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Inflation, output growth, and nominal and real uncertainty: Empirical evidence for the G7

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Abstract

We use univariate GARCH models of inflation and output growth and monthly data for the G7 covering the 1957–2000 period to test for the causal effect of real and nominal macroeconomic uncertainty on inflation and output growth, and the effect of inflation on inflation uncertainty. Our evidence supports a number of important conclusions. First, inflation is a positive determinant of uncertainty about inflation. Second, output growth uncertainty is a positive determinant of the output growth rate. Third, there is mixed evidence regarding the effect of inflation uncertainty on inflation and output growth. Hence, uncertainty about the inflation rate is not necessarily detrimental to economic growth. Finally, there is not much evidence supporting the hypothesis that output uncertainty raises inflation.

JEL classification: C22; C51; C52; E0

Keywords: Inflation; Output Growth; Uncertainty; Granger-causality; GARCH models

1. Introduction

The issue of the welfare costs of inflation has been one of the most researched topics in macroeconomics on both the theoretical and empirical fronts. Considerable ambiguity surrounds the impact of the average rate of inflation on the rate of economic growth at the theoretical level.

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Furthermore, the impact of inflation on output growth may take place indirectly, via the inflation uncertainty channel. Friedman (1977) argues that a rise in the average rate of inflation leads to more uncertainty about the future rate of inflation, it distorts the effectiveness of the price mechanism in allocating resources efficiently, and thus it creates economic inefficiency and a lower growth rate of output. Moreover, inflation uncertainty, by affecting interest rates, also impacts on the intertemporal allocation of resources. Hence, a comprehensive empirical study that tests for the real effects of inflation should control for the impact of inflation uncertainty on output. The positive correlation between inflation and inflation uncertainty reported in empirical studies can also arise from a positive causal effect of inflation uncertainty on inflation. Cukierman and Meltzer (1986) provide a theoretical model that explains such a causal effect. In the presence of more inflation uncertainty, less conservative central bankers have an incentive to surprise the public and generate unanticipated inflation, hoping for output gains.

Early approaches to the testing of the relationship between inflation uncertainty on the one hand, and inflation and output growth on the other, suffer from an important disadvantage. These studies did not distinguish between anticipated and unanticipated changes (the source of uncertainty) in inflation. By proxying inflation uncertainty by the moving standard deviation or variance of the inflation series, these studies measured inflation variability, not uncertainty. The development of Generalized Autoregressive Conditional Heteroskedasticity (GARCH) techniques allows the measurement of inflation uncertainty by the conditional variance of the inflation series and more accurate testing of the two parts of the Friedman hypothesis (e.g., Baillie et al., 1996; Grier and Perry, 1998, 2000; Fountas et al., 2004a; Karanasos et al., 2004; Conrad and Karanasos, 2005a; Karanasos and Schurer, 2006).

Output growth might be influenced by changes in real uncertainty (arising from the variability in output growth), in addition to changes in nominal or inflation uncertainty. Macroeconomic analysis before the 1980s treated the theories of the business cycle (and its variability) and economic growth independently. However, this assumption of independence between the variability of the business cycle and economic growth is questionable, as indicated by several theories (Mirman, 1971; Black, 1987; Pindyck, 1991; Blackburn and Pelloni, 2004, 2005). Empirical evidence has recently emerged that corroborates these theoretical findings (Caporale and McKiernan, 1996, 1998; Kneller and Young, 2001; Henry and Olekalns, 2002; Karanasos and Schurer, 2005). This empirical evidence, though, is still scant and it mainly applies to data from the UK and the US. A robust set of evidence in support of the relationship between output growth and its variability would provide a solid ground for the development of macroeconomic models that consider such a relationship as a fundamental building block. Changes in real uncertainty may also affect the rate of inflation positively (Devereux, 1989). Therefore, real uncertainty may have a significant impact on macroeconomic performance (inflation and output growth) and an evaluation of its importance becomes an important empirical issue.

Economic theory postulates certain causality relationships between nominal uncertainty, real uncertainty, the rate of inflation, and output growth. In total, including the relationships discussed above, 12 causality relationships exist among the above four variables. The empirical evidence on many of these relationships remains scant or nonexistent, as pertains, in particular, to international data in industrialized economies. The lack of a comprehensive study of the empirical relationships among the above four variables represents the motivation for the present study.

In this paper, the above issues are analyzed empirically for the G7 countries with the application of univariate GARCH-type models. Our estimated model is used to generate the conditional variances of inflation and output growth as proxies of inflation and output growth uncertainty, respectively, and to perform Granger-causality tests. This model allows us to test for evidence on the causal effects of real (output growth) and nominal (inflation) uncertainty on inflation and output growth. In total, five hypotheses are tested.[1] The focus on a small set of hypotheses is chosen in order to concentrate our interest on a set of hypotheses that have considerable theoretical backing.

The paper is outlined as follows. Macroeconomic theory provides us with the predicted effects for these relationships, discussed in Section 2. Section 3 summarizes the empirical literature to date. Section 4 presents our econometric model, and Section 5 reports and discusses our results and relates them to some recent studies. Finally, Section 6 summarizes our main conclusions and draws some policy implications.

2. Theory

2.1. The Friedman hypothesis

Friedman (1977) outlined an informal argument regarding the real effects of inflation. Friedman's point comes in two parts. In the first leg of the Friedman hypothesis, an increase in inflation may induce an erratic policy response by the monetary authority and therefore lead to more uncertainty about the future rate of inflation. In the second leg of the Friedman hypothesis, the increasing uncertainty about inflation distorts the effectiveness of the price mechanism in allocating resources efficiently, thus leading to negative output effects. Friedman's argument represents one of the few existing arguments on the rationalization of the welfare effects of inflation. The informal ideas advanced by Friedman were subsequently presented with the use of elegant theoretical models. Demetriades (1988) shows that in the presence of asymmetric information between the policymaker and the public and asymmetric stabilization policies (i.e., greater policy response to negative than to positive shocks), a positive correlation between inflation and its variance applies. However, the direction of causality between inflation and inflation uncertainty is not addressed by Demetriades (1988).

Ball (1992) focuses on the first leg of the Friedman hypothesis. He analyzes an asymmetric information game where the public faces uncertainty regarding the type of policymaker in office. Two types of policymaker are considered: a weak type that is unwilling to disinflate and a tough type that bears the cost of disinflation. The policymakers alternate stochastically in office. When current inflation is high, the public faces increasing uncertainty about future inflation, as it is not known which policymaker will be in office in the next period and consequently what the response to the high-inflation rate will be (i.e., what the money supply growth will be). Such an uncertainty does not arise in the presence of a low inflation rate. It is also possible that more inflation will lead to a lower level of inflation uncertainty. The argument advanced by Pourgerami and Maskus (1987) is that in the presence of rising inflation agents may invest more resources in forecasting inflation, thus reducing uncertainty about inflation. A formal analysis of this effect is presented in Ungar and Zilberfarb (1993).

[1] For an alternative empirical methodology focusing on four instead of five testable hypotheses and US data, see Grier and Perry (2000) and Grier et al. (2004). Fountas et al. (2002) employ a bivariate GARCH model and test for all 12 hypotheses using Japanese data.

The second part of Friedman's hypothesis predicts that increased inflation uncertainty would increase the observed rates of unanticipated inflation and hence will be associated with the costs of unanticipated inflation.[2] Such costs arise from the effect of inflation uncertainty on both the intertemporal and intratemporal allocation of resources. Nominal uncertainty affects interest rates (the inflation premium) and hence all decisions relating to the intertemporal allocation of resources. In a world of nominal rigidities, inflation uncertainty also affects the real cost of the factors of production and the relative prices of final goods, and therefore, the intratemporal allocation of resources. The effect of inflation uncertainty on output has been addressed formally by Dotsey and Sarte (2000). In a cash-in-advance model that allows for precautionary savings and risk aversion, they show that more inflation uncertainty can have a positive output growth effect. According to the authors' argument, an increase in the variability of monetary growth, and therefore inflation, makes the return to money balances more uncertain and leads to a fall in the demand for real money balances and consumption. Hence, agents increase precautionary savings, and the pool of funds available to finance investment increases. This result is analogous to the literature's finding that fiscal policy uncertainty is conducive to growth by encouraging precautionary savings.

2.2. The impact of inflation uncertainty on inflation

The opposite direction of causality to that examined by Friedman in the inflation/inflation uncertainty relationship has also been addressed by the theoretical literature. This literature examines the impact of a change in inflation uncertainty on the average rate of inflation. Cukierman and Meltzer (1986) employ a Barro and Gordon (1983) set up, where agents face uncertainty about the rate of monetary growth and therefore, inflation.[3] In the presence of this uncertainty, the policymaker applies an expansionary monetary policy in order to surprise the agents and enjoy output gains. This argument implies a positive causal effect from inflation uncertainty to inflation and has been dubbed by Grier and Perry (1998) the Cukierman–Meltzer hypothesis. Holland (1995) has supplied a different argument based on the stabilization motive of the monetary authority, the so-called 'stabilizing Fed hypothesis'. He claims that, as inflation uncertainty rises due to increasing inflation, the monetary authority responds by contracting money supply growth, in order to eliminate inflation uncertainty and the associated negative welfare effects. Hence, Holland's argument supports the opposite sign in the causal relationship, i.e., a negative causal effect of inflation uncertainty on inflation. The theoretical ambiguity surrounding this causal relationship necessitates an empirical investigation of the sign of the effect.

2.3. The effects of output uncertainty on inflation and output growth

The effect of output growth uncertainty on inflation has been examined by Devereux (1989). Devereux (1989) extends the Barro and Gordon (1983) model by introducing wage indexation endogenously. He considers the impact of an exogenous increase in real (output) uncertainty on

[2] This part draws on Huizinga (1993).

[3] Ball (1992) and Cukierman and Meltzer (1986) assume inflation uncertainty is caused by uncertainty about the rate of money growth. In contrast, Holland (1993a) assumes that inflation uncertainty arises from the uncertain effect of money growth on the rate of inflation. He provides US evidence in support of his prediction.

the degree of wage indexation and the optimal inflation rate delivered by the policymaker. He shows that more real uncertainty reduces the optimal amount of wage indexation and induces the policymaker to engineer more inflation surprises in order to obtain favorable real effects. The prediction of Devereux's theory regarding the positive causal effect of output uncertainty on the inflation rate is borne out also in a recent paper by Cukierman and Gerlach (2003). They show that, even if policymakers target the potential rate of unemployment, inflation bias à la Barro and Gordon (1983) obtains in the presence of more uncertainty about the level of output. This result hinges on the assumption that central banks are more sensitive to employment below than above its normal level. From a theoretical point of view, it is possible for more output uncertainty to reduce inflation. Higher output uncertainty reduces inflation uncertainty[4] and, therefore, the rate of inflation, according to the Cukierman–Meltzer hypothesis. Hence, the testable implication of these two effects combined is that more output growth uncertainty should lead to a lower rate of inflation.

The effect of output uncertainty on output growth has received considerable attention in the theoretical macroeconomic literature. However, there is no consensus among macroeconomists on the direction of this effect. Macroeconomic theory offers three possible scenarios regarding the impact of output variability on output growth. First, there is the possibility of independence between output variability and growth. In other words, the determinants of the two variables are different from each other. For example, according to some business cycle models, output fluctuations around the natural rate are due to price misperceptions in response to monetary shocks. On the other hand, changes in the growth rate of output arise from real factors such as technology (Friedman, 1968).

According to Pindyck (1991), the negative relationship between output volatility and growth arises from investment irreversibilities at the firm level. More recently, Blackburn and Pelloni (2005) use a stochastic monetary growth model with three different types of shocks (technology, preference and monetary) that have permanent effects on output due to wage contracts and endogenous technology. The authors show that output growth and output variability are negatively correlated irrespective of the type of shocks causing fluctuations in the economy.[5]

Finally, the positive impact of output variability on growth can be justified by a number of economic theories. First, more income variability (uncertainty) would lead to a higher savings rate (Sandmo, 1970) for precautionary reasons, and hence, according to Solow's (1956) neoclassical growth theory, a higher equilibrium rate of economic growth. This argument has been advanced by Mirman (1971). A second argument is due to Black (1987) and is based on the hypothesis that investments in riskier technologies will be pursued only if the expected return on these investments (average rate of output growth) is large enough to compensate for the extra risk. As real investment takes time to materialize, such an effect would be more likely to obtain in empirical studies utilizing low-frequency data. A number of recent studies based on endogenous growth caused by learning-by-doing also examine the relationship between output variability and growth. Blackburn (1999) shows that business cycle volatility raises the long-run growth of the economy. Blackburn and Pelloni (2004) in a stochastic monetary growth model show that the correlation between output growth and its variability is a function of the type of shocks buffeting the economy. The study concludes that the correlation will be positive

[4] The negative association between inflation and output variability is known in the literature as the Taylor effect.

[5] We thank Keith Blackburn for calling his papers to our attention.

(negative) depending on whether the real (nominal) shocks dominate. The causal relationships and the associated theories presented in Section 2 are summarized in the following table:

Testable hypotheses − theories	Sign of the effect
(1) *Inflation Granger-causes inflation uncertainty*	
Friedman (1977), Ball (1992)	+
Pourgerami and Maskus (1987), Ungar and Zilberfarb (1993)	−
(2) *Inflation uncertainty Granger-causes output growth*	
Friedman (1977)	−
Dotsey and Sarte (2000)	+
(3) *Inflation uncertainty Granger-causes inflation*	
Cukierman and Meltzer (1986)	+
Holland (1995)	−
(4) *Output uncertainty Granger-causes inflation*	
Devereux (1989), Cukierman and Gerlach (2003)	+
Taylor effect and Cukierman and Meltzer (1986)	−
(5) *Output uncertainty Granger-causes output growth*	
Business cycle models	Zero
Pindyck (1991)	−
Mirman (1971), Black (1987), Blackburn (1999)	+

3. The empirical evidence

Early empirical studies on the relationship between inflation and its uncertainty used the variance (or standard deviation) as a measure of uncertainty and hence measured inflation variability, as opposed to uncertainty. Following the development of the ARCH approach by Engle (1982), several studies measured inflation uncertainty using the conditional variance of unanticipated shocks to the inflation process. The findings of most of these studies are summarized in Holland (1993b) and Davis and Kanago (2000). In general, the majority of these studies find evidence supporting the first leg of the Friedman hypothesis that more inflation leads to more inflation uncertainty. Similar evidence is obtained in more recent studies that use GARCH measures of inflation uncertainty, as in Grier and Perry (1998), Fountas (2001), Fountas et al. (2004a), Karanasos et al. (2004) and Conrad and Karanasos (2005b). The second leg of the Friedman hypothesis is examined in a number of studies using various measures of inflation variability (see Holland, 1993b). GARCH studies of this issue that represent a more accurate test of the hypothesis that inflation uncertainty has negative welfare effects are much more limited and include mostly US data (e.g., Coulson and Robins, 1985; Jansen, 1989; Grier and Perry, 2000; Grier et al., 2004). The evidence is rather mixed. Grier and Perry (2000) (and Grier et al., 2004) and Coulson and Robins (1985) find evidence for a negative and positive effect, respectively, and Jansen (1989) fails to find evidence for a significant impact. Fountas et al. (2004a) and Conrad and Karanasos (2005b) test this hypothesis using data for European countries and find mixed evidence.

The causal impact of inflation uncertainty on inflation is tested empirically using the GARCH approach in Baillie et al. (1996), Grier and Perry (1998, 2000), Grier et al. (2004), Fountas et al. (2004a), Karanasos et al. (2004) and Conrad and Karanasos (2005b). Grier and Perry (2000), Grier et al. (2004) and Karanasos et al. (2004) use only US data, whereas the rest of the studies use international data. In general, the evidence is mixed. Baillie et al.

(1996) find evidence supporting the link between the two variables for the UK and some high-inflation countries, whereas Grier and Perry (1998) in their G7 study find evidence in favor of the Cukierman–Meltzer hypothesis for some countries and in favor of the Holland hypothesis for other countries. Fountas et al. (2004a) and Conrad and Karanasos (2005b) also obtain mixed evidence. Finally, the study by Grier and Perry (2000) finds no evidence for a significant effect of inflation uncertainty on inflation whereas Grier et al. (2004) and Karanasos et al. (2004) find evidence in favor of the Holland and the Cukierman–Meltzer hypotheses, respectively.

The early empirical literature on the association between output variability and output growth employed cross section and pooled data and obtained mixed results (see Kneller and Young, 2001 for a review). In a recent study, Kneller and Young (2001) using a panel-data framework find that output variability reduces growth. Empirical evidence on the causal effect of output growth uncertainty (as opposed to variability) proxied by the conditional variance of shocks to the output series on output growth has appeared only recently. Caporale and McKiernan (1998), Grier and Perry (2000) and Grier et al. (2004) obtain evidence of a positive causal effect using US data, supporting, among others, the Black hypothesis. Speight (1999) and Fountas et al. (2004b) find no relationship between output growth uncertainty and output growth and Henry and Olekalns (2002) find evidence of a negative effect. Finally, the available empirical evidence on the Devereux hypothesis is rather limited. To the best of our knowledge, the only empirical studies on this hypothesis are Grier and Perry (2000), Fountas et al. (2002) and Grier et al. (2004) which find no supporting evidence for the hypothesis.

4. GARCH models of inflation and output growth

We use bivariate VAR models to estimate the conditional means of the rates of inflation and output growth. Let π_t and y_t denote the inflation rate and real output growth, respectively, and define the residual vector ε_t as $\varepsilon_t = (\varepsilon_{\pi t}\varepsilon_{yt})'$. Note that a general bivariate VAR(p) model can be written as

$$x_t = \Phi_0 + \sum_{i=1}^{p} \Phi_i x_{t-i} + \varepsilon_t \tag{1}$$

with

$$\Phi_0 = \begin{bmatrix} \phi_{\pi 0} \\ \phi_{y0} \end{bmatrix} \quad \text{and} \quad \Phi_i = \begin{bmatrix} \phi_{\pi\pi,i} & \phi_{\pi y,i} \\ \phi_{y\pi,i} & \phi_{yy,i} \end{bmatrix},$$

where x_t is a 2×1 column vector given by $x_t = (\pi_t\ y_t)'$, Φ_0 is the 2×1 vector of constants and Φ_i, $i = 1, \ldots, p$, is the 2×2 matrix of parameters. In our empirical work, we estimate several bivariate VAR specifications for inflation and output growth. We use the optimal lag-length algorithm of the Schwarz Information Criterion (SIC) to determine the structure of the VAR process. Regarding ε_t, we assume that it is conditionally normal with mean vector 0 and diagonal covariance matrix H_t. That is, $(\varepsilon_t|\Omega_{t-1}) \sim N(0,H_t)$, where Ω_{t-1} is the information set up to time $t-1$.

Following Engle and Lee (1999), we specify the dynamic structure of the conditional volatility (h_{it}, $i = \pi,y$) as the sum of a short-run (s_{it}) component and a long-run (q_{it}) component

$$h_{it} = s_{it} + q_{it} \tag{2}$$

with

$$[1-(\alpha_i+\beta_i+c_iD_{i,t-1})L]s_{it}=(\alpha_i+c_iD_{i,t-1})\nu_{i,t-1}, \tag{3}$$

$$(1-\varphi_iL)q_{it}=\omega_i+\rho_i\nu_{i,t-1}, \tag{4}$$

where $\omega_i>0$ and $D_{i,t-1}$ is a dummy indicating the direction of the shock: $D_{i,t-1}=1$ if $\varepsilon_{i,t-1}<0$ and $D_{i,t-1}=0$ if $\varepsilon_{i,t-1}>0$. In other words, the treatment of Glosten et al. (1993) is used to allow shocks to affect the temporary volatility component asymmetrically.[6] Notice that the 'volatility innovation' ($\nu_{i,t-1}\equiv\varepsilon^2_{i,t-1}-h_{i,t-1}$) drives both components. We refer to the specification in Eq. (2) as the two-component asymmetric-GARCH(1,1) [2C-AGARCH(1,1)] model.[7] If $\varphi_i=\rho_i=0$ in Eq. (4), then the 2C-AGARCH(1,1) specification reduces to the simple AGARCH(1,1) formulation. If $c_i=0$ in Eq. (3), then the specification in Eq. (2) reduces to the 2C-GARCH(1,1) model.

We have also estimated VAR models where the Φ_i matrix is either lower triangular ($\phi_{\pi y,i}=0$), or upper triangular ($\phi_{y\pi,i}=0$), or diagonal ($\phi_{y\pi,i}=\phi_{\pi y,i}=0$). Our choice between the three models is based on the use of Granger-causality tests (Wald tests). These Granger-causality tests are performed under the assumption that the conditional variances follow GARCH-type processes.[8]

We estimate the system of Eqs. (1) and (2) using the Berndt et al. (1974) numerical optimization algorithm to obtain the maximum likelihood estimates of the parameters. To make our inference robust to possible non-normality, Eqs. (1) and (2) are jointly estimated under quasi-maximum likelihood using the consistent variance–covariance estimator of Bollerslev and Wooldridge (1992).

We measure inflation and output uncertainty by the estimated conditional variances of inflation and output growth, respectively. We then perform Granger-causality tests in order to examine the causal effect of real and nominal uncertainty on inflation and output growth and the effect of inflation on inflation uncertainty. The causality tests are performed in each equation with the dependent variable regressed on lags of all four variables. We apply the Wald test and use the heteroskedasticity- and autocorrelation-consistent standard errors suggested by Newey and West (1987). To make sure our results are robust to the lag length choice, we perform these causality tests for three different lag lengths: 4, 8, and 12. We have chosen the Granger-causality approach (see also Grier and Perry, 1998) over the simultaneous-estimation approach for three reasons. (1) It allows us to capture the lagged effects between the variables of interest. (2) The simultaneous approach is subject to the criticism of the potential negativity of the variance. (3) The Granger-causality approach minimizes the number of estimated parameters.

[6] Notice that the model, Eqs. (2)–(4), is a slight modification of that presented in Engle and Lee (1999) and is the model estimated by EVIEWS.

[7] Grier and Perry (2000) and Fountas et al. (2002, 2006) have also estimated the bivariate system imposing Bollerslev's (1990) constant correlation GARCH(1,1) structure on the conditional covariance matrix H_t.

[8] In the presence of conditional heteroskedasticity, Vilasuso (2001) investigates the reliability of causality tests based on least squares. He demonstrates that when conditional heteroskedasticity is ignored, least-squares causality tests exhibit considerable size distortion if the conditional variances are correlated. In addition, inference based on a heteroskedasticity and autocorrelation-consistent covariance matrix constructed under the least squares framework offers only slight improvement. Therefore, he suggests that causality tests be carried out in the context of an empirical specification that models both the conditional means and conditional variances. However, if the conditional variances are unrelated, then there is only slight size distortion associated with least-squares tests, and the inconsistency of the least squares standard errors is unlikely to be problematic.

5. Empirical analysis

5.1. US results

We first test for the relationships between output growth, inflation, output growth uncertainty, and inflation uncertainty using US data as the US represents the largest industrial country. In our empirical analysis we use the Consumer Price Index (CPI) and the Industrial Production Index (IPI) as proxies for the price level and output, respectively. The data have monthly frequency, range from 1957:02 to 2000:08 and are taken from the International Financial Statistics (IFS). Allowing for differencing and lags of dependent variables leaves 523 usable observations. Inflation is measured by the annualized monthly difference of the log CPI [$\pi_t = \log(\text{CPI}_t/\text{CPI}_{t-1}) \times 1200$]. Real output growth is measured by the annualized monthly difference in the log of the IPI [$y_t = \log(\text{IPI}_t/\text{IPI}_{t-1}) \times 1200$]. We test for the stationarity properties of our data using the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests. The results of these tests, reported in Table 1, imply that we can treat the inflation rate and the growth rate of industrial production as stationary processes. We check the sensitivity of our results to the order of augmentation of the unit root tests by including both a 'small' and a 'large' number of lagged differenced terms in the ADF regressions. Likewise, we use both a 'low' and a 'high' truncation lag for the Bartlett kernel in the PP tests.

Table 2a reports estimates of the chosen VAR–GARCH model. Estimates of the inflation rate uncertainty and the real output growth uncertainty are based upon a bivariate VAR-type model where the conditional variances $(h_{\pi t})h_{yt}$ follow the 2C-(A)GARCH(1,1) model defined in Eq. (2). The best model is chosen on the basis of Likelihood Ratio (LR) tests and the SIC (see Table 2b). The estimated parameters of the conditional mean and variance equations for inflation are reported in Eqs. (1) and (2) of Table 2a. The shock impacts on the short-run and the long-run components (represented by α_π and ρ_π, respectively) are very similar (0.07 and 0.06, respectively). The mean-reverting parameter for the permanent component (φ_π) is 0.94 whereas the estimate of ($\alpha_\pi + \beta_\pi + c_\pi$) for the transitory component is only 0.32. Since the 'leverage' term in the transitory component is positive, negative shocks predict higher volatility than positive shocks, but the effect is temporary. The estimation shows a significant improvement in the likelihood value of the asymmetric component model over the original symmetric component model. Eqs. (3) and (4) in Table 2a report estimates of the conditional mean and variance of output growth, respectively. The shocks' impact on the short-run component ($\alpha_y = 0.28$) is much larger than on the long-run component ($\rho_y = 0.01$). The estimates of α_y, β_y and φ_y are highly significant. The mean-reverting parameter of the transitory component ($\alpha_y + \beta_y = 0.67$) is smaller than the mean-reverting parameter of the permanent component ($\varphi_y = 0.99$).

Table 1
Unit root tests (US)

	ADF	PP
Inflation (CPI)	−2.66	−11.61
Output growth	−6.79	−14.91

Notes: ADF (PP) is the Augmented Dickey–Fuller (Phillips–Perron) test statistic. A constant and eight lagged differenced terms are used for the ADF test. The MacKinnon critical value for rejection of the unit root null hypothesis at 0.01 significance level is −3.45.

Table 2a
Autoregressive GARCH model (US)

$$\pi_t = -\underset{(0.28)}{1.36} + \underset{(0.05)}{0.34}\,\pi_{t-1} + \underset{(0.04)}{0.09}\,\pi_{t-2} + \underset{(0.05)}{0.14}\,\pi_{t-5} + \underset{(0.05)}{0.09}\,\pi_{t-7} + \underset{(0.04)}{0.11}\,\pi_{t-8} + \underset{(0.04)}{0.13}\,\pi_{t-12} + \underset{(0.01)}{0.02}\,y_{t-3} + \underset{(0.01)}{0.02}\,y_{t-5} + \underset{(0.01)}{0.02}\,y_{t-10}. \quad (1)$$

$$(h_{\pi t} - q_{\pi t}) = \underset{(0.10)}{0.07}\left(\varepsilon^2_{\pi,t-1} - q_{\pi,t-1}\right) - \underset{(0.14)}{0.01}\left(h_{\pi,t-1} - q_{\pi,t-1}\right) + \underset{(0.20)}{0.26}\,D_{\pi,t-1}\left(\varepsilon^2_{\pi,t-1} - q_{\pi,t-1}\right),$$
$$q_{\pi t} = \underset{(1.56)}{5.78} + \underset{(0.08)}{0.94}\,q_{\pi,t-1} + \underset{(0.04)}{0.06}\left(\varepsilon^2_{\pi,t-1} - h_{\pi,t-1}\right). \quad (2)$$

$$y_t = \underset{(0.89)}{4.74} + \underset{(0.05)}{0.18}\,y_{t-1} + \underset{(0.05)}{0.07}\,y_{t-2} + \underset{(0.05)}{0.14}\,y_{t-3} - \underset{(0.03)}{0.11}\,y_{t-12} - \underset{(0.12)}{0.17}\,\pi_{t-2} - \underset{(0.11)}{0.26}\,\pi_{t-4} - \underset{(0.14)}{0.23}\,\pi_{t-10} + \underset{(0.12)}{0.14}\,\pi_{t-12}. \quad (3)$$

$$\left(h_{yt} - q_{yt}\right) = \underset{(0.10)}{0.28}\left(\varepsilon^2_{y,t-1} - q_{y,t-1}\right) + \underset{(0.18)}{0.39}\left(h_{y,t-1} - q_{y,t-1}\right), \quad q_{yt} = \underset{(25.91)}{18.21} + \underset{(0.00)}{0.99}\,q_{y,t-1} + \underset{(0.01)}{0.01}\left(\varepsilon^2_{y,t-1} - h_{y,t-1}\right). \quad (4)$$

Notes: This table reports parameter estimates of the two autoregressive 2C-(A)GARCH(1,1) models for the US (CPI) data. $\pi_t(y_t)$ is the inflation (output growth) rate calculated from the Consumer Price (Industrial Production) Index. $h_{\pi t}(h_{yt})$ is the inflation (output growth) uncertainty. The numbers in parentheses are robust standard errors.

Next, we examine the LR tests for the linear constraints $c_i = 0$ (2C-GARCH(1,1) model) and $\varphi_i = \rho_i = 0$ (AGARCH(1,1) model).[9] The results of these tests are reported in Table 2b. As seen in the second column of Table 2b, the LR tests for inflation clearly reject both the 2C-GARCH(1,1) model and the AGARCH(1,1) model. Following the work of Grier and Perry (1998) and Engle and Lee (1999) among others, the LR test can be used for model selection. Alternatively, the SIC can be applied to rank the various GARCH models. According to the SIC, the optimal GARCH-type model is the 2C-AGARCH(1,1). Thus, the SIC results concur with the LR results. As reported in the third column of Table 2b, for the output growth equation, on the basis of LR tests support is found for the 2C-GARCH(1,1) model. The evidence from the LR tests is reinforced by the model ranking provided by the SIC.[10] We also calculate Ljung–Box Q statistics at 12 lags for the levels and squares of the standardized residuals for the estimated bivariate VAR–GARCH system. The results, reported in Table 2b, show that the time series models for the conditional means and the 2C-(A)GARCH(1,1) models for the residual conditional variances adequately capture the joint distribution of the disturbances.

As mentioned earlier, Grier and Perry (2000) have used an alternative econometric methodology based on a simultaneous, rather than a two-step, approach, and US data to test four of the hypotheses we are examining in this study. To check the sensitivity of their results to the choice of methodology, we are also using their data set and test the same five hypotheses. In the first

[9] As Engle and Lee (1999) point out, the test is conservative in the sense that a likelihood ratio statistic of an AGARCH(1,1) model against a two-component AGARCH(1,1) model will have parameters unidentified under the null and a distribution with fewer than two degrees of freedom. Following Grier and Perry (1998), we also test between the AGARCH(1,1) and 2C-AGARCH(1,1) models using an LR test between an AGARCH(1,1) and an AGARCH(2,2) model. The test shows the dominance of the component model.

[10] A recent study by Grier et al. (2004) uses monthly data for 1947.4–2000.10 for the US and finds that both inflation and growth display evidence of significant asymmetric response to positive and negative shocks of equal magnitude.

Table 2b
SIC, residual diagnosis and LR tests (US)

	Inflation	Output growth
SIC	4.86	7.27
$Q(12)$	11.19	9.18
$Q^2(12)$	8.93	9.21
LR_1	8.20	1.12
LR_2	14.20	24.08

Notes: SIC is the Schwarz information criterion. $Q(12)$ and $Q^2(12)$ are the Ljung–Box statistics for 12th-order serial correlation in the standardized residuals and their squares. LR_1 is the value of the following likelihood ratio (LR) test: $LR_1 = 2 \times [ML_u - ML_R]$, where ML_u and ML_R denote the maximum log likelihood values of the unrestricted (asymmetric) and restricted (symmetric) model, respectively. LR_2 is the value of the following LR test: $LR_2 = 2 \times [ML_u - ML_R]$, where ML_u and ML_R denote the maximum log likelihood values of the unrestricted [2C-(A)GARCH(1,1)] and restricted [(A)GARCH(1,1)] model, respectively.

step, in Table 3 we report the estimated coefficients of the conditional variance equations for inflation and output growth using the inflation, both the CPI and Producer Price Index (PPI), and the output growth data of Grier and Perry (2000).[11] These data have monthly frequency and cover the 1946–1996 period. The best fitting model is chosen according to the LR results and the minimum value of the SIC. For all four cases we choose an AGARCH(1,1) model. The results indicate that the two ARCH (α_π) coefficients and all GARCH (β_i, $i = \pi, y$) coefficients are statistically significant. The LR tests for the linear constraint $c_i = 0$ ($i = \pi, y$) clearly reject the symmetric GARCH models, indicating evidence of asymmetry (the SIC results concur with the LR results). For the inflation rate, since the 'leverage' term is negative, positive shocks predict higher volatility than negative shocks, whereas for output growth, the estimated coefficient of asymmetry is positive, implying that a positive output shock leads to less uncertainty about output growth than a negative one.

We now proceed to the testing of the five economic hypotheses using the Granger-causality approach. Table 4 reports the results of Granger-causality tests using both sets of data, i.e., our original set of data and the set used by Grier and Perry (2000). Using our 1957–2000 sample and measuring inflation by the CPI, the F statistics reported in Table 4 indicate the following results. First, the evidence on the Friedman hypothesis is quite clear: inflation affects inflation uncertainty positively; however, inflation uncertainty does not cause negative output effects. Second, the impact of inflation uncertainty on inflation is primarily zero, even though there is some weak evidence for a positive effect (at four lags), i.e., the Cukierman–Meltzer hypothesis. Third, the effect of output uncertainty on output growth could be positive, negative, or zero. Thus, we find some weak evidence for the Black hypothesis (at 4 lags) and some weak evidence for a negative relationship between output uncertainty and output, as predicted by Pindyck (1991) and others, as mentioned previously. Finally, we find evidence against the Devereux hypothesis. As mentioned in the theoretical part of our paper, the evidence against the Devereux hypothesis is consistent with the weak evidence for the Cukierman–Meltzer hypothesis at 4 lags. If we measure inflation by the PPI instead and use data for the 1957–2000 period (data obtained from the same source as the CPI data), the Granger-causality results reported in Table 4 are similar to the CPI results for three of the five hypotheses tested.[12] The primary

[11] We do not report the estimated results for the mean equation for space considerations.

[12] Due to space limitations, we have not reported the estimated equations for the conditional means and variances. They are available upon request from the authors.

Table 3
Asymmetric-GARCH models: US, Grier and Perry (2000) data

$h_{\pi t}$	CPI	PPI	h_{yt}	CPI	PPI
ω_π	0.33 (0.13)	2.48 (0.84)	ω_y	8.89 (3.33)	8.32 (3.23)
α_π	0.22 (0.07)	0.26 (0.08)	α_y	−0.01 (0.02)	−0.01 (0.01)
β_π	0.79 (0.05)	0.76 (0.06)	β_y	0.76 (0.06)	0.78 (0.06)
c_π	−0.12 (0.06)	−0.16 (0.07)	c_y	0.39 (0.15)	0.35 (0.14)
SIC	4.77	6.40	SIC	7.53	7.55
$Q(12)$	6.19	18.12	$Q(12)$	11.27	16.03
$Q^2(12)$	9.12	20.18	$Q^2(12)$	12.27	15.49
LR_1	4.60	6.00	LR_1	42.20	35.20
LR_2	5.60	0.20	LR_2	9.20	2.20

Notes: This table reports parameter estimates of the AGARCH (1,1) models for the Grier and Perry (2000) data. CPI (PPI) is the Consumer (Producer) Price Index. The term $\omega_\pi(\omega_y)$ is the constant term in the conditional variance of inflation (output growth); $\alpha_\pi(\alpha_y)$ denotes the ARCH parameter in the conditional variance of inflation (output growth); $\beta_\pi(\beta_y)$ denotes the GARCH parameter in the conditional variance of inflation (output growth); and $c_\pi(c_y)$ denotes the leverage parameter in the conditional variance of inflation (output growth). The numbers in parentheses are robust standard errors.

differences lie in (i) the much stronger evidence on the Cukierman–Meltzer hypothesis and (ii) the strong evidence for negative output effects of inflation uncertainty.

When the data from Grier and Perry (2000) are used and inflation is measured by CPI, the results of the Granger-causality tests are in several cases qualitatively similar to the analogous results from our sample, even though in some cases the results are less ambiguous. Again, the effect of inflation uncertainty on inflation seems to be zero in two of the three lag lengths tested. Some evidence on the Holland hypothesis also applies (12 lags). As previously, we find strong evidence in favor of the first leg of the Friedman hypothesis. Regarding the second lag lenths, though, we now find some evidence that inflation uncertainty raises output growth, as suggested by Dotsey and Sarte (2000). In addition, there is now no evidence for the Black hypothesis. In particular, the impact of output uncertainty on output is zero at all lags, supporting the belief that the variability of the business cycle is not linked to the growth rate of the economy. Moreover, we find no evidence on the Devereux hypothesis as in all lags the effect of output uncertainty on inflation is not statistically different from zero.

When we employ the Grier and Perry (2000) data and measure inflation by the PPI, we observe the following. First, the results are similar to the PPI results obtained from our data set. Second, the results change in comparison with the CPI results of the same data set in three of the five causal relationships. We still find evidence for the first part of the Friedman hypothesis and the zero effect of output uncertainty on output. However, three important differences emerge: first, we find support for the Cukierman–Meltzer hypothesis; second, we find strong support for the second leg of the Friedman hypothesis; and third, we find some evidence for a negative impact of output uncertainty on inflation. These differences between the CPI and PPI results reveal the sensitivity of the results to the choice of price index in measuring the inflation rate.

In summary, the Granger-causality results on US data reported in Table 4 lead to the following conclusions. First, there is overwhelming evidence for the first leg of the Friedman hypothesis. Evidence for the second leg of the hypothesis applies only when inflation is measured using the PPI index. Second, there seems to be strong evidence in support of the Cukierman–Meltzer hypothesis when using the PPI index. Third, there is very weak evidence for the Black hypothesis. Overall, the evidence points to the independence of economic growth

Table 4
Granger-causality tests between inflation, output growth, nominal uncertainty and real uncertainty (US)

Lags	CPI	PPI	CPI (GP)	PPI (GP)
H_0: Inflation does not Granger-cause nominal uncertainty				
4	5.88***(+)	3.40***(+)	37.31***(+)	7.81***(+)
8	2.65***(+)	2.50***(+)	17.82***(+)	5.21***(+)
12	2.02**(+)	21.69***(+)	12.48***(+)	3.97***(+)
H_0: Nominal uncertainty does not Granger-cause output growth				
4	0.32	3.71***(−)	1.23	4.03***(−)
8	1.15	3.16***(−)	2.23**(+)	3.30***(−)
12	0.91	2.68***(−)	1.57*(+)	3.30***(−)
H_0: Nominal uncertainty does not Granger-cause inflation				
4	1.89$^{\diamond}$(+)	3.99***(+)	1.55	5.51***(+)
8	0.99	4.83***(+)	0.88	4.12***(+)
12	0.80	4.71***(+)	2.92***(−)	4.96***(+)
H_0: Real uncertainty does not Granger-cause output growth				
4	2.96**(+)	1.81	1.15	0.72
8	1.44	1.18	0.38	0.64
12	2.11**(−)	1.05	0.98	0.84
H_0: Real uncertainty does not Granger-cause inflation				
4	2.15*(−)	2.13*(−)	0.61	3.74***(−)
8	1.95**(−)	1.38	0.91	1.83*(−)
12	1.14	0.89	0.38	1.28

Notes: GP indicates the data used are as in Grier and Perry (2000). Figures are F statistics. A +(−) indicates that the sum of the lagged coefficients of the causing variable is positive (negative); ***, ** and * denote significance at the 0.01, 0.05 and 0.10 levels, respectively; $^{\diamond}$ denotes significance at the 0.15 level.

from the variability of the business cycle (i.e., output growth uncertainty). Fourth, there is evidence against Devereux's theory.

5.2. Extension to the other G7 countries

Next, we apply the above empirical approach to the rest of the G7 countries, namely Canada, France, Germany, Italy, Japan, and the UK using data for the 1957–2000 period. As previously, we use monthly data on the CPI and IPI as proxies for the price level and output, respectively, to create the inflation and output growth variables. Table 5 presents the ADF and PP tests of the unit root null hypothesis for each country. The PP tests reject the null hypothesis of a unit root for all six countries at 0.01 significance level. For the inflation rate, the ADF tests for France and Italy fail to reject the null hypothesis of a unit root. However, we will consider inflation series in these two countries to be stationary, as implied by the PP test results. The best fitting VAR–GARCH model is chosen according to the LR results and the minimum value of the SIC.[13] For the conditional mean of inflation, we choose an AR(12) model in all six countries. For the conditional mean of output growth, we choose an AR(12) model for Canada, Italy and the UK, an AR(6) for France, an AR(8) for Germany and an AR(10) for Japan.[14] Moreover, using the approach outlined in Section 4, we

[13] We do not report the estimated results for the mean equation for space considerations.

[14] The equation for the conditional mean of output growth for France includes a dummy that takes the value one in the fifth month of 1968 in order to capture the negative shock to the economy of the social unrest. The dummy is highly significant.

Table 5
Unit root tests (the other six G7 countries)

	UK	Germany	France	Italy	Canada	Japan
Inflation (CPI)						
ADF	−4.04	−6.11	−2.03	−2.53	−2.91	−3.82
PP	−16.16	−16.12	−10.73	−8.90	−17.07	−19.93
Output growth						
ADF	−7.74	−6.62	−8.13	−6.92	−5.55	−4.24
PP	−27.15	−37.85	−33.02	−32.32	−27.32	−27.08

Notes: ADF (PP) is the Augmented Dickey–Fuller (Phillips–Perron) test statistic. A constant and eight lagged differenced terms are used for the ADF test. The MacKinnon critical values for rejection of the unit root null hypothesis at 0.01, 0.05 and 0.10 significance levels are −3.45, −2.87 and −2.57, respectively.

establish that in Canada, France, Germany and the UK, inflation affects output growth and vice versa. In addition, for Italy, there is evidence of an effect from inflation to output growth only (the matrix Φ_i is lower triangular), whereas for Japan there is evidence of an effect from output growth to inflation only (the matrix Φ_i is upper triangular).

In Table 6a, we report the estimated coefficients of the conditional variance equations for inflation and output growth for each country. For inflation, we choose an AGARCH(1,1) model for five countries and a 2C-AGARCH(1,1) model for the UK. The results indicate that almost all ARCH (α_π) and GARCH (β_π) coefficients are statistically significant. The LR tests for the linear constraint $c_\pi = 0$ clearly reject the symmetric GARCH models, indicating evidence of asymmetry in all countries (see Table 6b). The evidence obtained from the LR tests is reinforced by the model ranking provided by the SIC. Thus, purely from the perspective of searching for a model that best describes inflation uncertainty, the asymmetric-GARCH model appears the most satisfactory representation. This implies that negative and positive shocks to

Table 6a
'Best' GARCH models (the other six G7 countries)

	UK	Germany	France	Italy	Canada	Japan
$h_{\pi t}$						
ω_π	7.09 (4.04)	1.23 (0.59)	2.69 (0.48)	0.11 (0.03)	2.65 (1.00)	0.72 (0.40)
α_π	0.18 (0.07)	−0.02 (0.02)	0.94 (0.35)	0.11 (0.02)	0.18 (0.07)	0.12 (0.03)
β_π	0.86 (0.05)	0.78 (0.11)	0.13 (0.08)	0.95 (0.01)	0.48 (0.16)	0.91 (0.02)
c_π	−0.22 (0.10)	0.30 (0.22)	−0.61 (0.37)	−0.18 (0.03)	0.40 (0.27)	−0.11 (0.06)
φ_π	0.99 (0.01)	–		–	–	–
ρ_π	−0.02 (0.03)	–		–	–	–
h_{yt}						
ω_y	−27.77 (616.66)	373.75 (33.10)	95.29 (25.70)	229.40 (150.00)	9.04 (4.85)	5.77 (6.07)
α_y	0.56 (0.11)	0.17 (0.07)	0.69 (0.24)	0.17 (0.08)	0.08 (0.03)	0.007 (0.02)
β_y	0.04 (0.06)	0.09 (0.27)	0.23 (0.12)	0.51 (0.24)	0.87 (0.04)	0.94 (0.04)
c_y	−0.19 (0.16)	–	–	–	–	0.05 (0.03)
φ_y	0.99 (0.01)	0.94 (0.01)	–	–	–	–
ρ_y	0.04 (0.04)	−0.02 (0.01)	–	–	–	–

Notes: This table reports parameter estimates of the 'best' GARCH models for the other six G7 countries. The conditional volatility (h_{it}, $i = \pi, y$) for the general 2C-AGARCH(1,1) model is equal to the sum of a short-run component (s_{it}) and a long-run component (q_{it}): $h_{it} = s_{it} + q_{it}$, where $(1-\varphi_i L)q_{it} = \omega_i + \rho_i \nu_{i,t-1}$ and $[1 - (\alpha_i + \beta_i + c_i D_{i,t-1})L]s_{it} = (\alpha_i + c_i D_{i,t-1})\nu_{i,t-1}$. The numbers in parentheses are robust standard errors.

Table 6b
SIC, residual diagnostics and LR tests (the other six G7 countries)

	UK	Germany	France	Italy	Canada	Japan
Inflation						
SIC	6.19	5.32	4.99	5.15	5.57	6.68
$Q(12)$	15.02	6.62	17.83	16.98	8.27	7.64
$Q^2(12)$	15.30	9.75	8.89	6.04	8.57	10.66
LR_1	18.00	12.80	4.10	42.04	5.60	5.78
LR_2	30.60	0.40	1.10	0.60	4.70	1.34
Output growth						
SIC	8.27	8.96	8.70	9.51	8.26	8.49
$Q(12)$	9.53	4.70	12.62	8.45	3.93	6.88
$Q^2(12)$	7.74	7.95	8.68	18.57	17.27	14.99
LR_1	4.80	1.20	1.40	1.70	2.20	4.20
LR_2	33.90	23.80	4.60	3.30	6.20	1.40

Notes: SIC is the Schwarz information criterion. $Q(12)$ and $Q^2(12)$ are the Ljung–Box statistics for 12th-order serial correlation in the standardized residuals and their squares. LR_1 is the value of the following likelihood ratio (LR) test: $LR_1 = 2 \times [ML_u - ML_R]$, where ML_u and ML_R denote the maximum log likelihood values of the unrestricted (asymmetric) and restricted (symmetric) model, respectively. LR_2 is the value of the following LR test: $LR_2 = 2 \times [ML_u - ML_R]$, where ML_u and ML_R denote the maximum log likelihood values of the unrestricted [2C-(A)GARCH(1,1)] and restricted [(A)GARCH(1,1)] model, respectively.

the inflation process have a different impact on inflation uncertainty. For France, Japan, Italy, and the UK the estimated coefficient of asymmetry is negative, implying that a negative inflation shock leads to less uncertainty about inflation than a positive one. In sharp contrast, since for Canada and Germany the 'leverage' term is positive, negative shocks predict higher volatility than positive shocks. As seen in Table 6b, the LR tests clearly reject the 2C-AGARCH(1,1) model for all countries, except the UK. For the UK, the mean-reverting parameter for the permanent component (φ_π) is 0.99, whereas the estimate of ($\alpha_\pi + \beta_\pi + c_\pi$) for the transitory component is smaller (0.82).

For output growth we choose a GARCH(1,1) model for Canada, France and Italy, a 2C-GARCH(1,1) for Germany, an AGARCH(1,1) for Japan, and a 2C-AGARCH(1,1) for the UK. The results indicate that most of the estimated coefficients are statistically significant. As seen in Table 6b, the LR tests clearly reject the two-component GARCH model for all countries, except the UK and Germany. For the UK, the shocks' impact on the short-run component ($\alpha_y = 0.56$) is much larger than on the long-run component ($\rho_y = 0.04$). The mean-reverting parameter for the permanent component (φ_y) is 0.99 whereas the estimate of ($\alpha_y + \beta_y + c_y$) for the transitory component is only 0.41. Similarly, for Germany the mean-reverting parameter of the transitory component ($\alpha_y + \beta_y = 0.26$) is smaller than the mean-reverting parameter for the permanent component ($\varphi_y = 0.94$). For Germany the estimates of ρ_y and φ_y are highly significant. Furthermore, as seen in Table 6b, the LR tests clearly reject the asymmetric-GARCH models for all countries, except the UK and Japan. For the UK, since the 'leverage' term in the transitory component is negative, positive shocks predict higher volatility than negative shocks, but the effect is temporary. In sharp contrast, for Japan the estimated coefficient of asymmetry is positive, implying that a positive output shock leads to less uncertainty about output growth than a negative one. Table 6b also reports Ljung–Box Q statistics for autocorrelation of the standardized residuals and squared standardized residuals. In no cases do the tests reject the hypothesis of no autocorrelation. Thus, the Ljung–Box tests indicate that the estimated models fit the data very well.

Table 7 reports the Granger-causality test results of the five testable hypotheses in the rest of the G7 countries. These results are summarized as follows. First, uniform strong evidence (at 1%, or better) for the first leg of the Friedman hypothesis applies in all countries, except Germany. The negative and significant effect for Germany squares with the traditionally conservative stance of the Bundesbank and the credibility it has accumulated over the years. Second, inflation uncertainty seems to be costly only in Germany and the UK. In contrast, inflation uncertainty may cause higher output growth in Canada and Japan (at 12 lags only), thus supporting the Dotsey and Sarte (2000) argument. Third, the evidence on the effect of inflation uncertainty on inflation is mixed across countries. There is quite strong evidence supporting the Cukierman–Meltzer hypothesis in Germany and the Holland hypothesis in Canada. The evidence in Italy, Japan and the UK is mixed as it varies across lags. For the UK and Japan there is evidence for the Cukierman and Meltzer hypothesis at 4 and 8 lags, and for Italy at 4 lags only. Finally, in France inflation does not seem to respond to changes in inflation uncertainty. Fourth, evidence for the Black hypothesis applies in all countries, except Japan. The evidence is strong in the UK, France, Germany and Italy and weak in Canada (at 4 lags only). Finally, quite strong evidence for the Devereux hypothesis is obtained in Italy and the UK. In France the evidence is mixed. In the rest of the countries, the impact of output uncertainty on inflation depends on the lag length and it is negative or zero, thus contradicting the Devereux hypothesis. Interestingly, the evidence for a negative effect of output uncertainty on inflation for Germany (at 8 lags) and Japan (at 4 lags) squares with the evidence for the Cukierman–Meltzer hypothesis for these two countries, in accordance with the argument presented previously, where

Table 7
Granger-causality tests between inflation, output growth, nominal uncertainty and real uncertainty (CPI: the other six G7 countries)

Lags	UK	Germany	France	Italy	Canada	Japan
H_0: Inflation does not Granger-cause nominal uncertainty						
4	48.54***(+)	26.43***(−)	31.90***(+)	30.84***(+)	16.50***(+)	87.74***(+)
8	23.88***(+)	13.28***(−)	17.38***(+)	17.18***(+)	9.28***(+)	46.62***(+)
12	15.33***(+)	9.65***(−)	12.09***(+)	13.06***(+)	6.97***(+)	33.77***(+)
H_0: Nominal uncertainty does not Granger-cause output growth						
4	2.68**(−)	2.00*(−)	1.43	1.21	1.62	0.81
8	2.19**(−)	4.30***(−)	1.16	1.17	1.87*(+)	0.60
12	1.23	0.75	0.30	0.87	2.19***(+)	2.16***(+)
H_0: Nominal uncertainty does not Granger-cause inflation						
4	3.79***(+)	2.60**(+)	1.21	2.05*(+)	3.70***(−)	15.63***(+)
8	2.79***(+)	21.28***(+)	0.33	2.40**(−)	2.18**(−)	5.08***(+)
12	6.76***(−)	4.72***(+)	0.82	2.10**(−)	1.59*(−)	3.33***(−)
H_0: Real uncertainty does not Granger-cause output growth						
4	9.57***(+)	13.68***(+)	5.58***(+)	1.39	3.76***(+)	0.93
8	5.24***(+)	2.92***(+)	4.39***(+)	2.58***(+)	1.48	0.33
12	4.13***(+)	1.40	4.06***(+)	2.42***(+)	1.10	0.55
H_0: Real uncertainty does not Granger-cause inflation						
4	2.91**(+)	1.88	10.75***(+)	0.88	1.78	4.42***(−)
8	1.85*(+)	4.09***(−)	2.00**(−)	2.67***(+)	1.78*(−)	1.05
12	1.94**(+)	1.01	1.35	2.91***(+)	0.62	0.92

Notes: Figures are F statistics. A +(−) indicates that the sum of the lagged coefficients of the causing variable is positive (negative); ***, ** and * denote significance at the 0.01, 0.05 and 0.10 levels, respectively.

a negative effect of output uncertainty on inflation hinges on both the Taylor effect and the Cukierman–Meltzer hypothesis holding.

5.3. PPI results

We have also performed the analysis measuring inflation by the PPI for the rest of the G7 countries. As the PPI data for France and Italy start after 1977, we exclude these two countries from the analysis. We first estimate the 'best' GARCH models following the previously described methodology. For space considerations, these results are not reported. We then proceed to the Granger-causality tests and report the results of these tests in Table 8. In all countries we find strong evidence for the first leg of the Friedman hypothesis. The evidence is somewhat weaker in the UK. Strong evidence for the second leg of the Friedman hypothesis applies for Japan and there is weak evidence for Canada and the UK (at 12 and 4 lags, respectively). Hence, inflation uncertainty is quite costly in output terms for Japan and somewhat costly in Canada and the UK. Regarding the causality from inflation uncertainty to inflation, the evidence is mixed. Strong evidence for the Cukierman–Meltzer hypothesis applies in the UK and mixed evidence for Canada as the sign at 12 lags is negative. Strong evidence for the Holland stabilization hypothesis applies in Japan and weak evidence in Germany (at 4 lags only). We find strong evidence that output uncertainty is a positive determinant of output growth (the Black hypothesis) in Germany and the UK and weaker evidence for Japan (at 4 lags). In Canada, the evidence suggests that output uncertainty and output growth are independent. Finally, we do not find any evidence for the Devereux hypothesis in any country. The

Table 8
Granger-causality tests between inflation, output growth, nominal uncertainty and real uncertainty (PPI: the other four G7 countries)

Lags	UK	Germany	Canada	Japan
H_0: Inflation does not Granger-cause nominal uncertainty				
4	2.02*(+)	6.79***(+)	5.39***(+)	56.67***(+)
8	0.97	6.13***(+)	3.09***(+)	28.66***(+)
12	2.42***(+)	5.27***(+)	2.32***(+)	19.96***(+)
H_0: Nominal uncertainty does not Granger-cause output growth				
4	$1.75^{\diamond}$(−)	1.41	1.21	8.01***(−)
8	1.31	0.90	0.94	5.14***(−)
12	0.62	0.73	1.66*(−)	5.95***(−)
H_0: Nominal uncertainty does not Granger-cause inflation				
4	14.28***(+)	2.62**(−)	4.79***(+)	8.87***(−)
8	5.45***(+)	1.39	3.19***(+)	6.82***(−)
12	4.64***(+)	0.80	2.63***(−)	5.29***(−)
H_0: Real uncertainty does not Granger-cause output growth				
4	7.93***(+)	11.46***(+)	1.40	1.95*(+)
8	3.82***(+)	3.33***(+)	0.81	0.78
12	4.95***(+)	3.42***(+)	0.57	0.74
H_0: Real uncertainty does not Granger-cause inflation				
4	0.71	0.55	0.97	0.69
8	0.53	1.72*(−)	1.17	0.44
12	0.77	1.41	1.77**(−)	0.94

Notes: Figures are F statistics. A +(−) indicates that the sum of the lagged coefficients of the causing variable is positive (negative); ***, **, * and $^{\diamond}$ denote significance at the 0.01, 005, 0.10 and 0.15 levels, respectively.

effect of output uncertainty on inflation is zero in Japan and the UK and mildly negative in the rest of the countries, i.e., it applies only in one of the three lag lengths tested.

A comparison of these results with those obtained when inflation is measured by the CPI reveals that the results are in several respects qualitatively similar. In both cases, we find strong evidence for the first leg of the Friedman hypothesis, mixed evidence for the Cukierman–Meltzer hypothesis, significant evidence for the Black hypothesis, and some evidence for the second leg of the Friedman hypothesis (although stronger than that reported in Table 7). The main difference from the CPI results is that now no evidence appears for the Devereux hypothesis in any of the countries tested.

5.4. Discussion of results and related recent literature

The results presented above carry noteworthy implications for macroeconomic modeling and policymaking. Our very strong evidence on the first leg of the Friedman hypothesis is in broad agreement with the findings of the overwhelming majority of empirical studies. It implies that the rate of inflation is a significant determinant of nominal uncertainty. Our empirical support for the Black hypothesis suggests that macro theorists should incorporate the analysis of output uncertainty into growth models, as the two seem to be interrelated. The country-specific evidence on the Cukierman–Meltzer hypothesis is anticipated given that national central banks adjust their rate of money growth differently to inflation uncertainty depending on their relative preference toward inflation and output stabilization.

Our mixed evidence on the welfare effects of inflation uncertainty squares with the lack of any consensus that has been established by the broad empirical research on this matter. This literature, summarized in Holland (1993b), reports mixed results that are sensitive to factors such as the measure of inflation uncertainty, the chosen econometric methodology, the countries examined, and the sample period. For example, Grier and Perry (2000) and Grier et al. (2004) report a negative effect of inflation uncertainty on output growth. In contrast, Jansen (1989) reports an insignificant effect and Coulson and Robins (1985) and McTaggart (1992) report a positive impact. In a recent study Fountas et al. (2004a) using quarterly data for six European countries covering the period 1960–1999 have investigated the relationship between inflation uncertainty and output growth. They find that nominal uncertainty reduces output growth only in the UK. In sharp contrast, in the Netherlands and Spain, inflation uncertainty raises real output growth.

Regarding the causal effect of output uncertainty on the inflation rate, our time series evidence is rather mixed and points primarily toward a rejection of the Devereux hypothesis. It should be emphasized that the available evidence to date on this hypothesis is very scant as it includes only US data (Grier and Perry, 2000; Grier et al., 2004). It is noteworthy that evidence for the Devereux hypothesis is obtained for Italy and the UK. However, the invalidity of the Devereux hypothesis in Germany and Japan (eight and four lags) is not surprising as it concurs with the validity of the Cukierman–Meltzer hypothesis, as argued earlier.

The results presented above can be related to those obtained from previous very recent studies that have made use of the GARCH approach. First, a comparison can be made with the study by Grier and Perry (1998), which uses only CPI data for the period 1948–1993 for the G7 to test the relationship between inflation and inflation uncertainty. Therefore, the authors do not consider output in their analysis and only test for the link between inflation and inflation uncertainty. They test for asymmetry, reject it, and use the GARCH and component GARCH models. Given that the present study uses a different (more recent) sample period and a different methodological approach, it is not surprising that some of our results, in particular most of those on the causal effect of inflation uncertainty on inflation, are different from Grier and Perry (1998). Nevertheless, in six of the seven countries our results on the first leg of the Friedman hypothesis are identical to those of Grier and Perry (1998).

Grier and Perry (2000) use monthly data for 1948.7–1996.12 for the US and test the effects of uncertainty (nominal and real) on inflation and output growth. The authors use the simultaneous approach, as opposed to our choice of the two-step approach, and find that inflation uncertainty reduces output growth. No evidence for the Black, Cukierman–Meltzer or Devereux hypotheses is found and the results are robust to the use of CPI and PPI in measuring inflation. Our paper differs from Grier and Perry (2000) in the chosen econometric methodology and the scope of countries considered. Our use of the same US data as in Grier and Perry (2000) reveals some differences in the results. We find support for the Cukierman–Meltzer hypothesis when the PPI index is used (we also find some weak evidence for the Holland hypothesis when we use the CPI data) and support for the Dotsey and Sarte (2000) theory when the CPI index is used. As in Grier and Perry (2000), we find no evidence for the Black and Devereux hypotheses.

Finally, several of our results square with the findings of recent studies by Fountas et al. (2002), Fountas et al. (2004a) and Conrad and Karanasos (2005a). In particular, Fountas et al. (2002) employ Japanese data (1961–1999) and a bivariate GARCH model (where inflation is measured by PPI) and find similar results to the PPI results of the present study. The only difference is lack of evidence for the Black hypothesis in Fountas et al. (2002). Fountas et al. (2004a) use quarterly data and CPI inflation for six European Union countries, and an exponential GARCH model and test for three hypotheses: Friedman's two hypotheses and the Cukierman–Meltzer hypothesis. Their results have several similarities to those of the present paper. First, the results on the first leg of the Friedman hypothesis are identical with those of the present paper for all common countries, except Germany. Second, the evidence on the effects of inflation uncertainty on inflation and output growth is mixed in both papers. Conrad and Karanasos (2005) use parametric models of long memory in both the conditional mean and the conditional variance of inflation and monthly data in the US, Japan and the UK for the period 1961–2001 to examine the relationship between inflation and inflation uncertainty. Our results are almost identical to their study.

6. Conclusions

We have used data on inflation and output growth in the G7 countries to examine the causal effects of real and nominal uncertainty on inflation and output growth and the causal effect of inflation on the associated uncertainty. This approach allows us to test a number of economic theories including the Friedman, Cukierman–Meltzer, Black, and Devereux hypotheses. Our two-step approach that proxies uncertainty by the conditional variance of unanticipated shocks to the time series of inflation and output growth and applies causality tests leads to a number of important conclusions. First, inflation is a primary determinant of inflation uncertainty, as argued by Friedman (1977). Second, the uncertainty associated with the rate of inflation seems to have mixed effects on output growth. In other words, Friedman's belief that inflation uncertainty can be detrimental to the economy's real sector receives only some support in our study. This finding is in line with various studies that have documented a lack of consensus on the output effects of nominal uncertainty. Third, we obtain mixed evidence in favor of the Cukierman–Meltzer hypothesis. Thus, as expected, countries are anticipated to react differently to a change in the degree of uncertainty surrounding the inflation rate. Fourth, in most countries we find that output growth uncertainty is a positive determinant of the growth rate as predicted by Black (1987). This result has important implications for the development of macroeconomic theory as it provides the motivation for the simultaneous analysis of economic growth and business cycle variability in macroeconomic modeling. Fifth, output uncertainty does not seem to contribute to more inflation, i.e., the Devereux hypothesis does not receive much support. Our consideration of alternative sample periods and measures of inflation, and our comparison with other relevant studies, notably Grier and Perry (1998, 2000), points toward the sensitivity of the results to the chosen methodological approach, the time period examined and the measure of inflation. Therefore, our empirical study highlights the need for further work on the causal relationships between inflation, output growth, and real and nominal uncertainty.

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