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On the real effects of inflation and inflation uncertainty in Mexico

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Abstract

We estimate an augmented multivariate GARCH-M model of inflation and output growth for Mexico at business cycle frequencies. The main findings are: (1) inflation uncertainty has a negative and significant effect on growth; (2) once the effect of inflation uncertainty is accounted for, lagged inflation does not have a direct negative effect on output growth; (3) However as predicted by Friedman and Ball, higher average inflation raises inflation uncertainty, and the overall net effect of average inflation on output growth in Mexico is negative. That is, average inflation is harmful to Mexican growth due to its impact on inflation uncertainty. (4) The Mexican Presidential election cycle significantly raises inflation uncertainty both during the year of the election and the year following the election which has correspondingly negative effects on output growth.
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1. Introduction

The effect of inflation on economic performance is an important and complex topic. It is important, because if systematic inflation has real effects, governments can influence economic performance through monetary policy. There is little theoretical consensus on

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how inflation affects economic performance. Much of the empirical literature looks for a negative influence of inflation on growth. Yet many economic theories predict neutrality or even a positive effect of average inflation on economic performance.

Apart from the effect of trend inflation, inflation uncertainty may also influence output growth. As in the case of average inflation, the effect of uncertainty on growth can either be positive or negative. A further complicating factor is that there may be a relationship between average inflation and the degree of uncertainty about future inflation. That is, it has been argued that higher inflation is less predictable. A well constructed empirical test for the real effects of inflation should consider both average inflation, its predictability, and the potential correlation between these two factors. In this paper, we provide such a test.

Specifically, we investigate the effects of both inflation and inflation uncertainty on output growth in Mexico at business cycle frequencies. We study Mexico because it is a large, growing economy that is becoming an increasingly significant export market for the United States.[1] Further, the range of inflation experience is much wider in developing countries in general, and Mexico in particular, than in most rich countries. Developing countries provide a natural laboratory for empirical work on the real effects of inflation and inflation uncertainty and they are the polities most in need of effective inflation policies.

We estimate an augmented multivariate GARCH-M model for inflation and output growth using monthly data from 1972 to 2001. We find that while average inflation does have a net negative effect on output growth, this effect arises from average inflation's positive effect on inflation uncertainty. That is, we find that inflation uncertainty significantly lowers output growth and, as predicted by Friedman (1977) and Ball (1992), inflation uncertainty is higher at high levels of inflation. The direct effect of average inflation on output growth is estimated to be positive, but this is outweighed by average inflation's positive effect on inflation uncertainty, which significantly lowers output growth.

We also check for various non-linear effects of average inflation, both on output growth and on inflation uncertainty. While we find little evidence of a direct negative nonlinear effect of average inflation on growth, we do find that an increase in inflation when inflation is high raises uncertainty more than an equal increase in inflation when initial inflation is low. Given uncertainty's strong negative impact on output growth, this translates to an indirect nonlinear effect of inflation on growth. We find that the threshold level of inflation at which nonlinear effects are the most statistically significant is 40%. In all our results we find that any significant negative effect of average inflation on output growth in Mexico operates indirectly through its effect on inflation uncertainty.

Finally, we find that the Mexican Presidential election cycle significantly raises inflation uncertainty both the year of the election and the year after the election. Given the negative and significant effect of inflation uncertainty on output growth, this electorally induced uncertainty also has a deleterious effect on economic performance.

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[1] Economic stability and prosperity in Mexico are also important US policy goals that would ease some pressing problems between the countries, such as illegal immigration.

In what follows below, Section 2 summarizes economic theories relating inflation and inflation uncertainty to economic performance. Section 3 presents our model, discusses the data, and reports some specification tests. Section 4 presents the statistical results, while Section 5 discusses the implications of our results.

2. Inflation, uncertainty and economic performance

2.1. Theory

Economic theory can predict either a positive, negative, or zero effect of trend inflation on output growth, depending on the specific assumptions of the model. Tobin (1965) presents a model where inflation reduces accumulated wealth, which in turn raises current savings, investment, and growth. In contrast, Stockman (1981) shows that in an economy with a cash-in-advance constraint on both consumption and investment, inflation will lower growth. Sidrauski (1967) constructs a model of the super-neutrality of inflation.

Several recent papers use endogenous growth models to develop a rationale for negative growth effects of inflation (Gomme (1993), Jones and Manuelli (1995)). When these models are calibrated and simulated however, the estimated effects of inflation on welfare and growth are relatively small.[2]

However, there is another, less studied, theoretical link between the inflation process and economic performance. Specifically, several authors develop models where increased *inflation uncertainty* affects investment and output growth. Okun (1971) and Friedman (1977) argue informally that increased uncertainty reduces the informativeness of price movements and hinders long-term contracting, thus potentially reducing growth.

More formally, there is an extensive literature on the effects of uncertainty on investment. As Caballero (1991) notes, the structure of the model determines whether the effect of uncertainty will be negative or positive. With risk averse firms, the effect is negative (Craine (1989)), with competitive firms and symmetric (quadratic) adjustment costs, the effect of uncertainty is positive (Hartman (1972), Abel (1983)).[3]

Recently, much attention has been focussed on the case of postponable, but irreversible, investment, which is to say the case of asymmetric adjustment costs. Several papers use this case to generate a negative link between uncertainty and investment.[4] In these models, the decision to invest is viewed as an option. Firms can exercise the option by investing, or can delay the investment but continue to hold the option. This approach modifies the familiar positive net present value rule for evaluating investments by taking into account the effect of uncertainty on the value of the option. Greater uncertainty raises the option

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[2] Haslag (1997) reviews these and other papers in some detail.

[3] Caballero shows that this positive result is due more to the assumptions of constant returns and perfect competition than to the assumption of symmetric adjustment costs.

[4] The main papers in this area are Cukierman (1980), Bernanke (1983), McDonald and Siegel (1986), Pindyck and Solimano (1993) and Dixit and Pindyck (1993). The discussion in the paragraph below follows Pinkyck and Solimano.

value of waiting, in that it raises the required rate of return on current investment projects, causing some of them to be postponed.[5]

However, Dotsey and Sarte (2000) use a cash-in-advance model to show that inflation variability has a positive effect on economic growth through increased savings. Risk averse agents will tend to save more during periods of uncertainty. This extra pool of savings will then translate via higher investment into higher GDP growth.

Finally, there is the potential complication that higher average inflation may raise inflation uncertainty. This possibility is raised by Friedman (1977) and formalized by Ball (1992). In Ball's model, the public does not know the preferences of the policy maker, but uncertainty about the policymakers' preferences only affects inflation uncertainty when inflation is high. The idea is that at a low level of inflation, both types of policymakers in the model will tend to accept the existing rate, while at a high level of inflation, one type of policymaker may initiate a stabilization program and the other type may not.

If average inflation is correlated with inflation uncertainty, and both variables in theory affect output growth, then excluding either one will tend to produce a biased estimate of the coefficient of the included variable. Further, a simple GARCH conditional variance equation cannot capture this relationship, so some modification must be made to accommodate or test this view. To our knowledge, there are no existing tests of the effects of inflation on output growth that incorporate all three of the potential relationships reviewed here.

2.2. Empirical studies of inflation, inflation uncertainty, and growth

The theoretical case that inflation uncertainty affects output growth is at least as strong as the case for average inflation. However, few empirical papers include uncertainty measures along with average inflation in tests of inflation's effect on output growth. Those that do often use a simple volatility variable as their measure of uncertainty. For example, Grier and Tullock (1989) show in a broad sample of countries from 1960 to 1980 that inflation volatility, and not the level or the change of inflation, is what significantly lowers growth. Judson and Orphanides (1999), using annual data from 1960 to 1992 for a wide group of countries, find that both inflation and inflation uncertainty lower growth. Clark (1997), however, shows that neither average inflation nor inflation volatility is robustly related to economic growth. One problem with using volatility as a measure of uncertainty is that a variable may be both volatile and predictable. That is, volatility probably systematically overstates the level of uncertainty.

Others use survey data to create a measure of uncertainty. Here the dispersion of individual forecasts is used as the measure of inflation uncertainty. Holland (1993) surveys several papers which use this technique and reports that all of them find a negative relationship between this measure of inflation uncertainty and economic performance. However, variations in the dispersion of individual forecaster's point estimates over time

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[5] Note however, that Abel and Eberly (1999) argue that this literature only addressed part of the story, i.e. how uncertainty and irreversibility combine to raise the threshold for investment. They study the long run evolution of the capital stock and show that the sign for the effect of increased uncertainty on that variable is ambiguous.

may have little to do with fluctuations in uncertainty. It is easily possible that each forecaster has a large confidence interval on his or her estimate, but the group's individual point estimates show little dispersion. What would be desired is the confidence interval each forecaster places on her point estimate.

A third approach uses GARCH-in-Mean models to investigate the real effects of uncertainty. This method uses the conditional variance of inflation as the measure of inflation uncertainty. Specifically, Coulson and Robins (1985) find a positive association between this measure of inflation uncertainty and US economic performance while Jansen (1989) finds no significant relationship. Grier and Perry (2000) and Grier et al. (2004) both report a negative relation between inflation uncertainty and growth in the US.

The multivariate GARCH-M approach has the advantage that one estimates the uncertainty measure and its effects together in a simultaneous model. In addition, since the conditional variance is just the variance of the one step ahead forecasting error, the GARCH model seems like a natural choice to study the effects of uncertainty. However, none of these GARCH based papers allows average inflation to affect the conditional variance of inflation as we do in our empirical work.

Finally, there is an empirical literature on the nonlinear effects of inflation on output growth that is related to our work. Papers by Fischer (1993), Sarel (1996), Bruno and Easterly (1998), Burdekin et al. (2000), and Khan and Senhadji (2001) all find that the effect of inflation on output growth varies with the level of inflation. Since our GARCH measure of uncertainty is a non-linear combination of past inflation innovations, there is a link between their work and ours. We will investigate the possibility of non-linear effects of average inflation on output growth in a model that also accounts for the effect of inflation uncertainty.

3. A statistical model of inflation and output growth

Our purpose in this paper is to investigate the relationship between the conditional means and conditional variances of inflation and output growth in Mexico. Our base model for explaining the conditional means of the two series is a VAR type model, where lags of inflation and output growth explain inflation and output growth. We simultaneously estimate a time-varying variance covariance matrix, allowing the conditional variances to affect the conditional means. However, using a pure VAR-GARCH-M model would miss some potentially important causal factors, namely the importance of the US economy and oil prices for Mexican economic performance, the possible impact of budget deficits on inflation, and the effect of political events on the Mexican economy.

While NAFTA has heightened the sense of the importance of US economic growth for Mexican growth, the US has long been an important export market for Mexico. Popular analyses invariably point to US economic conditions as a major determining factor of Mexican economic performance.[6] In addition, domestic budget deficits are potentially

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[6] This view is captured in the aphorism "When the US sneezes, Mexico catches a cold." Or as Porfirio Diaz once said "Pity poor Mexico, so far from God, so close to the United States."

correlated with inflation or growth, due to the possibility of financing deficits with inflation or the potential stimulus from fiscal expansions. Mexico also is an important oil exporter and thus one should allow for the (positive) effects of oil price changes on Mexican economic performance.

Finally, the Mexican economy is closely tied to its own domestic politics. Even though Mexico was virtually a one-party state until the year 2000, presidential turnovers, which occur every 6 years, are often associated with economic upheaval. Grier and Grier (2000), Gonzalez (2000) and Whitehead (1990) all report evidence of a significant political business cycle in modern Mexico.

In order to capture the above factors, we will estimate an *augmented* GARCH-M model. We begin by determining the order of integration of the data series and then testing for the existence of conditional heteroskedasticity in the data. We use seasonally adjusted monthly data from 1972.01 to 2001.12 on Mexican consumer prices and industrial production, both of which are from the IMF's International Financial Statistics CD-ROM.[7] Data on Mexican budget deficits from 1974.1 to 2001.12 are also from the IMF CD, while data on US industrial production and oil prices are taken from the St. Louis Federal Reserves "FRED" online database.

3.1. Order of integration

In the case of industrial production, we test to see whether the level of the series is trend stationary or I(1). In the case of the price level, we test to see whether or not the inflation rate is stationary or I(1). Here we consider 3 different tests: (1) the Augmented Dickey Fuller (ADF) test with the lag length determined by the AIC criterion, (2) the Phillips–Perron test, and (3) the Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) test. The first two tests have non-stationarity as their null hypothesis while the KPSS test uses the null of stationarity. In case of disagreement, we will side with the majority view.

Table 1 presents the results of our stationarity tests for inflation, the level and growth of industrial production in Mexico and the US, Mexico's real budget deficit, and oil prices. In the case of Mexican industrial production the ADF and KPSS tests indicate non-stationarity while the PP test implies (trend) stationarity. However, the growth rate of Mexican industrial production is stationary according to all three tests. US industrial production is non-stationary in the levels but stationary in the growth rate according to all three tests. Oil prices and budget deficits are less clear cut. In the case of oil, all three tests imply the level is non-stationary, but the ADF and PP tests

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[7] These series were seasonally adjusted using the multiplicative adjustment procedure provided in EVIEWS. Note that these data are collected and reported at a monthly frequency, so that estimating models using data at lower frequencies (quarterly or annually) involves averaging or even discarding some information without gaining a longer sample, at least in the case of quarterly data. It is the span of the sample more than the frequency of the data that determines what kind of long run information we can get from a data set. In this case we have almost 30 years. However, using a quarterly sample, with the data sampled at the end of each quarter, does not materially change any of our key results and we will report some parallel quarterly results informally throughout the paper.

Table 1
Stationarity tests

Variable	Phillips–Peron	ADF-AIC	KPSS
Inflation	−4.29***	−3.11**	.361
Industrial production	−4.04***^{t}	−2.89^t	.199^t**
IP growth	−34.03***	−7.53***	.188
US industrial production	−1.87^t	−2.01^t	.387***
US IP growth	−13.72***	−7.76***	.038
Real budget deficit	−14.6***	−1.45	.545**
Growth in real deficits	−18.13***	−4.09***	.873***
Oil prices	−1.62	−1.90	1.96***
Growth in oil prices	−11.88***	−3.68***	.605**

** and *** denote significance at the 5% and 1% levels, respectively. t indicates a time trend was included.

indicate that the growth rate is stationary while the KPSS test continues to reject the null of stationarity. The budget deficit is non-stationary in the levels according to two of the three tests (ADF and KPSS) and stationary in the growth rates according to two of the three (ADF and PP).

In the case of Mexican inflation, we reject the null of a unit root at the 0.01 level using the Phillips–Perron test, at the 0.05 level using the ADF test and fail to reject the null of stationarity at the 0.05 level with the KPSS test. We thus conclude that the inflation rate is stationary and below will present models of the co-determination of industrial production growth and inflation.[8]

3.2. Statistical model

As we discussed above, we are interested in the effects of average inflation and inflation uncertainty on output growth in Mexico. Our baseline model is an augmented GARCH-M representation of the two series. Before estimating this simultaneous model, we checked for the appropriate number of lags of industrial production growth (inflation) to include in the inflation (output growth) equation, using F tests to eliminate insignificant groups of lags. Based on these tests, we include four lags of output growth in the inflation equation and eight lags of inflation in the output growth equation.

To control for the possible effects of the Mexican presidential election cycle, we construct two dummy variables, Elect and PostElect.[9] Elect is equal to 1 in the 12 months leading up to and including a presidential election, and is equal to 0 for all other periods; PostElect is equal to 1 for the 12 months following a presidential election and 0 otherwise. Using univariate GARCH models, we pre-tested for electoral effects and found that elections have no effect on the average inflation rate, but do have a

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[8] Specifically, we define inflation as the annualized monthly difference of the log of the Consumer Price Index [$\Pi_t = \log(CPI_t/CPI_{t-1})*1200$]. Real output growth ($Y_t$) is the annualized monthly difference in the log of industrial production [$Y_t = \log(IP_t/IP_{t-1})*1200$].

[9] Note that presidential elections are exogenously determined in Mexico and take place every 6 years.

significant effect on the variance of the inflation error term and average industrial production growth.[10]

In addition, given the importance of the US economy and oil for Mexico, we include US industrial production growth and oil price growth as exogenous regressors in the Mexican output growth equation (where they are expected to be positive and significant). We also include oil price inflation in the overall inflation equation.

We tested extensively for possible effects of domestic budget deficits on Mexican inflation and output growth. For our sample, however, we find that lagged deficits are never significantly correlated with either inflation or output growth. For that reason, we do not include deficits in our final model.[11] Given these pre-tests, our augmented GARCH-M model for inflation and output growth is:

$$\Pi_t = \beta_0 + \sum_{i=1}^{12} \beta_i \Pi_{t-I} + \sum_{i=1}^{4} \rho_i Y_{t-I} + \beta_{13} \text{Oil} + \epsilon_t \tag{1}$$

$$\sigma_{\epsilon t}^2 = \alpha_0 + \alpha_1 \text{Elect} + \alpha_2 \text{PostElect} + \sum_{i=1}^{k} \theta_i \epsilon_{t-k}^2 + \sum_{i=1}^{k} \mu_i \sigma_{\epsilon t-k}^2 + \alpha_5 \Pi_{t-1} \tag{2}$$

$$Y_t = \Theta_0 + \sum_{i=1}^{12} \Theta_i Y_{t-I} + \sum_{i=1}^{8} \gamma_i \Pi_{t-I} + \phi \text{USY}_t + \lambda \sigma_{\epsilon t} + \tau \text{Elect} + \delta \text{PostElect}$$

$$+ \Theta_{13} \text{Oil} + v_t \tag{3}$$

$$\sigma_{vt}^2 = \psi_0 + \sum_{i=1}^{k} \eta_i v_{t-k}^2 + \sum_{i=1}^{k} \omega_i \sigma_{vt-k}^2 \tag{4}$$

$$\text{COV}_t = \rho_{\epsilon v} \sigma_{\epsilon t} \sigma_{vt} \tag{5}$$

Eq. (1) describes the mean inflation rate as a function of lagged inflation, lagged output growth and the growth in oil prices. Eq. (2) models the error variance of inflation with one lag of the squared residual and one lag of the variance, along with dummy variables for the year before and the year after a presidential election (Elect and PostElect). As discussed earlier, we also allow this variance to vary with the level of lagged inflation. We use this estimated variance ($\sigma_{\epsilon t}$) as our time series measure of inflation uncertainty. Eq. (3) describes the conditional mean of real output growth as a function of lagged output growth, lags of inflation, US output growth, oil price growth, and the conditional variance of inflation. Eq. (4) models the conditional variance of output growth with one lag of the

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[10] We rechecked this exclusion in our final estimated models and it continues to be the case that once one controls for the effect of elections on the conditional variance of inflation, there is no significant electoral effect on the conditional mean.

[11] The lack of correlation from deficits to inflation corresponds with the finding of that of Rogers and Wang (1995), who do not find a positive relationship between the two in Mexico using a shorter (1977–1990) sample.

squared residual. Finally, Eq. (5) is a simple constant conditional correlation model of the covariance between ϵ and v.[12]

For our purposes, the key coefficients here are the γ_is, which represent the effect of lagged inflation on output growth; λ, which represents the real effect of inflation uncertainty; α_1 and α_2, which measure the effect of Presidential elections on the conditional variance of inflation; α_5, which represents any effect that average inflation has on inflation predictability, and τ and δ, which capture the direct electoral effects on output growth.[13]

3.3. Preliminary tests on the residuals

We first estimate Eqs. (1) and (3) above via Least Squares and then perform several diagnostic tests on the residuals. These are reported in Table 2. Part A reports Box–Pierce Q tests for residual autocorrelation at 4, 8 and 12 lags, showing no evidence of any remaining pattern in the residuals. Part B tests for conditional heteroskedasticity via LM style ARCH tests, estimating autoregressions using the lagged squared residuals from the first stage. In the case of inflation, the null hypothesis of no ARCH effects is rejected at the 0.01 level at all three reported lag lengths (1,4, and 8). Specifically, each of the first four lagged squared residuals have a positive coefficient with a t-statistic greater than 1.5. In the case of output growth, we again reject the null of no ARCH effects at the 0.01 level at all three lags lengths, but here only the first lagged squared residual is positive and significant. No other lag has a coefficient with a t-statistic greater than 1.0. Thus the conditional variance of inflation is a relatively persistent process, which we will preliminarily model as a GARCH(1,1), while the conditional variance of output growth is much less persistent. We will initially model it as a GARCH(1,0) (i.e. ARCH(1)) process. Eqs. (2′) and (4′) present the exact covariance specification we use, based on the tests described above.

$$\sigma^2_{\epsilon t} = \alpha_0 + \alpha_1 \text{Elect} + \alpha_2 \text{PostElect} + \alpha_3 \epsilon^2_{t-1} + \alpha_4 \sigma^2_{\epsilon t-1} + \alpha_5 \Pi_{t-1} \qquad (2')$$

$$\sigma^2_{vt} = \psi_0 + \psi_1 v^2_{t-1} \qquad (4')$$

Finally, Part C tests the appropriateness of the symmetry restriction implied in standard GARCH models, using the joint test proposed by Engle and Ng (1993).[14] The data reject

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[12] This type of model was developed by Bollerslev (1986, 1990). Note that the variance–covariance model here is somewhat restrictive. We are assuming that the covariance matrix is diagonal, which means that lagged inflation (output) errors do not appear in the conditional variance of output (inflation) and that the lagged product of the errors does not appear in either of those equations. We also assume that the conditional covariance is time-varying but that the conditional correlation coefficient between the two errors is constant. We later relax these assumptions at the cost of not being able to selectively add exogenous variables to the conditional variance of inflation equation.

[13] If no GARCH-in-Mean terms are relevant ($\lambda = 0$), then we could consistently estimate Eq. (1) with least squares. However, the GARCH ML estimator is more efficient, and the efficiency loss of OLS relative to the ML estimator can be quite large. If λ does not equal zero, then Eq. (1) cannot be consistently estimated by either least squares, or the multi-step or sequential GARCH estimation methods often discussed in texts.

[14] A standard GARCH model implies that the effect of an innovation on the conditional variance is independent of the sign of that innovation, which is often found not to be the case in stock market data. The test involves creating a dummy variable for positive innovations ($S+$) and one for negative innovations ($S-$) and estimating the following equation: $u^2_t = c_0 + c_1(S^-_{t-1}) + c_2(S^-_{t-1}*u_{t-1}) + c_3(S^+_{t-1}u_{t-1}) + z_t$. See Engle and Ng (1993) for more details.

Table 2
Preliminary tests on the residuals

Test	Inflation	Output growth	0.05 critical values
A. Autocorrelation			
Q_4	.0595	.7125	9.49
Q_8	.0929	1.299	15.51
Q_{12}	.3082	2.996	21.03
B. LM-ARCH			
TR_1^2	30.82	19.94	3.84
TR_4^2	48.37	25.17	9.49
TR_8^2	52.51	26.68	15.51
C. Asymmetry			
Joint (TR^2)	33.66	30.82	7.81

Qx are Box–Pierce Q tests for autocorrelation using x lags. TR_x^2 are tests for ARCH effects using x lags of the squared residuals. Joint (TR^2) is the Engle and Ng (1993) joint test for positive and negative sign bias (i.e. asymmetry) in the squared residuals.

that restriction. However, we are not going to be estimating a standard GARCH model; rather, we will include, at various points, exogenous variables representing elections and also the lagged level of inflation. If high inflation really is less predictable, as Friedman argues, then we should expect to see asymmetry in the conditional variance. Instead of accounting for this statistically as done in Glosten et al. (1993) or Fornari and Mele (1997), we will work up to our preferred conditional variance model and then test those residuals to see if we have indeed accounted for the asymmetry found by this test. To foreshadow the answer, the residuals from our preferred model will show no signs of asymmetry in an Engle–Ng test.

Our work shows that the real effects of inflation on output growth in Mexico are different from what has been seen previously in the literature. However, we begin somewhat traditionally by investigating the sign and significance of lagged inflation in the output growth equation, and the effects of Presidential elections on the Mexican economy when the effect of inflation uncertainty on output growth and the effect of average inflation on uncertainty are both constrained to zero.

4. Results

4.1. Augmented multivariate GARCH model

Table 3 reports the estimates of a GARCH system which constrains the effects of inflation uncertainty on the mean of output growth to be zero.[15] The mean and conditional residual variance equations for inflation are reported in Eqs. (1) and (2) of Table 3. Eqs. (3) and (4) report the estimates of the mean and conditional residual variance of output

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[15] Our multivariate GARCH models are estimated using RATS. Both the code and the data are available from the authors upon request.

Table 3
Inflation and output growth in Mexico, an augmented GARCH model

$$\Pi_t = \underset{(0.4)}{-.284} + \sum_{i=1}^{12} \beta_i \, \Pi_{t-i} + \sum_{i=1}^{4} \theta_i \, Y_{t-1} + \underset{(0.9)}{.018} \, \text{Doil}_{t-1} + \epsilon_t \qquad (1)$$
$${\scriptstyle[.01]}{\scriptstyle[.20]}$$

$$\sigma_{\epsilon t}^2 = \underset{(5.8)}{13.8} \, \underset{(4.8)}{.231} \, \epsilon_{t-1}^2 + \underset{(12.8)}{.553} \, \sigma_{\epsilon t-1}^2 + \underset{(4.1)}{33.8} \, \text{Elect} + \underset{(3.6)}{55.9} \, \text{PostElect} \qquad (2)$$

$$Y_t = \underset{(5.1)}{11.51} + \sum_{i=1}^{12} \Theta_i Y_{t-i} + \sum_{i=1}^{8} \gamma_i \Pi_{t-1} + \underset{(3.9)}{.491} \, \text{USY}_t - \underset{(0.9)}{3.32} \, \text{Elect} - \underset{(4.7)}{17.49} \, \text{PostElect} + \underset{(2.5)}{.191} \, \text{Doil}_{t-1} + \upsilon_t \quad (3)$$
$${\scriptstyle[.01]}{\scriptstyle[.01]}$$

$$\sigma_{\upsilon t}^2 = \underset{(7.2)}{525.7} + \underset{(3.4)}{.472} \, \upsilon_{t-1}^2 \qquad (4)$$

$$\text{COV}_t = \underset{(2.2)}{.115} \, \sigma_{\epsilon t} \sigma_{\upsilon t} \qquad (5)$$

	Inflation equation	Output equation
$Q(12)$	3.41	7.35
$Q^2(12)$	5.09	12.88
Log likelihood function $= -2373.4$		

Sample is 360 monthly observations. Π_t is the inflation rate calculated from the Consumer Price Index. Y_t is the growth rate of industrial production. Numbers in parentheses are t-statistics for individual coefficients while numbers in brackets are marginal significance levels for a group of lagged coefficients. $Q(12)$ is the Ljung–Box statistic for twelfth-order serial correlation in the residuals. $Q^2(12)$ is the Ljung–Box statistic for twelfth-order serial correlation in the squared residuals. The critical value for both statistics at the 0.05 level is 21.0.

growth. To save space (and since we do not focus on short run dynamics in this paper), we do not report the 36 individual coefficients for the lags of inflation and output growth that appear in Eqs. (1) and (3), but simply report the significance level of each group of lags.[16]

Eq. (1) shows that Mexican inflation is a fairly persistent stationary process. In addition, output growth has a positive and marginally significant effect on inflation while the lagged growth rate of oil prices is not significantly related to inflation.[17] From Eq. (2) we see that the variance of inflation innovations is significantly higher in the year before and after an election (Elect and PostElect). There is also a highly significant and stationary GARCH process in the conditional variance of the inflation residuals.

Eq. (3) shows that US industrial production growth is a significant determinant of Mexican growth, and that while there is no significant pre-election surge in output growth (the coefficient for Elect is around -3.3 with a t-statistic of .9), there is a significant decline in industrial production growth in the year following a Presidential election

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[16] The lagged inflation coefficients in the inflation equation are mostly positive and their size generally declines with distance, making for fairly smoothly decaying effects of shocks. The lagged output coefficients in the inflation equation are small and only marginally significant. The lagged output growth coefficients in the growth equation contain some negative values, causing the dynamic response to a shock to be damped but oscillating. Appendix B provides an example of the short run dynamics of the model.

[17] In looking for effects of oil prices on inflation and output growth, we experimented with a variety of lag lengths. In general, the first lag was the only one that attained significance.

(PostElect has a coefficient of -17.49 with a t-statistic of 4.7).[18] The lagged growth in oil prices is positively and significantly related to output growth at the .05 level. Eq. (3) also shows that lagged inflation has a small negative effect on output growth. The eight lagged inflation coefficients are significant as a group at the .01 level and sum to -0.09.[19]

These results have been obtained in a model imposing the restrictions that inflation uncertainty has no effect on output growth and that average inflation does not affect inflation uncertainty. Next, we re-estimate the model relaxing the first restriction and compare the results to the one obtained above.

4.2. Augmented multivariate GARCH-M model

We now introduce the conditional variance of inflation as an explanatory variable in the output growth equation. Table 4 presents these results. The equations for the mean and conditional variance of inflation are little changed from those reported in Table 3. US industrial production growth continues to be an important determinant of Mexican output growth rates, while the lagged growth of oil prices has a positive and significant (now at the .01 level) relationship with industrial output growth.

The results of interest here though are the effects of lagged inflation and inflation uncertainty on output growth. From Eq. (3), the conditional standard deviation of the inflation residuals (i.e. inflation uncertainty) is negative and significant at the 0.01 level in the output growth equation, lending support to the arguments of Okun (1971) and Friedman (1977). While we are investigating the effect of uncertainty on growth, our finding is also consistent with the work of Craine (1989) and Cukierman (1980), among others, who claim that uncertainty negatively impacts investment.

The 8 lags of average inflation retain their joint significance but their sum switches sign from negative to positive (from $-.09$ to 0.07). Further, neither of the electoral dummy variables is significant in the output growth equation, implying that the negative effects of Presidential elections on growth arise through increased uncertainty about inflation.[20]

The models in Tables 3 and 4 contain restrictions on the form of the estimated covariance matrix. In Table A1 of Appendix A, we estimate the model with a more general covariance matrix, namely the BEKK model of Engle and Kroner (1995). As mentioned above, our model restricts the conditional variances to be diagonal. In the BEKK model, that restriction boils down to the null hypothesis that 4 particular coefficients in the model

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[18] The results on the effects of the Mexican electoral cycle, namely that elections raise inflation uncertainty and lower output growth after the election, are consistent with the findings of Grier and Grier (2000) who use separate single equation models, quarterly data, and 1960-1997 sample period. We will see below that the second result will not continue to hold in our full multivariate model.

[19] Tests reported in the text are based on likelihood ratio tests. We experimented with the appropriate lag length for inflation by adding lags four at a time and testing for their joint marginal significance. With this method, 8 lags consistently turned out to be the "best" number of lags. For our purposes, this is the key result from Table 3, that without accounting for inflation uncertainty, lagged inflation is negatively correlated with growth. When we re-estimate the model using quarterly data we get this same result. Specifically the lags (in this case 3) sum to -0.26 and are significant at the 0.05 level.

[20] As was the case in Table 3, these key results also obtain when we estimate the model using end of quarter data. The coefficient for the effect of inflation uncertainty on growth is -1.08, significant at the .05 level, and the sum of the lagged inflation coefficients in the growth equation now sum to .13 and are marginally significant.

Table 4
Inflation and output growth in Mexico, an augmented GARCH-M model

$$\Pi_t = \underset{(0.8)}{-.613} + \sum_{i=1}^{12} \beta_i \, \Pi_{t-i} \underset{[.01]}{} + \sum_{i=1}^{4} \theta_i \, Y_{t-1} \underset{[.27]}{} + \underset{(0.9)}{.022} \, \text{Doil}_{t-1} + \epsilon_t \tag{1}$$

$$\sigma_{\epsilon t}^2 = \underset{(3.6)}{14.3} + \underset{(3.9)}{.234} \, \epsilon_{t-1}^2 + \underset{(7.9)}{.544} \, \sigma_{\epsilon t-1}^2 + \underset{(2.5)}{34.6} \, \text{Elect} + \underset{(2.2)}{56.3} \, \text{PostElect} \tag{2}$$

$$Y_t = \underset{(5.2)}{19.67} + \sum_{i=1}^{12} \Theta_i Y_{t-i} \underset{[.01]}{} + \sum_{i=1}^{8} \gamma_i \Pi_{t-1} \underset{[.01]}{} + \underset{(4.2)}{.607} \, \text{USY}_t + \underset{(0.8)}{3.67} \, \text{Elect} - \underset{(0.6)}{3.88} \, \text{PostElect} + \underset{(2.6)}{.193} \, \text{Doil}_{t-1}$$
$$\underset{(3.3)}{- 1.57} \, \sigma_{\epsilon t} + \upsilon_t \tag{3}$$

$$\sigma_{\upsilon t}^2 = \underset{(8.3)}{539.1} + \underset{(3.5)}{.411} \, \upsilon_{t-1}^2 \tag{4}$$

$$\text{COV}_t = \underset{(1.5)}{.080} \, \sigma_{\epsilon t} \sigma_{\upsilon t} \tag{5}$$

	Inflation equation	Output equation
$Q(12)$	3.24	7.37
$Q^2(12)$	5.25	16.86
Log likelihood function$=-2369.9$		

Sample is 360 monthly observations. Π_t is the inflation rate calculated from the Consumer Price Index. Y_t is the growth rate of industrial production. Numbers in parentheses are t-statistics for individual coefficients while numbers in brackets are marginal significance levels for a group of lagged coefficients. $Q(12)$ is the Ljung–Box statistic for twelfth-order serial correlation in the residuals. $Q^2(12)$ is the Ljung–Box statistic for twelfth-order serial correlation in the squared residuals. The critical value for both statistics at the 0.05 level is 21.0.

are jointly insignificant.[21] Table A1 Appendix A shows that one of these four coefficients is significant, implying some evidence against our diagonality assumption. However, the basic results we report in the text still hold using this alternative form of the covariance matrix. The conditional variance of inflation is a negative and significant variable in the output growth equation, while the 8 lags of inflation are significant as a group and sum to a positive number (around 0.10). These BEKK results do not have our election variables in the conditional variance as one cannot selectively add exogenous variables to specific parts of the covariance matrix using the BEKK functional form.

The results most comparable to Table A1 Appendix A are those in Table 4, which have a larger maximized value of the likelihood function (-2369 compared to -2381). While the models are not nested in a way that allows a formal test here, the data seem to prefer having the exogenous variables in the inflation variance to the non-diagonal terms provided by the BEKK formulation.

Taken at face value, the results in this section strongly imply that while inflation uncertainty significantly depresses output growth, lagged average inflation actually raises it. However, this model is still imposing the restriction that lagged average inflation does not influence inflation uncertainty, while the behavior (sign changes) of the lagged inflation coefficients when uncertainty is added to the output growth equation indicate that

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[21] Specifically the non-diagonal coefficients in the A and G coefficient matrices ($a12$, $a21$, $g12$, $g21$).

there likely is a significant correlation between the two. The following section allows for such a correlation.[22]

4.3. Allowing for the Friedman–Ball effect

So far our results show that it is the unpredictability of inflation, rather than its average level, that impacts Mexican industrial production growth. However, it is premature to conclude that average inflation is not important for growth, as it is possible that high inflation is less predictable. Friedman (1977) and Ball (1992) both argue for this possibility theoretically, and, among other work, Grier and Perry (1998) show that higher inflation Granger causes a previously estimated GARCH measure of inflation uncertainty.

A standard GARCH model does not allow average inflation to affect uncertainty (unless the equation for the conditional mean collapses to the intercept), so we modify the model to directly include the lagged inflation rate in the conditional variance, as in Eq. (2′) above. In this case, the error variance of inflation is a function of past prediction errors, the stage of the election cycle and the previous average level of inflation.

Table 5 reports the results of estimating this more complete model.[23] We also checked the residuals from this model and found that the evidence we initially encountered on the asymmetry of how positive and negative shocks affect the variance has disappeared. Now the Engle–Ng joint test yields χ^2 statistics of 2.96 for inflation and 4.44 for output growth, both comfortably below the 0.05 critical value of 7.81. We thus feel comfortable not employing any further statistical method to deal with asymmetry.

Turning to the substantive results, we find strong support for the Friedman–Ball hypothesis as lagged inflation is positive and highly significant in the equation for the time varying error variance of inflation. In turn, the coefficient for the standard deviation of this variance (our measure of inflation uncertainty) in the output growth equation is negative and significant. Thus, while lagged inflation continues to have a significant and positive direct effect on output growth, with a coefficient sum over the eight lags of around 0.32, lagged inflation also raises the conditional variance of inflation (with a coefficient of 1.18). As before, inflation uncertainty (as measured by the conditional standard deviation of inflation) significantly lowers output growth (coefficient of -2.77).[24]

The net effect of average inflation is the sum of these two effects, which in this model is estimated to be negative. That is, the negative indirect effect of inflation on growth via its relationship to uncertainty is significantly larger than the direct positive effect coming from the lagged inflation terms in the output growth equation.

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[22] Since our experiment here involves the addition of another exogenous variable in a specific part of the covariance matrix, we will continue to use the covariance formulation presented in the text instead of the BEKK model employed in Appendix A.

[23] Note that we have also dropped the lagged growth in oil prices from the inflation equation and the pre- and post-election dummies from the output growth equation as they are never significant, either individually or jointly. Leaving them in does not change our main results in any way.

[24] Once again, a quarterly version of the model produces the same key results: (1) lagged inflation raises inflation uncertainty (coefficient of 3.01, significant at the 0.01 level); (2) inflation uncertainty lowers output growth (coefficient of -2.07, significant at the 0.01 level); (3) the direct effect of lagged inflation on growth is positive (coefficients sum to 0.24, significant at the 0.01 level); and (4) the negative indirect effect of inflation on growth outweighs the positive direct effect.

Table 5
Inflation and output growth in Mexico, an augmented GARCH-M model, with lagged

$$\Pi_t = -\underset{(1.4)}{.997} + \sum_{i=1}^{12} \beta_i \, \Pi_{t-i} + \sum_{i=1}^{4} \theta_i \, Y_{t-1} + \epsilon_t \tag{1}$$
$$\underset{[.01]}{} \qquad \underset{[.12]}{}$$

$$\sigma_{\epsilon t}^2 = \underset{(0.7)}{.201} + \underset{(3.0)}{.136} \, \epsilon_{t-1}^2 + \underset{(6.0)}{.469} \, \sigma_{\epsilon t-1}^2 + \underset{(1.97)}{12.7} \; \text{Elect} + \underset{(2.4)}{57.9} \; \text{PostElect} + \underset{(5.1)}{1.18} \, \Pi_{t-1} \tag{2}$$

$$Y_t = \underset{(5.2)}{23.15} + \sum_{i=1}^{12} \Theta_i Y_{t-i} + \sum_{i=1}^{8} \gamma_i \Pi_{t-1} + \underset{(4.4)}{.579} \; \text{USY}_t + \underset{(2.7)}{.193} \, \text{Doil}_{t-1} - \underset{(3.9)}{2.77} \, \sigma_{\epsilon t} + \upsilon_t \tag{3}$$
$$\underset{[.01]}{} \qquad \underset{[.01]}{}$$

$$\sigma_{\upsilon t}^2 = \underset{(8.0)}{544.5} + \underset{(3.4)}{.413} \, \upsilon_{t-1}^2 \tag{4}$$

$$\text{COV}_t = \underset{(2.0)}{.109} \, \sigma_{\epsilon t} \sigma_{\upsilon t} \tag{5}$$

	Inflation equation	Output equation
$Q(12)$	4.01	8.09
$Q^2(12)$	12.9	18.69
Log likelihood function=−2349.6		

Sample is 360 monthly observations. Π_t is the inflation rate calculated from the Consumer Price Index. Y_t is the growth rate of industrial production. Numbers in parentheses are t-statistics for individual coefficients while numbers in brackets are marginal significance levels for a group of lagged coefficients. $Q(12)$ is the Ljung–Box statistic for twelfth-order serial correlation in the residuals. $Q^2(12)$ is the Ljung–Box statistic for twelfth-order serial correlation in the squared residuals. The critical value for both statistics at the 0.05 level is 21.0.

As a specific example, we simulate the effect of inflation permanently and predictably rising from a base of 10% up to 35% (which is a one standard deviation increase). In response, the equilibrium growth rate falls by around 1.6 percentage points. This net effect can be split into the direct effect of lagged inflation on growth, which is an *increase* of 4.5 percentage points, and the indirect effect of lagged inflation on growth via its effect on uncertainty which is a *fall* of 6.1 percentage points. Fig. 1 shows the estimated dynamics of industrial production growth associated with this particular permanent and predictable increase in inflation.[25]

4.4. Non-linear effects of average inflation

As discussed in Section 2 above, there is an empirical literature arguing that inflation has a non-linear effect on output. Our measure of inflation uncertainty is a non-linear combination of previous inflation innovations, so in that sense we do find non-linear effects of inflation innovations on output growth. In this subsection, we consider whether or not there is any evidence of non-linear effects of average inflation on output growth in Mexico. We take the model of Table 5 as a base and explore three different methods of incorporating a non-linear effect of average inflation. First, we use lagged squared inflation along with the lagged levels to allow for non-linearity. Second we create a dummy variable (High) that equals 1.0 when inflation is above a particular threshold in the

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[25] Note that this is a single deterministic simulation which treats inflation as an exogenous variable.
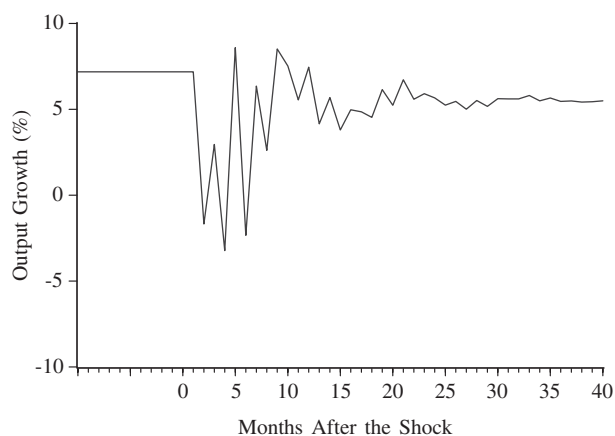
Fig. 1. The response of industrial production growth to a predictable permanent rise in inflation from 10% to 35%.

previous month and zero otherwise and add it to the model with the lagged levels of inflation. Third, we interact the lagged levels of inflation with the high inflation dummy variable, allowing the coefficients to shift when inflation rises above the chosen threshold.

We chose the numerical threshold by estimating the model with a coarse grid search (from 15 to 75 by 5) for the threshold inflation rate that maximized the log likelihood function. The level chosen by this procedure was 40%, though the likelihood function is relatively flat for threshold rates between 35% and 50%. Interestingly, both Fischer (1993) and Bruno and Easterly (1998) argue that a 40% threshold is where inflation begins to affect growth, even though they each use a sample and method distinct from ours.

Given our finding that high average inflation significantly raises inflation uncertainty, we use these new variables to test both for direct and indirect non-linear effects. We look for direct effects by putting the new variables in the output growth equation, while we look for indirect effects by putting them in the conditional variance of inflation equation.

The results are presented in Table 6. Panel A describes adding 8 lags of squared inflation to the output growth equation and one lag of squared inflation to the conditional variance of inflation equation. The 8 lagged squared terms are significant at the 0.05 level, but their coefficients sum to a very small but positive number (0.003). In the conditional variance of inflation equation, the lagged level becomes completely insignificant while the lagged square is positive and significant. In panel B, we use the High (>40%) inflation dummy variable. This variable is positive but completely insignificant in the output growth equation and positive and significant at the 0.01 level in the conditional variance of inflation equation. In both Panels A and B, the conditional variance of inflation continues to have a large, negative, and significant effect on output growth, so we are seeing evidence of indirect non-linear effects of inflation on output growth in both experiments.

In Panel C, we interact the High inflation dummy with lagged inflation, so that the coefficients on lagged inflation change when the inflation threshold is crossed. The sum of the coefficients both on lagged inflation and the interaction coefficients are both positive so that we find that the direct effect of lagged inflation on output growth is still positive, even when inflation is above the 40% threshold. However, looking at the conditional variance of

inflation equation, we see that the effect of lagged inflation on inflation uncertainty more than quadruples when inflation crosses the 40% threshold. In addition, the coefficient relating inflation uncertainty to output growth is even more negative than it was in Table 5.

To again consider a specific example, we calculate the effect of a permanent and predictable one standard deviation increase in inflation, but this time from a base of 25% (i.e. an increase from 25% to 50%). This increase crosses the high inflation threshold and the estimated net effect is a decline in output growth of about 5.9 percentage points which is three times larger than the effect found in our previous example, where inflation rose from 10% to 35%.

Table 6
Testing for non-linear effects of high average inflation on inflation uncertainty

A. Adding lagged squared inflation

Variables in output growth eq	Coefficient	Marginal sig. level
8 lags of inflation	0.348	0.01
8 lags of squared inflation	0.003	0.03
Conditional variance of inflation	−3.41	0.01

Inflation conditional variance eq.

$$\sigma^2_{\epsilon t} = \underset{(2.1)}{16.4} + \underset{(2.9)}{.130}\,\epsilon^2_{t-1} + \underset{(4.7)}{.392}\,\sigma^2_{\epsilon t-1} + \underset{(0.9)}{6.07}\,\text{Elect} + \underset{(2.4)}{46.7}\,\text{PostElect} - \underset{(0.7)}{.447}\,\Pi_{t-1} + \underset{(2.5)}{.036}\,\Pi_{t-1}{}^2$$

Log-likelihood function:	−2339.7

B. Adding a dummy for inflation over 40% in the previous month

Variables in output growth eq.	Coefficient	Marginal sig. level
8 lags of inflation	0.603	0.01
Dummy for high inflation	12.25	0.90
Conditional variance of inflation	−4.44	0.01

Inflation conditional variance eq.

$$\sigma^2_{\epsilon t} = \underset{(2.1)}{11.4} + \underset{(3.5)}{.132}\,\epsilon^2_{t-1} + \underset{(5.9)}{.389}\,\sigma^2_{\epsilon t-1} + \underset{(1.2)}{7.23}\,\text{Elect} + \underset{(2.2)}{34.7}\,\text{PostElect} + \underset{(2.1)}{.53}\,\Pi_{t-1} + \underset{(2.8)}{136.2}\,\text{High}$$

Log-likelihood function:	−2340.2

C. Adding interaction terms (High*Lagged Inflation)

Variables in output growth eq.	Coefficient	Marginal sig. level
8 lags of inflation	0.478	0.01
8 lags of High*Inflation$_{t-1}$	0.330	0.02
Conditional variance of inflation	−4.57	0.01

Inflation conditional variance eq.

$$\sigma^2_{\epsilon t} = \underset{(2.2)}{10.1} + \underset{(3.2)}{.114}\,\epsilon^2_{t-1} + \underset{(6.9)}{.423}\,\sigma^2_{\epsilon t-1} + \underset{(1.3)}{6.93}\,\text{Elect} + \underset{(2.4)}{35.9}\,\text{PostElect} + \underset{(2.2)}{.56}\,\Pi_{t-1} + \underset{(4.1)}{1.92}\,\text{High*Inflation}_{t-1}$$

Log-likelihood function:	−2334.4

The results of this subsection reinforce the view we articulated above: that in the case of Mexico, average inflation affects output growth negatively predominantly through its positive effect on inflation uncertainty and uncertainty's negative effect on output growth.

5. Discussion

In this paper, we develop an augmented multivariate GARCH-M system of inflation and industrial production growth in Mexico. We find that inflation uncertainty lowers output growth, while the direct effect of average inflation on output is actually positive and significant. However, we also find a strong positive statistical relationship between average inflation and the conditional variance of inflation. In our models this indirect negative effect of average inflation on growth outweighs the direct positive effect. Thus, average inflation does lower output growth in Mexico, but it does so by raising uncertainty about future inflation, as predicted by Friedman and by Ball.

We also find that the 6 year Mexican Presidential election cycle is associated with significantly higher inflation uncertainty in both the year before and year after elections. This also seems to be the proximate cause of the post-election slump in output growth; once we control for the effect of inflation variability on output growth, the post-election dummy becomes insignificant in the growth equation.

Our results are important in that they are the first to demonstrate the existence of this indirect negative effect of average inflation on growth via uncertainty. Our findings also help to explain the often-mixed results in the literature because we demonstrate that there is a fairly complex empirical relationship between average inflation, its conditional variance and output growth. Not only is it the case that studies examining only average inflation or uncertainty will tend to produce misleading results, as both effects are important, but that even when both are studied together, there is, at least in these Mexican data, a systematic and non-linear relationship between the two that needs to be taken into account.

Acknowledgment

Appendix A. Estimating the model with the BEKK covariance parameterization

The constant correlation parameterization used in the text is convenient in that each coefficient has a specific intuitive meaning and it is easy to insert exogenous variables into a particular part of the conditional covariance. It is, however, a restrictive parameterization. In this appendix, we re-estimate the model without any electoral variables, using a more general model for the conditional covariance in order to test the robustness of our finding that inflation uncertainty is an important correlate for industrial production growth in Mexico.

We have chosen to use the so-called BEKK model (Engle and Kroner, 1995), which (for a GARCH(1,1) model) is given by:

$$H_t = C_0^{*\prime}C_0^* + A_{11}^{*\prime}\epsilon_{t-1}\epsilon_{t-1}'A_{11}^* + G_{11}^{*\prime}H_{t-1}G_{11}^* \tag{A.1}$$

Here H is the conditional covariance matrix, C^*, A^* and G^* are 2×2 coefficient matrices (C^* is triangular), ϵ is a 2×1 vector of the contemporaneous inflation and output growth residuals, and the symbol $'$ indicates the transpose operator.

We can write the corresponding individual equations for the variance of inflation errors, the variance of output errors, and their covariance as follows:

$$h_1 = c_{11} + a_{11}^{*2}\epsilon_1^2 + 2a_{11}^*a_{21}^*\epsilon_1\epsilon_2 + a_{21}^{*2}\epsilon_2^2 + g_{11}^{*2}h_1^2 + 2g_{11}^*g_{21}^*h_1h_2 + g_{21}^{*2}h_2^2 \tag{A.2}$$

$$h_{12} = c_{12} + a_{11}^*a_{12}^*\epsilon_1^2 + (a_{21}^*a_{12}^* + a_{11}^*a_{22}^*)\epsilon_1\epsilon_2 + a_{21}^*a_{22}^*\epsilon_2^2 + g_{11}^*g_{12}^*h_1$$
$$+ (g_{21}^*g_{12}^* + g_{11}^*g_{22}^*)h_1h_2 + g_{21}^*g_{22}^*h_2 \tag{A.3}$$

$$h_2 = c_{13} + a_{12}^{*2}\epsilon_1^2 + 2a_{12}^*a_{22}^*\epsilon_1\epsilon_2 + a_{22}^{*2}\epsilon_2^2 + g_{12}^{*2}h_1^2 + 2g_{12}^*g_{22}^*h_1h_2 + g_{22}^{*2}h_2^2 \tag{A.4}$$

Table A1
Augmented VAR-GARCH-M model using the BEKK Conditional Covariance Parameterization

A: Mean equations

$$\Pi_t = \underset{(1.7)}{1.31} + \sum_{i=1}^{12}\beta_i\Pi_{t-i} + \sum_{i=1}^{4}\underset{[.90]}{\theta_i} Y_{t-1} + \epsilon_t$$

$$Y_t = \underset{(5.1)}{18.69} + \sum_{i=1}^{12}\Theta_iY_{t-i} + \sum_{i=1}^{8}\underset{[.01]}{\gamma_i}\Pi_{t-1} + \underset{(5.1)}{.889}\,USY_t + \underset{(2.7)}{.202}\,Doil_{t-1} - \underset{(4.6)}{1.49}\sigma_{\epsilon_t} + \upsilon_t$$

Log likelihood function $= -2381.6$

B: Conditional covariance coefficients

|	C^*matrix	A^*matrix		G^*matrix	
c_{11}	-2.46 (3.7)	a_{11}	0.56 (9.8)	g_{11}	0.77 (19.5)
c_{12}	-24.2 (17.8)	a_{12}	-0.21 (1.1)	g_{12}	-0.13 (0.7)
c_{22}	$-.0003$ (0.0)	a_{21}	-0.09 (4.2)	g_{21}	0.07 (3.1)
		a_{22}	0.63 (7.5)	g_{22}	0.002 (0.0)

Sample is 360 monthly observations. Π_t is the inflation rate calculated from the Consumer Price Index. Y_t is the growth rate of industrial production. Numbers in parentheses are *t*-statistics for individual coefficients while numbers in brackets are marginal significance levels for a group of lagged coefficients.

Appendix B. The model's response to a one time, 10 percentage point inflation shock

Here we take the estimated coefficients from Table 5, ignore any possible electoral effects, and illustrate how the main endogenous variables, inflation, growth, and inflation

uncertainty would respond to a temporary inflation shock. As can be seen in the graphs below, both inflation and its conditional variance respond in an almost monotonically damped manner, while the response of growth shows damped oscillations. In all three cases it takes about 2 years (24 months) for the effect of the shock to disappear.

The Response of Inflation

The Response of Output Growth

The Response of the Conditional Variance of Inflation
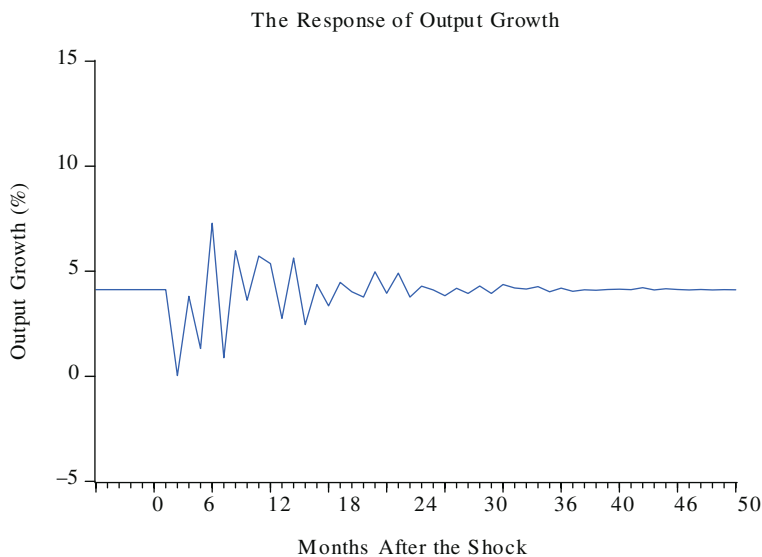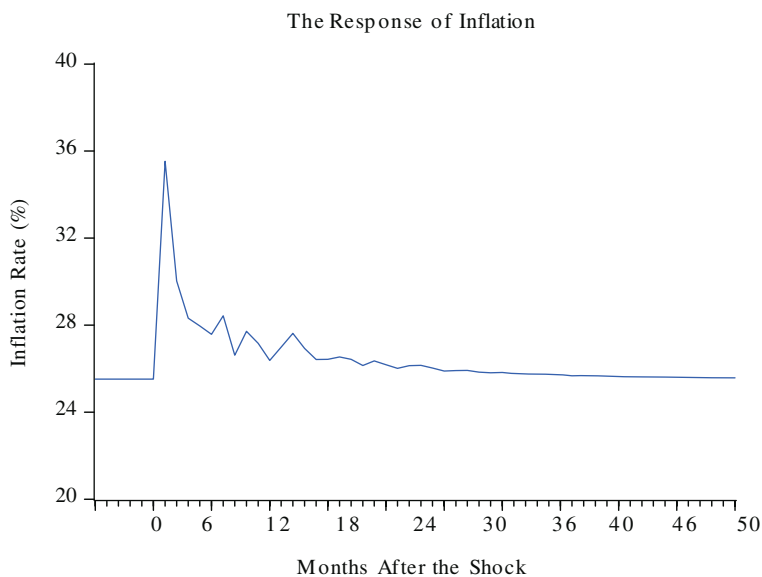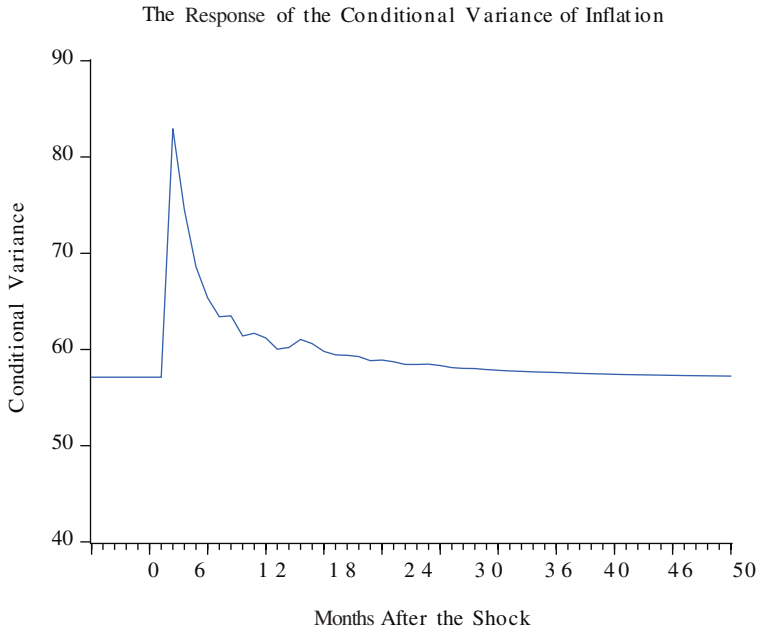
Appendix C. Summary statistics

Variable	Mean	Std.Dev.
Inflation-CPI	26.83	25.4
Mexican industrial production growth	3.68	38.3
US industrial production Growth	2.73	9.41
Growth in oil prices	4.73	19.71
Growth in Mexico's real budget deficit	−438	5073.3

Sample period is monthly, from 1971.02 to 2001.12. Monthly inflation rates are seasonally adjusted and are calculated from the Consumer Price Index at annual rates. Industrial Production is the seasonally adjusted monthly growth rate of the Industrial Production Index at an annual rate.

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