Inflation, Growth and their variabilities

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SUMMARY OF RESULTS

The inflation equation:

$h_\pi \xrightarrow{+} \pi$ (Cukierman and Meltzer hypothesis: Monetary authorities react to nominal uncertainty by using expansionary monetary policy; $\delta_{\pi\pi} > 0$)

$h_\pi \xrightarrow{-} \pi$ (Holland hypothesis: Monetary authorities react to nominal uncertainty by using contractionary monetary policy; $\delta_{\pi\pi} < 0$)

$h_y \rightarrow h_\pi \rightarrow \pi$ (indirect effect via the nominal uncertainty)

$y \xrightarrow{+} \pi$ Briault conjecture; $\gamma_{\pi y} > 0$

$$\pi_t = \phi_{\pi\pi} + \gamma_{\pi\pi}\pi_{t-1} + \gamma_{\pi y}y_{t-m} + \delta_{\pi\pi}h_{\pi t} + \delta_{\pi y}h_{yt} + \varepsilon_{\pi t},$$

The growth equation:

$h_y \stackrel{+}{\rightarrow} y$ (Black hypothesis: investments in riskier technologies will be pursued only if the expected return on these investments (average rate of output growth) is large enough to compensate for the extra risk; $\delta_{yy} > 0$)

$h_y \stackrel{-}{\rightarrow} y$ (Keynes theory: the larger the output fluctuations, the higher the perceived riskiness of investment projects and, hence, the lower the demand for investment and output growth; $\delta_{yy} < 0$)

$h_\pi \stackrel{-}{\rightarrow} y$ (second leg of the Friedman hypothesis: higher uncertainty about inflation distorts the effectiveness of the price mechanism in allocating resources efficiently, thus leading to negative output effects; $\delta_{y\pi} < 0$)

$\pi \stackrel{-}{\rightarrow} y$ (Most empirical literature finds that inflation affects growth negatively; $\gamma_{y\pi} < 0$)

$$y_t = \phi_{yy} + \gamma_{yy} y_{t-1} + \gamma_{y\pi} \pi_{t-m} + \delta_{y\pi} h_{\pi t} + \delta_{yy} h_{yt} + \varepsilon_{yt},$$

The variance of inflation equation:

$\pi \xrightarrow{+} h_\pi$ (First leg of the Friedman hypothesis: an increase in inflation may induce an erratic policy response by the monetary authority and therefore lead to more uncertainty about the future rate of inflation; $\lambda_{\pi\pi} > 0$)

$y \xrightarrow{-} h_\pi$ (Brunner conjecture: while Friedman's hypothesis is plausible, one could also imagine that when economic activity falls off, there is some uncertainty generated about the future path of monetary policy, and consequently, about the future path of inflation; $\lambda_{\pi y} < 0$)

$h_y \xrightarrow{-} h_\pi$ (Fuhrer theory: defines optimal monetary policy as a policy that minimizes variability of the Fed's ultimate objectives about their targets. His theory implies a trade-off between the variabilities of inflation and growth; $b_{\pi y} < 0$)

$$h_{\pi t} = \omega_\pi + a_\pi \varepsilon^2_{\pi t-1} + b_\pi h_{\pi t-1} + b_{\pi y} h_{yt-1} + e^{\lambda_{\pi\pi}\pi_{t-1}} + e^{\lambda_{\pi y} y_{t-1}}$$

The variance of growth equation:

$\pi \xrightarrow{+} h_\pi \xrightarrow{+} h_y$ (Dotsey and Sarte hypothesis: when a liquidity constraint applies only to a small fraction of investment, then as the average inflation rate increases, and as a result the variance of inflation also rises, the degree of substitution between consumption and investment becomes more intensive creating a wider dispersion between the possible levels of state contingent growth rates; $\lambda_{y\pi} > 0$)

$h_\pi \xrightarrow{+} h_y$ (Logue and Sweeney argue that producers operating in a highly inflationary economy might be unable to distinguish real shifts in demand from nominal shifts. Real growth in investment, and all other economic activity will be more variable than it would be in an environment where less guessing as to the source of an increase in nominal demand was necessary; $b_{y\pi} > 0$)

$h_\pi \xrightarrow{-} h_y$(Fuhrer theory; $b_{y\pi} < 0$)

$y \xrightarrow{-} h_\pi \xrightarrow{+} h_y$ (Combination of Brunner and Dotsey and Sarte theory; $\lambda_{yy} < 0$)

$$h_{yt} = \omega_y + a_y \varepsilon^2_{\pi t-1} + b_y h_{yt-1} + b_{y\pi} h_{\pi t-1} + e^{\lambda_{y\pi} \pi_{t-1}} + e^{\lambda_{yy} y_{t-1}}$$

INFLATION-GROWTH LINK

- Mean inflation and output growth are interrelated. Temple (2000) presents a critical review of the emerging literature which tends to discuss how inflation affects growth. Most empirical literature finds that inflation affects growth negatively: $\pi \xrightarrow{-} y$
- The summary of the findings in Gillman and Kejak (2005a, JES) establishes clearly a robust significant negative inflation-growth effect across a range of growth models.
- Recent findings, for example, of Barro (2001,AER) compound the evidence of a strongly significant negative impact.

- Briault (1995, BEQB) argues that there is a positive relation 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: $y \stackrel{+}{\rightarrow} \pi$.
- For simplicity, in what follows we will refer to this positive influence as the Briault conjecture.

- Let π_t and y_t represent the inflation rate and real output growth respectively

$$
\begin{aligned}
\pi_t &= \gamma_{\pi\pi}^{(0)} + \sum_{l=1}^{p_\pi} \gamma_{\pi\pi}^{(l)} \pi_{t-i} + \gamma_{\pi y} y_{t-m} + \varepsilon_{\pi t}, \\
y_t &= \gamma_{yy}^{(0)} + \sum_{l=1}^{p_y} \gamma_{yy}^{(l)} y_{t-i} + \gamma_{y\pi} \pi_{t-n} + \varepsilon_{yt},
\end{aligned}
$$

- we would expect $\gamma_{y\pi} < 0$, according to the Gillman and Kejak (2005a,b JES,EJ, 2009, Economica) theory
- and $\gamma_{\pi y} > 0$ according to the Briault (1995, BEQB) conjecture

Inflation-Growth link

	π	y
π	x	Briault:+ conjecture
y	Gillman-Kejak: -	x

- While much of the debate has been with a focus on the levels of the two series, there are many economic theories that highlight the importance of the effects which are due to the interaction of the levels and the volatilities.

- As mentioned by Stock and Watson (2007, JMCB) inflation is much less volatile than it was in the 1970s and early 1980s.
- Kumar and Okimoto (2007, JMCB) point out that there was also a marked increase in concerns about deflation in the early part of the decade.
- A number of studies have examined the extent to which a decline in the average rate of inflation and its volatility may reflect improved monetary policy design and implementation, increasing globalization, as well as the role of the informational technology revolution (Kumar and Okimoto, 2007).

- Moreover, many recent studies in macroeconomics have found growing stability in the U.S. economy.
- For example, Kim and Nelson (1999, RES) and McConnell and Perez-Quiros (2000, AER) find that there was reduction in the volatility of output since 1984.

VOLATILITY RELATIONSHIP

- While there has been considerable debate about the optimal level of inflation, Fuhrer (1997, JMCB) defines optimal monetary policy as a policy that minimizes variability of the Fed's ultimate objectives about their targets.
- As Fuhrer (1997, JMCB) puts it: "It is difficult to imagine a policy that embraces targets for the level of inflation or the output gap without caring about their variability around their target".

- His theory implies a trade-off between the variabilities of inflation and growth.
- For example, he argues that if the Fed wishes to make the variance in output small, it must allow shocks that affect inflation to persist, thus increasing the variance in inflation.
- On the other hand, in order to make the variance in inflation small, in the face of demand and supply shocks, the Fed must vary real output a great deal in order to stabilize inflation (Fuhrer, 1997): $h_{\pi} \overset{-}{\leftrightarrow} h_{y}$.

- In sharp contrast, Logue and Sweeney (1981) argue that producers operating in a highly inflationary economy might be unable to distinguish real shifts in demand from nominal shifts.
- Real growth in investment, and all other economic activity will be more variable than it would be in an environment where less guessing as to the source of an increase in nominal demand was necessary.
- For this reason, greater variability of inflation leads to greater uncertainty in production, investment, and marketing decisions, and greater variability in real growth: $h_\pi \xrightarrow{+} h_y$.

Variance relationship

	h_π	h_y
h_π	x	Fuhrer: - Devereux: $+$
h_y	Logue-Sweeney: $+$ Fuhrer: -	x

- The two conditional variances (of inflation and output growth at time t) are denoted by

$$\begin{aligned} \mathbb{E}(\varepsilon_{\pi,t}^2 | \mathcal{F}_{t-1}) &= h_{\pi t}, \\ \mathbb{E}(\varepsilon_{y,t}^2 | \mathcal{F}_{t-1}) &= h_{yt}, \end{aligned}$$

We impose the following GARCH(1,1) structure on the conditional variances:

$$\begin{aligned} h_{\pi t} &= \omega_{\pi} + a_{\pi\pi}\varepsilon^2_{\pi t-1} + b_{\pi\pi}h_{\pi t-1} + b_{\pi y}h_{yt-1} \\ h_{yt} &= \omega_{y} + a_{yy}\varepsilon^2_{yt-1} + b_{yy}h_{yt-1} + b_{y\pi}h_{\pi t-1} \end{aligned}$$

- In a matrix form we can write

$$\mathbf{B} = \begin{bmatrix} b_{\pi\pi} & b_{\pi y} \\ b_{y\pi} & b_{yy} \end{bmatrix}$$

- we would expect $b_{\pi y} < 0$, according to the Fuhrer (1997, JMCB) theory
- and $b_{y\pi} > 0$ according to the Logue and Sweeney (1981, JMCB) theory.

- Macroeconomists have placed considerable emphasis on the impact of economic uncertainty on the state of the macroeconomy.
- The profession seems to agree that the objectives of monetary policy are inflation and output stabilisation around some target levels.

FOUR IN-MEAN EFFECTS

- Cukierman and Meltzer's (1986, E) model explains the positive association between inflation and its uncertainty:
- The policy maker chooses monetary control procedures that are less precise, so that uncertainty about inflation is higher.
- The reason is that greater ambiguity about the contact of monetary policy makes it easier for the government to create the monetary surprises that increase output.
- This causes the rate of inflation to be higher on average: $h_\pi \xrightarrow{+} \pi$

- Holland (199) claims that, as inflation uncertainty rises due to increasing inflation, the monetary authority responds by contracting money supply growth, in order to eliminate inflation uncertainty and the associated negative welfare effects: $h_{\pi} \overset{-}{\longrightarrow} \pi$

- The impact of nominal uncertainty on output growth, has received considerable attention in the literature.
- Friedman (1977) argues that higher uncertainty about inflation distorts the effectiveness of the price mechanism in allocating resources efficiently, thus leading to negative output effects.
- According to Pindyck (1991) the effect might work through its impact on investment.
- Inflation variability increases the uncertainty regarding the potential returns of investment projects and therefore provides an incentive to delay these projects, thus contributing to lower investment and output growth: $h_\pi \overset{-}{\rightarrow} y$

- Macroeconomic theory offers three possible scenarios regarding the impact of output variability on output growth.
- First, there is the possibility of independence between output variability and growth. In other words, the determinants of the two variables are different from each other.
- For example, according to some business cycle models, output fluctuations around the natural rate are due to price misperceptions in response to monetary shocks.

- According to Keynes (1936) the larger the output fluctuations, the higher the perceived riskiness of investment projects and, hence, the lower the demand for investment and output growth: $h_y \overset{-}{\longrightarrow} y$
- The alternative explanation is due to Black (1987) and is based on the hypothesis that investments in riskier technologies will be pursued only if the expected return on these investments (average rate of output growth) is large enough to compensate for the extra risk: $h_y \overset{+}{\longrightarrow} y$

- Moreover, the different analyses of the relation between growth and its variance reach different conclusions depending on what type of model is employed, what values for parameters are assumed and what types of disturbance are considered (see Blackburn and Pelloni, 2005, OEP and the references therein).
- The conclusions reached, on the question of how the structure of the bysiness cycle (the volatility, frequency and persistence of fluctuations) might affect long-term growth, differ markedly between models and depend essentially on the mechanism responsible for generating technological progress.

- In one class of models, where the mechanism is 'creative destruction' the relation/correlation between short-term volatility and long-term growth is positive: $h_y \xrightarrow{+} y$
- In sharp contrast, in models where the mechanism is 'learning-by-doing' the same relation is negative (see Blackburn, 1999, EJ and the references therein): $h_y \xrightarrow{-} y$

- Moreover, real variability may affect the rate of inflation.
- In particular, it would be expected to have a negative impact on inflation via a combination of the Fuhrer and the Cukierman-Meltzer effects: $h_y \xrightarrow{-} h_\pi \xrightarrow{+} \pi$

To take into account the four in-mean effects we estimate the following AR-GARCH(1, 1)-in-mean model

$$\begin{aligned}
\pi_t &= \gamma_{\pi\pi}^{(0)} + \sum_{l=1}^{p_\pi} \gamma_{\pi\pi}^{(l)} \pi_{t-i} + \gamma_{\pi y} y_{t-m} + \delta_{\pi\pi} h_{\pi t-r_1} + \delta_{\pi y} h_{yt-r_2} + \varepsilon_{\pi t}, \\
y_t &= \gamma_{yy}^{(0)} + \sum_{l=1}^{p_y} \gamma_{yy}^{(l)} y_{t-i} + \gamma_{y\pi} \pi_{t-n} + \delta_{yy} h_{yt-r_3} + \delta_{y\pi} h_{\pi t-r_4} + \varepsilon_{yt}.
\end{aligned}$$

Note that our specification allows the conditional variances to have either a contemporaneous or a lagged effect on the level variables.

- We can write the four in-mean coefficients in a matrix form as

$$\Delta_r = \begin{bmatrix} \delta_{\pi\pi} & \delta_{\pi y} \\ \delta_{y\pi} & \delta_{yy} \end{bmatrix},$$

- the two own in-mean effects: $\delta_{\pi\pi} > 0$, according to the Cukierman and Meltzer (1986, E) theory;
- and $\delta_{yy} \gtrless 0$, according to the Blackburn and Pelloni(2005, OEP) theory
- the two cross in-mean effects: $\delta_{y\pi} < 0$, according to the Friedman (1977, JPE) hypothesis and Pindyck (1991, JEL);
- and $\delta_{\pi y} < 0$: via a combination of the Fuhrer and the Cukierman-Meltzer effects: $h_y \xrightarrow{-} h_\pi \xrightarrow{+} \pi$

Inflation In-mean effects

	h_π
π	Cukierman-Meltzer: $+$
	Holland: -
y	Friedman/Pindyck: -
	Dotsey-Sarte: $+$

Growth In-mean effects

	h_y
π	Fuhrer (-) and Cukierman-Meltzer $(+)$:-
	Cukierman-Gerlach: $+$
y	Blackburn-Pelloni : $\pm$

LEVEL EFFECTS

- Ungar and Zilberfarb (1993, JMCB) provide a theoretical model of the relation between inflation and its unpredictability and specify the necessary conditions for a positive link.
- It may be positive as argued by, among others, Friedman (1977, JPE):
- an increase in inflation may induce an erratic policy response by the monetary authority and therefore lead to more uncertainty about the future rate of inflation: $\pi \xrightarrow{+} h_{\pi}$

- Dotsey and Sarte (2000, JME) analyze the effects of inflation and its uncertainty on growth and real uncertainty in a linear neoclassical growth model where money is introduced via a cash-in-advance constraint. In their setting they control for the fraction of investment, in both physical and human capital, which is subject to the cash-in-advance constraint.
- They show that when a liquidity constraint applies only to a small fraction of investment, then as the average inflation rate increases, and as a result the variance of inflation also rises, the degree of substitution between consumption and investment becomes more intensive creating a wider dispersion between the possible levels of state contingent growth rates.

- Thus, their model suggests that as average money growth rises, nominal variability increases and real growth rates become more volatile: $\pi \xrightarrow{+} h_\pi \xrightarrow{+} h_y$.
- The fact that variable monetary policy has implications for the volatility of growth rates has thus been overlooked in empirical studies (Dotsey and Sarte, 2000, JME).[1]

[1] In their New Keynesian model, Ball et al. (1988), Higher average inflation reduces the real effects of nominal disturbances and hence also lowers the variance of output: $\pi \xrightarrow{-} h_y$.

- The sign of the impact of output growth on macroeconomic volatility is negative.
- Consider first the influence on nominal uncertainty.
- As Brunner (1993, JMCB) puts it: 'While Friedman's hypothesis is plausible, one could also imagine that when economic activity falls off, there is some uncertainty generated about the future path of monetary policy, and consequently, about the future path of inflation'.
- We will use the term 'Brunner conjecture' as a shorthand for this negative effect: $y \overset{-}{\rightarrow} h_{\pi}$.
- Finally, consider now the effect of growth on its variability.
- An increase in growth, given that the Brunner(1993, JMCB) conjecture and the Logue-Sweeney (1981, JMCB) hypothesis hold, decreases its variance: $y \overset{-}{\rightarrow} h_{\pi} \overset{+}{\rightarrow} h_y$.

- Thus, we augment the variance specification in order to allow for level effects: $\mathbf{e}^{\wedge\Lambda\mathbf{y}_{t-1}}$

$$
\begin{aligned}
h_{\pi t} &= \omega_{\pi} + a_{\pi\pi}\varepsilon^{2}_{\pi t-1} + b_{\pi\pi}h_{\pi t-1} + b_{\pi y}h_{yt-1} + e^{\lambda_{\pi\pi}\pi_{t-1}} + e^{\lambda_{\pi y}y_{t-1}} \\
h_{yt} &= \omega_{y} + a_{yy}\varepsilon^{2}_{yt-1} + b_{yy}h_{yt-1} + b_{y\pi}h_{\pi t-1} + e^{\lambda_{yy}y_{t-1}} + e^{\lambda_{y\pi}\pi_{t-1}}
\end{aligned}
$$

We choose the exponential specification for the level effects, because it ensures that our non-negativity conditions are still sufficient for guaranteeing positive conditional variances.
Note, that we can easily control for lagged level effects by adding the respective terms to the above equation.

- We can write the four level coefficients in a matrix form as

$$\Lambda = \begin{bmatrix} \lambda_{\pi\pi} & \lambda_{\pi y} \\ \lambda_{y\pi} & \lambda_{yy} \end{bmatrix},$$

- we would expect the two inflation effects to be positive: $\lambda_{\pi\pi} > 0$, according to the Ungar and Zilberfarb (1993, JMCB) theory;
- and $\lambda_{y\pi} > 0$, according to the Dotsey and Sarte (2000, JME) conjecture
- the two growth effects to be negative: $y \xrightarrow{-} h_{\pi}$, according to the Bruner (1993, JMCB) conjecture: $\lambda_{\pi y} < 0$
- and $y \xrightarrow{-} h_{\pi} \xrightarrow{+} h_{y}$, according to the Brunner conjecture and the Logue-Sweeney (1981, JMCB) hypothesis: $\lambda_{yy} < 0$

Inflation Level Effects

	π
h_π	Ungar-Zilberfard: $\pm$
h_y	Dotsey-Sarte: $+$
	Ball et al.:-

Growth Level Effects

	y
h_π	Brunner: - conjecture
h_y	Brunner (-) and Logue-Sweeney (+):-

- A series of papers, published (in the JMCB) during the last thirty years
- (see, for example, Logue and Sweeney, 1981, Evans, 1991, Brunner, 1993, Evans and Wachtel, 1993, Ungar and Zilberfarb, 1993, Holland, 1993, 1995, Fuhrer, 1997, Elder, 2004),
- highlights how important are the aforementioned causal relations for policy making and macroeconomic modeling.

- Brunner and Hess (1993, JBES) was one of the first papers to employ a univariate GARCH model in order to test for the first leg of the Friedman hypothesis (see also Baillie et al., 1996, JAE).
- During the last decade researchers have employed various bivariate GARCH-in-mean models to investigate the relation between the two uncertainties (see, for example, Conrad et al., 2010b, EL)
- and/or to examine their impact on the levels of inflation and growth (see, for example, Elder, 2004, JMCB and Grier et al., 2004, JAE).
- However, the econometric specifications which are employed in most of these studies are typically characterized by two limitations.

- First, the impact from the variabilities on the levels (the so-called in-mean effects) is typically restricted to being contemporaneous (as, for example, in Sheilds et al., 2005, RES).
- However, since the theoretical rational for the in-mean effects usually suggests that it takes some time for them to materialize
- (e.g. in the Cukierman and Meltzer, 1986, E theory it requires a change in monetary policy),
- it appears more appropriate to investigate such effects within a specification that includes several lags of the variances in the mean equations (see also Elder, 2004, JMCB).

- Second, the existing literature focuses almost exclusively on the impact of macroeconomic uncertainty on performance, but neglects the effects in the opposite direction (level effects).
- Moreover, the few studies that take level effects into account, focus on own but not cross level effects.

- It is worth reiterating in just a few sentences what we see to be the main benefits of our model.
- First, it does not require us to make the dubious assumption that there is a positive link between the two variabilities.
- That is, the sign of the coefficients in the **B** matrix that capture the volatility-relation $(b_{\pi y},\ b_{y\pi})$ is not restricted a priori.
- Second, several lags of the conditional variances, i.e., $\delta_{\pi\pi} h_{\pi t-r_1}$, $\delta_{\pi y} h_{yt-r_2}$, $\delta_{yy} h_{yt-r_3}$, $\delta_{y\pi} h_{\pi t-r_4}$ are added as regressors in the mean equation.
- Third, distinguishing empirically between the in-mean and level effects found in theoretical models is extremely difficult in practice
- so it makes sense to emphasize that both are relevant: $e^{\lambda_{\pi\pi}\pi_{t-1}}$, $e^{\lambda_{\pi y}y_{t-1}}$, $e^{\lambda_{yy}y_{t-1}}$, $e^{\lambda_{y\pi}\pi_{t-1}}$

- We employ deseasonalized monthly data obtained from the FRED database at the Federal Reserve Bank of St. Louis.
- The annualized inflation and output growth series are calculated as 1200 times the monthly difference in the natural log of the Consumer Price Index and the Industrial Production Index, respectively.
- The data range from 1960:01 to 2010:01 and, hence, comprise 600 usable observations.

- The best model was chosen on the basis of three alternative information criteria.
- In the inflation/output equations the best model includes 12/4 lags of inflation/output.
- For reasons of brevity, we refrain from presenting the estimation results for the autoregressive parameters.
- Instead, in the Table below we concentrate on the main parameters of interest.

- First, there is strong evidence supporting the Gillman-Kejak theory and the Briault conjecture.

$$\pi_t = \ldots + \underset{(0.011)}{0.025}\ y_{t-3} \ldots + \underset{(0.016)}{0.032}\ h_{\pi t-3} - \underset{(0.0008)}{0.0018}\ h_{yt-1} + \varepsilon_{\pi t},$$
$$y_t = \ldots - \underset{(0.087)}{0.359}\ \pi_{t-2} \ldots - \underset{(0.062)}{0.226}\ h_{\pi t} + \underset{(0.010)}{0.030}\ h_{yt} + \varepsilon_{yt}$$

- In particular, inflation affects growth negatively
- whereas growth has a positive effect on inflation
- Thus there is a mixed bidirectional feedback between the two variables.

- First, since $b_{y\pi}$ is positive and significant there is strong evidence that nominal uncertainty has a positive impact on real volatility , as predicted by Logue and Sweeney (1981, JMCB) .

$$
\begin{aligned}
h_{\pi t} &= \cdots + \underset{(0.055)}{0.592} h_{\pi t-1}, \\
h_{yt} &= \cdots + \underset{(0.478)}{0.727} h_{\pi t-1}.
\end{aligned}
$$

- Second, although there is no direct impact on the opposite direction,
- real variability has an negative indirect effect on nominal uncertainty that works via either the inflation or growth channel (see below):
- $h_\pi \xrightarrow{+} \pi \xrightarrow{+} h_y$ Cukierman-Meltzer hypothesis and Dotsey-Sarte conjecture
- This indirect influence provides is in line with the Fuhrer (1997, JMCB) theory .

- Whether higher nominal uncertainty increases or decreases inflation depends on the central bank's reaction function.
- If a central bank is sufficiently independent and primarily focused on achieving price stability, the central bank will react to higher nominal variability by reducing the inflation rate (see Holland, 1995, JMCB).
- If on the other hand the central bank is targeting inflation as well as output growth, then the reaction of the central bank will depend on the respective weights that are given to the two targets. If the weight on growth is sufficiently large, the central bank has an incentive to increase inflation in the presence of higher nominal uncertainty (see Cukierman and Meltzer, 1986, E)

- Higher nominal uncertainty leads to higher inflation rates as suggested by Cukierman and Meltzer (1986, E)
- with a lag of three months: $\delta_{\pi\pi} > 0$

$$\pi_t = \ldots + \underset{(0.011)}{0.025}\ y_{t-3} \ldots + \underset{(0.016)}{0.032}\ h_{\pi t-3} - \underset{(0.0008)}{0.0018}\ h_{yt-1} + \varepsilon_{\pi t},$$

- This finding is in line with the observation that the Fed is targeting both inflation and growth and, hence, suggests that across our sample considerable weight has been given to the latter.

- The finding that $\delta_{y\pi}$ is negative and significant in equation

$$y_t = \ldots - \underset{(0.087)}{0.359}\ \pi_{t-2} \ldots - \underset{(0.062)}{0.226}\ h_{\pi t} + \underset{(0.010)}{0.030}\ h_{yt} + \varepsilon_{yt}$$

- supports the second leg of the Friedman (1977, JPE) hypothesis that increasing inflation uncertainty affects output growth negatively
- and is also consistent with the argument by Pindyck (1991, JEL).

- Interestingly, the two in-mean effects of real uncertainty are also significant.
- With a time delay of one month, Increasing output volatility appears to lower the average inflation rate ($\delta_{\pi y}$ in the equation below is negative).

$$\pi_t = \ldots + \underset{(0.011)}{0.025}\; y_{t-3} \ldots + \underset{(0.016)}{0.032}\; h_{\pi t-3} - \underset{(0.0008)}{0.0018}\; h_{yt-1} + \varepsilon_{\pi t},$$

- Note that this is in line with the indirect effect which works via growth and nominal uncertainty (see Section below):

- $h_y \quad \overbrace{\overset{+}{\longrightarrow}}^{\text{Blakburn-Pelloni /Black}} \quad y \quad \overbrace{\overset{-}{\longrightarrow}}^{\text{Brunner}} \quad h_\pi \quad \overbrace{\overset{+}{\longrightarrow}}^{\text{Cukierman-Meltzer}} \quad \pi$

- In addition, higher real variability appears to increase output growth (δ_{yy} is positive and significant in the equation below).

$$y_t = \ldots - \underset{(0.087)}{0.359}\ \pi_{t-2} \ldots - \underset{(0.062)}{0.226}\ h_{\pi t} + \underset{(0.010)}{0.030}\ h_{yt} + \varepsilon_{yt}$$

- This finding is consistent with the theoretical predictions in Blackburn and Pelloni (2004, EL) who study the relation between output growth and its variability in a stochastic monetary growth model.

- It is important to highlight again that the effects of the two uncertainties to inflation arise with some time delay (insignificant contemporaneous parameters are not presented), which is to be expected when working with monthly data.

$$\pi_t = \ldots + \underset{(0.011)}{0.025}\ y_{t-3} \ldots + \underset{(0.016)}{0.032}\ h_{\pi t-3} - \underset{(0.0008)}{0.0018}\ h_{yt-1} + \varepsilon_{\pi t},$$

- In the previous studies which employed GARCH-in-mean models the uncertainties were restricted to affecting the levels contemporaneously , often resulting in insignificant parameter estimates (see the Section below).

- The two own in-mean effects are positive .

$$\pi_t = \ldots + \underset{(0.011)}{0.025}\; y_{t-3} \ldots + \underset{(0.016)}{0.032}\; h_{\pi t-3} - \underset{(0.0008)}{0.0018}\; h_{yt-1} + \varepsilon_{\pi t},$$

$$y_t = \ldots - \underset{(0.087)}{0.359}\; \pi_{t-2} \ldots - \underset{(0.062)}{0.226}\; h_{\pi t} + \underset{(0.010)}{0.030}\; h_{yt} + \varepsilon_{yt},$$

- Whereas the two cross in-mean effects are negative .

- The two expressions in the equation below present the estimates for the level coefficients λ_{ij}, $i, j = \pi, y$.

$$h_{\pi t} = \cdots + \exp(\underset{(0.032)}{0.105}\ \pi_{t-1}) \exp -\underset{(0.084)}{0.201}\ \mathbf{1}_{\{y_{t-1}<0\}} y_{t-1},$$
$$h_{yt} = \cdots + \exp(\underset{(0.081)}{0.205}\ \pi_{t-1})$$

- The coefficient estimate, $\lambda_{\pi\pi} > 0$, indicates that higher lagged inflation tends to increase nominal uncertainty , thus supporting the Friedman/Ungar-Zilberfarb theory :$\pi \xrightarrow{+} h_{\pi}$
- This finding highlights the harmful effects of inflation which is found to lead to less predictability. Since this unpredictability can reduce economic activity and misallocate resources in the economy, the incentive for lowering inflation is clear.

- Since $\lambda_{y\pi} > 0$, we also provide strong evidence in support of the Dotsey-Sarte conjecture $\pi \xrightarrow{+} h_y$ Thus inflation breeds uncertainty in many forms.

$$
\begin{aligned}
h_{\pi t} &= \cdots + \exp(\underset{(0.032)}{0.105}\ \pi_{t-1}) \exp -\underset{(0.084)}{0.201}\ \mathbf{1}_{\{y_{t-1}<0\}} y_{t-1}, \\
h_{yt} &= \cdots + \exp(\underset{(0.081)}{0.205}\ \pi_{t-1})
\end{aligned}
$$

- Our results suggest the importance of devoting greater explicit attention to the effects of inflation on the variability in output growth.

- We now turn to the effects of growth on the two volatilities.
- We find that only negative growth rates affect nominal uncertainty:

$$
\begin{aligned}
h_{\pi t} &= \cdots + \exp(\underset{(0.032)}{0.105}\ \pi_{t-1}) \exp - \underset{(0.084)}{0.201}\ \mathbf{1}_{\{y_{t-1}<0\}} y_{t-1}, \\
h_{yt} &= \cdots + \exp(\underset{(0.081)}{0.205}\ \pi_{t-1})
\end{aligned}
$$

- As predicted by Brunner , the coefficient estimate, $\lambda_{\pi y} < 0$, provides support for a negative impact on inflation variability .[2]

[2] Since we found no significant effect for positive growth rates, we employed a specification with $\mathbf{1}_{\{y_{t-1}<0\}} y_{t-1}$.

- We do not find a significant direct effect of growth on its uncertainty.
- However, there is a negative indirect impact (see below). This result is consistent with the theoretical underpinnings that predict a negative indirect effect because
- of the interaction of the Brunner conjecture : $y \xrightarrow{-} h_{\pi}$ with the Logue-Sweeney theory : $h_{\pi} \xrightarrow{+} h_{y}$.

- Table 4 summarizes all twelve effects . As can be seen, the two mixed bidirectional feedbacks between the levels $(\pi \overset{-}{\underset{+}{\rightleftarrows}} y)$ and the variances $(h_y \overset{-}{\underset{+}{\rightleftarrows}} h_\pi)$ are mixed.
- That is, inflation and real uncertainty have a negative impact on growth and nominal variability respectively, whereas the two effects in the opposite direction are positive.

	π	y	h_π	h_y
π		$+$	$+$	-
y	-		-	$+$
h_π	$+$	-		-^{l}
h_y	$+$	-^{l}	$+$	

- Moreover, the two own in-mean effects are positive ($h_\pi \xrightarrow{+} \pi$; $h_y \xrightarrow{+} y$) whereas the two cross in-mean effects are negative ($h_\pi \xrightarrow{-} y$; $h_y \xrightarrow{-} \pi$).

	π	y	h_π	h_y
π		+	+	-
y	-		-	+
h_π	+	-		-^{I}
h_y	+	-^{I}	+	

- Finally, higher inflation increases macroeconomic uncertainty ($\pi \xrightarrow{+} h_\pi, h_y$), whereas the effect of growth is negative ($y \xrightarrow{-} h_\pi, h_y$).

- The latter result is in line with Fountas and Karanasos (2008, IEJ) who find that in four out of five European countries macroeconomic performance affects real variability negatively and that the effect of growth on its uncertainty works via the inflation channel.
- Interestingly the mixed bidirectional feedback between growth and its uncertainty ($h_y \overset{+}{\underset{-}{\rightleftarrows}} y$) is in line with a number of economic theories (see Blackburn and Pelloni, 2005, OEP) which predict that the two variables could be either positively or negatively correlated.

- The four variables are connected by a rich network of relations, which may be causal (direct effects), or reflect shared causal pathways (indirect effects).

- An empirically important issue is that it is difficult to separate the nominal variability from inflation as the source of the possible negative impact of the latter on growth.
- As a policy matter this distinction is important.
- Recall that inflation can affect growth either directly or indirectly (via the nominal uncertainty channel).
- As Judson and Orphanides (1999) point out: 'If inflation volatility is the sole culprit, a high but predictably stable level of inflation achieved through indexation may be preferable to a lower, but more volatile, inflation resulting from an activist disinflation strategy.
- If on the other hand, the level of inflation per se negatively affects growth, an activist disinflation strategy may be the only sensible choice'.

- In our analysis, we find that the effect of nominal variability on growth is negative ($\delta_{y\pi} < 0$; the second leg of the Friedman hypothesis).
- Most importantly, even when we control for the impact of inflation on its variability (the first leg of the Friedman hypothesis) and on growth (the direct effect), the evidence in support of the second leg remains.
- That is, as we can see from the Table below, the likelihood ratio tests reject the null hypotheses: $\text{H}_0 : \lambda_{\pi\pi} = \delta_{y\pi} = 0$, $\text{H}_0 : \gamma_{y\pi} = 0$.
-

$\pi_t \xrightarrow{+} h_{\pi t+1} \xrightarrow{-} y_{t+1}$ (2 legs of the Friedman hypothesis)	$H_0 : \lambda_{\pi\pi} = \delta_{y\pi} = 0$, H_0: $\gamma^{(2)}_{y\pi}$=0	10.55 [<0.01]

- Moreover, inflation, via the nominal uncertainty channel, affects not only growth but real variability as well.
- That is, the indirect evidence regarding the positive impact of inflation on real uncertainty ($\pi_t \overset{+}{\rightarrow} h_{\pi t+1} \overset{+}{\rightarrow} h_{yt+2}$)
- agrees well with the direct evidence supporting the Dotsey and Sarte conjecture.
- In particular, the likelihood ratio test rejects the null hypotheses: H$_0$: $\lambda_{\pi\pi} = b_{y\pi} = 0$ (see the Table below).
-

$\pi_t \overset{+}{\rightarrow} h_{\pi t+1} \overset{+}{\rightarrow} h_{yt+2}$ (2 legs of the Dotsey-Sarte conjecture)	$H_0 : \lambda_{\pi\pi} = b_{y\pi} = 0$	13.68 [<0.01]

- Similarly to the Friedman hypothesis, the Dotsey and Sarte conjecture has two legs.
- The first one is identical to the first leg of the Friedman hypothesis ($\pi_t \xrightarrow{+} h_{\pi t+1}$)
- while the second one is the Logue and Sweeney theory ($h_{\pi t+1} \xrightarrow{+} h_{yt+2}$).

- Next, we hypothesize that the effects of growth on its variability could work through changes in inflation uncertainty as well.
- Theoretically speaking the impact is based on the interaction of two effects.
- A higher growth rate will reduce nominal uncertainty (the Brunner conjecture) and, therefore, real variability (the Logue-Sweeney theory): $y_t \overset{-}{\rightarrow} h_{\pi t+1} \overset{+}{\rightarrow} h_{yt+2}$.
- The evidence for both these influences confirms the negative indirect impact.
- In particular, the null hypothesis H$_0$: $\lambda_{\pi y} = b_{y\pi} = 0$ is rejected (see the Table below)
-

$y_t \overset{-}{\rightarrow} h_{\pi t+1} \overset{+}{\rightarrow} h_{yt+2}$ (Brunner conjecture/Logue-Sweeney)	$H_0 : \lambda_{\pi y} = b_{y\pi} = 0$	9.10 [0.01]

- That is, both inflation and growth affect real uncertainty indirectly via the nominal variability channel.
- Whereas the former impact is positive (as predicted by Dotsey and Sarte) the latter one is negative.
- Interestingly inflation breeds uncertainty in many ways and forms.
- In particular, higher inflation increases both variabilities, nominal and real, directly (the first leg of the Friedman hypothesis, and the Dotsey-Sarte conjecture respectively)
- These results suggest the importance of devoting explicit attention to the effects of macroeconomic performance on its uncertainty.

- Recall again that the two legs of the Friedman hypothesis imply that growth is negatively affected by inflation via the nominal uncertainty channel.
- Our results also suggest that real variability is related indirectly to nominal uncertainty through inflation: $h_{\pi t} \xrightarrow{+} \pi_{t+3} \xrightarrow{+} h_{yt+4}$.
- As we can see from the Table below, the null hypothesis H_0: $\delta_{\pi\pi} = \lambda_{y\pi} = 0$ is rejected.
-

$h_{\pi,t} \xrightarrow{+} \pi_{t+3} \xrightarrow{+} h_{yt+4}$ (Cukierman-Meltzer/Dotsey-Sarte)	$H_0 : \delta_{\pi\pi} = \lambda_{y\pi} = 0$	4.29 [0.12]

- Similarly, the indirect negative influence of real variability on nominal uncertainty through its (first lag) impact on inflation, $h_{yt} \overset{-}{\rightarrow} \pi_{t+1} \overset{+}{\rightarrow} h_{\pi t+2}$,
- tells essentially the same story with the indirect evidence which is consistent with the Blackburn-Pelloni theory and supports the Brunner conjecture: $h_{yt} \overset{+}{\rightarrow} y_t \overset{-}{\rightarrow} h_{\pi t+1}$.
- That is, the likelihood ratio tests reject the null hypotheses H_0: $\delta_{\pi y} = \lambda_{\pi\pi} = 0$, H_0: $\delta_{yy} = \lambda_{\pi y} = 0$ and confirm the two indirect effects (see the last two rows below).
-

$h_{yt} \overset{-}{\rightarrow} \pi_{t+1} \overset{+}{\rightarrow} h_{\pi t+2}$ (⋆/Ungar-Zilberfarb)	$H_0 : \delta_{\pi y} = \lambda_{\pi\pi} = 0$	16.50 [<0.01]
$h_{yt} \overset{+}{\rightarrow} y_t \overset{-}{\rightarrow} h_{\pi t+1}$ (Blackburn-Pelloni/Brunner conjecture)	$H_0 : \delta_{yy} = \lambda_{\pi y} = 0$	11.44 [<0.01]

- In sharp contrast, there is a lack of a direct impact. As mentioned earlier this indirect evidence is in line with the Fuhrer theory.

- Finally, both types of evidence, direct and indirect, point unequivocally to a negative effect of growth variability on inflation.
- That is, the direct evidence supporting the negative effect is in line with the evidence which is
- consistent with the Blackburn-Pelloni theory, and supports the Brunner conjecture and the Cukierman-Meltzer theory: $h_{yt} \overset{+}{\rightarrow} y_t \overset{-}{\rightarrow} h_{\pi t+1} \overset{+}{\rightarrow} \pi_{t+4}$.
- In other words the likelihood ratio test rejects the null hypothesis H_0: $\delta_{yy} = \lambda_{\pi y} = \delta_{\pi\pi} = 0$ (see the row below): $\underset{[<0.01]}{22.84}$
-

$h_{yt} \overset{+}{\rightarrow} y_t \overset{-}{\rightarrow} h_{\pi t+1} \overset{+}{\rightarrow} \pi_{t+4}$ (Blackburn-Pelloni/Brunner/Cukierman-Meltzer)	$H_0 : \delta_{yy} = \lambda_{\pi y} = \delta_{\pi\pi} = 0$

- Whereas real uncertainty affects inflation directly after one month, the indirect effect takes four months to show up.

- In this section we analyze the robustness of our findings with respect to changes in our baseline specification.
- As a first robustness check we express the in-mean effects in terms of standard deviations instead of conditional variances.

$$\begin{aligned} \pi_t &= \cdots + \gamma_{\pi y} y_{t-m} + \delta_{\pi\pi} \sqrt{h_{\pi t - r_1}} + \delta_{\pi y} \sqrt{h_{yt - r_2}} + \varepsilon_{\pi t}, \\ y_t &= \cdots + \gamma_{y\pi} \pi_{t-n} + \delta_{yy} \sqrt{h_{yt - r_3}} + \delta_{y\pi} \sqrt{h_{\pi t - r_4}} + \varepsilon_{yt}. \end{aligned}$$

- Our main conclusions remain unchanged.

- The in-mean effects are significant ($\delta_{\pi y}$ at the 10% level, the other coefficients at the 1% or 5% level) and of the same signs as before.
- While the impact of inflation on real uncertainty is no longer significant, we now find a significantly negative level effect of growth on real uncertainty.
- This direct negative impact is line with the indirect influence via the Brunner conjecture and the Logue-Sweeney theory discussed above.

- We replace the exponential by linear level effects. Again, our results remain unchanged,
- i.e. the level effect of inflation on nominal and real variability is significant and positive, while growth has a negative impact on nominal uncertainty.
- The sign and the significance of all four in-mean effects is as before.

- We also investigate the robustness of our findings with respect to the lag order of the level variables (results not reported).
- Recall that in the baseline specification we employ only the first lag of inflation and output growth.
- However, we find the level effects of higher order lags to be either of the same sign as before or insignificant.
- In particular, the negative effect of growth on nominal uncertainty is confirmed at lag two for negative as well as positive growth rates.
- (Recall that with the first lag only negative growth rates have a significant level effect on inflation uncertainty.)

- In order to control for possible changes in the conduct of monetary policy, we reestimate our favored specification by interacting the main variables of interest with dummy variables for the period 1980-2010 (results not reported).
- While our conclusions regarding the link between the two variabilities remain unchanged, we find some changes in the in-mean effects.
- Among the four interaction terms only those on the own in-mean effects are significant.
- That is, the one on nominal uncertainty in the inflation equation and the one on real variability in the growth equation. Both own in-mean effects tail off from the 1980's onwards.

- The fact that the positive effect of nominal uncertainty on inflation becomes weaker is line with the observation that the FED became more inflation focused during that time and, hence, supports the Holland argument.
- A damped negative effect of real variability on growth is expected from the literature on the Great Moderation, i.e. the observation that the volatility of growth has considerably declined since the early 1980's.[3]

[3] The recent studies by McConnell and Perez-Quiros (2000) and Stock and Watson (2002) highlight the importance of the reduction in US GDP growth volatility in the last two decades and its implications for growth theory.

- As a final robustness check, we reestimate our model using quarterly data.
- Again, we find that inflation has a direct and highly significant negative effect on output growth.
- To the contrary, the direct effect of growth on inflation is positive but significant at the 12% level only.
- Three out of the four in-mean effects are significant. Inflation uncertainty increases inflation while it affects growth negatively (both significant at the five percent level).
- Real uncertainty reduces inflation (significant at the 12% level), but has no significant influence on growth.

- All four in-mean effects have the same signs as for the monthly data, but are now contemporaneous.
- Similarly, the level effects of inflation on the two uncertainties are positive and significant.