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IS VOLATILITY GOOD FOR GROWTH? EVIDENCE FROM THE G7

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Is Volatility Good for Growth?
Evidence from the G7

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Abstract

We provide empirical support for an analytical DSGE model with nominal wage stickiness where growth is driven by learning-by-doing and money shocks and their variance are allowed to impact on long-run output growth. In our theoretical model the variance of monetary shocks has a negative effect on growth, while output volatility is good for growth as a positive relationship exists. Using a bivariate GARCH-M model we test the empirical conditional mean and variance relationships of nominal money and production growth rates in the G7 countries. We corroborate the theoretical model predictions with evidence from Bonferroni multiple tests across the G7.

JEL classification: C32, E32, O42.

Keywords: growth uncertainty, learning-by-doing, monetary uncertainty, multivariate GARCH-in-mean, nominal rigidity.

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I. Introduction

This study investigates the question posed in the title (Is volatility good for growth?) by empirically testing a growth model with real and nominal shock uncertainty.[1]

Our theoretical analysis is based on a stochastic monetary model of an imperfectly competitive economy with learning-by-doing, which admits a closed-form solution. Three alternatives are considered regarding the functioning of the labour market so as to capture the different features in this respect of the countries in our sample: perfect wage flexibility, nominal wage rigidity and wage indexation. In fact while nominal wage rigidities are likely to be present in all the G7 economies, the degree of their presence varies (see Cahuc and Zylberberg, 2004, chap.8).

A long-standing tradition in macroeconomics—at both theoretical and empirical levels—is the separation of the study of growth from the study of business cycles. However recently the question of precisely how cyclical fluctuations might affect secular trends has been the subject of an expanding body of literature, analysed by Steindl and Tichy (2009), who focus on industrial countries, and Aizenman and Pinto (2005) who focus on developing countries. In their overview of the theoretical results on volatility and growth Aghion and Banerjee (2005) notice that in "creative destruction'' models where production and R&D are substitutes the relationship between volatility and growth will be positive. However the relationship will become negative if, due to financial markets imperfections, R&D has to be financed by current profits, a condition more relevant for developing countries.

[1] Throughout the paper we use the terms uncertainty, volatility and variance interchangeably to define the conditional standard deviation of a variable. For instance, growth uncertainty is equivalent to the volatility/variability of the innovation of output growth rate conditional on its mean dynamic behaviour and that of other variables which is estimated by a parametric dynamic volatility model, the details of which are discussed in the empirical Section III.

When growth is driven by learning-by-doing (Romer, 1986), volatility can have a negative effect on growth (see Blackburn, 1999, Pelloni, 1997, Martin and Rogers, 2000 and Blackburn and Galindev 2003). However when taking account of optimal savings de Hek (1999) shows that under learning-by-doing volatility can have a negative effect on growth only if risk aversion is so low as to be inconsistent with empirical estimates. Canton (2002) finds a positive relationship in a model where growth is driven by human capital accumulation and Jones *et al*. (2005) show that the relationship is positive in a large class of convex models of endogenous growth. Coming to monetary models, Dotsey and Sarte (2000) and Varvarigos (2008) show that in a convex model with perfect price flexibility there will be a positive effect of money volatility on growth, while Blackburn and Pelloni (2004) and Annicchiarico et al. (2011a) and (2011b) introduce nominal rigidities in a learning-by-doing model and find this effect to be negative.

The relationship between output uncertainty and growth has also been studied empirically. Some papers find a negative effect based on cross-section or panel approaches (Ramey and Ramey, 1995, Martin and Rogers, 2000, Kose, Prasad, and Terrones 2005, Hnatkovska and Loayza 2005). Evidence from time series work is mixed with positive (Caporale and McKiernan, 1996) and negative (Peel and Speight, 1998) correlations. Inflation uncertainty is found to affect negatively output growth in GARCH type models by Elder (2004), Fountas *et al*. (2006), Grier and Perry (2000) and Grier, *et al*. (2004). Fountas and Karanasos (2007) find mixed results about the effects of inflation uncertainty on output growth for the G7 countries using a univariate GARCH approach. Bredin and Fountas (2009) use a bivariate GARCH type model for output growth and inflation and find that output growth and its uncertainty are negatively related for the majority of the EU countries during the period 1962-2003.

To preview our results the theoretical model implies that the variance of nominal shocks has a negative effect on growth, while the variance of real shocks has a positive effect. We test the theoretical hypotheses of our model by empirically investigating linkages between money and output growth and their uncertainties using time-series data spanning around four decades for the G7 countries since the early 1960s. A bivariate GARCH-in-Mean (GARCH-M) model is estimated that allows output and money growth rates and their uncertainties to interact. The money and output growth dynamic equations are a function of their lags and of the time-varying conditional innovation variances that represent the uncertainty factors. We focus on money shocks as they are a direct indicator of monetary policy volatility whereas inflation is contaminated by other shocks within the economy. We find a significant, negative relationship between output growth and money shock uncertainty for most of the G7 countries, in particular those with a higher degree of rigidity in nominal wages, and a significant positive relationship between output growth and nominal money growth average for all G7. When we apply Bonferroni multiple tests across the G7 countries we find full support for the theoretical predictions of our model.

The structure of the paper is as follows. Section II describes the theoretical model. Section III presents the empirical GARCH-M model and explains the testable hypotheses derived from the theoretical model. Section IV details the empirical results for the G7 countries. Section V concludes the paper.

II. The Theoretical Analysis

In this section we present a stochastic monetary model, in which long-run growth is sustained by learning-by-doing. Our setting is similar to the one in Blackburn and Pelloni (2004) however our analysis is somewhat more general as we consider an intermediate sector with imperfect competition and we distinguish three cases as regards the functioning of the labour market (perfect competition, nominal wage setting by unions or wage indexation) and show that results on the effect of money volatility on growth are different in the three cases. In our model an increase in the volatility of preferences leads, through precautionary savings, to an increase in the rate of growth under all assumptions on the labour market. The volatility of money growth will instead reduce the rate of income growth, but only in the case of nominal wage setting. The overall relationship between the rate of growth and its volatility turns out to be positive. We thus show that it is important to isolate the source of volatility, as well as to consider the degree of nominal rigidity in the economy before one can answer the question of whether and how volatility affects growth. Another result we derive is that average money growth has a positive effect on average income growth, under nominal wage setting, if the variance of money growth does not change. Over the next few sections we will present our theoretical model in full.

2.1. Firms

There is a continuum of intermediate goods Y(i) where $i \in$ (0,1). Final output, which can be consumed or invested, is given by

$$Y_t = \left(\int_0^1 Y_{it}^{\sigma} di \right)^{1/\sigma} \tag{1}$$

where $\sigma \in (0,1)$. Equation (1) displays constant returns to scale. When $\sigma = 1$ there is perfect competition in the intermediate sector. The final good sector is competitive.

First order conditions for profit maximization imply demand functions for intermediate goods given by:

$$P_{it} = P_t \left(\frac{Y_{it}}{Y_t} \right)^{\sigma - 1} \tag{2}$$

where P_t is the price of the final good which has a depreciation rate of 100%,[2] and P_{it} is the price of the *i*th intermediate good.

The technology for producing an intermediate commodity is Cobb-Douglas:

$$Y_{it} = \overline{K_t}^{1-\psi} N_{it}^{\ \alpha} K_{it}^{\ \psi}, \quad \alpha, \psi \in (0,1). \tag{3}$$

where N_{it} is labour, K_{it} capital and $\overline{K_t}$ is the economy-wide average capital. 'Learning-by-doing through investing' is a possible rationale for increasing returns to capital, as in Romer (1986), who assumes perfect competition. However, Dasgupta and Stiglitz (1988) notice that learning-by-doing is consistent with perfect competition only at the implausible condition that knowledge is totally non excludable. Imperfect competition allows us to consider the case of increasing returns at the firm level, which we obtain when $\alpha + \psi \geq 1$, that is when technical improvements can at least be partially appropriated by the firm (notice the maximand, i.e. profits, is jointly concave in N_{it}, K_{it} whenever $\sigma(\alpha + \psi) \leq 1$ so the maximization problem will have a well defined solution). Labour and capital are hired from households at the real wage rate W_t / P_{it} and real rental rate R_t respectively, where W_t is the nominal wage. By profit maximization we get:

$$\frac{W_t}{P_{it}} = \alpha\sigma \overline{K}_t^{\psi} N_{it}^{\alpha-1} K_{it}^{\psi} = \frac{\alpha\sigma Y_{it}}{N_{it}}, \tag{4}$$

[2] As usual, this hypothesis is needed for obtaining a closed form solution.

$$R_t = \phi \overline{K}_t^{\psi} N_{it}^{\alpha} K_{it}^{\psi-1} = \frac{\psi\sigma Y_{it}}{K_{it}}. \qquad (5)$$

A free entry condition ensures that profits are zero in equilibrium. To keep things simple we assume every intermediate commodity is produced with the same technology and we focus on a symmetric equilibrium. This means that

$Y_{it} = Y_t, K_{it} = \overline{K}_t, N_{it} = N_t, P_{it} = P_t, \forall i$ while:

$$Y_t = N_t^{\alpha} K_t, \quad . \qquad (6)$$

and (4) and (5) become:

$$\frac{W_t}{P_t} = \alpha\sigma N_t^{\alpha-1} K_t = \frac{\alpha\sigma Y_t}{N_t}, \qquad (7)$$

$$R_t = \psi\sigma N_t^{\alpha} = \frac{\psi\sigma Y_t}{K_t}. \qquad (8)$$

2.2. Households

We assume a constant population normalised to one of identical, immortal households. At time *t*, the representative household wants to maximize:

$$E_t U = \sum_{s=0}^{\infty} \beta^{t+s} E_t \left[\gamma_{t+s} \log(C_{t+s}) + \theta \log\left(\frac{M_{t+s-1}\phi_{t+s}}{P_{t+s}} \right) - \lambda L_{t+s} \right], \quad \beta \in (0,1), \theta, \lambda > 0$$

where E_t denotes expectations, C_t consumption, and L_t labour, varying in [0, 1] and γ_t represents a preference shock, at time t. The quantity M_{t-1} denotes beginning-of-period t (i.e. end-of-period t-1) nominal cash balances which are increased by a proportional stochastic monetary transfer, ϕ_t.[3] Money supply, M_t, is then given by:

$$M_t = M_{t-1}\phi_t. \tag{9}$$

We assume that both disturbances $\{\gamma_t, \phi_t\}$ are governed by independent, stationary stochastic processes with constant means and constant variances. Moreover the shocks are assumed to have bounded positive supports. The bounds on employment are then always respected (i.e. we do not have corner solutions). The unconditional expected values and variances of the disturbances are denoted, respectively, by $\{\mu_\gamma, \mu_\phi\}$ and $\{\sigma_\gamma^2, \sigma_\phi^2\}$. The budget constraint at time t for the household is given by

$$C_t + \frac{M_t}{P_t} + A_{t+1} \leq \frac{W_t}{P_t} L_t + \frac{M_{t-1}\phi_t}{P_t} + R_t A_t + \Pi_t, \tag{10}$$

where A_t is real assets and Π_t the firms' profits.

Each agent maximises the expected value of utility subject to its intertemporal budget constraint. Agents are assumed to know the values of all parameters, the current and past values of all variables and the probability distributions of all shocks. Households choose consumption, money balances and asset holdings according to the following necessary conditions:

$$\frac{\gamma_t}{C_t} = \beta E_t\left(\frac{\gamma_{t+1} R_{t+1}}{C_{t+1}}\right), \tag{11}$$

$$\frac{\gamma_t}{P_t C_t} = \frac{\theta}{M_t} + \beta E_t\left(\frac{\gamma_{t+1}\phi_{t+1}}{P_{t+1} C_{t+1}}\right), \tag{12}$$

[3] The assumption that monetary transfers are proportional (rather than lump-sum) is made for tractability (see Benassy 1995).

We now spell out our three alternative assumptions on the labour market. The first is perfect competition between workers with wage flexibility, the second is nominal wage setting by unions and the third is real wage setting by unions. Under the first assumption, a further optimising condition is:

$$\lambda P_t C_t = \gamma_t W_t \tag{13}$$

which simply equates the real wage to the marginal rate of substitution between consumption and leisure. Under the second assumption monopolistic unions choose a nominal wage at which households supply whatever labour is demanded by firms. We assume that wage setting takes place prior to the realisation of shocks on the basis of one-period contracts and that the contract wage is chosen so as to maximise households' expected utility, taking into account labour demand. The optimal wage is then found to satisfy

$$\lambda E_{t-1}(N_t) = \alpha W_t E_{t-1}\left(\frac{\gamma_t N_t}{P_t C_t}\right). \tag{13'}$$

Finally under the third assumption monopolistic unions choose a real wage w_t^* for the following period and households supply whatever labour is demanded by firms at that wage. The nominal wage W_t is given by: $W_t = w_t^* P_t$.

In words the nominal wage is indexed to the price level so as to reach the level of the privately optimal real wage set in the previous period. At time *t*-1 the real wage which maximises the expected utility of workers, given labour demand, is:

$$\frac{\lambda}{E_{t-1}(\alpha\gamma_t / C_t)} = w_t^* \tag{13''}$$

The equilibrium behaviour of the household is characterised completely by the first-order conditions in (8) and (9), the budget constraint (10), either (13) or (13') or (13''), and finally the transversality conditions

$$\lim{}_{\tau\to\infty} \beta^{\tau} E_t((\gamma_{t+\tau} M_{t+\tau-1}\phi_{t+\tau})/P_{t+\tau}C_{t+\tau}) = \lim{}_{\tau\to\infty} \beta^{\tau} E_t(\gamma_{t+\tau} A_{t+\tau+1}/C_{t+\tau}) = 0 .$$

2.4 General Equilibrium

The general equilibrium solution is computed by combining the optimising conditions obtained so far with the market clearing conditions $C_t + K_{t+1} = Y_t$ (for goods), $K_t = A_t$ (for capital), and $N_t = L_t$ (for labour) plus the already assumed one that money supply equals money demand. The following relations are then obtained (see Appendix A for details):

$$C_t = \frac{(1-a)\gamma_t}{(1-a)\gamma_t + a\mu_\gamma} Y_t, \tag{14}$$

$$\frac{M_t}{P_t} = \frac{(1-a)\theta}{(1-\beta)[(1-a)\gamma_t + a\mu_\gamma]} Y_t, \tag{15}$$

$$K_{t+1} = \frac{a\mu_\gamma}{(1-a)\gamma_t + a\mu_\gamma} Y_t, \tag{16}$$

where $a \equiv \sigma\beta\psi$. For a given level of output, consumption increases while investment and money demand decrease with higher realisations of the demand shock, γ_t. These responses are non-linear: an increase in the volatility of preference shocks causes a rise of investment and money demand for given income. Also notice that these increases are not influenced by money shocks or the structure of the labour market. Finally notice that the rate of saving is increasing in σ .

If the labour market is competitive we have:

$$N_t = \frac{\sigma\alpha[(1-a)\gamma_t + a\mu_\gamma]}{\lambda(1-a)}. \tag{17}$$

while, with nominal wage contracts we have:

$$N_t = \frac{\alpha^2\sigma[(1-a)\gamma_t + a\mu_\gamma]\phi_t}{\lambda(1-a)\mu_\phi}. \tag{17'}$$

and with wage indexation:

$$N_t = \frac{\alpha^2 \sigma \mu_\gamma}{\lambda(1-a)} \qquad (17'')$$

(derivations can be found in Appendix A). In all cases the higher is the elasticity of substitution between intermediates and the higher is the average of the demand shock the higher is employment. In the first case and in the third case, money is neutral. If the labour market is competitive employment responds linearly to the current preference shock so its expected value does not depend on the variance of the shock. Under total wage indexation labour does not respond to shocks (it would if different kinds of shocks were considered, for instance technology shocks). Finally in the case of nominal wage setting employment is linear in both shocks.

2.5 Growth and Cycles

If the labour market is competitive, using (6), (16) and (17) we get:

$$\Delta Y_t := \frac{Y_{t+1}}{Y_t} = \frac{a\mu_\gamma}{(1-a)\gamma_t + a\mu_\gamma}\left[\frac{\sigma\alpha[(1-a)\gamma_{t+1} + a\mu_\gamma]}{\lambda(1-a)}\right]^\alpha. \qquad (18)$$

The rate of growth is concave in the current realisation of the preference shock, due to the decreasing marginal productivity of labour. The rate of growth is however convex in the lagged realisation of the shock. This is because of saving behaviour: from (16) we see that the propensity to save out of current income is a convex function of the preference shock. This is transmitted linearly to production, given the constant marginal productivity of capital. We have, using a second order approximation:

$$E(\Delta Y) := E\left(\frac{Y_{t+1}}{Y_t}\right) \cong A\left(1 + \frac{(1-a)^2[\alpha(\alpha-1)+2]}{2{\mu_\gamma}^2}\sigma_\gamma^2\right) \qquad (19)$$

$$\mathrm{var}(\Delta Y) := Var\left(\frac{Y_{t+1}}{Y_t}\right) \cong \frac{A^2(1-a)^2\left(\alpha^2+1\right)}{{\mu_\gamma}^2}\sigma_\gamma^2 \qquad (20)$$

where A= $a\left(\frac{\sigma\alpha\mu_{\gamma}}{\lambda(1-a)}\right)^{\alpha}$. The lower is the market power of firms (the higher is σ) the higher are both the mean and the variance of growth. Both moments are also increasing in the variance of the preference shock: the positive effect of this variance on the rate of growth through the precautionary saving channel more than offsets the negative effect through the employment channel.

Let us now consider the economy with nominal contracts. We have, using (6), (16) and (17')

$$\Delta Y_t := \frac{Y_{t+1}}{Y_t} = \frac{a\mu_{\gamma}}{(1-a)\gamma_t + a\mu_{\gamma}}\left[\frac{\sigma\alpha^2[(1-a)\gamma_{t+1} + a\mu_{\gamma}]\phi_{t+1}}{\lambda(1-a)\mu_{\phi}}\right]^{\alpha}. \tag{18'}$$

The growth rate of output, ΔY_t, is now dependent on the realisations of both real and nominal shocks. The mean and variance of the growth rate are approximated, respectively, by

$$E(\Delta Y) := E\left(\frac{Y_{t+1}}{Y_t}\right) \cong \alpha^{\alpha} A\left(1 + \frac{(1-a)^2[\alpha(\alpha-1)+2]}{2\mu_{\gamma}^{2}}\sigma_{\gamma}^2 + \frac{\alpha(\alpha-1)}{2\mu_{\phi}^2}\sigma_{\phi}^2\right) \tag{19'}$$

$$\mathrm{var}(\Delta Y) := Var\left(\frac{Y_{t+1}}{Y_t}\right) \cong \left(\alpha^{\alpha} A\right)^2\left(\frac{(1-a)^2\left(\alpha^2+1\right)}{\mu_{\gamma}^{2}}\sigma_{\gamma}^2 + \frac{\alpha^2}{\mu_{\phi}^2}\sigma_{\phi}^2\right) \tag{20'}$$

By comparing (19) and (19') we see that the impact on average growth of the variance of real shocks is strictly analogous with or without contracts, so the previous analysis holds. As for money shocks, we can notice that with zero variance in money growth there are no effects of average money growth on output growth. Money super-neutrality under certainty is in fact expected when, as in our model, the utility function is additively separable in consumption, money and labour (see Wang and Yip, 1992). However, for a given variance of money growth, an increase in average money growth leads to higher output growth because it means an improvement in the information available to agents when they choose the nominal wage and therefore a reduction in the related distortion. In general average growth falls while its cyclical volatility rises with an increase in the variance of the monetary growth shock. This type of disturbance impacts on growth through its (linear) effect on employment, of which output is a concave function, by virtue of diminishing returns to labour. The fact that the average and the variance of money growth have opposite effects on output growth, together with the fact that in reality the two tend to be highly correlated, may provide a partial rationale for some of the inconclusive results in the empirical literature of growth and inflation.

Finally for the economy with wage indexation we have:

$$\Delta Y_t := \frac{Y_{t+1}}{Y_t} = \frac{\alpha^{\alpha} A \mu_{\gamma}}{(1-a)\gamma_t + a\mu_{\gamma}}. \qquad (18'')$$

and approximating:

$$E(\Delta Y) := E\left(\frac{Y_{t+1}}{Y_t}\right) \cong \alpha^{\alpha} A\left[1 + (1-a)^2 \sigma_{\gamma}^2 / \mu_{\gamma}{}^2\right] \qquad (19'')$$

$$Var\left(\frac{Y_{t+1}}{Y_t}\right) \cong \alpha^{2\alpha} A^2 (1-a)^2 \frac{\sigma_{\gamma}^2}{\mu_{\gamma}{}^2} \qquad (20'')$$

As in the case of a perfectly competitive labour market, money has no real effects, while the variance of the demand shock has a positive effect on growth. This effect, for plausible values of α, will be lower than in the competitive case.

For the purposes of the empirical analysis we combine equations (19) and (20) (or (19') and (20') or (19'') and (20'')) to derive a relationship between output growth and its variance. We obtain (21), (21') and (21''), the first pertaining to an economy with a perfectly competitive labour market, the second to an economy with nominal contracts and the third to an economy with wage indexation:

$$E(\Delta Y) \cong A + \frac{[\alpha(\alpha-1)+2]}{2A(\alpha^2+1)} \operatorname{var}(\Delta Y) \tag{21}$$

$$E(\Delta Y) \cong \alpha^\alpha A + \frac{[\alpha(\alpha-1)+2]}{2\alpha^\alpha A(\alpha^2+1)} \operatorname{var}(\Delta Y) - A\frac{\alpha^{\alpha+1}(\alpha+1)}{(\alpha^2+1)} \frac{\sigma_\phi^2}{2\mu_\phi^2} \tag{21'}$$

$$E(\Delta Y) \cong \alpha^\alpha A + \frac{\operatorname{var}(\Delta Y)}{A\alpha^\alpha} \tag{21''}$$

It is now evident that the mean and the variance of output growth will always be positively correlated, whereas monetary shock uncertainty will have a negative effect (or no effect) on average output depending on the structure of the labour market. Moreover, under nominal wage setting the average money growth will have a positive effect on average output growth. These theoretical propositions constitute empirically testable hypotheses as demonstrated in the context of the empirical models below.

III. Bivariate GARCH-M Model

In this section we present the details of the empirical model and its connection with the theoretical model and some of its testable implications. The discussion on the empirical results follows in Section IV.

The bivariate Generalised AutoRegressive Conditional Heteroscedastic in Mean (GARCH-M) model provides the setup for examining a set of hypotheses that evaluates if there is empirical support for the theoretical propositions derived in the previous section. The relationship between money and output and their uncertainties is modelled by a bivariate GARCH-M(1,1) with constant conditional correlation in the spirit of Bollerslev (1990):

$$\Delta M_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i} \Delta M_{t-i} + \sum_{i=1}^{q} \beta_{2i} \Delta Y_{t-i} + \beta_3 \sigma_{\Delta M,t}^2 + \beta_4 \sigma_{\Delta Y,t}^2 + \varepsilon_t \tag{22}$$

$$\sigma_{\Delta M,t}^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \alpha_2 \sigma_{\Delta M,t-1}^2 \tag{23}$$

$$\Delta Y_t = \beta_5 + \sum_{i=1}^{p} \beta_{6i} \Delta Y_{t-i} + \sum_{i=1}^{q} \beta_{7i} \Delta M_{t-i} + \beta_8 \sigma^2_{\Delta M,t} + \beta_9 \sigma^2_{\Delta Y,t} + \nu_t \quad (24)$$

$$\sigma^2_{\Delta Y,t} = \alpha_3 + \alpha_4 \nu^2_{t-1} + \alpha_5 \sigma^2_{\Delta Y,t-1} \quad (25)$$

$$COV_t = \rho_{\varepsilon\nu} \sigma_{\Delta M,t} \sigma_{\Delta Y,t} \quad (26)$$

Equation (22) describes the dynamic conditional mean of nominal money growth, ΔM_t, as a function of the past history of both money and real output growth, ΔY_t, and their conditional variances given by $\sigma^2_{\Delta M,t}$ and $\sigma^2_{\Delta Y,t}$, respectively, which are estimated by equations (23) and (25). Equation (23) specifies the dynamics of the conditional variance of nominal money growth shocks and represents a parametric measure of money uncertainty that affects the conditional mean equations of money growth (22) as well as output growth (24). In particular equation (23) captures the time-varying behaviour of money uncertainty as shown by the autoregressive structure of $\sigma^2_{\Delta M,t}$ which may be associated with time-varying policy shocks. In an analogous manner equation (25) is the dynamic conditional variance of innovations in output growth. Equation (24) describes the conditional mean of real output growth as a function of lags of output and money growth and their conditional variances, $\sigma^2_{\Delta M,t}$ and $\sigma^2_{\Delta Y,t}$. Finally (26) specifies the constant conditional covariance between ε_t and ν_t. It is assumed that the two error terms, ε_t and ν_t, are jointly conditionally normal with zero means and conditional variances given by equations (23) and (25). The above system of equations allows for the feedback relationship between the two variables and models jointly both the conditional mean and variance (or linear and nonlinear) dynamics which are estimated simultaneously using Maximum Likelihood methods. In the context of equation (24) we examine the empirical support of the theoretical propositions regarding the effects of money and output growth uncertainty,

$\sigma^2_{\Delta M,t}$ and $\sigma^2_{\Delta Y,t}$ respectively, on growth ΔY_t.[4] In order to explain the difference in the notation between the empirical and theoretical models we note that in the former specification the time series processes of money and output growth, denoted by ΔM_t and ΔY_t respectively, are governed by dynamics in the conditional mean and variances, $E_{t-1}(\Delta M_t)$, $E_{t-1}(\Delta Y_t)$ and $\sigma^2_{\Delta M,t}$, $\sigma^2_{\Delta Y,t}$, respectively, and specified by the bivariate GARCH-M equations above. In the theoretical model (equations (21), (21'), (21'')) $E(\Delta Y)$ (μ_ϕ) indicates both the conditional and the unconditional mean of output (money) growth due to the simplifying assumptions needed for tractability, which imply that the process for output (money) growth is not autoregressive, but only depends on parameters and innovations. The same is true for the uncertainties of output and money growth, $\text{var}(\Delta Y)$ and σ^2_ϕ, which in the theoretical model are assumed to be constant over time, again for tractability.

The GARCH-M model and variations of it are also adopted in Elder (2004) and Grier and Perry (2000) to study the relationship between US growth, inflation and their volatilities, as well as Fountas *et al.* (2006) and Fountas and Karanasos (2007) for the G7 and Bredin and Fountas (2009) for EU countries. The parametric measure of volatility implied by the GARCH specifications is consistent with our theoretical notion of uncertainty as the variance of the unpredictable innovation of a variable (e.g. Cukierman and Meltzer, 1986), instead of simply calculating the unconditional standard deviations of money and output growth.[5]

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[4] Inflation is endogenous in our model. Hence we focus on money and output growth that closely match the theoretical model predictions.

[5] Note that although we have a measure of conditional innovation uncertainty we do not consider the Levine and Renelt (1992) conditioning information set as Ramey and Ramey (1995) since we follow a time-series approach and some of those variables are either not available at the monthly frequency or do not exhibit any temporal variation for studying in a time series context. Although additional explanatory variables can augment our conditional mean equations at this stage we choose to focus an

The stationarity and dependence properties of the GARCH equations (23) and (25) provide a framework to interpret the effects of shocks in the uncertainty of output and nominal money growth rates.[6] In particular, the model (22)-(26) allows us to examine three different useful aspects of volatilities: (i) if output growth uncertainty follows a GARCH process then we can evaluate if the variance of output growth or other economic variables have significant dynamic effects; (ii) if the GARCH output coefficients, e.g. ($\alpha_1 + \alpha_2$) e.g. in equation (23), are statistically significant and equal to or close to unity then this yields an Integrated GARCH (IGARCH) process according to which shocks in output uncertainty are expected to have a persistent effect in volatility; and (iii) if in addition the relationship between the mean and volatility is empirically supported by a GARCH-in-Mean process as in e.g. equation (24) then it implies that money and output uncertainty ($\sigma^2_{\Delta M,t}$ and $\sigma^2_{\Delta Y,t}$) have a significant effect on the average output growth. This is due to the fact that the variance enters the conditional mean growth equation say (22) and its partial correlation with output growth can be examined in the presence of other uncertainty factors as well as other mean/average growth rate variables. Hence this model provides a context to disentangle the mean and variance effects of say nominal money on output growth by modelling all the conditional moments and estimating their interactions simultaneously. In addition, it allows us to examine the causality-in-mean and causality-in-variance hypotheses (Granger, 1988) which relate to our theoretical propositions regarding the direction of causality of the uncertainty of real and nominal shocks on output growth. Last but not least, the GARCH-M model allows us to disentangle the empirical effects of the average and the variance of money growth on output growth by jointly estimating a system of dynamic

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empirical model as close as possible to our theoretical model by considering a bivariate model of five simultaneous equations for each country and joint hypotheses tests for all the G7 countries.

conditional moments. Indeed, some studies emphasize that it is difficult to separate the effects of inflation/money average and variance on growth given the high correlation between the two variables (Temple, 2000, Dotsey and Sarte, 2000).

We now turn to the testable hypotheses relating to the theoretical predictions of the model analysed in Section II regarding the effects and sources of uncertainty on growth for the G7 countries using the GARCH-M model. Money growth, ΔM_t, is measured by the rate of growth of the narrow nominal money supply and output growth, ΔY_t, by the index of production (IOP) growth rates. The model is estimated using monthly, seasonally adjusted data for the G7 countries over the maximum sample 1960 to 2006. **Our choice of the sample period takes into account that 2007 can be considered as a structural break marked by the start of the 2007 global economic crisis following studies e.g. by Bataa et al. (2012) who find that the post 2006 there is an increase in inflation volatility for the G7 countries (see Figures). For the US in particular the period ending in 2007 marks the end of the 'Great Moderation' era i.e. end of the decline in the volatility of output and many other real macroeconomic variables (see also Ćorić, 2012).** The choice of monthly data sampling frequency reflects our objective to estimate conditional variances from short-run cyclical dynamics and time-varying policy shocks. The monthly difference of production with lags of up to a year is an attempt to capture both short- and relatively long-run growth effects.[7] Focusing on the G7 allows us to study a relatively

[6] Prior the estimation of the model (22)-(26) we test the unit root hypothesis and find that output and money growth rates (or first log differences) are stationary reported in Table B3 in Appendix B.
[7] The details of the data definitions, data sources and the exact sample period for each country are found in Table B1, Appendix B. In the same Appendix in Table B2 we report the outliers removed from the output and money growth rates, following Stock and Watson's (2003) inter-quartile range method. Most outliers are associated with events which correspond to either global economic events such as oil crises or country-specific events. Table B2 provides a list of such events for each country and corresponding set of dates where this is applicable.

homogenous group of countries which corresponds more closely to the theoretical assumptions of the model. Summary statistics for money and output growth rates are presented in Table B3, Appendix B. The summary statistics show that the normality hypothesis is rejected for almost all the G7 series considered due to mostly excess kurtosis. This is a stylized fact that can indeed be modelled by GARCH-type specifications. The Augmented Dickey Fuller (ADF) tests reported in Table B3 show that the growth rates of output and money are stationary.

We estimate the empirical model in equations (22)-(26) for each country and our objective is to examine the support of the following theoretical model propositions using both individual i.e. country-specific as well as multiple i.e. G7-group hypothesis testing.

- Hypothesis (i) examines whether nominal money uncertainty is time varying as modelled by the (G)ARCH-type equation (23) (testing the H_0: $\alpha_1 = 0$ and $\alpha_2 = 0$). In addition, if the sum of these GARCH coefficients is close to unity then a shock in money uncertainty will have a persistent effect.
- Hypothesis (ii) tests whether the growth uncertainty specified in (G)ARCH equation (25) provides a time varying measure of the growth variability (H_0: $\alpha_4 = 0$ and α_5 =0).
- Hypotheses (iii) (H_0: $\beta_3 = 0$) and (iv) (H_0: $\beta_4 = 0$) examine the significance of money and output uncertainty, respectively, in the money equation (22).
- Hypotheses (v) (H_0: β_8 =0) examine the effects of money uncertainty during recessions and (vi) (H_0: β_9 =0) of output uncertainty in the output equation (24). The alternative hypotheses, H_1: β_8<0 and H_1: β_9 >0 derive their signs from the

theoretical predictions (see equations (21), (21') and (21'')). Note that the first coefficient is predicted to be negative if there is nominal rigidity.

- Hypothesis (vii) (H_0: β_{7i} =0, i=1,….,q) examines the effects of money growth on output growth in equation (24). The alternative hypothesis derived from the theoretical model suggests that the overall effect will be positive, after controlling for its variance effects and if there are nominal wage contracts (see equation (21')).

IV. Empirical Results

In this section we discuss the empirical support of the hypotheses detailed in the previous section using the bivariate GARCH-M models for the G7 countries. Table 1 presents the summary results for each hypothesis tested and the corresponding estimated GARCH-M coefficients and p-values based on robust Bolleslev and Wooldridge (1992) t-statistics. The detailed estimation and misspecification results of equations (22)-(26) for each country can be found in Appendix C.[8] The estimation utilises the BFGS numerical optimisation algorithm with robust standard errors to calculate the maximum likelihood estimates of the parameters in (22)-(26) (estimated in RATS 7.1). The general-to-specific procedure is adopted for specifying the significant lags in the linear equations.

First we investigate the significance of the conditional volatility estimates for money and growth since they represent the building blocks of the theoretical and empirical models. The results of hypotheses (i) and (ii) in Table 1 provide strong

[8] Appendix C is available from the web-site http://www.socialsciences.manchester.ac.uk/disciplines/economics/research/discussionpapers/. This

evidence regarding the significance of most (G)ARCH parameters α_i's governing the estimated conditional variances in all countries (except the output volatility in Japan). These results unfold an interesting property of these macroeconomic variables for the G7, namely the existence of nonlinear dynamics present in their conditional variances. In addition, we provide evidence regarding the effects of shocks in the nominal uncertainty as measured by the volatility persistence of money growth. In the GARCH equation (23) of money growth the persistence coefficient, $(\alpha_1 + \alpha_2)$, is close to unity for Canada, France, Japan and the US, which implies that shocks in nominal money uncertainty have a persistent effect in these countries.[9] Similarly, the countries characterised by significant and persistent volatility dynamics in output growth, $(\alpha_4 + \alpha_5)$ in equation (25), are Italy and the UK.

Next we examine the effects of nominal money shock variability, $\sigma^2_{\Delta M,t}$, and growth uncertainty, $\sigma^2_{\Delta Y,t}$, on money growth (shown in equation (22) and tested via hypotheses (iii) and (iv)) and on output growth (shown in equation (24) and examined by hypotheses (v) and (vi)). As mentioned earlier, these are particularly interesting given the theoretical propositions that nominal shock uncertainty exerts a negative effect on growth if there are nominal rigidities, H_0: β_8=0 and H_1: β_8<0, and the corresponding hypothesis that output growth uncertainty has a positive effect on growth, H_0: β_9=0 and H_1: β_9>0. We investigate this hypothesis using two statistical procedures. First, we test each individual hypothesis for each country separately at a given level of significance, α. Second, we combine these k=1,..,7 individual hypotheses

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Appendix also includes the time series graphs of the monthly growth rates of money and industrial production growth rates used for estimating the bivariate GARCH-CCC model.

[9] Diebold (1986) and Lamourex and Lastrapes (1990) present empirical evidence that volatility persistence may be a spurious effect due to structural breaks or outliers in the sample. However, in the present analysis the estimated persistence effects are not due to outliers since these have been removed from the data before the estimation as shown in Table B2, Appendix B.

and apply a multiple test of significance based on a Bonferroni procedure. In this context we view each of the G7 as an alternative sample realisation that yields individual statistics used to examine the empirical support for the global G7 null hypothesis made up of the intersection of the individual null hypotheses such that $H_0^g=\{H_0^k, k=1,\ldots,7\}$. Appropriate methods are adopted to adjust the significance level to the multiple hypothesis test and a sequential test is performed to examine the sources of rejection, discussed below. If no empirical support is found for any of the H_0^k at the adjusted significance level then we conclude that there is no empirical support for the global null hypothesis for the G7 group.[10]

Following the individual hypothesis test approach we find that nominal shock uncertainty has a negative effect on monetary growth in all the G7 and a significant one in Canada, Italy (at the 5% significance level) as shown in Table 1, hypothesis (iii). Output growth uncertainty has a significant positive effect on money growth in Italy and the UK (shown in Table 1, hypothesis (iv)). More interestingly, turning to the output growth equation (24), we examine the empirical support of the theoretical prediction that nominal uncertainty has a negative effect on output growth. In results on hypothesis (v) in Table 1 show that money uncertainty has a negative effect on output growth in five of the G7 and reports that this is significant in three of the G7 countries, namely Canada, Germany and the US. The exceptions to this result are France, Italy and the UK where the estimated money uncertainty variable is positive and significant only in the UK. This can be interpreted using our theoretical analysis by recalling that nominal volatility will have negative effects on growth only if there is nominal wage rigidity, which is estimated to be higher in the US and Canada (see Cahuc and Zylberberg 2004 chapter 8). France, Italy and the UK had at times a very high degree of

[10] The Bonferroni procedure is valid even if the alternative individual statistics of the hypotheses H_0^k are not strictly independent (see for instance, Gourieroux and Monfort, 1996).

wage indexation and underwent periods of high inflation, see Bruno and Sachs (1986) and Manacorda (2002). In particular the UK had a period of high inflation in the seventies: Card and Hyslop (1997) among many others provide evidence that in a higher inflation environment wage adjustments occur more quickly thus reducing the degree of nominal wage stickiness. In the other economies price indexation has always been very limited (the US) or forbidden by law (Germany). In addition we examine hypothesis (vi) regarding the effects of output uncertainty on growth. In Table 1 output uncertainty turns out to be positive for six of the G7 and it is significant in Canada, France and the US. This is consistent with our theoretical predictions and distinguishes our work from many other studies that find a negative effect of volatility on growth.

The last hypothesis (vii) refers to the effect of money growth on output growth. The joint F-test for zero restrictions on the lagged coefficients of ΔM_{t-i}, H_0: $\beta_{7i}=0$, $i=1,..,q$ provides strong evidence against the null hypothesis for all countries except Italy and the UK. The reported sum of β_{7i} coefficients supports our theoretical model prediction that nominal money growth has a positive effect on output growth (apart from the UK)**.** To explain these results we recall that this prediction is conditional on the degree of nominal rigidity, which is likely to be very low especially in the UK during some periods, as mentioned above.

We now turn to the Bonferroni multiple test procedure for the global G7 hypothesis denoted H_0^g which has an asymptotic bound with adjusted significance levels of α^k=0.007 and 0.014 (given α=5% and 10%, respectively). Hochberg (1988) and Rom (1990) *inter alia*, suggest a modified Bonferroni approach following a sequentially rejective procedure according to which one starts by examining the largest *p*-value, $p(m)$, of the individual hypotheses, H_0^k. If $p(m) \leq \alpha^k$ then all hypotheses are rejected. If not, then one cannot reject H_0^g and goes on to compare the next largest *p*-

value, *p(m-1)*, with an adjusted confidence interval based on the reduction of the sample size. If that is not rejected the above procedure is implemented in a sequential manner. Following the multiple significance test approach the empirical results show that the global null hypothesis for (iv) is rejected for the G7 group. This implies that output uncertainty has a significant effect on monetary growth given that the maximum *t*-value for hypothesis (iv) is *t(m)*=4.04 which yields an equivalent Bonferroni adjusted *p*-value, *p(m)*=0.00001. In addition, the global hypothesis (iii) is rejected by the data (at the 10% significance level with corresponding p-value 0.014) since the Bonferroni procedure yields *t(m)*=2.57 and corresponding *p(m)*=0.010. Hence money uncertainty has a significant, negative effect on money growth at the 10% multiple test significance level. Yet, more importantly, the multiple test results for hypotheses (v) and (vi) show that both money and output volatilities have a significant effect on output growth. Specifically, the Bonferroni adjustment shows that money volatility in the G7 yields a significant, negative effect on output based on *t(m)*=2.36 and *p(m)*=0.0184 (at the 10% Bonferroni significance level corresponding to a p-value=0.02). Similarly, output uncertainty has a significant positive effect on output growth since *t(m)*=6.43 and *p(m)*=0.00001.

V. Robustness considerations

We consider a number of robustness checks for the above empirical findings. First we perform a number of specification tests for the bivariate GARCH in Mean Constant Conditional Correlation (GARCH-M-CCC) model for each of the G7 reported in Table 2. The first two rows of Table 2 show that the volatility effects of money and output growth are jointly significant in at least one of the two equations of the GARCH-M-CCC model. In addition a number of residual specification tests are performed. The

Tse (2000) test evaluates the null hypothesis of Constant Conditional Correlation (CCC) in our bivariate GARCH-M models. The Tse test results reported in row (3) of Table 2 show that this null hypothesis is supported for all G7 which implies that there is no empirical evidence of dynamic conditional correlation. [11] In addition, the Portmanteau tests reported in rows (4)-(7) of Table 2 aim at testing the null hypothesis of no remaining linear or second-order dependence in the residuals using the Ljung-Box (Q) and McLeod-Li (Q^2) tests, respectively. The reported results for the standardised residuals of both the money and output growth equations show that there is no additional linear or second-order dependence in the residuals of the GARCH(1,1)-M-CCC model. An additional hypothesis of interest in such models is the effect of business cycle dynamics. Hence we examine if there are any significant effects associated with either the recessions phases of the business cycle using the recession binary variable indicator approach which is widely used in the literature (see recently, Piazzesi and Swanson, 2008), or whether there are any asymmetry effects associated with a threshold or asymmetric volatility effect similar in spirit to Glosten et al., (1993).[12] The tests for the significance of the recession indicator in the standardised residuals of the two equations of the GARCH-M-CCC model are reported in rows (8)-(10) of Table 2.[13] The results show that the recession indicator turns out to be insignificant in both the mean and volatility of the residuals of the money and output

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[11] Related robustness checks for the dynamic conditional correlation multivariate GARCH-M models are reported in Table 3 and discussed below.

[12] A complementary approach is to estimate multivariate GARCH-M models with Markov Switching capturing regimes business cycle phases regimes. However, given that the above two residual specification tests do not provide support that there is neglected systematic information in the residuals of the GARCH-M-CCC regarding business cycle phases.

[13] The classical business cycle phases for recession are obtained from the Economic Cycle Research Institute (http://www.businesscycle.com). A recession phase is dated to commence in the month following a peak and finishes at the trough month. Using these we construct a recession binary variable indicator denoted DREC which takes the value one during recessions and zero otherwise for each of the G7.

growth of the GARCH-M-CCC equations. Similarly the results reported in row (11) of Table 2 show that there are no neglected threshold or asymmetric effects in the squared residuals of the GARCH-M-CCC.

Another approach to evaluate the robustness of our empirical findings which are based on the bivariate GARCH-M-CCC is to examine their sensitivity using alternative multivariate GARCH specification which assume dynamic instead of constant conditional correlation as well as to compare such models using Information Criteria that measure the relative goodness of fit of the models. In particular we estimate the bivariate GARCH in Mean of named after Baba, Engle, Kraft and Kroner (GARCH-M-BEKK) specification (Engle and Kroner, 1995) and the GARCH-M Dynamic Conditional Correlation (GARCH-M-DCC) model of Engle (2002) models and compare them with the GARCH-M-CCC in terms of the Akaike and Schwarz Information Criteria (AIC and SIC, respectively). These results are reported in Table 3. The first two rows of Table 3 show that the GARCH-M-CCC model minimises both the AIC and SIC relative to the GARCH-M-BEKK and GARCH-M-DCC models. More importantly we evaluate the empirical support of our main theoretical hypotheses (iii)-(vii) using the GARCH-M-BEKK and GARCH-DCC models in order to assess the sensitivity of our empirical results to the alternative multivariate GARCH specifications. Overall we find that the empirical results presented in the previous section and summarised in Table 2 based on the bivariate GARCH-M-CCC model are robust to the different specifications of the conditional correlation. In particular Table 2 shows that hypotheses (vi) and (vii) are robust across all three multivariate model specifications. The rest of the hypotheses (iii)-(v) are also overall less sensitive to the alternative models and it appears that the bivariate GARCH-M-CCC model provides relatively more significant evidence for these hypotheses compared to the other models with dynamic conditional correlation. The fact that the bivariate GARCH-M-CCC model minimises the two Information Criteria (AIC and SIC) in Table 3 and is a well-specified model based on the tests performed in Table 2 suggests that it is a reliable statistical model to examine the empirical support of our theoretical hypotheses.

Finally we also examine the robustness of our hypotheses using other multivariate parametric volatility models which incorporate asymmetries such as the Threshold GARCH as well as Exponential GARCH (EGARCH) specifications and the results are qualitatively the same with those using the GARCH-M-CCC reported in Table 1. This result is consistent with the misspecification tests results reported in Table 2 which show that he recession indicator is insignificant in the standardised residuals of the GARCH-M-CCC model. In addition we examine the sensitivity of the findings in Table 1 using other measures of money aggregates. We find that similar results apply especially with respect to nominal money shock uncertainty. For some of the G7 we also expanded the information set to include some additional explanatory variables in the conditional mean equations such as short-run interest rates and find that the results in Table 1 still hold.

V. Conclusions.

The paper contributes to the analysis of the relationship between growth and its volatility by examining how short-run nominal and real uncertainty affects output growth. The theoretical model predicts that the variability of output shocks yields a positive effect on growth while the variability of nominal shocks has a negative effect on growth, in economies with nominal wage rigidity. Moreover, in these economies the average money growth has a positive effect on growth after controlling for the money uncertainty effect. In the context of a bivariate GARCH-M model, we empirically investigate the effects of nominal money shock and output growth uncertainties on output growth by estimating simultaneously the effects of the dynamic volatilities of monthly money and output growth for the G7 countries in the conditional mean equations of the money and output growth rates.

Summarising the empirical analysis we derive the following results. First, there is strong evidence of significant conditional heteroskedasticity effects in the time series behaviour of monthly production and nominal money growth rates during the period of the early 1960s to 2006. Shocks to nominal money growth uncertainty have a persistent effect in Canada, France, Japan and the US whereas shocks to output uncertainty are relatively less persistent in the G7 except in Italy and the UK. Second, there is a positive and significant effect of output growth uncertainty on growth in the G7 using the Bonferroni procedure. Following the individual hypothesis we find empirical support for this hypothesis for Canada, France and the US. Third, we find a negative effect of nominal money shock uncertainty on output growth in the five of the G7 and this turns out to be significant using the Bonferroni inequality for a multiple hypothesis test. Following the individual hypothesis test approach we find that money shocks uncertainty exerts a significant influence on growth in Canada, Germany and the US. A possible explanation of the insignificant and non-negative effects of nominal money uncertainty in the growth equation in France, Italy and the UK could be the wage indexation and the high inflation experienced in the 1970s by these economies. Finally, the empirical analysis also presents evidence that average money growth has a positive effect on the average output growth in all G7 countries.

This paper shows that it can be instructive to use an approach that separates nominal and output growth uncertainties to understand how these relate to long-run growth both theoretically and empirically. Our analysis shows that output volatility is good for growth for all the G7 using the multiple test approach.

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Table 1: Testing our theoretical hypotheses in the Bivariate GARCH-M-CCC model for the money and output growth in the G7

Hypotheses (i) – (vii):	**Parameter Restrictions**	**Canada**	**France**	**Germany**	**Italy**	**Japan**	**UK**	**US**
(i) Money volatility in eq. (23)	$\alpha_1 = 0$	0.0911 (0.0013)*	0.0567 (0.1232)	0.2041 (0.0002)*	0.4481 (0.0003)*	0.2429 (0.0004)*	0.3153 (0.0000)*	0.2021 (0.0006)*
	$\alpha_2 = 0$	0.8634 (0.0000)*	0.9362 (0.0000)*	0.0533 (0.6750)	0.0591 (0.5612)	0.5682 (0.0000)*	0.1045 (0.0015)*	0.7159 (0.0000)*
(ii) Output volatility in eq. (25)	$\alpha_4 = 0$	0.1061 (0.0167)*	0.1765 (0.0008)*	0.3749 (0.0000)*	0.0428 (0.0000)*	0.1156 (0.0227)*	0.0540 (0.0000)*	0.1629 (0.0012)*
	$\alpha_5 = 0$	0.5697 (0.0000)*	0.1964 (0.4822)	0.1476 (0.0321)*	0.9525 (0.0000)*	0.0843 (0.8351)	0.9433 (0.0000)*	0.2627 (0.2699)
(iii) Money volatility in money growth eq. (22)	$\beta_3 = 0$	-0.1605 (0.0103)*	-0.0121 (0.8638)	-0.1929 (0.3649)	-0.1823 (0.0220)*	-0.1139 (0.1304)	-0.1760 (0.4254)	-0.2253 (0.1948)
(iv) Output volatility in money growth eq. (22)	$\beta_4 = 0$	0.0673 (0.7527)	-0.1134 (0.1771)	-0.0250 (0.4906)	0.1027 (0.0001)*	0.0032 (0.9871)	0.0607 (0.0000)*	0.1512 (0.3276)
(v) Money volatility in output growth eq. (24)	$\beta_8 = 0$	-0.1325 (0.0381)**	-0.0099 (0.9011)	-0.4354 (0.0184)*	0.0062 (0.9200)	-0.0053 (0.9458)	0.4737 (0.0018)*	-0.4789 (0.0468)*
(vi) Output volatility in output growth eq. (24)	$\beta_9 = 0$	0.9954 (0.0034)*	0.2098 (0.0227)*	0.0437 (0.4101)	0.0117 (0.7172)	0.2937 (0.6609)	-0.0238 (0.3759)	1.0396 (0.0000)*
Sum of money coeffs in eq. (24)	$\sum \beta_{7i}$	0.0945	0.2046	0.3944	0.2094	0.1810	0.0412	0.0951
(vii) Money coefficients in output growth eq. (24)	$\beta_{7i} = 0$ i=1,…,q	39.8360 (0.0000)*	16.7075 (0.0002)*	21.7959 (0.0000)*	8.8272 (0.0656)**	15.2310 (0.0094)*	1.1904 (0.2752)	6.1071 (0.0135)*

Note: We report the estimated parameters of the bivariate GARCH-M-CCC in equations (22)-(26) and the corresponding p-value in the parentheses associated with testing the null hypotheses from our theoretical model as listed in the parameter restrictions column and discussed in detail in Section III. (*) and (**) denote rejection of the null hypothesis at the 10% and 5% significance levels, respectively.

Table 2: Specification Tests of Bivariate GARCH-M-CCC model for the money and output growth in the G7

	Canada	France	Germany	Italy	Japan	UK	US
Model Parameter restrictions tests:							
(1) Test for GARCH-M parameters in money equation $\sigma^2_{\Delta Mt} = \sigma^2_{\Delta Yt}=0$	6.6016 (0.0369)**	1.6434 (0.4397)	1.3298 (0.5143)	22.0755 (0.0000)*	8.8985 (0.0117)*	121.6345 (0.0000)*	2.7600 (0.2516)
(2) Test for GARCH-M parameters in output equation $\sigma^2_{\Delta Mt} = \sigma^2_{\Delta Yt}=0$	12.0441 (0.0024)*	5.8877 (0.0527)**	5.7303 (0.0570)**	0.1371 (0.9337)	0.9880 (0.6102)	14.7447 (0.0006)*	46.1968 (0.0000)*
Residual based tests:							
(3) Tse Test for CCC	1.3733 (0.2413)	0.0396 (0.8423)	3.4385 (0.0637)	3.8331 (0.0502)	0.0014 (0.9697)	1.9950 (0.1578)	1.4539 (0.2279)
(4) Ljung-Box test in money residuals							
Q(4)	1.427 (0.8394)	2.088 (0.7196)	4.541 (0.3377)	3.488 (0.4797)	1.598 (0.8092)	2.573 (0.6316)	1.569 (0.8143)
Q(6)	1.893 (0.9293)	4.927 (0.5532)	4.651 (0.5893)	1.699 (0.9452)	4.260 (0.6415)	5.277 (0.5088)	2.507 (0.8677)
(5) McLeod-Li test in money residual							
$Q^2(4)$	5.497 (0.2400)	1.416 (0.8415)	0.560 (0.9674)	2.472 (0.6497)	0.169 (0.9966)	2.354 (0.6709)	1.999 (0.7359)
$Q^2(6)$	6.669 (0.3526)	6.153 (0.4062)	1.011 (0.9852)	3.115 (0.7943)	7.844 (0.2498)	3.385 (0.7592)	2.112 (0.9091)
(6) Ljung-Box test in output residuals							
Q(4)	0.429 (0.9801)	4.188 (0.3811)	0.176 (0.9963)	1.674 (0.7954)	0.744 (0.9458)	2.791 (0.5934)	2.372 (0.6677)
Q(6)	4.642 (0.5904)	7.573 (0.2711)	0.762 (0.9930)	0.958 (0.9872)	1.891 (0.9295)	2.912 (0.8198)	5.359 (0.4987)
(7) McLeod-Li test in output residual							
$Q^2(4)$	0.778 (0.9414)	6.296 (0.1781)	0.928 (0.9205)	6.586 (0.1595)	0.834 (0.9339)	7.470 (0.1130)	2.340 (0.6735)
$Q^2(6)$	4.237 (0.6446)	9.826 (0.1322)	0.899 (0.9892)	4.416 (0.6206)	10.253 (0.1144)	7.529 (0.2747)	4.021 (0.6739)

Table 2 continued:

Residual-based tests (continued):							
(8) Significance of Recession Indicator in the mean of the residuals							
(i) money	0.1860	0.0448	1.0083	1.5335	0.0168	2.8117	0.0094
$\delta_{1,\Delta Mt}$ (coeff. of REC_D)= 0	(0.6663)	(0.8324)	(0.3153)	(0.2156)	(0.8969)	(0.0936)	(0.9227)
(ii) output	0.0131	0.3215	7.2661	2.8256	1.3216	0.4995	1.5581
$\delta_{1,\Delta Yt}$ (coeff. of REC_D) = 0	(0.9088)	(0.5707)	(0.0070)*	(0.0928)	(0.2503)	(0.4797)	(0.2119)
(9) Significance of Recession Indicator in the							
money and output volatility in the means residuals	2.0505	0.9233	0.0945	0.6419	0.6183	0.8768	0.3220
of	(0.1522)	(0.3366)	(0.7586)	(0.4230)	(0.4317)	(0.3491)	(0.5704)
(i) money	2.8529	0.8907	1.2405	4.6414	0.1054	3.5910	0.1032
$\delta_{2,\Delta Mt}$ (coeff. of $\sigma^2_{\Delta M,t}$* REC_D) = 0	(0.0912)	(0.3453)	(0.2654)	(0.0312)*	(0.7454)	(0.0581)	(0.7480)
$\delta_{3,\Delta Yt}$ (coeff. of $\sigma^2_{\Delta y,t}$* REC_D) = 0							
	1.1841	0.1119	2.0515	0.3254	0.0508	0.1322	0.3175
(ii) output	(0.2765)	(0.7380)	(0.1521)	(0.5684)	(0.8217)	(0.7162)	(0.5731)
$\delta_{2,\Delta Mt}$ (coeff. of $\sigma^2_{\Delta M,t}$* REC_D) = 0	0.1858	2.5541	0.0053	0.0005	0.0128	0.9626	1.9412
$\delta_{3,\Delta Yt}$ (coeff. of $\sigma^2_{\Delta y,t}$* REC_D) = 0	(0.6664)	(0.1100)	(0.9422)	(0.9830)	(0.9099)	(0.3265)	(0.1635)
(10) Test for business cycle effects in volatility of	3.5205	1.1257	4.1522	0.9112	5.5579	1.4155	0.0294
(i) money	(0.1720)	(0.5696)	(0.1254)	(0.6341)	(0.0621)	(0.4927)	(0.9854)
$\theta_{3,\Delta Mt}$ (coeff. of $\sigma^2_{\Delta M,t}$* REC_D) = 0	0.0172	2.1552	1.5617	0.7766	5.3275	0.6825	1.4426
(ii) output	(0.9914)	(0.3404)	(0.4580)	(0.6782)	(0.0697)	(0.7109)	(0.4861)
$\theta_{3,\Delta Yt}$ (coeff. of $\sigma^2_{\Delta Y,t}$* REC_D) = 0							
(11) Test for asymmetric volatility (threshold							
effects) **$I\{\Delta i<0\}* \sigma^2_{\Delta i,t}$**					0.9767		
(i) in money	0.7951	1.2526	0.7695	0.1469	(0.3230)	1.4311	0.0654
$\beta_{1,\Delta Mt}$ (coeff. of **$I\{\Delta M_t<0\}$**$*\sigma^2_{\Delta M,t}$)=0	(0.3726)	(0.2631)	(0.3804)	(0.7015)	1.5812	(0.2316)	(0.7981)
(ii) in output	0.3518	0.6770	0.0397	0.0018	(0.2086)	0.0159	0.0143
$\beta_{1,\Delta Yt}$ (coeff. of **$I\{\Delta Y_t<0\}$**$*\sigma^2_{\Delta Y,t}$)=0	(0.5531)	(0.4106)	(0.8421)	(0.9662)		(0.8998)	(0.9048)

Notes: Specification parameter and residual-based tests are reported for the bivariate GARCH-CCC model with the corresponding p-values in the brackets. (*) denote rejection of the null hypothesis at 5% significance level. The Tse test (2000) in row (3) evaluates the null hypothesis of constant conditional correlation. In rows (4)-(7) the Ljung Box (Q) and McLeod-Li (Q^2) tests examine if there is any remaining linear and second-order temporal dependence in the residuals, respectively, of the money and output growth equation of the GARCH-CCC model. In rows (8)-(10) the significance of the recession indicator is examined in the mean and volatility of the residuals of the money and output growth equations of the GARCH-CCC. The auxiliary regression for the conditional mean in the tests (8)-(9) is $u_{i,t} = \delta_{0,i} + \delta_{1,i}$*REC_D+$\delta_{2,i}$*REC_D* $\sigma^2_{\Delta M,t}$ +$\delta_{3,i}$*REC_D* $\sigma^2_{\Delta Y,t}$ + v_t and for tests in (10) in the conditional variance are $u^2_{i,t} = \theta_{1,i} + \theta_{2,i}$*REC_D + $\theta_{3,i}$*REC_D* $\sigma^2_{i,t}$ + v_t, where $u_{it} = \varepsilon_t/\sigma_{\Delta i,t}$ for i=M(Money) and Y(Output) growth rates. REC_D is a binary dummy variable that takes the value 1 during recessions and zero otherwise. The binary variable REC_D is constructed using the official recession dates for each of the G7. In row (11) we test the asymmetric volatility effects associated with different volatility during realizations of money and output growth, similar to the threshold effects of volatility (see Glosten et al., 1993). In order to test if there are any remaining threshold or asymmetric effects in the squared residuals of the GARCH-CCC we use the following auxiliary regression $u^2_{i,t} = \beta_0 + \beta_{1i} I\{\Delta i<0\}*\sigma^2_{\Delta i,t}+\omega_t$ where i=M(Money) and Y(Output) growth with the following binary variables: $I\{\Delta M_t <0\}$ equals 1 when the output growth is negative and zero otherwise. Similarly, $I\{\Delta Y_t <0\}$equals 1 when ΔY_t is negative and zero otherwise. In (11) we test the null that the coefficient of $I\{\Delta i<0\}* \sigma^2_{\Delta i,t}$, namely β_{1i}=0.

Table 3: Testing the robustness of our main theoretical hypotheses to multivariate GARCH in Mean (GARCH-M) models with alternative conditional correlations.

	Canada			France			Germany			Italy			Japan			UK			US		
Information criteria	**GARCH CCC**	**GARCH BEKK**	**GARCH DCC**	**GARCH CCC**	**GARCH BEKK**	**GARCH DCC**	**GARCH CCC**	**GARCH BEKK**	**GARCH DCC**	**GARCH CCC**	**GARCH BEKK**	**GARCH DCC**	**GARCH CCC**	**GARCH BEKK**	**GARCH DCC**	**GARCH CCC**	**GARCH BEKK**	**GARCH DCC**	**GARCH CCC**	**GARCH BEKK**	**GARCH DCC**
AIC	6.231†	6.243	6.232	5.976†	5.989	5.984	6.160†	6.184	6.199	6.555†	6.566	6.745	6.411†	6.425	6.411†	3.893†	3.907	4.015	2.809†	2.922	2.920
SIC	6.463†	6.507	6.472	6.180†	6.224	6.196	6.384†	6.441	6.432	6.779†	6.825	6.978	6.660†	6.700	6.662	4.117†	4.168	4.249	3.036†	3.180	3.155
Main Hypothesis																					
(iii) Money volatility in (22): β_3=0	-0.160 (0.010)*	-0.202 (0.034)*	-0.168 (0.039)*	-0.012 (0.864)	0.005 (0.950)	-0.011 (0.880)	-0.193 (0.365)	-0.093 (0.724)	0.307 (0.503)	-0.182 (0.022)*	-0.197 (0.007)*	0.078 (0.844)	-0.114 (0.130)	-0.133 (0.067)*	-0.122 (0.089)*	-0.176 (0.425)	0.187 (0.500)	0.054 (0.225)	-0.225 (0.195)	-0.308 (0.163)	-0.226 (0.327)
(iv) Output volatility in (22): β_4=0	0.067 (0.753)	0.521 (0.625)	0.065 (0.804)	-0.113 (0.177)	-0.173 (0.267)	-0.123 (0.171)	-0.025 (0.491)	-0.033 (0.438)	-0.007 (0.865)	0.103 (0.000)*	0.112 (0.000)*	0.049 (0.003)*	0.003 (0.987)	-0.293 (0.577)	0.175 (0.421)	0.061 (0.000)*	0.042 (0.254)	-0.003 (0.756)	0.151 (0.328)	0.071 (0.463)	0.036 (0.615)
(v) Money volatility in (24): β_8=0	-0.133 (0.038)*	-0.251 (0.018)*	-0.128 (0.077)*	-0.010 (0.901)	-0.010 (0.900)	0.006 (0.942)	-0.435 (0.018)*	-0.514 (0.338)	-0.064 (0.866)	0.006 (0.920)	0.022 (0.697)	0.280 (0.586)	-0.005 (0.946)	-0.039 (0.503)	-0.022 (0.688)	0.474 (0.002)*	0.443 (0.264)	0.126 (0.219)	-0.479 (0.047)*	-0.331 (0.283)	-0.329 (0.175)
(vi) Output volatility in (24): β_9=0	0.995 (0.003)*	3.159 (0.348)	1.098 (0.024)*	0.210 (0.023)*	0.181 (0.101)	0.212 (0.019)*	0.044 (0.410)	0.123 (0.188)	0.026 (0.685)	0.012 (0.717)	0.016 (0.564)	-0.010 (0.768)	0.294 (0.661)	0.004 (0.994)	0.253 (0.391)	-0.024 (0.376)	-0.020 (0.774)	-0.016 (0.496)	1.040 (0.000)*	0.416 (0.030)*	0.422 (0.036)*
(vii) Sum of money coeffs in (24): $\sum\beta_{7i}$	0.095	0.094	0.094	0.205	0.200	0.209	0.394	0.422	0.398	0.209	0.206	0.204	0.181	0.211	0.173	0.041	0.064	0.008	0.095	0.109	0.097
Money coeffs in (24): $\beta_{7i}= 0$	39.836 (0.000)*	21.106 (0.000)*	33.928 (0.000)*	16.707 (0.000)*	11.302 (0.004)*	17.748 (0.000)*	21.796 (0.000)*	21.830 (0.000)*	21.507 (0.000)*	8.827 (0.066)*	13.470 (0.009)*	6.730 (0.151)*	15.231 (0.009)*	26.719 (0.000)*	25.151 (0.000)*	1.190 (0.275)	0.236 (0.627)	0.038 (0.846)	6.107 (0.013)*	4.314 (0.038)*	4.037 (0.045)*

Note: We report the AIC and SIC for the bivariate GARCH-M using the Constant Conditional Correlation (CCC) (Bollerslev, 1990), the Dynamic Conditional BEKK (Engle and Kroner, 1995) and the Dynamic Conditional Correlation (DCC) (Engle, 2002) specifications. † denotes the minimum of the AIC & SIC among the three multivariable specifications. We also report the estimated coefficients and their corresponding p-values that test the statistical significance of the main theoretical hypotheses. (*) denote rejection of the null hypothesis at the 10% significance levels.

Appendix A: Theoretical Derivations

Derivation of equations (14) and (16): substituting the expression for the interest rate in terms of income and capital from (8) in (11) and recall the that $C_t + K_{t+1} = Y_t$ we are able to rewrite (11) as

$$\frac{\gamma_t K_{t+1}}{C_t} = \sigma\beta\psi\mu_\gamma + \sigma\beta\psi E_t\left(\frac{\gamma_{t+1}K_{t+2}}{C_{t+1}}\right), \tag{1A}$$

this defines a stochastic difference equation. Considering the transversality condition $\lim ._{\tau\to\infty}\beta^\tau E_t(\gamma_{t+\tau}K_{t+\tau+1}/C_{t+\tau}) = 0$ its solution is given by:

$$K_{t+1} = \frac{a\mu_\gamma}{(1-a)\gamma_t}C_t, \tag{2A}$$

where $a \equiv \sigma\beta\psi$. Given $C_t + K_{t+1} = Y_t$ (2A) implies (14) and (16) in the text.

Given $H_t = H_{t-1}\phi_t$ and $M_t = H_t$ (12) becomes

$$\frac{\gamma_t M_t}{P_t C_t} = \theta + \beta E_t\left(\frac{\gamma_{t+1}M_{t+1}}{P_{t+1}C_{t+1}}\right). \tag{3A}$$

solving (3A) by using the other transversality condition

$$\lim ._{\tau\to\infty}\beta^\tau E_t((\gamma_{t+\tau}M_{t+\tau-1}\phi_{t+\tau})/P_{t+\tau}C_{t+\tau}) = 0.$$

we get: $\frac{\gamma_t M_t}{P_t C_t} = \frac{\theta}{1-\beta}$ and substituting in for consumption its expression in terms of income given by (14) we have (15) in the text.

Derivation of equation (17): this is obtained by substituting in (13) for consumption its expression in terms of income given by (14) and then using (7).

Derivation of equation (17'): by substituting in (13') for consumption its expression in terms of income given by (14) and then using (7) we obtain: $E_{t-1}N_t = \frac{\alpha^2 \mu_\gamma \sigma}{\lambda(1-a)}$.

Substituting in (15) the expression for income in terms of labour and the real wage given by (7) we get:

$$N_t = \frac{\alpha\sigma(1-\beta)\left((1-a)\gamma_t + \mu_\gamma\right)}{(1-a)\theta W_t} M_t$$

(4A)

Or, taking expectations: $E_{t-1}N_t = \frac{\alpha\sigma(1-\beta)\mu_\gamma}{(1-a)\theta W_t} E_{t-1}M_t$. Equating the two expressions for $E_{t-1}N_t$ we get the optimal wage: $W_t = \frac{\lambda(1-\beta)E_{t-1}(M_t)}{\alpha\theta}$. Finally substituting this expression for the optimal wage in (4A) we get (17').

Derivation of equation (17''): eliminating the real wage from (7) and (13'') we get: $\alpha\sigma N_t^{\alpha-1} = \frac{\lambda}{E_{t-1}\gamma_t K_t / C_t}$. Using (14) to express consumption in terms of income and then using (6) to eliminate Y_t we get: $\alpha\sigma N_t^{\alpha-1} = \frac{\lambda}{E_{t-1}\alpha\left[(1-a)\gamma_t + a\mu_\gamma\right]/(1-a)N_t^{\alpha}}$ which, since at time t-1 N_t is known , can be rearranged to give (17'') in the text.

Appendix B: Data Appendix

Table B1: G7 Data Definitions and Descriptions

Country	Money	Output
Canada	M1 money supply, Datastream CNM1....B (1961m1-2006m10)	OECD industrial production index (excluding construction)
France	OECD M1 money supply (1960-1977 from OECD Historical Statistics), SA NSA M1 Money Supply: - French Contribution to the Euro Area, Datastream FRM1....A (1980-2006m10)	OECD industrial production index (excluding construction)
Germany	M1 MONEY SUPPLY- (Contribution to Euro Basis from 1995m1), SA , Datastream BDM1....B (1960-2003m7)	OECD index of industrial production (excluding construction)
Italy	OECD M1 money supply (1964-1980 from OECD Historical Statistics), SA. NSA M1 Money Supply: - Italian Contribution to the Euro Area, Datastream ITM1....A (1980-2006m10)	OECD industrial production index (excluding construction)
Japan	M1 money supply, Datastream JPM1FMONB (1960-2006m10)	OECD industrial production index (excluding construction)
US	FRED M1 money stock (M1SL) (1960-2006m12)	FRED industrial production index (excluding construction, INDPRO)
UK	Money Supply M0: Notes & Coins in circulation outside Bank of England, Datastream UKM0....B (1969m6-2006m12)	OECD industrial production index (excluding construction)

Note: Data Sources are the OECD – Organisation for Economic Co-operation and Development and the FRED – Federal Reserve Economic Data.

Table B2: G7 Outliers Removed

Country	Money	Output
Canada	1981m12 (Global oil crisis)	none
France	1968m5; (May protests in France) 1977m12 (Oils Price shocks) 1995m12 (Strikes in France)	1963m3,4; 1968m5-7 (May protests in France)
Germany	1964m1; 1965m1; 1966m1; 1967m1, 11; 1968m1, 11; 1969m1 (monetary policy targeting) 1973m5; (Oil Price Shocks) 1990m6, 12 (German re-unification)	1968m1, (Germany reaches its petroleum production peak) 1984m6, 7 (Global oil crisis)
Italy	1970m1; 1972m12; 1973m1 (Global oil crisis)	1974m1 (Global oil crisis)
Japan	1990m5; (Japanese asset price bubble) 2002m3	none
US	2001m9-10 (9/11 attacks at World Trade Centre twin tower in the US)	1974m11-12 (Oil Price Shock)
UK: M0	1971m2,4 (Decimalisation of Sterling) 1999m12 (Large amount of withdrawals from cash machines as people fear “millennium bug”) 2000m2 (cash balances returned)	1972m2-3(miner’s strike leads to imposition of a 3-day working week); 1974m1 (3-day working week & miner’s strike); 1978m4; 1979m1-2, (Global oil crisis) 2002m6 (Queen’s Jubilee holiday, lower production in June as less working days)

Note: The above outlier observations are removed based on Stock and Watson’s (2003) inter-quartile range (IQR) procedure. An outlier is defined as an observation which is more than four times the interquartile range from the median. The outlier is then replaced with the median of the 5 preceding observations. The Gauss code (fcst.prc) used in Stock and Watson (2003) and can be found within the zip file for this publication on Professor Mark Watson's webpage. The table reports the outliers removed from the data and the associated events with these dates when these apply.

Table B3: Summary Statistics for Money and Output growth

	Mean	Skewness	Kurtosis	Jacque-Bera Normality test	ADF	Ljung-Box Q test	McLeod-Li Q^2 test	ARCH test	t-test of recession dummy in AR(p)-GARCH-M
Money Growth									
Canada	0.652	0.144	4.537	56.468 (0.000)*	-6.292 (0.000)*	9.225 (0.056)***	39.954 (0.000)*	15.747 (0.000)*	0.655 (0.118)
France	0.600	0.119	4.990	94.588 (0.000)*	-4.864 (0.000)*	0.622 (0.961)	5.596 (0.231)	2.505 (0.114)	0.001 (0.970)
Germany	0.663	0.165	5.283	116.430 (0.000)*	-4.913 (0.000)*	5.294 (0.258)	1.666 (0.797)	0.703 (0.402)	0.204 (0.389)
Italy	0.963	-0.409	4.176	44.011 (0.000)*	-4.499 (0.000)*	0.965 (0.915)	31.030 (0.000)*	12.061 (0.001)*	0.025 (0.489)
Japan	0.837	-0.047	4.907	86.049 (0.000)*	-4.838 (0.000)*	0.185 (0.996)	55.243 (0.000)*	41.002 (0.000)*	0.127 (0.448)
UK	0.564	0.549	4.797	83.220 (0.000)*	-3.428 (0.011)**	3.206 (0.524)	39.937 (0.000)*	38.804 (0.000)*	0.032 (0.637)
US	0.412	0.029	4.007	24.292 (0.000)*	-4.108 (0.001)*	0.512 (0.972)	47.161 (0.000)*	30.955 (0.000)*	-0.008 (0.120)
Output Growth									
Canada	0.264	-0.179	3.643	12.620 (0.002)*	-5.683 (0.000)*	7.408 (0.116)	21.925 (0.038)**	2.592 (0.107)	-0.028 (0.167)
France	0.180	0.225	4.503	58.031 (0.000)*	-6.950 (0.000)*	5.086 (0.279)	31.359 (0.000)*	12.239 (0.001)*	-0.030 (0.271)
Germany	0.202	0.082	4.416	44.742 (0.000)*	-5.428 (0.000)*	6.270 (0.180)	9.416 (0.152)	6.354 (0.012)**	-0.121 (0.646)
Italy	0.169	0.136	5.133	99.507 (0.000)*	-6.008 (0.000)*	4.142 (0.387)	49.485 (0.000)*	26.477 (0.000)*	-0.003 (0.913)
Japan	0.374	-0.175	3.031	2.848 (0.241)	-6.010 (0.000)*	0.681 (0.954)	3.826 (0.430)	3.660 (0.056)***	-0.049 (0.835)
UK	0.097	-0.134	4.606	50.260 (0.000)*	-6.628 (0.000)*	1.262 (0.868)	12.512 (0.014)**	11.942 (0.001)*	-0.030 (0.388)
US	0.289	-0.211	4.544	60.617 (0.000)*	-6.234 (0.000)*	4.078 (0.396)	22.442 (0.000)*	20.346 (0.000)*	0.057 (0.671)

Note: Sample descriptive statistics are performed for the sample moments of mean, skewness and kurtosis. The Jarque-Bera (JB) normality test tests the normality hypothesis based on the skewness and kurtosis. The Augmented Dickey Fuller (ADF) test is performed on the growth rates of money and output. The null hypothesis of a unit root is rejected and that implies that the money and output growth rates are I(0). We estimate an AR(p) model for the money and industrial production growth rates choosing p with the SIC criterion. We perform the Ljung-Box (Q), McLeod-Li (Q^2) and ARCH(1) tests for the residuals of these models. For the Q test we use the 4th lag for all countries. For the Q^2 we use the 4th lag for all countries except for Canada and Germany in the output growth for which we use the 12th and 6th lag respectively.

Appendix C: Full Results Tables for G7

Table C1: Linear and GARCH-M Results for Canada

Canada	Linear	GARCH-M-CCC
Equation (22): β_0	0.7775 [9.41]*	1.0320 [4.17]*
M_{t-1}	-0.0826 [-1.94]***	-0.0790 [-2.05]**
M_{t-3}	0.1171 [2.73]*	0.1090 [2.89]*
M_{t-5}	-0.0792 [-1.86]***	-0.0894 [-3.11]*
M_{t-9}	0.0687 [1.60]	0.0729 [2.27]**
M_{t-12}	-0.1252 [-2.93]*	-0.1245 [-4.03]*
Y_{t-9}	-0.0533 [-1.04]	-0.0936 [-1.87]***
Y_{t-11}	-0.1597 [-3.13]*	-0.1746 [-3.59]*
$\sigma^2_{\Delta M_t}$		-0.1605 [-2.57]**
$\sigma^2_{\Delta Y_t}$		0.0673 [0.32]
Equation (23): α_0		0.0818 [1.45]
ε^2_{t-1}		0.0911 [3.22]*
$\sigma^2_{\Delta M_{t-1}}$		0.8634 [16.74]*
Q(4)	3.153 (0.5330)	1.427 (0.8394)
Q^2(4)	40.924 (0.0000)	5.497 (0.2400)
Q(6)	6.733 (0.3460)	1.893 (0.9293)
Q^2(6)	48.355 (0.0000)	6.669 (0.3526)
Equation (24): Θ_0	0.0995 [1.61]	-0.6625 [-1.84]***
Y_{t-1}	-0.1589 [-3.80]*	-0.1579 [-4.22]*
Y_{t-3}	0.2465 [6.00]*	0.2356 [6.44]*
Y_{t-4}	0.1322 [3.08]*	0.1300 [3.36]*
Y_{t-5}	0.0799 [1.90]***	0.0873 [2.27]**
Y_{t-8}	0.1163 [2.77]*	0.1285 [3.58]*
Y_{t-12}	-0.0805 [-1.97]**	-0.1336 [-3.49]*
M_{t-2}	0.1068 [3.18]*	0.1088 [3.76]*
M_{t-4}	0.0896 [2.65]*	0.0898 [3.43]*
M_{t-12}	-0.0873 [-2.57]**	-0.1041 [-3.95]*
$\sigma^2_{\Delta M_t}$		-0.1325 [-2.07]**
$\sigma^2_{\Delta Y_t}$		0.9954 [2.93]*
Equation (25): α_3		0.3328 [2.92]*
v^2_{t-1}		0.1061 [2.39]**
$\sigma^2_{\Delta Y_{t-1}}$		0.5697 [4.58]*
Q(4)	0.945 (0.9180)	0.429 (0.9801)
Q^2(4)	6.804 (0.1470)	0.778 (0.9414)
Q(6)	4.113 (0.6610)	4.642 (0.5904)
Q^2(6)	6.887 (0.3310)	4.237 (0.6446)
Equation (26): $\rho_{\varepsilon v}$		0.0708 [1.73]***

Note: t-statistics are in square brackets after each coefficient. The diagnostic tests are the Ljung Box Q-statistics for standardised residuals or squared residuals (4) lags are used for both of these tests). The tests are reported as chi-squared statistics with p-values in round brackets. Estimation for GARCH-M is by BFGS method with robust standard errors

Table C2: Linear and GARCH-M Results for France

France	Linear	GARCH-M-CCC
Equation (22): β_0	0.2840 [3.96]*	0.4457 [3.00]*
M_{t-1}	-0.2022 [-4.96]*	-0.1791 [-4.05]*
M_{t-3}	0.2330 [5.60]*	0.2744 [7.15]*
M_{t-4}	0.1145 [2.74]*	0.1148 [2.76]*
M_{t-5}	0.0910 [2.19]**	0.0892 [2.78]*
M_{t-6}	0.1973 [4.79]*	0.1958 [4.90]*
M_{t-11}	0.1293 [3.18]*	0.1262 [3.50]*
Y_{t-2}	-0.0801 [-2.35]**	-0.0932 [-2.64]*
Y_{t-12}	-0.0771 [-2.27]**	-0.0604 [-1.77]***
$\sigma^2_{\Delta M_t}$		-0.0121 [-0.17]
$\sigma^2_{\Delta Y_t}$		-0.1134 [-1.35]
Equation (23): α_0		0.0106 [0.76]
ε^2_{t-1}		0.0567 [1.54]
$\sigma^2_{\Delta M_{t-1}}$		0.9362 [21.30]*
Q(4)	5.628 (0.2290)	2.088 (0.7196)
Q^2(4)	8.531 (0.0740)	1.416 (0.8415)
Q(6)	5.760 (0.4510)	4.927 (0.5532)
Q^2(6)	12.048 (0.0610)	6.153 (0.4062)
Equation (24): Θ_0	0.0926 [1.41]	-0.1786 [-0.98]
Y_{t-1}	-0.3014 [-7.54]*	-0.3104 [-8.21]*
Y_{t-6}	0.1875 [4.66]*	0.1842 [4.69]*
Y_{t-12}	-0.0731 [-1.80]***	-0.0745 [-1.81]***
M_{t-1}	0.1220 [2.63]*	0.1059 [3.20]*
M_{t-5}	0.0783 [1.70]***	0.0987 [2.77]*
$\sigma^2_{\Delta M_t}$		-0.0099 [-0.12]
$\sigma^2_{\Delta Y_t}$		0.2098 [2.28]**
Equation (25): α_3		0.8798 [2.44]**
v^2_{t-1}		0.1765 [3.35]*
$\sigma^2_{\Delta Y_{t-1}}$		0.1964 [0.70]
Q(4)	3.311 (0.5070)	4.188 (0.3811)
Q^2(4)	36.004 (0.0000)	6.296 (0.1781)
Q(6)	4.470 (0.6130)	7.573 (0.2711)
Q^2(6	38.454 (0.0000)	9.826 (0.1322)
Equation (26): $\rho_{\varepsilon v}$		-0.1286 [-3.08]*

Table C3: Linear and GARCH-M Results for Germany

Germany	Linear	MGARCH-M-CCC
Equation (22): β_0	0.4437 [7.11]*	0.6714 [3.60]*
M_{t-5}	0.0724 [1.68]***	0.0895 [2.27]**
M_{t-6}	1.1066 [2.46]**	0.1152 [2.71]*
M_{t-12}	0.1834 [4.20]*	0.1734 [4.12]*
Y_{t-7}	-0.0787 [-2.87]*	-0.0887 [-3.11]*
Y_{t-8}	-0.0505 [-1.89]***	0.0658 [-2.27]**
Y_{t-10}	0.0470 [1.79]***	0.0511 [1.86]***
$\sigma^2_{\Delta M_t}$		-0.1929 [-0.91]
$\sigma^2_{\Delta Y_t}$		-0.0250 [-0.69]
Equation (23): α_0		0.6950 [5.57]*
ε^2_{t-1}		0.2041 [3.74]*
$\sigma^2_{\Delta M_{t-1}}$		0.0533 [0.42]
Q(4)	6.053 (0.1950)	4.541 (0.3377)
Q^2(4)	3.826 (0.4300)	0.560 (0.9674)
Q(6)	6.172 (0.4040)	4.651 (0.5893)
Q^2(6)	4.123 (0.6600)	1.011 (0.9852)
Equation (24): Θ_0	-0.0687 [-0.77]	0.2030 [1.15]
Y_{t-1}	-0.3383 [-7.71]*	-0.3208 [-6.72]*
Y_{t-2}	-0.0825 [-1.81]***	-0.0765 [-2.49]**
Y_{t-3}	0.1682 [3.69]*	0.1562 [3.69]*
Y_{t-4}	0.1227 [2.70]*	0.1012 [2.38]**
Y_{t-5}	0.1071 [2.33]**	0.1052 [2.72]*
Y_{t-6}	0.0994 [2.27]**	0.1043 [2.42]**
M_{t-6}	0.1943 [2.83]*	0.1769 [2.90]*
M_{t-11}	0.1911 [2.75]*	0.2175 [3.59]*
$\sigma^2_{\Delta M_t}$		-0.4354 [-2.36]**
$\sigma^2_{\Delta Y_t}$		0.0437 [0.82]
Equation (25): α_3		1.6632 [7.65]*
v^2_{t-1}		0.3749 [4.13]*
$\sigma^2_{\Delta Y_{t-1}}$		0.1476 [2.14]**
Q(4)	0.487 (0.9750)	0.176 (0.9963)
Q^2(4)	11.906 (0.0180)	0.928 (0.9205)
Q(6)	0.769 (0.9930)	0.762 (0.9930)
Q^2(6)	12.115 (0.0590)	0.899 (0.9892)
Equation (26): $\rho_{\varepsilon v}$		0.0234 [0.53]

Table C4: Linear and GARCH-M Results for Italy

Italy	Linear	MGARCH-M-CCC
Equation (22): β_0	0.5203 [6.06]*	0.5035 [4.50]*
M_{t-2}	0.1536 [3.44]*	0.0949 [2.30]**
M_{t-3}	0.2486 [5.54]*	0.1881 [4.75]*
M_{t-9}	0.1224 [2.65]*	0.0939 [2.93]*
M_{t-12}	-0.0698 [-1.51]	-0.0955 [-2.30]**
Y_{t-9}	-0.0183 [-0.76]	-0.0342 [-1.23]
$\sigma^2_{\Delta M_t}$		-0.1823 [-2.29]**
$\sigma^2_{\Delta Y_t}$		0.1027 [4.04]*
Equation (23): α_0		0.5611 [4.34]*
ε^2_{t-1}		0.4481 [3.61]*
$\sigma^2_{\Delta M_{t-1}}$		0.0591 [0.58]
Q(4)	0.609 (0.9620)	3.488 (0.4797)
Q^2(4)	21.551 (0.0000)	2.472 (0.6497)
Q(6)	1.516 (0.9580)	1.699 (0.9452)
Q^2(6)	33.426 (0.0000)	3.115 (0.7943)
Equation (24): Θ_0	-0.0110 [-0.07]	-0.0815 [-0.71]
Y_{t-1}	-0.2683 [-6.05]*	-0.2239 [-5.69]*
Y_{t-3}	0.0642 [1.44]	0.0181 [0.65]
Y_{t-6}	0.1587 [3.57]*	0.0962 [3.41]*
M_{t-3}	0.0657 [0.79]	0.0883 [1.92]***
M_{t-5}	0.1303 [1.53]	0.0724 [1.43]
M_{t-8}	-0.0086 [-0.10]	0.0705 [1.73] ***
M_{t-12}	-0.0362 [-0.44]	-0.0218 [-0.54]
$\sigma^2_{\Delta M_t}$		0.0062 [0.10]
$\sigma^2_{\Delta Y_t}$		0.0117 [0.36]
Equation (25): α_3		0.0031 [0.63]
v^2_{t-1}		0.0428 [4.16]*
$\sigma^2_{\Delta Y_{t-1}}$		0.9525 [111.29]*
Q(4)	1.767 (0.7790)	1.674 (0.7954)
Q^2(4)	41.946 (0.0000)	6.586 (0.1595)
Q(6)	2.308 (0.8890)	0.958 (0.9872)
Q^2(6)	47.249 (0.0000)	4.416 (0.6206)
Equation (26): $\rho_{\varepsilon v}$		0.0176 [0.40]

Table C5: Linear and GARCH-M Results for Japan

Japan	Linear	MGARCH-M-CCC
Equation (22): β_0	0.3723 [3.97]*	0.3681 [0.76]
M_{t-1}	-0.1716 [-4.12]*	-0.1612 [-1.99]**
M_{t-3}	0.2574 [6.13]*	0.2693 [6.22]*
M_{t-4}	0.1254 [2.99]*	0.1596 [2.06]**
M_{t-5}	0.1071 [2.60]*	0.1397 [1.48]
M_{t-6}	0.1419 [3.27]*	0.1643 [1.87]***
M_{t-9}	0.0859 [1.99]**	0.1368 [1.82]***
M_{t-11}	0.0914 [2.22]**	0.0947 [0.67]
M_{t-12}	-0.0742 [-1.74]***	-0.0922 [-0.65]
Y_{t-9}	-0.0533 [-1.36]	-0.0558 [-1.40]
$\sigma^2_{\Delta M_t}$		-0.1139 [-1.51]
$\sigma^2_{\Delta Y_t}$		0.0032 [0.02]
Equation (23): α_0		0.3068 [1.90]***
ε^2_{t-1}		0.2429 [3.53]*
$\sigma^2_{\Delta M_{t-1}}$		0.5682 [4.77]*
Q(4)	0.217 (0.9950)	1.598 (0.8092)
Q^2(4)	66.737 (0.000)	0.169 (0.9966)
Q(6)	0.254 (1.0000)	4.260 (0.6415)
Q^2(6)	67.588 (0.0000)	7.844 (0.2498)
Equation (24): Θ_0	0.0183 [0.22]	-0.3707 [-0.51]
Y_{t-1}	-0.2548 [-6.08]*	-0.2509 [-5.82]*
Y_{t-2}	0.1793 [4.45]*	0.1882 [4.76]*
Y_{t-3}	0.3841 [9.64]*	0.3815 [7.82]*
Y_{t-4}	0.1924 [4.61]*	0.1981 [4.85]*
M_{t-1}	0.1527 [3.94]*	0.1418 [2.89]*
M_{t-2}	0.1347 [3.27]*	0.1308 [1.57]
M_{t-3}	0.1110 [2.71]*	0.1098 [1.90]***
M_{t-5}	-0.0969 [-2.34]**	-0.0967 [-1.29]
M_{t-6}	-0.1038 [-2.53]**	-0.1046 [-2.70]*
$\sigma^2_{\Delta M_t}$		-0.0053 [-0.07]
$\sigma^2_{\Delta Y_t}$		0.2937 [0.44]
Equation (25): α_3		1.1316 [2.01]**
v^2_{t-1}		0.1156 [2.28]**
$\sigma^2_{\Delta Y_{t-1}}$		0.0843 [0.21]
Q(4)	0.658 (0.9560)	0.744 (0.9458)
Q^2(4)	5.313 (0.2570)	0.834 (0.9339)
Q(6)	0.805 (0.9920)	1.891 (0.9295)
Q^2(6)	8.051 (0.2340)	10.253 (0.1144)
Equation (26): $\rho_{\varepsilon v}$		-0.0886 [-2.09]**

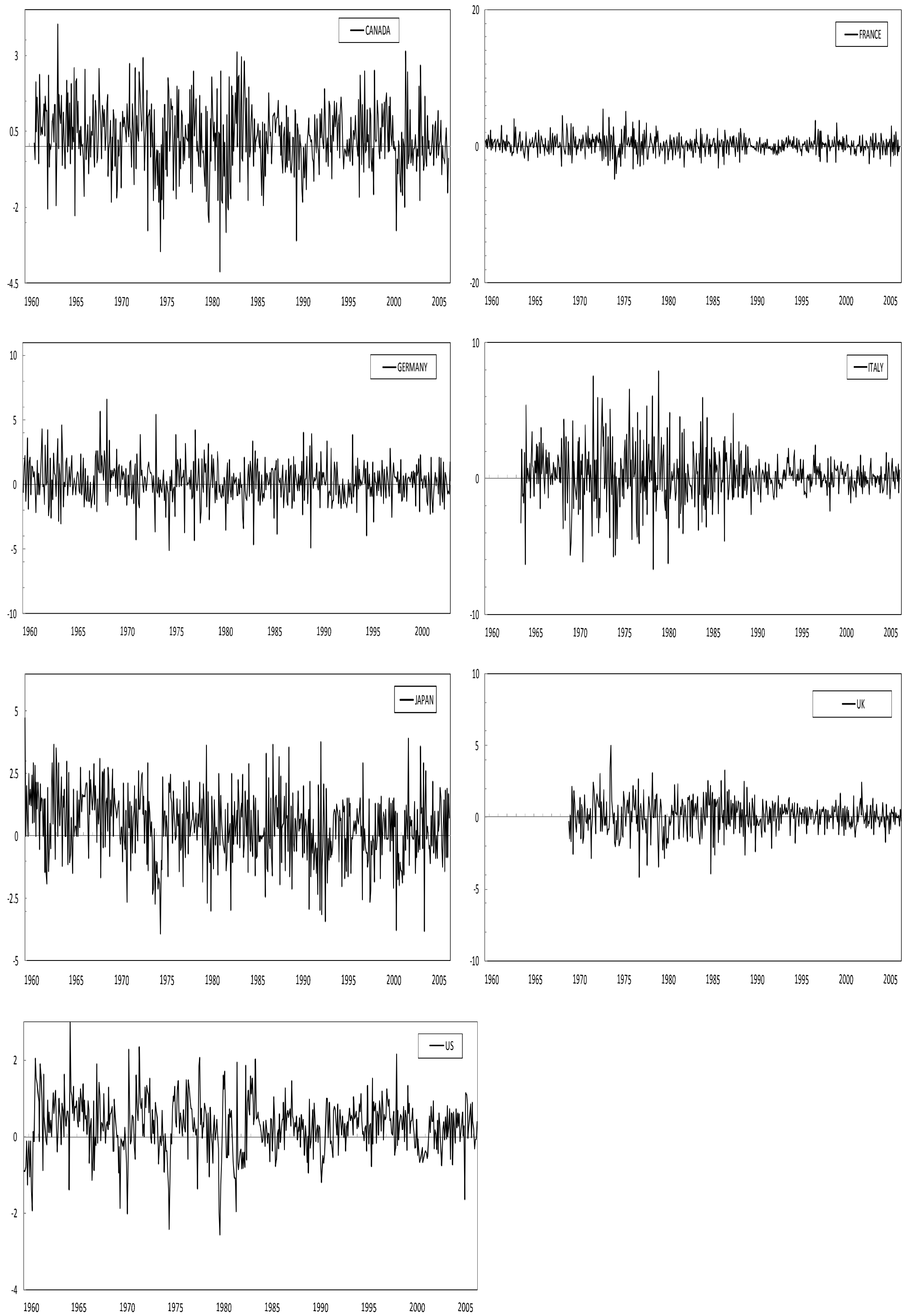
Table C6: Linear and GARCH-M Results for UK

UK	Linear	MGARCH-M-CCC
Equation (22): β_0	0.2131 [4.92]*	0.1463 [2.67]*
M_{t-1}	0.2234 [4.82]*	0.2857 [6.44]*
M_{t-3}	0.1419 [3.03]*	0.0971 [2.82]*
M_{t-8}	0.1470 [3.14]*	0.1298 [6.19]*
M_{t-10}	0.1058 [2.29]**	0.1135 [2.46]**
Y_{t-4}	0.0306 [1.74]***	0.0270 [1.64]
Y_{t-12}	-0.0358 [-2.06]**	-0.0315 [-2.28]**
$\sigma^2_{\Delta M_t}$		-0.1760 [-0.80]
$\sigma^2_{\Delta Y_t}$		0.0607 [4.66]*
Equation (23): α_0		0.1282 [11.88]*
ε^2_{t-1}		0.3153 [5.11]*
$\sigma^2_{\Delta M_{t-1}}$		0.1045 [3.17]*
Q(4)	7.058 (0.1330)	2.573 (0.6316)
Q^2(4)	36.254 (0.0000)	2.354 (0.6709)
Q(6)	11.396 (0.0770)	5.277 (0.5088)
Q^2(6)	36.832 (0.0000)	3.385 (0.7592)
Equation (24): Θ_0	0.1679 [1.95]***	0.0139 [0.67]
Y_{t-1}	-0.0548 [-1.16]	-0.1407 [-3.25]*
Y_{t-5}	0.1182 [2.50]**	0.0942 [2.06]**
Y_{t-9}	-0.0881 [-1.89]***	-0.0707 [-1.63]
Y_{t-12}	-0.0707 [-1.52]	-0.0613 [-1.38]
M_{t-6}	-0.1083 [-0.91]	0.0412 [1.09]
$\sigma^2_{\Delta M_t}$		0.4737 [3.13]*
$\sigma^2_{\Delta Y_t}$		-0.0238 [-0.89]
Equation (25): α_3		0.0021 [1.28]
v^2_{t-1}		0.0540 [19.13]*
$\sigma^2_{\Delta Y_{t-1}}$		0.9433 [553.86]*
Q(4)	0.931 (0.9200)	2.791 (0.5934)
Q^2(4)	14.018 (0.0070)	7.470 (0.1130)
Q(6)	1.354 (0.9690)	2.912 (0.8198)
Q^2(6)	26.289 (0.0000)	7.529 (0.2747)
Equation (26): $\rho_{\varepsilon v}$		-0.0119 [-0.29]

Table C7: Linear and GARCH-M Results for US

US	Linear	MGARCH-M-CCC
Equation (22): β_0	0.1272 [4.06]*	0.0795 [1.13]
M_{t-1}	0.3107 [8.02]*	0.3678 [13.30]*
M_{t-3}	0.1728 [4.28]*	0.1767 [6.20]*
M_{t-5}	0.0900 [2.20]**	0.0889 [3.84]*
M_{t-6}	0.1295 [3.04]*	0.1192 [4.21]*
M_{t-9}	0.1530 [3.75]*	0.1367 [4.39]*
M_{t-12}	-0.0992 [-2.48]**	-0.0886 [-3.49]*
Y_{t-3}	-0.1037 [-4.01]*	-0.0737 [-2.93]*
Y_{t-11}	-0.0462 [-1.75]***	-0.0535 [-2.65]*
Y_{t-12}	0.0505 [1.91]***	0.0604 [2.92]*
$\sigma^2_{\Delta M_t}$		-0.2253 [-1.30]
$\sigma^2_{\Delta Y_t}$		0.1512 [0.98]
Equation (23): α_0		0.0155 [1.90]***
ε^2_{t-1}		0.2021 [3.41]*
$\sigma^2_{\Delta M_{t-1}}$		0.7159 [7.77]*
Q(4)	0.355 (0.9860)	1.569 (0.8143)
Q^2(4)	34.944 (0.0000)	1.999 (0.7359)
Q(6)	0.709 (0.9940)	2.507 (0.8677)
Q^2(6)	52.468 (0.0000)	2.112 (0.9091)
Equation (24): Θ_0	0.0867 [2.05]**	-0.7369 [-6.49]*
Y_{t-1}	0.2021 [4.75]*	0.0384 [0.75]
Y_{t-2}	0.1228 [2.86]*	0.0435 [1.41]
Y_{t-3}	0.0984 [2.29]**	0.0835 [2.83]*
Y_{t-4}	0.0788 [1.86]***	0.0613 [1.79]***
Y_{t-9}	0.0883 [2.19]**	0.0404 [1.24]
Y_{t-12}	-0.0673 [-1.67]***	-0.0523 [-1.46]
M_{t-2}	0.1280 [2.31]**	0.0951 [2.47]**
$\sigma^2_{\Delta M_t}$		-0.4789 [-1.99]**
$\sigma^2_{\Delta Y_t}$		1.0396 [6.43]*
Equation (25): α_3		0.2044 [2.55]**
v^2_{t-1}		0.1629 [3.23]*
$\sigma^2_{\Delta Y_{t-1}}$		0.2627 [1.10]
Q(4)	0.382 (0.9840)	2.372 (0.6677)
Q^2(4)	21.227 (0.0000)	2.340 (0.6735)
Q(6)	2.738 (0.8410)	5.359 (0.4987)
Q^2(6)	22.103 (0.0010)	4.021 (0.6739)
Equation (26): $\rho_{\varepsilon v}$		-0.0574 [-1.21]

Figures I: Time series graphs of industrial production growth rates of the G7



Figures II: Time series graphs of money growth rates of the G7