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Paúl Castillo
Alberto Humala
Vicente Tuesta

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REGIME SHIFTS AND INFLATION UNCERTAINTY IN PERU

PAÚL CASTILLO AND ALBERTO HUMALA*

Banco Central de Reserva del Perú and Universidad del Pacífico

VICENTE TUESTA

CENTRUM Católica

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The link between inflation and inflation uncertainty is evaluated using Peruvian data, in a context of changing monetary policies because of regime shifts. A Markov regime-switching heteroskedasticity model that includes unobserved components is used. The model shows how periods of high (low) inflation accompany periods of high (low) short- and long-run uncertainty in inflation. The results of the model also illustrate how, during the recent period of price stability in Peru, both permanent and transitory shocks in inflation show a decrease in volatility. Finally, a time-varying measure of inflation uncertainty is derived from the estimates, giving additional evidence on the positive link between the level of inflation and its uncertainty.

JEL classification codes: C22, E31, E42, E52

Key words: inflation dynamics, monetary policy, Markov-switching models, unobserved components models, stochastic trends

I. Introduction

The literature and empirical evidence suggest the costs of high inflation rates are considerably larger when inflation uncertainty is high. Ball and Cecchetti (1990), for

* Alberto Humala (corresponding author): Deputy Director of the Monetary Policy Operations Sub-Division of the BCRP and Professor of the Universidad del Pacífico, Escuela de Postgrado, 441-445 Miró Quesada, Lima 1, Lima, Perú; e-mail: alberto.humala@bcrp.gob.pe. Phone: (511) 613 2785. Paúl Castillo: Deputy Director of the Monetary Policy Design Sub-Division of the BCRP and Professor of the Universidad del Pacífico, Escuela de Postgrado; e-mail: paul.castillo@bcrp.gob.pe. Vicente Tuesta: Professor of CENTRUM Católica, Pontificia Universidad Católica de Perú; e-mail: vtuesta@pucp.edu.pe. We thank Martin Ellison, Carlos Montoro, Gabriel Rodríguez and two anonymous referees for useful comments and suggestions. We also thank participants in seminars organized by the Bank of Mexico and the ECB, and by the Banco Central de Reserva del Perú (BCRP) and the CCBS of the Bank of England. Any remaining errors are the authors' own responsibility. The views expressed herein are those of the authors and do not necessarily reflect those of their institutions.

instance, found a positive relationship between inflation and inflation uncertainty for long horizons by differentiating inflation into its stochastic trend and its stationary (autoregressive) components. While valid in a situation in which a policy maker decides to disinflate the economy, in other circumstances Ball and Cecchetti's empirical work can be subject to the Lucas critique (Gordon 1990). Consequently, empirical measures of inflation uncertainty at any horizon may be misleading if the econometric specification does not properly capture regime switching in monetary policy and inflation dynamics. In this regard, Kim (1993) and Kim and Nelson (1999) extended Ball and Cecchetti's (1990) study by assuming regime switching might be a key source of inflation uncertainty, and found associations between high uncertainty about long-run inflation and positive shifts in the inflation level in the USA. Moreover, high uncertainty about short-term inflation is linked to negative shifts in inflation levels.¹

The high and volatile inflation experiences in emerging markets promise to provide insight into the relationship between high and volatile inflation and offer policy lessons for monetary authorities in recently acquired low-inflation scenarios in developing economies. Peru represents a particularly interesting case study because monetary policy has evolved from money growth management to interest rate management, under different macroeconomic scenarios of price (in)stability. Peru suffered hyperinflation in the late 1980s; implemented successfully a stabilization program in the early 1990s; and adopted a fully-fledged inflation-targeting regime in 2002. Yet, no formal assessment of the link between inflation and inflation uncertainty exists in the literature. The goal of this paper is to assess empirically this link for the Peruvian economy in a long-span data set that includes the years 1949–2010. Over such a long period, different monetary policy regimes existed, which lends the data set to an analysis of inflation dynamics subject to regime shifts.

Methodologically, this paper is structured as follows. First, a Markov switching heteroskedasticity model of inflation is applied, whereby inflation dynamics is differentiated into a stochastic trend and a mean-reverting (stationary) component, both of which are subject to regime change in their disturbances, as suggested in Kim (1993) and Kim and Nelson (1999). Then, by calculating the standard deviation of the forecast error of inflation, based on the estimated model and on the smooth transition probabilities inferred from the data, a time varying measure of inflation uncertainty is derived.

¹ Similarly, Evans and Wachtel (1993) developed a model of inflation from which they derived measures of inflation uncertainty associated to different regimes. The evidence showed costs of high-level inflation in terms of long-term uncertainty exits.

The main empirical results in this study indicate a link exists between inflation and inflation uncertainty in Peru, which is stronger for long-term uncertainty but also relevant for short-term uncertainty. This link is associated with regime shifts ranging from low to high, and very high (hyperinflationary) variance scenarios in inflation shocks. High-variance states of permanent and transitory shocks to inflation trends coincide with regime shifts towards a higher inflation mean. The time-varying measure of inflation uncertainty shows an important difference between previous low, stable inflation regimes and the more recent stance of price stability. In the latter, although reduced short-term volatility has been reached with lags with respect to long-term inflation volatility decline, it seems both temporary and permanent inflation are firmly kept low in a stable regime. In contrast, short-term shocks in previous episodes of price stability remained sporadically volatile with respect to long-term price stability.

The rest of the paper is organized as follows. Section II provides a historical review of the Peruvian experience of inflation and shifts in monetary policy regimes. The section also offers arguments in favor of modeling inflation dynamics nonlinearly. In Section III, estimation results from a model developed by Kim and Nelson (1999), which allows conditional and unconditional heteroskedasticity in shocks to be linked to permanent and transitory inflation components, are presented and discussed. Regime shift parameter estimates provide the basis for estimating an overall measure of inflation uncertainty. The last section concludes the paper.

II. Monetary policy and inflation

A. Policy shifts in perspective

The institutional framework for monetary policy in Peru has changed substantially over the period under discussion. Before the 1990s, the Central Bank of Peru was not entirely autonomous and for several years, active money creation financed fiscal deficits. Consequently, the evolution of the fiscal deficit partially conditioned monetary policy and, especially, money growth rates. The link between fiscal deficit and money creation was particularly strong during periods of adverse terms of trade, such as the first two years of the 1970s and the 1980s. Printing money was also an important source of funding for the government during the 1985–1990 period, when official access to international financial markets was restricted. During this latter period, both fiscal deficits and money growth rates reached their historically highest levels.²

² For a historical perspective of monetary policy in Peru see Guevara (1999).

Changes in the government's role in the economy also affected monetary and fiscal policies. During the 1970s, the fiscal sector expanded rapidly due to more foreign-owned business expropriations and increased public investment. The government kept fiscal deficits close to 3% for most of 1970s. Monetary policy was passive and oriented to financing government expenditure. At the end of the 1970s, with a growing external debt and rising inflation, a stabilization program cut down government spending and restored fiscal and monetary discipline.

In 1980, a newly elected government received an improved fiscal position, the benefit of previous fiscal adjustments and high terms of trade at the end of the 1970s. Nonetheless, a series of adverse external and domestic shocks seriously damaged the performance of the economy. First, in 1981, the rise in international interest rates and fall of commodity prices significantly increased fiscal deficits, from 1% in 1979 to 6.9% in 1981. In 1983, natural disasters associated with "El Niño" (a climatic phenomenon) negatively affected tradable production, further decreasing the fiscal accounts to a 10% deficit in that year. During the period 1980-1985, the average fiscal deficit reached 6.9% (5.6% between 1975 and 1979); money growth and inflation rates were 110.4% and 105%, respectively (59% and 55% in 1975-1979); and external debt increased to 40% of GDP (32% between 1975 and 1979).

From 1985 onwards, further expansionary fiscal policies caused a deep deterioration in macroeconomic balances. The fiscal deficit rose from 9.7% in 1986 to 16.3% in 1988. The public sector's access to external funding was seriously restricted by the decision of the government in 1987 to limit external debt payments to 10% of exports, and money printing started to finance a larger fraction of the public deficit. Money growth rates increased from 70% in 1986 to 5214% in 1990, triggering an exponential increase in inflation from 63% in 1986 to 7649% in 1990.

In 1990 a significant change in monetary policy occurred as part of a vast and deep stabilization program. A quantity target for money growth along with a flexible exchange rate regime was established.³ In 1991, money printing stopped funding fiscal deficits. In 1993, a new Peruvian Constitution and Central Bank Charter granted the central bank formal autonomy and established price stability as the sole objective for monetary policy.⁴ The new Central Bank Charter also established a series of restrictions that further enhanced the bank's credibility. Among those

³ A fixed exchange rate regime was discarded as a monetary anchor given its previous history of failures to stabilize inflation, see Velarde and Rodriguez (1992).

⁴ For a detailed account of monetary policy in Peru from 1991 to 2001 see Quispe (2000) and De la Rocha (1999).

restrictions were prohibitions to finance the government and establish multiple exchange rate regimes.

Rapid reduction of money growth and the fiscal deficit helped bringing inflation down from around 7600% in 1990 to 10% in 1994. In order to reinforce credibility in its price stability policy, the Central Bank pre-announced inflation targets in 1994. Inflation fell to international levels by the end of the 1990s and the fiscal stance improved significantly to reach a fiscal surplus in 1997.

In 2002, the Central Bank adopted a fully-fledged inflation-targeting regime, a decision aimed at anchoring long-term inflation expectations and locking in hard-obtained price stability. Monetary policy shifted its main instrument from money-based growth to the short-term nominal interest rate.⁵ Overall, average inflation fluctuated around a 2% target during the 2000's. Monetary stability helped reduce financial dollarization from levels near 80% at the end of the 1990s to 45% in 2010. Furthermore, enhancement of the fiscal position (several years of primary surplus) allowed cutting government external debt to 25 % of GDP by 2010, from 48% in 2000.

B. Inflation and inflation uncertainty: a first glance

With the shifts in monetary policy, average inflation and inflation volatility in Peru have changed drastically in the last six decades or so. A simple look in Table 1 at the mean and volatility of the quarterly inflation rate per decade, since 1950, shows the magnitude of those changes were far from being negligible.

Table 1. Summary statistics

Period	Quarterly inflation rate		Quarterly M0 growth rate	
	Mean	Std. dev	Mean	Std. dev
1951-1960	1.8	1.7	n.a	n.a
1961-1970	2.4	1.8	4.0	5.1
1971-1980	7.5	6.0	8.2	7.8
1981-1990	67.7	135.0	52.7	84.9
1991-2000	5.9	8.0	6.7	6.7
2001-2010	0.6	0.7	4.4	4.3

⁵ For an account of the adoption of the inflation-targeting regime, see Armas and Grippa (2006) and Rossini (2000).

The quarterly average inflation rate increased from around 2.4% during the 1960s to 7.5% during the 1970s, accompanied by an increase in inflation volatility from 1.8% to 6.0% across the decades. During the 1980s, average inflation and volatility reached their highest levels, 67.7% and 135.0%, whereas during the 2000s those measures found their lowest levels, 0.6% and 0.7%.⁶

A link between inflation's mean and volatility emerges neatly from those basic statistics, even after adjusting for scale factors. Likewise, the statistics suggest some structural breaks in inflation dynamics. Monetary policy, the main long-run determinant of inflation, evolved from money-aggregate targeting (with restricted independence before the 1990s) to an inflation-intolerant regime (after 1994) suggesting feasible regime switches in the permanent component of inflation.⁷ Although no distinction of short and long-run volatility can be crystallized from the indicators, the unobserved components could be estimated from the inflation data. In order to account properly for the link between inflation and inflation uncertainty in the Peruvian economy, it is necessary to use a framework that simultaneously deals with regime shifts and unobserved components in inflation dynamics. In the following section, such a model is discussed.

III. Regime switching and inflation uncertainty

A. Model description for inflation uncertainty

With the evidence of regime shifting in the dynamics of inflation, this section follows the Kim and Nelson (1999) model closely in order to test for inflation uncertainty in Peru. In Kim and Nelson's components, the stochastic trend and the stationary (autoregressive) component are subject to regime switching. A key feature of the model is that it allows for conditional and unconditional heteroskedasticity. The equations for the model are the following:

⁶ We also find some evidence for a relationship between inflation and inflation uncertainty by following Ball and Cecchetti (1990) closely. The inflation rate series is differentiated into its permanent and temporary components so that measures of short and long-term inflation uncertainty can be obtained. Inflation uncertainty is defined as the variance of the forecast error of inflation. Estimation results show evidence that effects of average inflation on the standard deviation of the permanent shock is positive and significant. The evidence also supports a possible link between the level of inflation and short-run uncertainty.

⁷ As the previous section makes clear, the Central Bank of Peru started to announce annual inflation targets after 1994 and it adopted inflation targeting fully in 2002.

$$\pi_t = \pi_t^T + \mu_2 S_{1,t} + \mu_3 S_{2,t} + \mu_4 S_{1,t} S_{2,t} + (h_0 + h_1 S_{2,t}) \eta_t, \quad (1)$$

$$\pi_t^T = \pi_{t-1}^T + (Q_0 + Q_1 S_{1,t}) \varepsilon_t, \quad (2)$$

where π_t denotes the level of current inflation, π_t^T denotes stochastic trend inflation, $\eta_t \sim N(0,1)$ is the shock to the transitory autoregressive component of inflation, and $\varepsilon_t \sim N(0,1)$ is the shock to trend inflation. The notation is consistent with Ball and Cecchetti (1990), where the following two-equation unobserved component model for inflation is postulated: $\pi_t = \pi_t^T + \eta_t$ and $\pi_t^T = \pi_{t-1}^T + \varepsilon_t$, with π_t^T following a random walk. The stochastic component is subject to regime switching and $S_{1,t}$ is the unobserved state variable that represents the regime shift. Similarly, the transitory component is also subject to shifts in regime and $S_{2,t}$ captures the states for it. Both $S_{1,t}$ and $S_{2,t}$ are assumed to evolve according to two independent (of each other) first-order two-state Markov chains. Each state variable defines a low-variance state for the shocks, for which the variable takes on the value 0, and a high-variance regime for which the variable takes on the value 1. The transition probabilities representing the discrete Markov processes are the following:

$$\Pr[S_{1,t} = 0 | S_{1,t-1} = 0] = p_{00}, \quad \Pr[S_{1,t} = 1 | S_{1,t-1} = 1] = p_{11}, \quad (3)$$

$$\Pr[S_{2,t} = 0 | S_{2,t-1} = 0] = q_{00}, \quad \Pr[S_{2,t} = 1 | S_{2,t-1} = 1] = q_{11}. \quad (4)$$

Shocks to the permanent (transitory) component take on the value Q_0 (h_0) if they are in a low-volatility state and $Q_0 + Q_1$ ($h_0 + h_1$) otherwise. This model of inflation involves the existence of up to four different economic states resembling possible combinations of regime occurrence at time t . Regime 1 corresponds to a low-variance state for both Markov chains ($S_{1,t} = 0$ and $S_{2,t} = 0$), with Q_0 and h_0 . Regime 2 stands for a low permanent and high transitory variance state ($S_{1,t} = 0$ and $S_{2,t} = 1$), with Q_0 and $h_0 + h_1$, and regime 3 for a high permanent and low transitory variance state ($S_{1,t} = 1$ and $S_{2,t} = 0$), with $Q_0 + Q_1$ and h_0 . Finally, regime 4 represents a high variance state for both chains ($S_{1,t} = 1$ and $S_{2,t} = 1$), with $Q_0 + Q_1$ and $h_0 + h_1$. High-variance states of shocks to stochastic and transitory inflation affect its mean through parameter μ_2 if permanent shocks are highly volatile, μ_3 if transitory shocks are highly volatile, and μ_4 if both shocks are in a high-variance state.

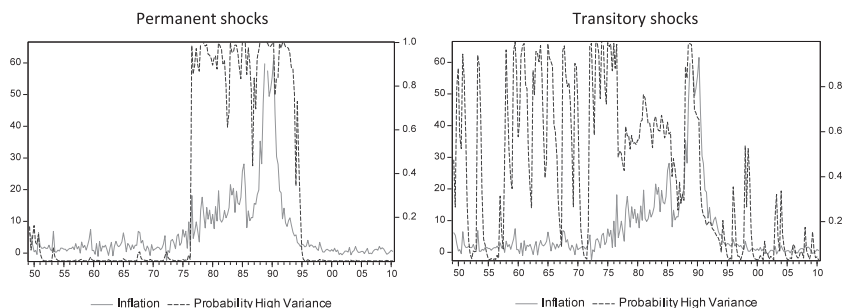
B. Inflation regimes and estimation results

The model is estimated using quarterly data for inflation rates for the period 1949–2010. In order to facilitate the computation of the likelihood function inflation rates are rescaled using the monotonic transformation $\pi = \ln f / (100 + \ln f)$, where $\ln f$ is the quarterly inflation rate as a percentage.⁸ Estimation results show evidence of regime shifting during the sampled period. An important outcome of this model estimation is the inference of regime probabilities at each observation. In particular, plots of the inflation rate and the probability of high variance regimes for permanent and transitory shocks are illustrative of the switching nature of shocks.

For the permanent component of inflation, probabilities reveal low-variance regimes for the periods 1949–1976 and 1995–2010, and a high-variance regime for the period 1976–1994 (see the first panel in Figure 1). High volatility of transitory shocks in the first regime of price stability, during the 1950s and 1960s, are frequent but clearly associated with inflation peaks. Peaks become more persistent during times of higher mean and variance of inflation (see the second panel of Figure 1). Of note is the period of high-variance inflation coinciding with the sample period where fiscal dominance was stronger and where macroeconomic imbalances were clearer, which suggests the high-variance regime constitutes one in which the monetary policy was particularly weak.

In addition, the estimation suggests the second shift in trends occurs at the beginning of 1994 and a low-variance regime of permanent shocks follows thereafter. At this shift date, the Peruvian central bank started to pre-announce inflation objectives although it was still not committed to a fully-fledged inflation-targeting

Figure 1. Probability high-variance regime, 1949–2010



⁸ The authors are thankful to an anonymous referee for suggesting the use of this transformation.

scheme. Transitory shocks remain at a high-variance state for a while longer, but finally die out around 1999 and remain in a low-variance state thereafter. In contrast to the previous price-stability period of the 1950s and 1960s, the more recent low-level and low-variance inflation regime involves not only a stable trend but also a very stable sequence of transitory shocks. The non-existence of shifts to high-volatility regimes, both in the permanent and transitory components of inflation, is not due exclusively to the adoption of the inflation targeting scheme of monetary policy from 2002 onwards, but to the downward-expectations orientation of the monetary policy since 1994, after successfully fighting hyperinflation. The lower probability of returning to high volatile regimes prevents agents adjusting inflation expectations with transitory shocks (actually, q_{00} increases substantially with respect to the first sample). The merit of the inflation-targeting regime is to reinforce the process of anchoring inflation expectations by smoothing transitory shocks around the inflation target.

Parameter estimates and their standard deviations (see Table 2, columns 2 to 4) further support the previous conclusions. The results show clear links between inflation and inflation volatility (all parameters, h_0 , h_1 , Q_0 and Q_1 are significant). For the low-variance regime, permanent shocks contribute 0.22% (Q_0) to inflation uncertainty whereas they add a further 4.76% (Q_1) under a high-variance regime.

Table 2. Regime switching heteroskedasticity model of inflation in Peru. 1949–2010

Parameters	1949 -2010 period			1976 - 1994 period		
	Estimates	St. dev.	t-stat	Estimates	St. dev.	t-stat
p_{11}	0.9829	0.0149	65.8558	0.8993	0.0944	9.5309
p_{00}	0.9967	0.0035	282.0317	0.9815	0.0229	42.8196
q_{11}	0.9120	0.0637	14.3146	0.9410	0.0602	15.6445
q_{00}	0.9291	0.0383	24.2499	0.9022	0.0947	9.5280
Q_0	0.2210	0.0605	3.6506	1.6105	0.4423	3.6412
h_0	0.5714	0.0840	6.8011	0.6601	0.7625	0.8657
Q_1	4.7647	0.9886	4.8196	7.5669	2.1259	3.5594
h_1	1.7467	0.2449	7.1322	3.5405	0.9480	3.7347
μ_2	0.9373	0.4344	2.1576	4.4383	2.0695	2.1446
μ_3	2.9317	0.8880	3.3014	7.7569	2.9787	2.6041
μ_4	12.2935	3.7990	3.2360	1.9904	6.9015	0.2884
Q_1/Q_0	21.560			4.699		
h_1/h_0	3.057			5.364		
Log likelihood	546.527			237.444		

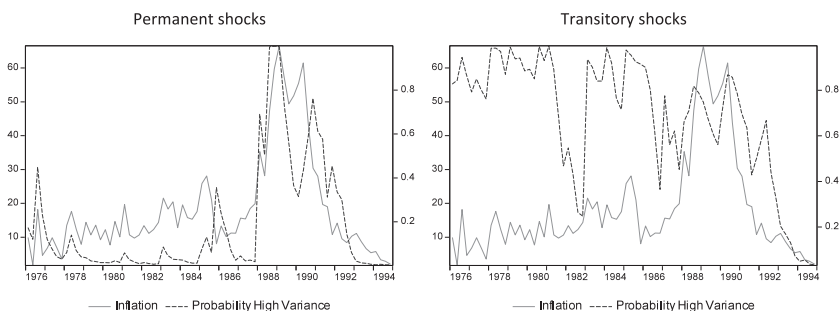
In the case of the transitory component, volatility increases an additional 1.74% (h_1), from 0.57% (h_0), between the low and high variance regimes. Notice the relative larger effect on inflation uncertainty for high-variance permanent shocks given by the ratio Q_1/Q_0 (21.6). The effects of high-variance transitory shocks on inflation uncertainty are also relatively stronger than low-variance shocks; however, the ratio h_1/h_0 is less pronounced (3.1).

The effects of high-variance shocks on the inflation mean are both positive (μ_2 of 0.93 and μ_3 of 2.93) and are further emphasized by their simultaneous occurrence (μ_4 of 12.3). Because μ_2 is statistically significant and positive, the move from stable inflation to volatile inflation accompanies an increase in the inflation mean.

Simple inspection of inflation levels within the sample period of high-variance inflation suggests the possibility of a third regime characterized by very high levels of inflation. To evaluate this possibility, the model for sub-sample 1976–1994 was estimated. Plots of the inferred probabilities of high variance regimes represent clearly the hyperinflation period as a shift to high variance in permanent shocks (see the first panel in Figure 2). Meanwhile, large volatility of transitory shocks span most of this sample, which ends with the implementation of major anti-inflationary policies in 1990 (see the second panel of Figure 2).

For robustness a simple Markov switching autoregressive (MS-AR) model was estimated for the inflation rate vector (column) π_t , as in $\pi_t = c(s_t) + \sum_{j=1}^p \beta_j(s_t) \pi_{t-j} + \eta_t$, where $s_t \in (1, \dots, M)$ is an unobservable state variable, with up to M possible regimes, and $\eta_t \sim NID(0, \sigma(s_t))$. The regime generating process is assumed a discrete-state homogeneous Markov chain defined by the transition probabilities: $p_{ij} = \text{PR}(s_{t+1} = j | s_t = i)$ and the condition that $\sum_{j=1}^M p_{ij} = 1, \forall i, j \in \{1, \dots, M\}$. Following

Figure 2. Probability high-variance regime, 1976–1994



nomenclature from Krolzig (1997), the model selected to fit the inflation rate for Peru is a MSIAH(3)-AR(1). Results show strong evidence of three clearly differentiated regimes over the entire sample, as smoothed transition probabilities from this preliminary model. The first regime corresponds to a low-level inflation rate, low volatility and low persistence. The first regime includes periods 1949–1975 and 1994–2006. The second regime refers to high-level inflation and highly volatile scenarios. Periods considered into this second inflation regime are 1975–1987, and 1991–1994. The third regime appears for an extremely volatile and outlier-type hyperinflation period in Peru (1988–1991).

Estimation results reported in columns 5 to 7 of Table 2 show two regimes of high inflation and hyperinflation for the period 1976–1994 (all parameters, h_0 , h_1 , Q_0 , and Q_1 are significant). In the hyperinflation scenario (1988–1990), volatility of both types of shocks has strong effects on the inflation level and uncertainty. During this period, permanent shocks contribute 7.6% (Q_1) to inflation uncertainty, while transitory shocks increase inflation uncertainty by 3.5% (h_1). The corresponding values in the low variance regime for Q_0 and h_0 are 1.6 and 0.7%. These values are consistent with the results for the high-variance regimes in the entire sample estimation. The ratios Q_1/Q_0 and h_1/h_0 (4.7 and 5.4) reveal the strong difference in the effects of both shocks in the hyperinflation period, a high-variance regime with respect to the high inflation period. In the high inflation regime, an explicit and drastic shift in the money growth trends (as actually happened in the early 1990s) can shift inflation dynamics out of its spiral. Because inflation persistence increases with inflation and inflation uncertainty, it is extremely hard to abandon accelerating inflation scenarios unless the monetary authority commits itself to a non-indulgent inflation fighting policy.

Summing up the results, the heteroskedasticity model indicates that regime shifts occur in both permanent and transitory unobserved inflation components. Thus, for permanent (transitory) shocks, a high-variance scenario is identified to alternate with a low-variance regime over a sample spanning almost six decades, although it excludes the hyperinflation regime. Inflation dynamics are subject to permanent and transitory shocks, which in turn are subject to shifts between calm and volatile regimes.

The implications for the conduct of monetary policy from the above discussion are important. A commitment to keep inflation shocks to a minimum are certainly fruitful for bringing inflation down, but a further commitment to anchor inflation expectations reinforces low-variance scenarios in both permanent and transitory inflation, by reducing the probability of returning to a volatile regime. As inflation

targeting succeeds in keeping inflation under control, price stability feeds back into its own dynamics. Of course, regime shifts in the transitory component of inflation might occur for reasons other than monetary policy, but credibility in the central bank's commitment should help to keep inflation anchored at the chosen target. Once authorities (for whatever reason) start losing control, the chances of rapidly shifting into a high-variance regime increases, bringing along rising inflation expectations.

C. A time-varying measure of inflation uncertainty

Parameter estimates from the regime shift model provides the basis for deriving an overall measure of inflation uncertainty.⁹ In particular, the time-varying measure of inflation uncertainty combines both short and long run uncertainty. In order to construct the measure, inflation uncertainty is defined as the conditional standard deviation of the forecast error of inflation h periods ahead. For this derivation, the focus is only on the case of $h=1$. From equations (1) and (2), the inflation forecast error one period ahead reads as follows:

$$\pi_{t+1} - E_t \pi_{t+1} = \varepsilon_{t+1} + \eta_{t+1}. \quad (5)$$

For the regime-shift model, the variance of the one-step forecast error for each observation within the sample is given by the joint weighted average variance (for permanent and transitory shocks) over all possible states and all smoothed probabilities inferred from (y_t) . The conditional variance of the one-step forecast error for each period is given by the following

$$E_t (\pi_{t+1} - E_t \pi_{t+1})^2 = \sum_{r=0}^{\infty} \sum_{n=0}^{\infty} \left(\sum_{i=0}^{i=1} \sum_{j=0}^{j=1} [\sigma_\varepsilon^2(S_{1,t}=i) + \sigma_\eta^2(S_{2,t}=j)]^* \right) \Pr[S_{1,t+1}=i, S_{2,t+1}=j | S_{1,t}=r, S_{2,t}=n] \Pr[S_{1,t}=r, S_{2,t}=n | y_t], \quad (6)$$

where $S_{1,t}$ and $S_{2,t}$ represent the two Markov chains that capture regime shifting for permanent (ε_t) and transitory (η_t) shocks to inflation. Their transition probability matrices (2×2) are given by the following:

⁹ This measure of inflation uncertainty is a straight-forward derivation of the regime-switching features of the model. Nonetheless, the authors have not seen previous uses of this measure in Markov switching applications.

$$p = \begin{bmatrix} p_{00} & 1-p_{00} \\ 1-p_{11} & p_{11} \end{bmatrix} \text{ for } S_{1,t} \text{ and } q = \begin{bmatrix} q_{00} & 1-q_{00} \\ 1-q_{11} & q_{11} \end{bmatrix} \text{ for } S_{2,t}.$$

The Kronecker product of p and q gives the joint probability matrix (4×4), PP :

$$PP = p \otimes q. \quad (7)$$

The following column vector (4×1) collects total variances for the four possible states:

$$VV = [V_{00} V_{01} V_{10} V_{11}]', \quad (8)$$

where $V_{00} = \sigma_\varepsilon^2(0) + \sigma_\eta^2(0) = Q_0^2 + h_0^2$; $V_{01} = \sigma_\varepsilon^2(0) + \sigma_\eta^2(1) = Q_0^2 + (h_0 + h_1)^2$; $V_{10} = \sigma_\varepsilon^2(1) + \sigma_\eta^2(0) = (Q_0 + Q_1)^2 + h_0^2$ and $V_{11} = \sigma_\varepsilon^2(1) + \sigma_\eta^2(1) = (Q_0 + Q_1)^2 + (h_0 + h_1)^2$ with Q_0 , Q_1 , h_0 , and h_1 defined as in equations (1) and (2). The joint weighted average variance vector for all possible states gives the one-step ahead variance vector, EVV (4×1). The variance vector is estimated as follows:

$$EVV = PP * VV. \quad (9)$$

Smoothed probabilities inferred from data (in y_t), as represented by $\Pr[S_{1,t} = r, S_{2,t} = n | y_t]$, are collected in a matrix PR ($T \times 4$), with T the number of observations in the sample. Hence, the time varying measure of inflation uncertainty, SD ($T \times 1$) is estimated by: the following:

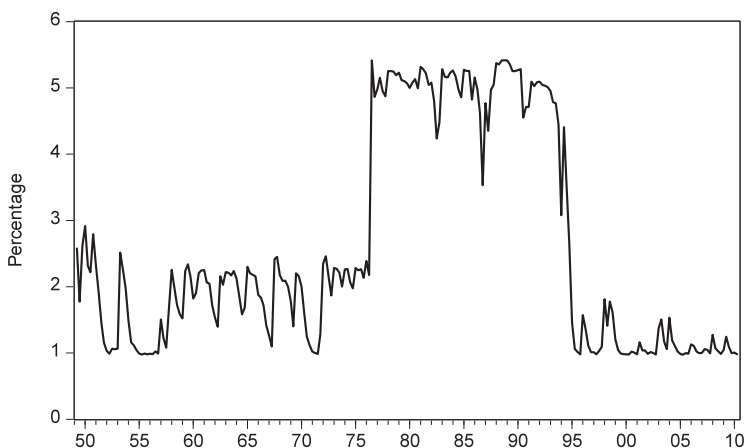
$$SD = (PR * EVV)^{1/2}. \quad (10)$$

Therefore, the conditional standard deviation of the one-step ahead expected inflation implied from the estimated model (see Figure 3) measures overall inflation uncertainty through the entire estimation sample. It reveals three clearly differentiated periods of overall uncertainty. For the period from 1949 to approximately 1976, inflation uncertainty fluctuates around 2 %. Thereafter, uncertainty increases considerably to around 5 % until 1993. If inflation uncertainty is linked to inflation expectations and inflation levels, periods of high inflation could be explained by regime shifts in both monetary and fiscal policies. Notably, the third period from 1994 onwards shows a persistent decline in inflation uncertainty to around 1 %.

This pattern is consistent with the inflation-intolerant monetary policy anchoring expectations from 1994 onwards.¹⁰

The inflation uncertainty measure for the sub-sample 1976–1994 emphasizes the large upsurge in overall uncertainty for the hyperinflation period of 1988–1990 (Figure 4). At its peak uncertainty surpasses 9 % to decline rapidly by 1992–1994 to less than 3 %. Of course, this is consistent with the estimation for the entire sample in which the uncertainty for the period 1976–1994 is roughly around 5 %.

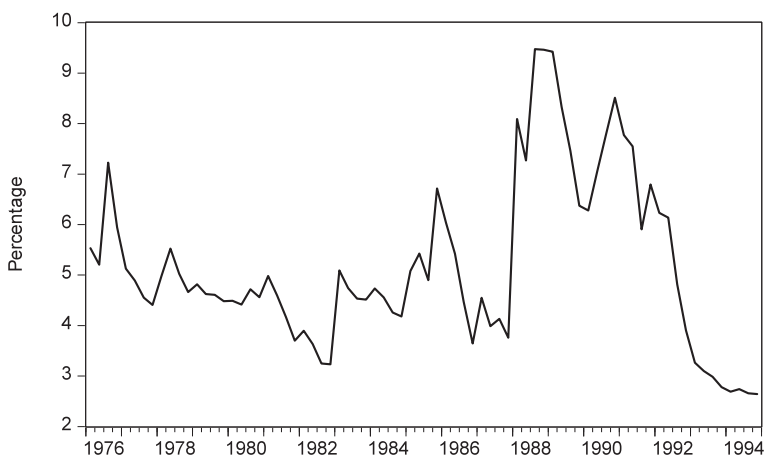
Figure 3. Inflation uncertainty, 1949–2010



Note: standard deviation of one-period ahead forecast error.

¹⁰ Although no link to monetary variables or policy was pursued empirically, shifting regimes in inflation trends are known to be associated with money market considerations. A MS-AR model shows clear evidence of the presence of regime shifts in money growth (measured as M2, total liquidity in domestic currency). As in the case of inflation, three regimes are indentified for the money growth rate. Dates of regimes shifts in money growth coincide, or are very similar, to those of inflation. Because of data availability, sample estimation is defined from 1964 (not 1949, as in the case of inflation) onwards. Estimation results are available from the authors upon request.

Figure 4. Inflation uncertainty, 1976-1994



Note: standard deviation of one-period ahead forecast error.

IV. Conclusions

The link between inflation and inflation uncertainty in the Peruvian economy was investigated in a context in which monetary policy has been subject to regime shifts. The results support the importance of inflation uncertainty and regime shifts for explaining inflation dynamics.

Some novel results stand out from the empirical estimations. First, there is evidence that inflation levels are associated to variance of both permanent and transitory components. It seems the link between inflation and long-term uncertainty (higher instability in trend inflation) is stronger than between inflation and short-term variability. Given that monetary policy and actions explain inflation trends, the results suggest high-level inflation makes policy less stable and, hence, higher inflation implies rising stabilization costs.

Important implications arise for the orientation of monetary policy. Keeping trend inflation under control and dragging inflation expectations down reinforces credibility in a central bank's inflation-intolerant policy. Long-term, permanent shocks to inflation trends should be avoided consistently and permanently. Once monetary authorities start losing control of inflation trends, the chances of rapidly shifting to a high-level, high-variance inflation regime are not negligible and the danger of falling into a hyperinflation spiral is latent. Domestic impulses to short-run transitory shocks are

weakened if, on top of a downward trend in inflation management, inflation expectations are anchored towards low-level and low-variance inflation. The perspective presented in this paper allows assessing inflation targeting regimes' contribution to monetary policy efficiency better.

Overall, the empirical evaluation justifies studying inflation dynamics that incorporate pre-hyperinflation observations to capture and distinguish regime shifts. The recent experience of price stability reveals inflation-fighting policy's contribution to anchoring inflation expectations, once the experience is set in historical perspective and benefits from the rich information provided by past inflation dynamics.

Using univariate modeling proves valuable for revealing inflation dynamics, but reaches its limits when uncertainty about the sources of shocks is at issue. Further research will be directed towards Markov switching structural multivariate models of inflation dynamics, along the line of Sims and Zha (2005). Structural identification of the sources of regime shifting is required to assess if shifting policy orientations or the shifting nature of volatility shocks are responsible for the inflation patterns studied here so far. Extending Kim and Nelson's (1999) model by adding a third regime to capture a hyperinflationary period within the context of a single model is also an avenue worth pursuing.

References

- Armas, Adrian, and Francisco Grippa (2005), Targeting inflation in a dollarized economy: the Peruvian experience, Working Paper 538, Inter-American Development Bank.
- Ball, Laurence, and Stephen G. Cecchetti (1990), Inflation uncertainty at short and long horizons, *Brooking Papers on Economic Activity* 1: 215–45.
- Bratsiotis, George J., Jakob Madsen, and Christopher Martin (2002), Inflation targeting and inflation persistence, Economics and Finance Discussion Paper 12, Brunel University.
- De la Rocha, Javier (1999), The transmission mechanism of monetary policy in Peru, in *The transmission mechanism of monetary policy in emerging market economies*, Policy Papers 3, Bank for International Settlements.
- Evans, Martin, and Paul Wachtel (1993), Inflation regimes and the sources of inflation uncertainty, *Journal of Money Credit and Banking* 25: 475–511.
- Gordon, Robert J. (1990), Inflation uncertainty at short and long horizons: Comments, *Brooking Papers on Economic Activity* 1: 246–52.
- Guevara, Guillermo (1999), La política monetaria del Banco Central del Perú, una perspectiva histórica, *Revista de Estudios Económicos* 5: 17–50, Banco Central de Reserva del Perú.
- Hamilton, James D. (1989), A new approach to the economic analysis of nonstationary time series and the business cycle, *Econometrica* 57: 357–84.
- Kim, Chang-Jin (1993), Unobserved-component time series models with Markov-switching heteroskedasticity: changes in regime and the link between inflation rates and inflation uncertainty, *Journal of Business and Economic Statistics* 11: 341–49.

- Kim, Chang-Jin, and Charles R. Nelson (1999), *State-space models with regime switching. Classical and Gibbs-sampling approaches with applications*, Cambridge, MA, MIT Press.
- Krolzig, Hans-Martin (1997), *Markov-switching vector autoregressions. Modelling, statistical inference, and application to business cycle analysis*, Lecture notes in economics and mathematical systems, Berlin, Springer.
- Quispe, Zenón (2000), Monetary policy in a dollarized economy, the case of Peru, in L. Mahadeva and G. Sterne, eds., *monetary policy framework in a global context*, London, Routledge.
- Rodríguez, Gabriel (2004), An empirical note about additive outliers and nonstationarity in Latin-American inflation series, *Empirical Economics* **29**: 361–72.
- Rossini, Renzo (2001), Aspectos de la adopción de un régimen de metas de inflación en el Perú, *Revista de Estudios Económicos* **7**: 1–13, Banco Central de Reserva del Perú.
- Rudd, Jeremy, and Karl Whelan (2007), Modeling inflation dynamics: a critical review of recent research, *Journal of Money, Credit and Banking* **39**: 155–70.
- Sims, Christopher A., and Tao Zha (2006), Were there regime switches in US monetary policy?, *American Economic Review* **96**: 54–81.
- Velarde, Julio, and Martha Rodríguez (1992), El programa económico de agosto de 1990: evaluación del primer año, Documento de Trabajo 2, CIUP - Consorcio de Investigación Económica.