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The relationship between economic growth and real uncertainty in the G3 ☆

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Abstract

We use a long series of annual output data that span about one and a half centuries to examine the relationship between output growth and output growth uncertainty in the G3. Our econometric methodology employs GARCH models and proxies output uncertainty by the conditional variance of shocks to output growth. We find that first, more uncertainty about output growth leads to a higher rate of output growth in two of the three countries and second, output growth reduces its uncertainty in two of the three countries. Our results are robust to the choice of the distribution of the error term and the form in which the time varying variance enters the specification of the mean.

JEL classification: C22; E32

Keywords: Output growth; Output growth uncertainty; GARCH

1. Introduction

Until the 1980s, the analysis of the real business cycle (RBC) and the study of economic growth were treated separately by macroeconomic theorists. Despite important contributions in the business cycle theory during the 1980s that integrated the theories of the business cycle and economic growth in their models, no consideration was given to the possibility that the variability of the business cycle might relate to the rate of economic growth. A recent study by Stock and Watson (2002), among others, highlights the importance of the analysis of the reduction in US GDP growth volatility in the last two decades and its implications for growth theory. A similar

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reduction in GDP growth volatility is reported for other industrialized countries as well. The reduction in macroeconomic volatility has been dubbed by economists the "Great Moderation". The apparent dichotomy in macroeconomic theory between economic growth and the variability of economic fluctuations should be reconsidered given several theories advanced over the last 30 years that relate the two.[1] These theories predict that the association between growth and variability may be positive, negative, or zero. The empirical evidence to date, based on cross-section country studies, panel data studies, or time series analyses of individual countries is also rather mixed. The theoretical and empirical ambiguity surrounding the RBC variability–economic growth relationship provides us with the motivation to expand on the empirical aspects of this issue.

We attempt to cover a gap in the existing empirical literature by employing a long span of annual output data on the G3 that starts in the mid 1800s. Our approach has three advantages over existing studies. First, we are able to analyze the RBC variability–growth relationship over a period that spans over 100 years, thus including in our analysis periods of significant variation in output growth. Second, as explained below, the use of annual data allows us to perform a more appropriate test of the hypothesis that predicts a positive effect of output variability and uncertainty on the growth rate of output. Third, we also examine the bidirectional causality between output growth and uncertainty in contrast with the existing literature that focuses exclusively on the effect of output uncertainty on growth.

The rest of the paper is structured as follows. Section 2 presents a survey of the theoretical and empirical literature. Section 3 outlines our econometric model. Section 4 presents and interprets our main results, and then relates them to the findings of other relevant studies. Finally, Section 5 summarises our main conclusions and their implications.

2. Theory and evidence

2.1. Theory

Macroeconomic theory offers three possible scenarios regarding the impact of output variability on output growth. First, there is the possibility of a positive impact of output variability on average growth. A number of economic theories predict this outcome. Black (1987) argues that investments in riskier technologies will be pursued only if the expected return on these investments (expressed as the 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.[2] Blackburn (1999) in a study where economic growth arises from learning-by-doing shows that business cycle volatility raises an economy's long-run growth rate.[3]

[1] In fact, most of these theories outlined in the following section examine the relationship between output growth and output growth uncertainty, as opposed to variability. Therefore, in this paper we proxy output growth uncertainty instead of variability. Notice that output growth uncertainty is a narrower concept as it includes only the unanticipated component of the variability in output growth.

[2] Bean (1990) and Saint-Paul (1993) show that higher volatility may increase long-run growth because it enhances inventive activity. However, their argument is based on the expected (predictable) component of volatility which does not lead to uncertainty.

[3] Blackburn and Pelloni (2004) in a stochastic monetary growth model show that the sign of the correlation between output growth and its variability depends on the type of shocks buffeting the economy. Their study concludes that if real (nominal) shocks dominate the correlation will be positive (negative).

A second possibility is for output variability and growth to be independent from each other. For example, output fluctuations around its natural rate are due to price misperceptions in response to monetary shocks, whereas changes in the growth rate of output arise from real factors such as technology. Finally, output variability may exert a negative impact on growth. Higher volatility in output growth leads to unexpected changes in output growth and makes future demand for a firms' product more uncertain. Hence, firms face increasing risk and are less likely to invest in plant and equipment. Therefore, the demand for investment falls and the growth rates of the capital stock and output both decline. The negative association between output volatility and growth arises from investment irreversibilities at the firm level. This line of reasoning advanced by Bernanke (1983), Pindyck (1991) and Ramey and Ramey (1991) leads to the testable implication that output volatility (and hence uncertainty) reduces average output growth.

Another strand of the literature employs small general equilibrium models based on the AK growth models in order to investigate the relationship between income volatility and growth from a theoretical point of view. This literature includes Smith (1996), Jones et al. (2000) and Turnovsky and Chattopadhyay (2003). The main argument is that the effect of volatility (risk) on savings and growth depends on the magnitude of the elasticity of intertemporal substitution. When consumers do not like to substitute consumption over time (elasticity of intertemporal substitution smaller than one), as suggested by aggregate consumption data, an increase in the volatility (uncertainty) of income leads to an increase in savings and, therefore, growth. If, on the other hand, consumers prefer to substitute consumption over time (elasticity of intertemporal substitution greater than one), an increase in the volatility of income leads to a decrease in savings and growth.

In the present theoretical framework, we may also examine the opposite type of causality running from output growth to output growth uncertainty, which has, with a few exceptions, been disregarded by the empirical literature. Theoretically speaking, the sign of this causality relationship is ambiguous. First, consider the argument for a negative effect. An increase in output growth (and output) leads to more inflation (the short-run 'Phillips curve'effect).[4] On the basis of the Friedman (1977) hypothesis, this will lead to more inflation uncertainty. As, according to Taylor (1979), there is a trade off between inflation uncertainty (or variability) and output uncertainty (or variability) the above means that output uncertainty will fall. Economic theory is also consistent with a positive impact of output growth on its uncertainty. As output growth falls, the response of monetary policy and, therefore, the rate of inflation becomes more uncertain (Brunner, 1993). Again, making use of the Taylor effect, we conclude that output growth uncertainty falls.

2.2. Empirical evidence

Early empirical studies focused on the association between output variability, rather than uncertainty, and average growth and obtained mixed evidence. More recent studies measure output uncertainty, as opposed to output variability, by the conditional variance of unanticipated shocks to output growth that is estimated from Generalised Autoregressive Conditional Heteroskedasticity

[4] Whereas the traditional short-run Phillips curve implies that an increase in output above its natural level would result in inflationary pressures, another strand of the literature asks how a rise in the output growth can affect the rate of inflation. Briault (1995) argues that there is a positive relationship between growth and inflation, at least over the short-run, with the direction of causation running from higher growth (at least in relation to productive potential) to higher inflation. For simplicity, in what follows we will refer to this positive effect as the 'Phillips curve'effect.

(GARCH) models. Overall, the evidence that is based on various (mostly US) data sets and GARCH models is rather mixed. Using US data, Caporale and McKiernan (1998) and Grier and Perry (2000) obtain evidence for a positive effect of output uncertainty on growth. In contrast, the evidence in Henry and Olekalns (2002) supports a negative effect. Speight (1999) finds no evidence for a relationship between output uncertainty and growth in the UK. Fountas et al. (2002) and Fountas et al. (2004) find no evidence of a significant effect for Japan. Fountas et al. (in press) in a G7 study report evidence in favour of the Black hypothesis in all countries except Japan. From the above list of papers that employ a univariate or multivariate GARCH approach, only Caporale and McKiernan (1998) have used low-frequency (annual) data and hence provided a more appropriate test of the Black hypothesis.[5]

Nearly all of the studies listed above focused only on the causal effect of output growth uncertainty on growth. However, the correlation between growth and uncertainty, which has been studied, for example, by Blackburn and Pelloni (2004) may be due to causality running in the other direction. Hence, an empirical investigation of this causality relationship is also a matter of considerable importance. To the best of our knowledge, this reverse type of causality has been considered only by Karanasos and Schurer (2005), Fountas and Karanasos (2006), and Fountas et al. (in press). In the first paper, the authors employ monthly Italian data for the period 1962–2004 and find a strong negative bidirectional feedback between the two variables. In the second study, using historical data, the authors find that in four out of five European countries growth affects uncertainty negatively. Similarly, Fountas et al. (in press) find that in three of the G7 countries where a statistically significant result obtains, output growth has a negative effect on uncertainty regarding the growth rate of output.

3. The model

First, we denote output growth by y_t and define its mean equation as

$$C(L)y_t = c + \gamma\sigma_t^2 + u_t \qquad (t \in Z), \tag{1}$$

with

$$C(L) \equiv 1 - \sum_{i=1}^{r} c_i L^i, \quad and \quad u_t = \epsilon_t \sigma_t.$$

We also assume that $\{u_t\}$ is conditionally normal with mean zero and variance σ_t^2. Put differently, $\{u_t\}$, $(u_t|\Omega_{t-1}) \sim (0, \sigma_t^2)$, where Ω_{t-1} is the information set up to time $t-1$. Next, we specify the dynamic structure of the conditional volatility as a GARCH(1,1) process

$$\sigma_t^2 = \phi + a u_{t-1}^2 + b\sigma_{t-1}^2 + \delta y_{t-1}. \tag{2}$$

We will refer to the model given by Eqs. (1) and (2) as the AR–GARCH–ML model. By including lagged output growth in the conditional variance equation (the level effect), and the conditional variance in the output growth equation (the in-mean effect), we can simultaneously test for the Black hypothesis (the significance of the γ coefficient in Eq. (1)) and for the effect of

[5] Rafferty (2005) tests for the impact of both unexpected and expected volatility on growth in a cross-section of 18 countries for the period 1880–1990. He finds that unexpected volatility lowers long-run growth.

Table 1
Unit root tests

	ADF(4)	PP(4)
Germany	−5.72	−10.02
Japan	−4.88	−7.41
USA	−7.67	−11.62

Notes: ADF and PP are the augmented Dickey-Fuller and Phillips-Perron unit root tests, respectively. The tests include a constant. Order of augmentation (ADF) and lag truncation (PP) in parentheses. The MacKinnon critical values are −3.45 (1%), −2.87(5%), −2.57(10%).

the lagged output growth on the output growth uncertainty (the significance of the δ coefficient in Eq. (2)).

It is also useful to write the conditional variance in an ARMA form. Hence, in the right hand side of (2) we add and subtract $a\sigma_{t\text{-}1}^2$, in order to get the ARMA representation of the σ_t^2

$$(1-\beta L)\sigma_t^2 = \phi + av_{t-1} + \delta y_{t-1}, \tag{3}$$

where $\beta \equiv a+b$, and the 'volatility innovation' $v_t\,(v_t \equiv u_t^2 - \sigma_t^2)$ is a serially uncorrelated term with an expected value zero.

Finally, in what follows we provide the univariate ARMA representations of the process and its conditional variance. We also give the unconditional variance of the errors $\{u_t\}$. The univariate ARMA representations for the output growth and output uncertainty are

$$A(L)y_t = \xi + (1-\beta L)u_t + \gamma a v_{t-1}, \tag{4}$$

$$A(L)\sigma_t^2 = \zeta + C(L)av_{t-1} + \delta L u_t, \tag{5}$$

with

$$A(L) \equiv C(L)(1-\beta L) - \delta\gamma L,$$

and

$$\xi \equiv \gamma\phi + (1-\beta)c, \quad \zeta = \phi C(1) + \delta c,$$

where $C(L)$ is defined in (1). If all the roots of the autoregressive polynomial $A(L)$ lie outside the unit circle (stationarity condition), and $\zeta > 0$, then the first moment of the conditional variance is $E(\sigma_{\mathrm{t}}^2) = \zeta / A(1)$, where $A(1)$ and ζ are defined in (5).

4. Data and empirical results

We employ annual data that cover about one and a half centuries. Our sample includes the group of the three largest economies in the world, namely, USA, Japan, and Germany (G3) and ends in 1999. The starting point differs across the countries of our sample.[6] The choice of annual data is based on the time lags required for investment changes to take place and allows a more accurate test of the Black hypothesis. Output data are proxied by the index of industrial production. The source of our data series is Mitchell (1998) and the Main Economic Indicators

[6] The sample period starts in 1850 for Germany, 1860 for the US, and 1874 for Japan.

Table 2
AR–GARCH–ML model

	Germany	Japan	USA
γ	2.064 [0.813]	11.200 [4.682]	1.901 [1.564]
c_1	0.482 [0.078]	0.401 [0.102]	–
c_2	–	−0.078 [0.092]	–
c_3	–	0.142 [0.071]	–
c_4	–	–	−0.156 [0.070]
c_5	–	–	−0.177 [0.070]
c_6	–	–	−0.025 [0.0951]
c	0.006 [0.006]	−0.013 [0.018]	0.036 [0.015]
δ	−0.034 [0.007]	−0.005 [0.004]	−0.018 [0.009]
a	0.316 [0.079]	0.221 [0.084]	0.163 [0.070]
b	0.525 [0.025]	0.668 [0.105]	0.756 [0.131]
ϕ	0.002 [0.000]	0.001 [0.000]	0.001 [0.001]
Q_4	2.335 (0.670)	2.825 (0.590)	1.688 (0.790)
Q_4^2	2.771 (0.600)	6.488 (0.170)	4.997 (0.290)
$1-A(1)$	0.847	0.885	0.856
$E(\sigma_t^2)$	0.007	0.005	0.008

Notes: For each of the three countries, Table 2 reports parameter estimates for the following AR-GARCH-ML model:

$$[1-\sum_{i=1}^{r} c_i L^i]y_t = c + \gamma\sigma_t^2 + u_t, \quad \sigma_t^2 = \phi + a u_{t-1}^2 + b\sigma_{t-1}^2 + \delta y_{t-1}.$$

Standard errors (probabilities) are given in brackets (parentheses).
$(Q_4^2)Q_4$ is the 4th-order Ljung-Box test for (squared)standardized residuals.
$1-A(1)$ is given by $\beta + \gamma\delta + \sum_{i=1}^{r} c_i(1-\beta)$.
The last row reports the estimated unconditional variance of output growth.
The bold numbers indicate the γ and δ parameters which are much larger than their standard errors.

(OECD database). The growth rate of output is measured by the year-to-year changes in the log of industrial production.

We first test for the stationarity properties of our transformed data (i.e., output growth rates) using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. The results presented in Table 1 imply strong rejection of the unit root null hypothesis. Within the AR–GARCH–ML framework we will analyze the dynamic adjustments of both the conditional mean and the conditional variance of output growth for the G3 countries, as well as the implications of these dynamics for the direction of causality between output growth and its uncertainty. Maximum likelihood estimates of the AR–GARCH–ML model are shown in Table 2. These were obtained by quasi-maximum likelihood (QML) estimation as implemented by Bollerslev and Wooldridge (1992). Several findings emerge from this table. The best model for each country is chosen on the basis of the minimum value of the Schwarz Information Criterion (SIC). The information criterion selects an AR(1), AR(3) and AR(6) model for Germany [7], Japan and USA, respectively. Moreover, the GARCH(1,1) specification for the conditional variance is chosen for all three countries. Not surprisingly, for all three specifications, the GARCH parameters (a and b) are significantly different from zero.

The hypothesis of uncorrelated standardized and squared standardized residuals is well supported in all countries, indicating that there is no statistically significant evidence of

[7] The autoregressive model of Germany includes a dummy variable that captures Germany's separation in 1946.

Table 3
LR test statistics

Restrictions	Germany	Japan	USA
γ, δ=0	22.308[5.991]	20.260	7.186[3.841]
γ=0	7.346[3.841]	16.022	–
δ=0	13.640	4.088[6.635]*	–

Notes: For each of the three countries, Table 3 reports the value of the following LR test. $\text{LR}=2[\text{ML}_u-\text{ML}_r]$, where ML_u and ML_r denote the maximum log-likelihood values of the unrestricted and restricted models, respectively.
For Germany and Japan we compare the in-mean-level (γ, $\delta\neq0$) model with either the in-mean ($\delta=0$) or level ($\gamma=0$) or 'simple'(γ, $\delta=0$) model. For the USA we compare the level model with the 'simple'one.
The numbers in [·] are 5% critical values. *The number in [·] is 1% critical value.

misspecification. Moreover, note that the condition for the existence of the unconditional variance is $1-A(1)\equiv\sum_{i=1}^{r} c_i(1-\beta)+\beta+\gamma\delta<1$. Table 2 reports the estimated values $1-A(1)$ for the three AR–GARCH–ML models. In all cases $1-A(1)$ is less than one. The three estimated unconditional variances are also reported in the last row of Table 2. Recall that for the positivity of the unconditional variance we need $\zeta=\phi C(1)+\delta c>0$.

The results reported in Table 2 lead to two conclusions regarding the causal relationship between output growth and output growth uncertainty. First, we find the effect of output uncertainty on growth to be positive and significant in Germany and Japan and positive and insignificant in the US. These results support Black's hypothesis in two of the three countries. Second, in all three countries the effect of output growth on output growth uncertainty is negative. However, it is significant only in Germany and the US. This result is in agreement with the theory outlined in Section 2. An increase in output growth raises inflation (the Phillips curve effect) and therefore inflation uncertainty (the Friedman effect).[8] Since inflation and output growth uncertainty are negatively related (the Taylor effect), uncertainty about output growth falls.[9] In Japan we find that output uncertainty is independent of changes in output growth. The implication of these findings is that macroeconomic theory should explicitly examine the interrelationship between economic growth and the variability of the business cycle rather than treat them independently as has been the case so far with a few exceptions.

To test for the presence of in-mean and/or level effects, we also examine the likelihood ratio (LR) tests for the linear constraints $\gamma=\delta=0$ ('simple' GARCH model). As seen in Table 3, the LR tests clearly reject the GARCH null hypotheses against either the GARCH in-mean (Japan) or level (USA) or in-mean-level (Germany) models. Thus, purely from the perspective of searching for a model that best describes the mean and the variance of the German growth series, the AR–GARCH–ML model appears to be the most satisfactory representation.

Following the work of Conrad and Karanasos (2005a,b) among others, the LR test can be used for model selection. Alternatively, the SIC and the Akaike information criterion (AIC) can be applied to rank the various GARCH type models. These model selection criteria check the robustness of the LR testing results discussed above and are reported in Table 4. According to the

[8] The empirical studies generally find that a rise in growth has a positive impact on inflation (see, for example, Karanasos and Zeng, 2006). Similarly, the majority of the empirical studies find evidence supporting the first leg of the Friedman hypothesis that more inflation leads to more inflation uncertainty (see, for example, Fountas and Karanasos, in press).

[9] The existence or absence of a variance relationship is examined, among others, in Karanasos and Kim (2005a,b) and Karanasos et al. (2006). For example, evidence in support of the unidirectional negative feedback between German nominal and real uncertainty with the line of causation running from the former to the latter is given in Karanasos and Kim (2005a).

Table 4
Information criteria

	ML	M	L	S
SIC				
Germany	**−2.282**	−2.224	−2.266	−2.199
Japan	−2.413	**−2.419**	−2.321	−2.326
USA	−1.696	−1.738	**−1.790**	−1.773
AIC				
Germany	**−2.444**	−2.366	−2.408	−2.321
Japan	**−2.643**	−2.626	−2.528	−2.509
USA	−1.892	−1.912	**−1.964**	−1.925

Notes: SIC and AIC are the Schwarz and Akaike information criteria, respectively.
ML and M refer to the in-mean-level and in-mean models, respectively.
L and S refer to the level and 'simple' models, respectively.
The bold numbers indicate the model chosen by the SIC and AIC.

two information criteria, in Germany the optimal GARCH type model is the in-mean-level (ML) one. It also appears that the volatility dynamics in the USA are better modelled by the level process since both the AIC and SIC favor the level (L) model over either the in-mean (M) or the ML model. Further, for Japan the SIC chooses the in-mean model instead of either the ML or the L models. Hence, the model selection criteria are in accordance with the LR testing results.

To check the sensitivity of our results to the form in which the time varying variance enters the specification of the mean, we also use the conditional standard deviation as a regressor in the conditional mean. In addition, the existence of outliers causes the distribution of growth to exhibit excess kurtosis. To accommodate the presence of such leptokurtosis, we estimate the AR–GARCH–ML models using non-normal distributions. As reported by Karanasos and Kim (2006), the use of a student-*t*-distribution is widespread in the literature. The results, reported in Table 5, are very similar to those obtained using the methodology which assumes linearity between the conditional variance and the growth of output, regardless of the distributional assumptions. In

Table 5
AR–GARCH–ML model

(Standard Deviation in the mean)	Germany	Japan	USA
Normal distribution			
γ	**0.211** [0.101]	**1.631** [0.647]	0.113 [0.149]
δ	**−0.031** [0.007]	−0.004 [0.004]	**−0.037** [0.009]
t-distributed errors			
γ	**0.566** [0.235]	**1.798** [0.854]	0.131 [0.223]
δ	**−0.023** [0.010]	−0.005 [0.004]	**−0.045** [0.017]

Notes: For each of the three countries, Table 5 reports, for the normal and *t*-distributions, the estimated in-mean (γ) and level (δ) parameters for the following AR–GARCH–ML model:

$$[1-\sum_{i=1}^{r} c_i L^i]y_t = c + \gamma\sigma_t + u_t, \quad \sigma_t^2 = \phi + a u_{t-1}^2 + b\sigma_{t-1}^2 + \delta y_{t-1}.$$

Standard errors are given in brackets. The bold numbers indicate parameters which are much larger than their standard errors.

particular, Black's hypothesis regarding the positive growth effects of real uncertainty receives support in Germany and Japan. However, neither of the two theories (Pindyck's or Black's) is supported in the USA, where growth is independent from changes in its uncertainty. The δ parameter captures the impact of changes in growth on its uncertainty. Statistically significant effects are present for two out of the three countries. That is, there is strong evidence that growth affects its uncertainty negatively in Germany and the USA.

Our main empirical results support some of the reported evidence in the literature. Fountas and Karanasos (2006) use historical data on five European countries and find evidence for Black's hypothesis in three of the five countries. Moreover, the authors find that in four of the five European countries, output growth affects output uncertainty negatively. These results square with the two results of the present paper. Our finding of a lack for evidence for Black's hypothesis in the US contrasts with the results of the papers by Caporale and McKiernan (1998) and Henry and Olekalns (2002), who find positive and negative effects of output uncertainty on output growth, respectively. However, these two papers use a different econometric methodology and different (shorter and more recent) sample periods. Our Japanese evidence for the Black hypothesis contrasts also with the lack of evidence for such an effect reported in Fountas et al. (2002) and Fountas et al. (2004). However, both of these studies are based on monthly frequency data that only cover the second half of the last century.

5. Conclusions

We have used long time series of annual data that span almost one and a half centuries for the G3 to test for the relationship between output growth and its uncertainty. We use the methodology of GARCH–ML models and proxy uncertainty about output growth by the conditional variance of shocks to the output growth series. We derive two main conclusions. First, in two of the three countries considered (Germany and Japan) uncertainty about output growth is a positive determinant of growth. Second, we find evidence that in two countries (Germany and USA) output growth affects output growth uncertainty negatively. Our chosen GARCH models are consistent with a number of model selection criteria. Furthermore, our results regarding the causal relationship between growth and uncertainty are robust to the distribution of the error term and the form in which the time varying variance enters the specification of the mean.

Our two conclusions regarding the causal relationship between growth and uncertainty have crucial implications for the development of the theoretical modelling of both economic growth and the variability (and uncertainty) of the business cycle. They highlight the importance of treating the theory of economic growth in tandem with the variability (and uncertainty) of the business cycle, rather than separately, as has been the case to a large degree in the theoretical macroeconomics literature to date. In addition, the discrepancy of our results from those derived from other studies highlights the sensitivity of the results to the time period examined, the frequency of the time series data and the countries considered. Therefore, this apparent inconclusiveness warrants the need for further investigation of the relationship between growth and uncertainty.

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