month MSD for Russia, but calculating the sum of the coefficients on lagged inflation we find that this effect is negative, which is in contrast with Friedman's-Ball hypothesis that inflation raises inflation uncertainty. Thus we find no impact of inflation on uncertainty neither for Saudi Arabia nor for Russia.

Panel (C) provides evidence that the null hypothesis that inflation uncertainty does not Granger-cause output growth does not rejected for Saudi Arabia. However this causal effect is rejected for Russia at eight and twelve lags. These findings are confirmed both with 6-month and 12-month MSD series supporting Friedman's claim that a higher inflation uncertainty lowers the growth.

Table 12a: Causality tests for inflation and inflation uncertainty, *using GARCH variance series*

Countries	Canada	France	Germany	Italy	Japan
Panel (A) H_0: Inflation uncertainty does not Granger-cause inflation **($h_t \nrightarrow \pi_t$)**					
Measure of uncertainty	GARCH(1,1)	GARCH(1,1)	GARCH(1,2)	GARCH(2,1)	GARCH(2,1)
Four lags	0.704	4.984***(+)**	2.068*****(+)**	4.986***(+)**	12.890***(+)**
	(0.589)	(0.000)	(0.086)	(0.000)	(0.000)
Eight lags	0.728	1.910****(+)**	1.179	2.838***(+)**	2.224****(+)**
	(0.668)	(0.050)	(0.312)	(0.004)	(0.024)
Twelve lags	1.369	1.910****(+)**	0.664	2.685***(+)**	2.272***(-)**
	(0.177)	(0.031)	(0.783)	(0.001)	(0.008)
Panel (B): H_0: Inflation does not Granger-cause inflation uncertainty **($\pi_t \nrightarrow h_t$)**					
Measure of uncertainty	GARCH(1,1)	GARCH(1,1)	GARCH(1,2)	GARCH(2,1)	GARCH(2,1)
Four lags	3.269****(+)**	6.917***(+)**	5.174***(+)**	43.069***(+)**	22.601***(+)**
	(0.011)	(0.000)	(0.000)	(0.000)	(0.000)
Eight lags	2.171****(+)**	4.221***(+)**	2.650***(+)**	21.556***(+)**	12.777***(+)**
	(0.028)	(0.000)	(0.008)	(0.000)	(0.000)
Twelve lags	2.028****(+)**	3.315***(+)**	2.532***(+)**	16.281***(+)**	11.462***(+)**
	(0.020)	(0.000)	(0.004)	(0.000)	(0.000)

Notes: The numbers in table are the F-statistics.
P-values are in parenthesis.
GARCH models for variance series as measures of uncertainty, chosen in terms of AIC and SBC information criteria.
A (+) indicates that the sum of the coefficients on lagged inflation/inflation uncertainty is positive and significant.
A (-) indicates that the sum of the coefficients on lagged inflation/inflation uncertainty is negative and significant.
* Significance at 1% level.
** Significance at 5% level.
*** Significance at 10% level.

Table 12b: Causality tests for inflation and inflation uncertainty, *using GARCH variance series*

Countries	S.Africa	Turkey	U.K	U.S	Euro Area
Panel (A) H_0: Inflation uncertainty does not Granger-cause inflation **($h_t \rightarrow \pi_t$)**					
Measure of uncertainty	GARCH(1,1)	GARCH(1,0)	GARCH(1,1)	GARCH(1,1)	GARCH(1,1)
Four lags	10.579***(+)**	0.565	9.491***(+)**	3.158****(+)**	5.056***(-)**
	(0.000)	(0.688)	(0.000)	(0.014)	(0.000)
Eight lags	3.758***(+)**	0.708	3.188***(+)**	2.633***(+)**	2.979***(-)**
	(0.000)	(0.683)	(0.001)	(0.007)	(0.004)
Twelve lags	2.690***(+)**	2.550***(-)**	3.663***(+)**	1.433	2.526***(-)**
	(0.001)	(0.003)	(0.000)	(0.147)	(0.005)
Panel (B): H_0: Inflation does not Granger-cause inflation uncertainty **($\pi_t \rightarrow h_t$)**					
Measure of uncertainty	GARCH(1,1)	GARCH(1,0)	GARCH(1,1)	GARCH(1,1)	GARCH(1,1)
Four lags	93.451***(+)**	91.176***(+)**	40.367***(+)**	2.387****(+)**	0.669
	(0.000)	(0.000)	(0.000)	(0.050)	(0.614)
Eight lags	46.259***(+)**	49.509***(+)**	19.362***(+)**	3.950***(+)**	0.881
	(0.000)	(0.000)	(0.000)	(0.000)	(0.534)
Twelve lags	29.998***(+)**	60.753***(+)**	12.765***(+)**	2.991***(+)**	1.420
	(0.000)	(0.000)	(0.000)	(0.000)	(0.168)

Notes: The numbers in table are the F-statistics.
P-values are in parenthesis.
GARCH models for variance series as measures of uncertainty, chosen in terms of AIC and SBC information criteria.
A (+) indicates that the sum of the coefficients on lagged inflation/inflation uncertainty is positive and significant.
A (-) indicates that the sum of the coefficients on lagged inflation/inflation uncertainty is negative and significant.
* Significance at 1% level.
** Significance at 5% level.

Table 12c: Causality tests for inflation and inflation uncertainty, *using GARCH variance series*

Countries	China	India	Indonesia	Korea	Mexico
Panel (A) H_0: Inflation uncertainty does not Granger-cause inflation **($h_t \rightarrow \pi_t$)**					
Measure of uncertainty	GARCH(1,0)	GARCH(1,1)	GARCH(1,1)	GARCH(1,1)	GARCH(1,0)
Four lags	1.360	2.493****(-)**	2.797****(+)**	8.267***(+)**	6.622***(-)**
	(0.247)	(0.042)	(0.025)	(0.000)	(0.000)
Eight lags	2.051****(+)**	1.922****(-)**	2.644*****(+)**	3.954***(+)**	4.381***(-)**
	(0.040)	(0.054)	(0.077)	(0.000)	(0.000)
Twelve lags	1.665*****(+)**	1.707*****(-)**	2.658***(+)**	1.786****(+)**	3.802***(-)**
	(0.073)	(0.062)	(0.001)	(0.047)	(0.000)
Panel (B) H_0: Inflation does not Granger-cause inflation uncertainty **($\pi_t \rightarrow h_t$)**					
Measure of uncertainty	GARCH(1,0)	GARCH(1,1)	GARCH(1,1)	GARCH(1,1)	GARCH(1,0)
Four lags	0.806	2.973****(+)**	20.774***(+)**	47.872***(+)**	103.531***(+)**
	(0.521)	(0.019)	(0.000)	(0.000)	(0.000)
Eight lags	1.164	3.505***(+)**	19.180***(+)**	21.899***(+)**	61.499***(+)**
	(0.320)	(0.000)	(0.000)	(0.000)	(0.000)
Twelve lags	0.787	2.623****(+)**	9.976***(+)**	16.580***(+)**	99.491***(+)**
	(0.663)	(0.002)	(0.000)	(0.000)	(0.000)

Notes: The numbers in table are the F-statistics.

P-values are in parenthesis.

GARCH models for variance series as measures of uncertainty, chosen in terms of AIC and SBC information criteria.

A (+) indicates that the sum of the coefficients on lagged inflation/inflation uncertainty is positive and significant.

A (-) indicates that the sum of the coefficients on lagged inflation/inflation uncertainty is negative and significant.

* Significance at 1% level.

** Significance at 5% level.

*** Significance at 10% level.

Table 13: Causality tests for inflation uncertainty and output growth, *using GARCH variance series*

Countries	Canada	France	Germany	Italy	Japan
H_0: Inflation uncertainty does not Granger-cause output growth **($h_t \nrightarrow y_t$)**					
Measure of uncertainty	GARCH(1,1)	GARCH(1,1)	GARCH(1,2)	GARCH(2,1)	GARCH(2,1)
Four lags	0.961	1.026	0.124	1.835	0.534
	(0.428)	(0.393)	(0.973)	(0.120)	(0.710)
Eight lags	0.882	1.843**(-)**	0.479	2.343**(+)**	0.404
	(0.531)	(0.067)	(0.869)	(0.017)	(0.917)
Twelve lags	0.860	2.327*(-)*	0.364	2.489*(+)*	0.409
	(0.587)	(0.000)	(0.974)	(0.003)	(0.959)

Countries	S.Africa	Turkey	U.K	U.S	Euro Area
H_0: Inflation uncertainty does not Granger-cause output growth **($h_t \nrightarrow y_t$)**					
Measure of uncertainty	GARCH(1,1)	GARCH(1,0)	GARCH(1,1)	GARCH(1,1)	GARCH(1,1)
Four lags	1.999***(+)**	1.338	1.142	2.141**(-)**	1.386
	(0.093)	(0.256)	(0.335)	(0.074)	(0.242)
Eight lags	1.308	0.575	0.985	2.037**(-)**	0.974
	(0.236)	(0.797)	(0.446)	(0.040)	(0.459)
Twelve lags	0.965	0.831	0.955	1.562***(-)**	0.723
	(0.481)	(0.617)	(0.491)	(0.099)	(0.725)

Countries	India	Indonesia	Korea	Mexico
H_0: Inflation uncertainty does not Granger-cause output growth **($h_t \nrightarrow y_t$)**				
Measure of uncertainty	GARCH(1,0)	GARCH(1,1)	GARCH(1,1)	GARCH(1,0)
Four lags	0.844	0.462	0.398	0.609
	(0.497)	(0.763)	(0.810)	(0.655)
Eight lags	1.507	0.220	0.573	1.300
	(0.151)	(0.987)	(0.799)	(0.242)
Twelve lags	1.507	0.447	0.694	1.183
	(0.117)	(0.943)	(0.756)	(0.293)

Notes: The numbers in table are the F-statistics.
P-values are in parenthesis.
GARCH models for variance series as measures of uncertainty, chosen in terms of AIC and SBC information criteria.
A (+) / (-) indicates that the sum of the coefficient on the lagged output growth is positive/negative and significant.
*, **, *** denotes significance at the 1% 5%and 10% level, respectively.

Table 14: Causality tests for inflation, inflation uncertainty and output growth, *using moving standard deviation series* for Saudi Arabia and Russia (No- Arch- effect).

Countries	Saudi Arabia		Russia	
Panel (A) H_0: Inflation uncertainty does not Granger-cause inflation **($h_t \nrightarrow \pi_t$)**				
Measure of uncertainty	6-Month MSD	12-Month MSD	6-Month MSD	12-Month MSD
Four lags	0.5332	0.567	10.717*(+)	2.709**(+)
	(0.711)	(0.686)	(0.000)	(0.031)
Eight lags	0.610	0.393	242.424*(+)	2.627*(+)
	(0.769)	(0.924)	(0.000)	(0.009)
Twelve lags	0.609	0.376	262.032*(+)	11.200*(+)
	(0.834)	(0.971)	(0.000)	(0.000)
Panel (B) H_0: Inflation does not Granger-cause inflation uncertainty **($\pi_t \nrightarrow h_t$)**				
Measure of uncertainty	6-Month MSD	12-Month MSD	6-Month MSD	12-Month MSD
Four lags	0.309	0.527	1.004	0.754
	(0.871)	(0.715)	(0.406)	(0.556)
Eight lags	0.399	0.607	1.863***(-)	0.237
	(0.920)	(0.771)	(0.069)	(0.983)
Twelve lags	0.603	0.776	1.173	0.786
	(0.839)	(0.674)	(0.306)	(0.663)
H_0: Inflation uncertainty does not Granger-cause output growth **($h_t \nrightarrow y_t$)**				
Measure of uncertainty	6-Month MSD	12-Month MSD	6-Month MSD	12-Month MSD
Four lags	0.278	0.729	1.144	1.948
	(0.891)	(0.572)	(0.337)	(0.105)
Eight lags	0.228	0.460	2.743*(-)	2.269**(-)
	(0.985)	(0.883)	(0.007)	(0.025)
Twelve lags	0.195	0.249	1.853*(-)	1.798**(-)
	(0.998)	(0.995)	(0.044)	(0.052)

Notes: The numbers in table are the F-statistics.

P-values are in parenthesis.

MSD denotes the moving standard deviation series for inflation uncertainty.

A (+) / (-) indicates that the sum of the lagged coefficients are positive/negative and significant.

*, **, *** denotes significance at the 1% 5%and 10% level, respectively.

5.6 Summary of the Results and Discussion

Our empirical analysis shows that the inferences for the relationship between inflation and inflation uncertainty depend on the econometric methodology we use each time. However the Cukierman-Meltzer and Friedman-Ball hypothesis are supported for most of the countries considering both approaches. Limited but not negligible are the findings for Holland prediction regarding the negative effect of inflation uncertainty on inflation. Finally for the majority of the country cases, inflation uncertainty seems not to be detrimental to output growth. In only three cases the effect is negative and in two cases the effect is positive consistent with the model of Dotsey and Sarte. In other words Friedman's argument that uncertainty can be detrimental to the economies real sectors, receives very little support in our study.

Table 15: Summary of results

Countries	*Inflation uncertainty affects inflation*		*Inflation affects inflation uncertainty*	*Inflation uncertainty affects output growth*	
	C & M (+)	*Holland (-)*	*Friedman-Ball (+)*	*Friedman (-)*	*Dotsey &Sarte (+)*
Industrial Countries					
Canada			*		
France	* *		*	*	
Germany	*		*		
Italy	* *		*		*
Japan	*		* *		
South Africa	*	*	*		*
Turkey		*	*		
United Kingdom	* *		* *		
United States	*		* *	*	
Euro Area	*	*			
MiddleEast Countries					
Saudi Arabia					
Asia Countries					
China	* *				
India		* *	* *		
Indonesia	* *		* *		
Korea	* *		* *		
Russia	*			*	
West Hemisphere					
Argentina	X	X	X	X	X
Brazil	X	X	X	X	X
Mexico		*	*		

Blue / Yellow colored cells are GARCH-M / Causality tests results, denoting the power of a hypothesis.
No-colored cells denote that the hypothesis does not supporting with any of tests.
X denotes that no GARCH model satisfying all theory parameter restrictions estimated.

6 Conclusions

In this study we use GARCH and GARCH-M techniques to construct measures of inflation uncertainty in the G-20 countries for varying sample periods and then we examine the relationship between inflation, inflation uncertainty and output growth for these countries. In order to test the impact of inflation uncertainty on inflation and the impact of inflation on inflation uncertainty we employ a GARCH-M model enriched with lagged inflation in the conditional variance equation to estimate the relationship between the two variables simultaneously. The results of this approach indicate that the Cukierman-Meltzer hypothesis that inflation uncertainty raises inflation holds for France, Italy, United Kingdom, Euro Area, China, Indonesia and Korea while the Friedman-Ball argument that higher inflation rate leads to more uncertainty holds for Japan, United Kingdom, United States, India, Indonesia and Korea. Moreover, there is evidence in favour of Holland prediction regarding the negative effect of inflation uncertainty on inflation for South Africa and India.

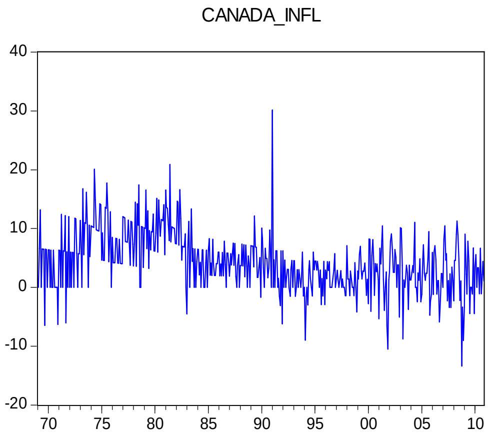
In addition, the investigation for the relationship between the inflation and its uncertainty is approached also with a two-step procedure, where we first estimate the conditional variance of inflation, the proxy for uncertainty, and then perform Granger causality tests for the impact of this variance. The results of this two-step approach confirm those of augmented GARCH-M model, except in the case of South Africa and Euro Area where according the causality tests, in Euro Area there is evidence for Holland's theory, while for South Afriaca there is evidence for Cukierman-Meltzer hypothesis. The results of causality tests support also the Cukierman-Meltzer hypothesis for Germany, Japan and United States, the Holland's theory for Turkey and Mexico and the Friedman-Ball argument for all countries except Euro Area.

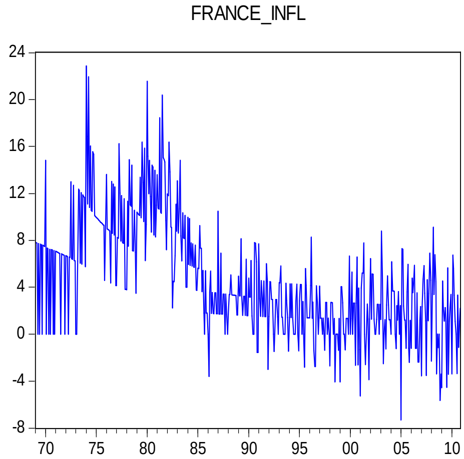
For S.Arabia and Russia where there is no evidence for GARCH effect, we proxy the inflation uncertainty using the moving standard deviation (MSD) of series. The results of causality test show evidence for the Cukierman-Meltzer hypothesis for Russia.

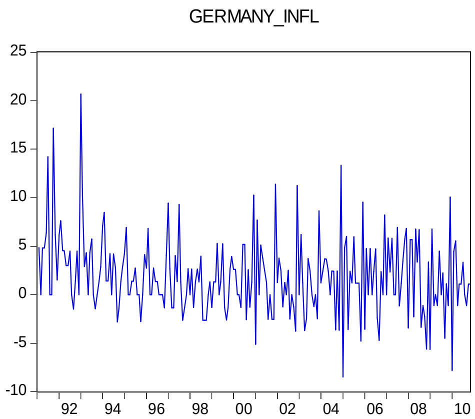
Finally, exploring the second part of Friedman's argument that inflation uncertainty affects negatively the output growth, we only find limited support. The empirical analysis shows that there is significant evidence for France, United States and Russia, while in two cases (Italy and South Africa) the effect is positive, in support of the theoretical model of Dotsey and Sarte.

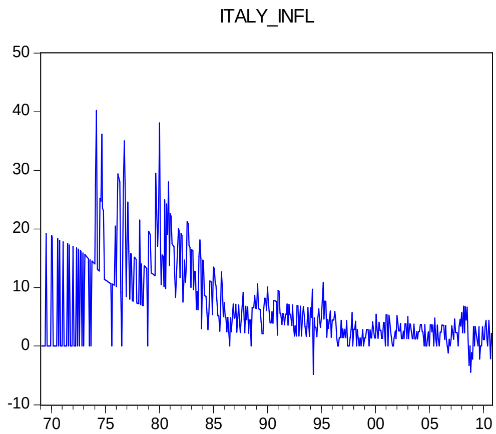
APPENDIX

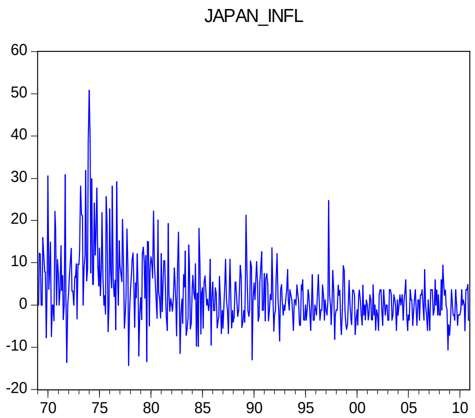
A) Graphs of inflation rates for G-20

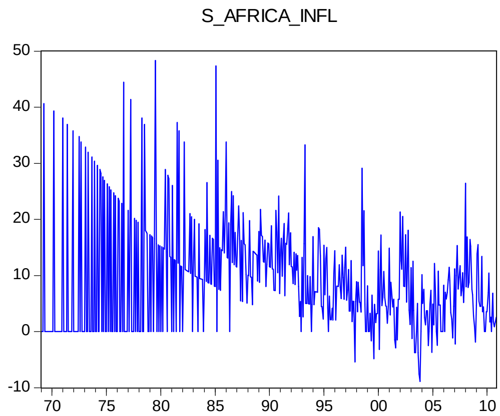


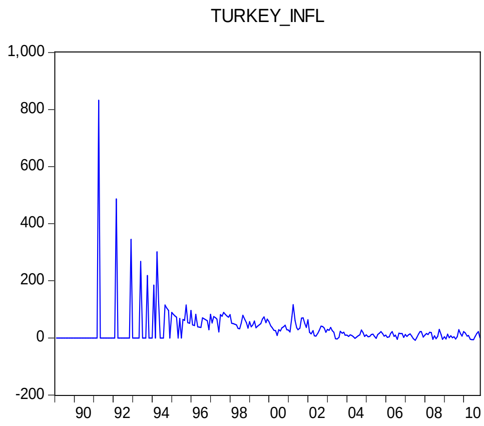








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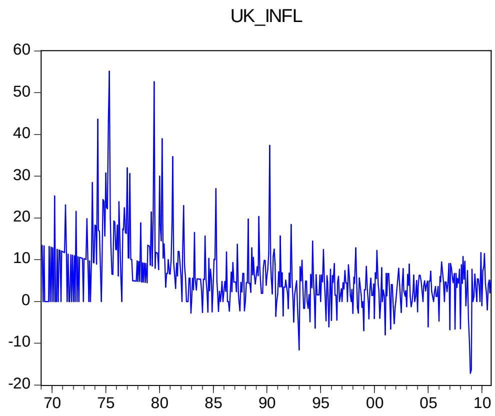
1,000
800
600
400
200
0
-200
90 92 94 96 98 00 02 04 06 08 10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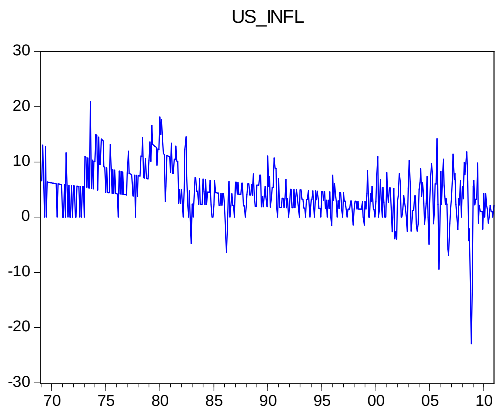
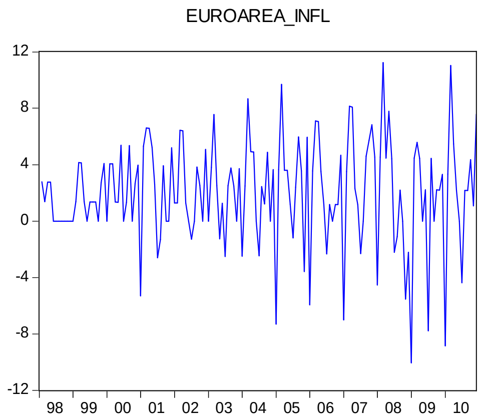
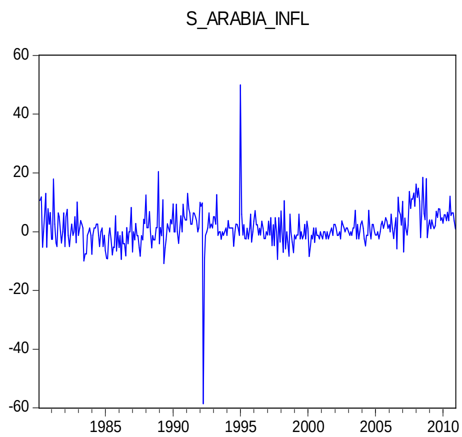
60
50
40
30
20
10
0
-10
-20
70 75 80 85 90 95 00 05 10


US_INFL
30
20
10
0
-10
-20
-30
70 75 80 85 90 95 00 05 10


EUROAREA_INFL
12
8
4
0
-4
-8
-12
98 99 00 01 02 03 04 05 06 07 08 09 10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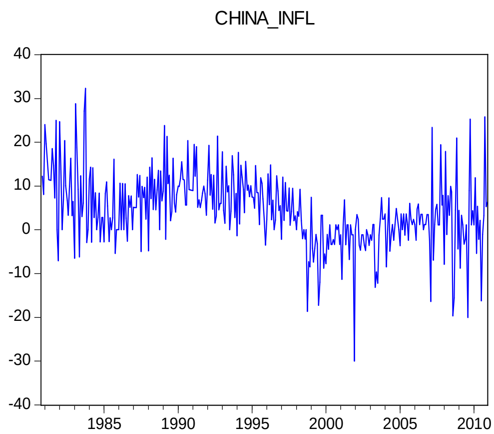
40
20
0
-20
-40
-60
1985 1990 1995 2000 2005 2010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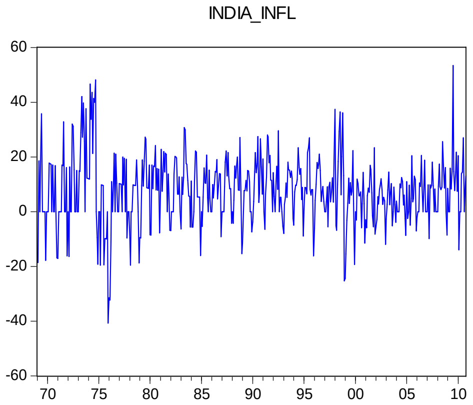
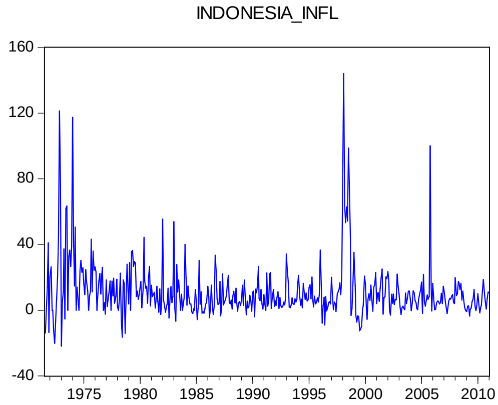
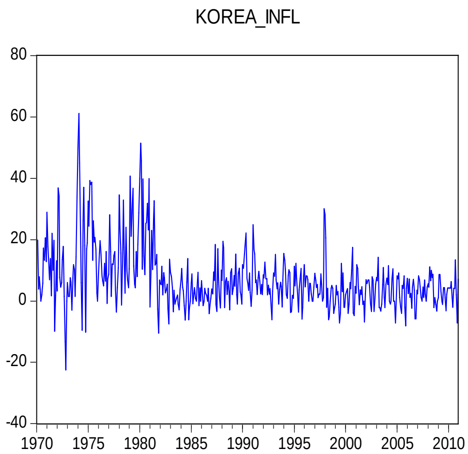
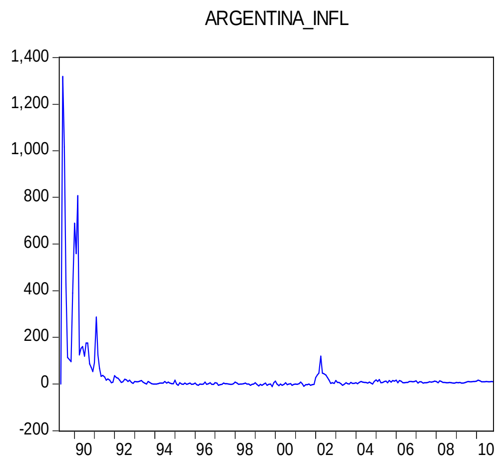
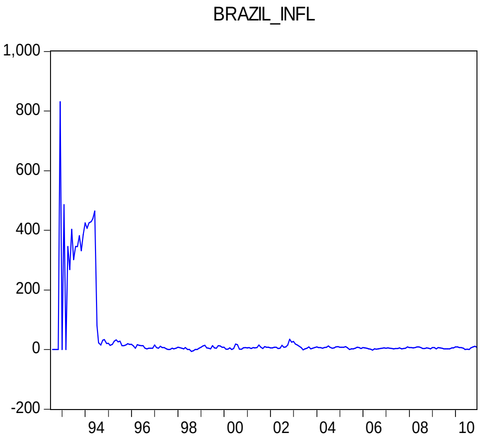
40
30
20
10
0
-10
-20
-30
-40
1985 1990 1995 2000 2005 2010

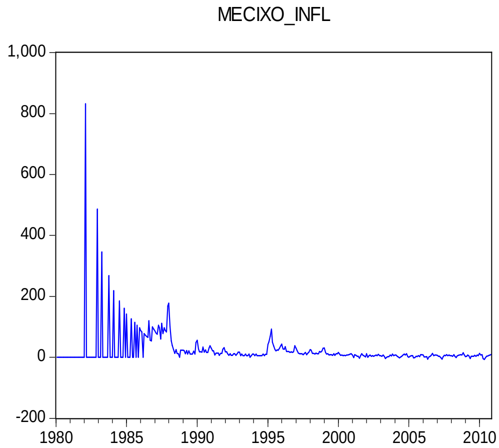

INDIA_INFL

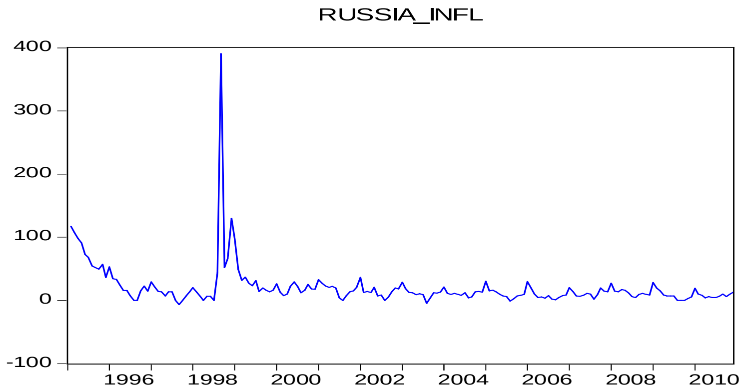

INDONESIA_INFL


KOREA_INFL

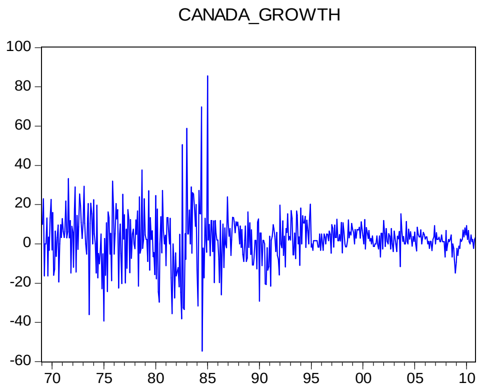

ARGENTINA_INFL

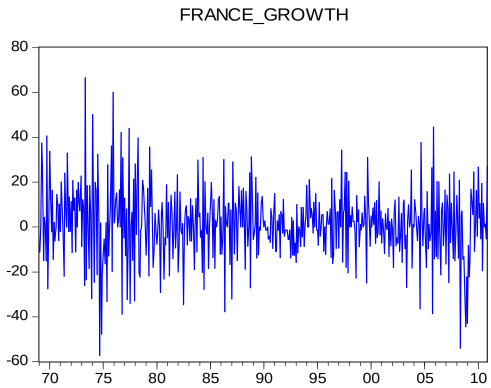

BRAZIL_INFL

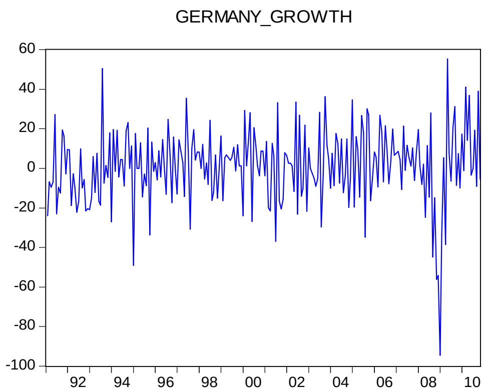

MECIXO_INFL

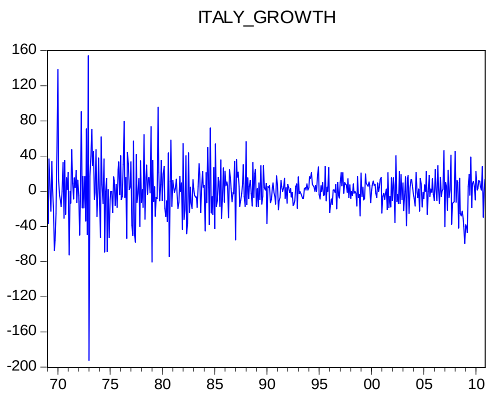


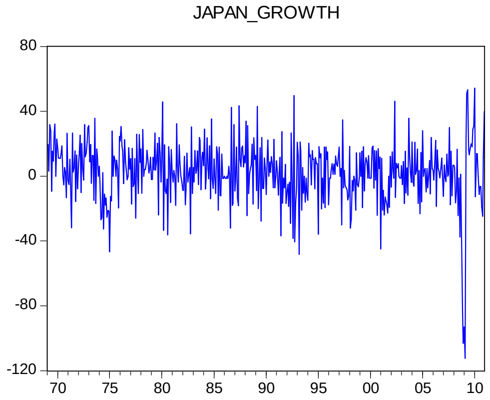
B) Graphs of Output Growth for G-20










JAPAN_GROWTH
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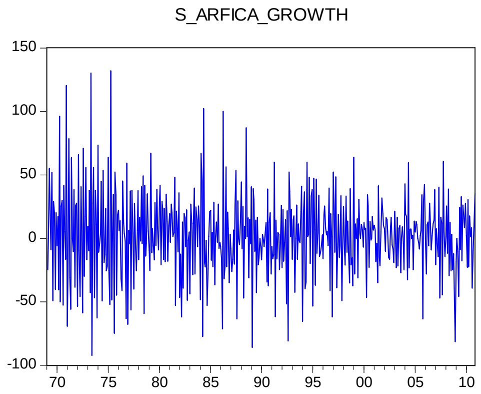
40
0
-40
-80
-120
70
75
80
85
90
95
00
05
10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0
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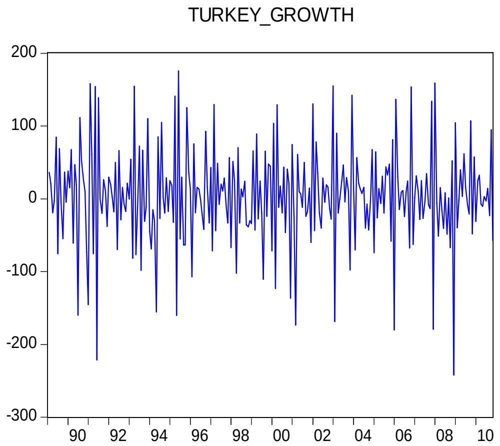
70
75
80
85
90
95
00
05
10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-100
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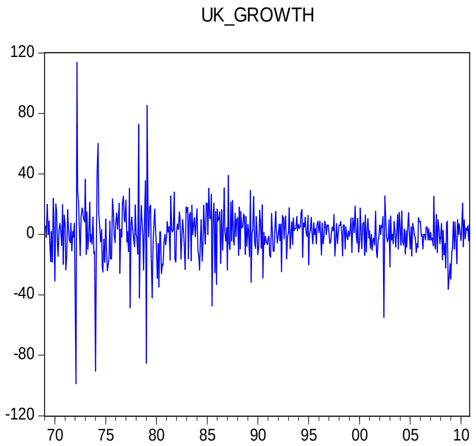
-300
90
92
94
96
98
00
02
04
06
08
10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-120
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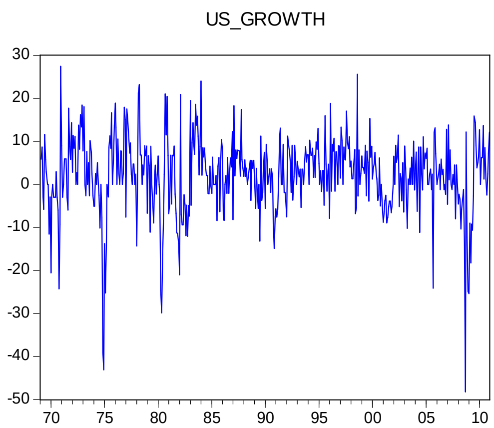
75
80
85
90
95
00
05
10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75
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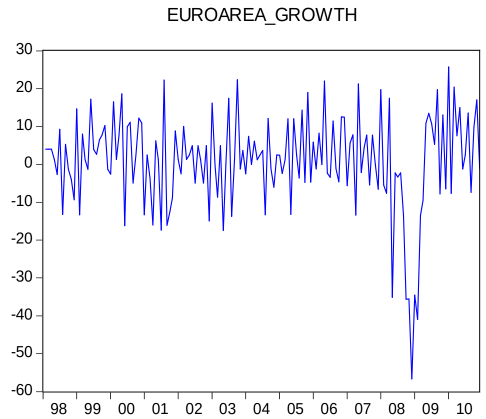
00
05
10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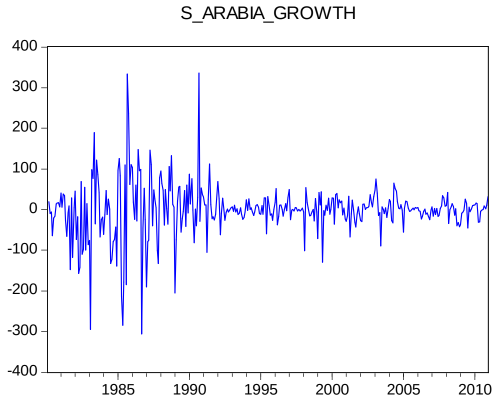
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-200
-300
-400
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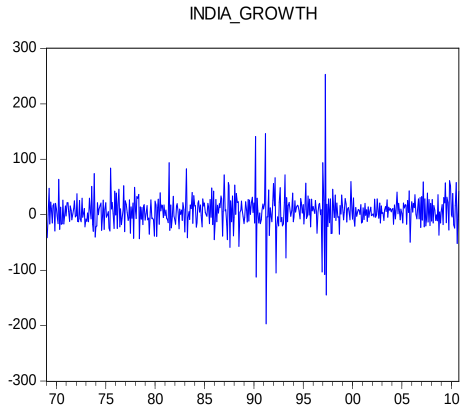
1990
1995
2000
2005
2010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05
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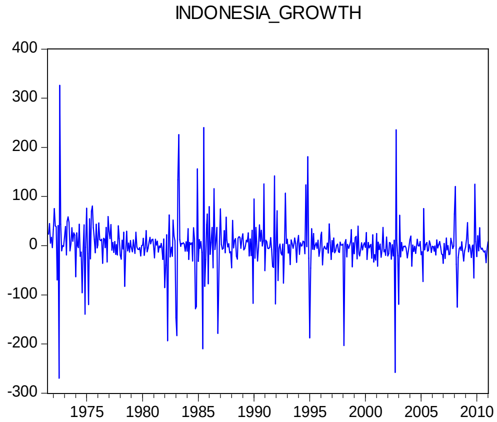
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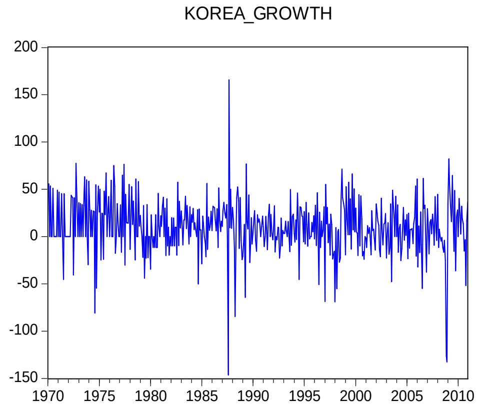
1975
1980
1985
1990
1995
2000
2005
2010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1970
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1980
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2005
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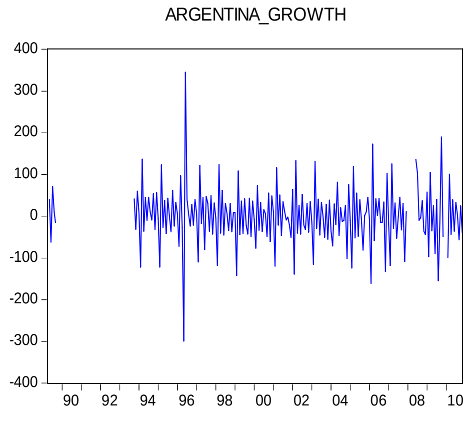
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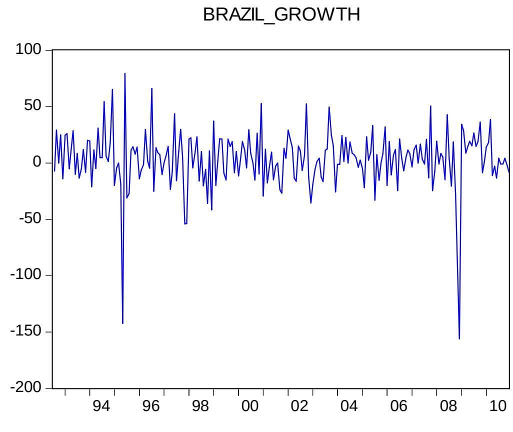
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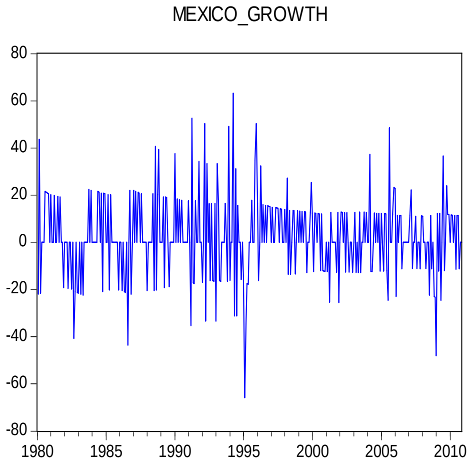
94
96
98
00
02
04
06
08
10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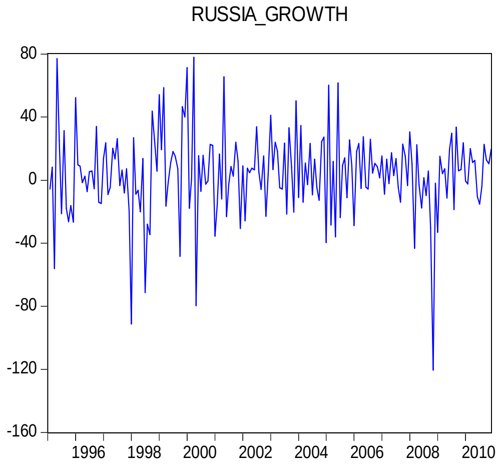
-60
-80
1980
1985
1990
1995
2000
2005
2010


RUSSIA_GROWTH
80
40
0
-40
-80
-120
-160
1996
1998
2000
2002
2004
2006
2008
2010

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