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Monetary Policy Credibility and Inflation Risk Premium: a model with application to Brazilian data*

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Abstract

We derive a simple asset pricing-Taylor rule model to explain Inflation Risk Premium and show that monetary policy credibility is one of its main determinants. We then investigate how credible has been monetary policy in Brazil since 2001. Short run inflation surprises had a significant effect in medium run inflation expectations for most of our sample. This phenomenon leads to a less effective monetary policy, as its output cost is higher. This can be a symptom of at least one of two problems: (i) Inflation inertia due to indexation of the economy; and/or (ii) lack of credibility of the monetary authority. The remedy depends on the cause, for instance, if the reason is simply indexation, central bank independence would not help. As our model suggests, looking at comovements of inflation risk premium and inflation surprises helps to identify if lack of credibility is one of the causes. By doing so, we confirm that this was the case in Brazil untill very recently.

JEL classification: E58, E44, G12, E65

1 Introduction

When monetary policy lacks credibility, central banks have to impose a higher interest rate than otherwise in order to control inflation. Knowing that, many countries have adopted inflation targeting (IT) regime to better anchor inflation expectations and, so, reduce the output cost of monetary policy. Following the spread of IT as the most fashionable monetary arrangement across the globe, the academic literature on monetary policy credibility have flourished. Empirically, the extent of the credibility has been evaluated

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in basically two ways[1]: (i) by running regressions on inflation expectations, as in Cerisola and Gelos (2005) or (ii) by looking at the inflation implicit in nominal and real bonds, the "break-even inflation" as in Svensson (1993), Laxton and N'Diaye (2002) and Gürkaynak et al (2005).

The information contained in this data can be better explored. As reckoned by Bernanke (2004), policymakers have a lot to learn from asset prices but "some of the potentially most valuable information in financial markets often requires considerable theoretical and empirical sophistication to extract". That's what we try to do in this paper. The difference between the yield on nominal and real bonds, referred to as "break even inflation " or "market inflation", is not explained solely by the expected inflation: it include a risk premium as well[2]. Differently from the aforementioned papers, to investigate the credibility of monetary policy we separate the "break-even inflation" into two components: the expected inflation and the inflation risk premium. We present an asset pricing model with a Taylor rule and an equation for inflation dynamics which allow us to interpret this "inflation risk premium" and conclude that monetary policy credibility is one of its main determinants. We apply its results to investigate monetary policy credibility in Brazil.

Other branch of the (very recent) literature is also somehow related to our work as they explore the dynamics of real bonds. Ang and Bekaert (2005) develop a term structure model to separate the nominal yield curve components into expected inflation, real rates and inflation risk premium. It is a reduced form model and in the estimation, they use only data on nominal yield curve and current inflation. Similarly, Buraschi and Jiltsov (2005) present a monetary structural RBC type model and estimate it with Nominal yield and current inflation data. Our approach is different: we use the data on inflation risk premium directly - so there is no need to use any model to decompose it - and our model is derived in order to give us a clear economic interpretation on the determinants of this inflation risk premium data. Our main focus is its application to the study of monetary policy credibility.

A very rich data-set, containing real bonds, nominal bonds and survey of inflation expectation for many horizons allows us to use the methodology proposed to analyze the recent Brazilian experience. An extra reason for choosing this country is that one of the most popular subjects among macroeconomist these days in Brazil is the inflation resilience to the high interest rate. Many possible reasons have been raised: fiscal dominance, subsidized credit[3] with interest rate not sensitive to the short rate determined by the monetary authority, fiscal policy not being tight enough, the short run expansionary effect of the

[1] Some other methods: Rossi and Rebucci (2004) that studies the credibility of the disinflation program in Turkey using a Bayesian approach and Agénor and Taylor (1993) that use the difference between exchange rate quoted in official and black market.

[2] Other component is the liquidity premium since Real bonds are attractive to buy-and-hold investors (such as pension funds), in contrast to nominal securities, which are extensively used for trading and hedging. We ignore this problem in our analysis.

[3] National Development Bank's (BNDES) loans constitute approxematelly 40% of the total availble credit to private sector.

expansion of the credit to consumers and so on. In this paper we will point out that credibility of the monetary authority has been also an important factor hampering the transmission channels of monetary policy. However, recently, there was a substantial improvement in our measure of credibility.

The paper has 5 sections, including this introduction. Section 2 present the empirical evidence that short run inflation surprises affects positively 12 month inflation expectations in Brazil. This could be happening either by inflation inertia or by lack of credibility on monetary authority. How could we know if credibility is part of the explanation for this problem? In section 3 we derive a theoretical model that shows that movements in inflation risk preimium can help to identify that. Section 4 then shows that inflation risk premium is very sensitive to inflation surprises, indicating lack of credibility of monetary policy during most of the sample period analyzed. Section 5 concludes and provides some conjectures on possible causes for the lack of credibility.

2 Evidence of the Effects of Short Run Surprises in Medium Run Inflation Expectations

Before deriving the model of inflation risk premium, we start by motivating the exercise. Why would someone be interested in looking at this risk premium? As we will show later, the answer is: because there is a lot of information contained in it, including information about the expected response of the monetary authority to future inflation shocks. In other words, by looking at that inflation risk premium one could infer if market participants expect a more dovish or more hawkish response by monetary authority in the future. For this reason, in the present section we use the case of Brazil to motivate the model and start the study of monetary policy credibility.

Inflation target regime in Brazil begun in 1999. The Central Bank target is over the consumer price index - IPCA. The targets are usually defined and announced in June[4]. The table below present the targets, objectives and results of inflation targeting in Brazil since the adoption of IT:

Since the targets are valid only for the calendar year, we calculated the 12 month ahead target by interpolating the official calendar-year targets. Through out the paper we work with monthly data, so on the coming notation, each t represents a month. Define "Expected Deviation from the Target" as the expected 12 month ahead inflation minus the interpolated 12 month ahead target:

- Expected Deviation from the Target $= E_t\left(\sum_{s=t+1}^{t+12} CPI_s\right) -$ (Interpolated CB Target for the next 12 months).

Twelve months ahead inflation expectations were collected from Brazilian Central Bank's expectation survey. We present in the Chart 1 below the interpolated Central Bank announced target for the next 12

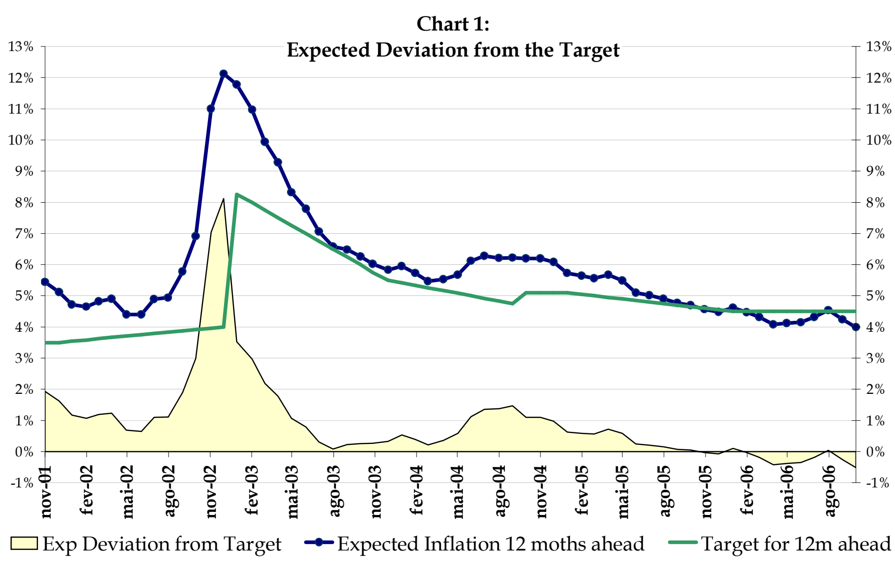
[4] There has been a history of changes in this policy objectives. When a big shock hits the economy and the target is no longer credible, the CB usually announce the objective that it will aim.

Year	Setting Date	Target		CPI Inflation	GDP Growth
1999	30/6/99	8.00%	± 2,00%	8.94%	0.79%
2000	30/6/99	6.00%	± 2,00%	5.97%	4.36%
2001	30/6/99	4.00%	± 2,00%	7.67%	1.31%
2002	28/6/00	3.50%	± 2,00%	12.53%	1.93%
2003	28/6/01	3.25%	± 2,00%	-	-
2003*	27/6/02	4.00%	± 2,50%	-	-
2003*	21/1/03	8.50%	± 2,50%	9.30%	0.54%
2004	27/6/02	3.75%	± 2,50%	-	-
2004*	25/6/03	5.50%	± 2,50%	7.60%	4.94%
2005	25/6/03	4.50%	± 2,50%	-	-
2005**	23/9/04	5.10%	-	5.69%	2.30%
2006	30/6/04	4.50%	± 2,00%	3.07%+	2.98%+
2007	22/6/05	4.50%	± 2,00%	4.15%+	3.49%+

* - Revised Targets.
** - Objective.
\+ - Consensus forecasts (means) on November 17, 2006

Figure 1:

months (solid green line), the inflation expectation for the next 12 months (dark blue line with circles) and the expected deviation from the target (filled area below), which is the difference between them:

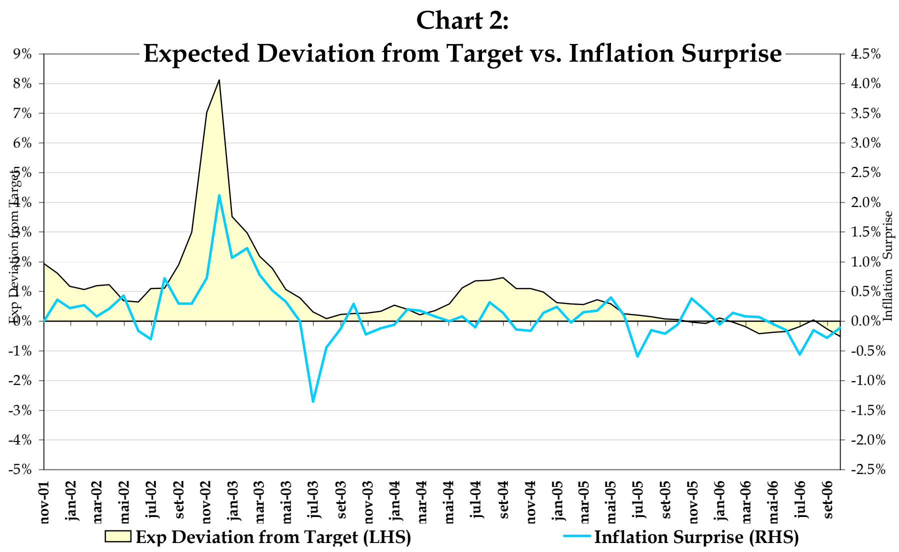


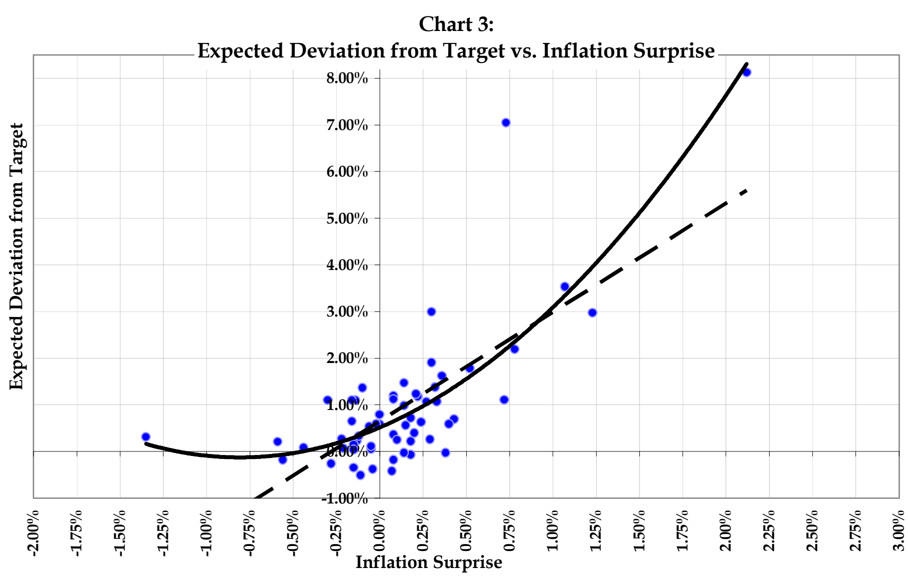
But have short run inflation surprises been affecting these deviations from the announced target in Brazil? We proceed in an empirical investigation to estimate this effect. Define "inflation surprise" as the actual monthly inflation minus the expected inflation for this same month one month ago:

- "Inflation Surprise" $= CPI_t - E_{t-1}(CPI_t)$

In the Appendix we discuss this IPCA inflation surprise in more detail and show its daily-data dynamics. Also in the Appendix we present the a chart depicting the observed 12 month IPCA inflation, the target and the "12 month surprise".

Returning to our point here, the empirical evidence of co-movement between the 1 month inflation surprise and expected deviation from target 12 month ahead in Brazil is presented on Charts 2 and 3 below.





What should be the effect of inflation surprise on the deviation from the target? Under perfect credibility and full commitment to the target, no effect should be observed. The story is different, however, the Central Bank (correctly) accommodates to some extent supply shocks. But even then, we should have a coefficient smaller than one since not all surprises are due to supply shocks. It is important to highlight that the measure of 12 month ahead inflation expectation that we use does not include the current month inflation. For this reason, under perfect credibility and no inflation inertia, the effect on inflation surprise on deviations from the target should always be zero even if the (current) supply shock is accomodated.

The figures above suggest that short run inflation surprises induce significant variation on medium run inflation expectation in Brazil. Linear and polynomial trends were included in the scatter plot and the polynomial one seem to provide a better fit. This indicates that the effect of inflation surprise on the expected deviation from the inflation target is non-linear: it increases with the size of the surprise and negative surprise seem to have negligible effect. This evidence goes against the null of good credibility of monetary policy or no inflation inertia in Brazil.

More careful econometric analysis is certainly needed to investigate that. To control for economic supply side pressures on inflation expectation, we included in our regressions the monthly exchange rate depreciation and also variation in the CRB commodity index. To control for demand side forces expected inflation, we use the CNI's seasonally adjusted installed capacity utilization. Since in the time period analyzed we had a severe confidence crises due to the 2002 elections, we look not only for the whole sample, but we also break it in different sub-periods even with our limited sample size[5].

The regressions presented below reinforce the impression we had by looking at the charts. When we run the regression for the whole period, the effect of inflation surprise on the expected IPCA deviation from the target is statistically significant, even controlling for exchange rate and commodity price effects with a coefficient of 0,77. An interesting fact is the asymmetric effect of positive and negative shocks in the whole sample: a 1% unexpected inflation shock leads to an increase of 1.75% on the 12 month inflation expectation above the CB's target while a negative surprise has no effect[6].

Results from regressions on the different sub-periods[7] indicates that the effect of short run inflation surprise on inflation expectation is diminishing over time. From Nov/2001 to Jun/2003 a 1% unexpected inflation shock provoked a 2,4% increase in expected deviation from the target. On the second subperiod, from Jul/03 to Dec/04, the effect diminished significantly as the effect of the same shock would lead only to an increase of 0,28% on 12 month ahead expected deviation from inflation target. On the more recent period, the effect is not significantly different from zero. Also interesting is the fact that the exchange rate effect on inflation expectations is also diminishing over time. The effects of a 10% depreciation on the expected inflation was around 1% on the first period, decreased to 0,5% in the second period and is now equals to zero.

[5] The sample is limited by the availability of data for inflation expectations, which started to be collected by the Brazilian Central Bank in 2001.

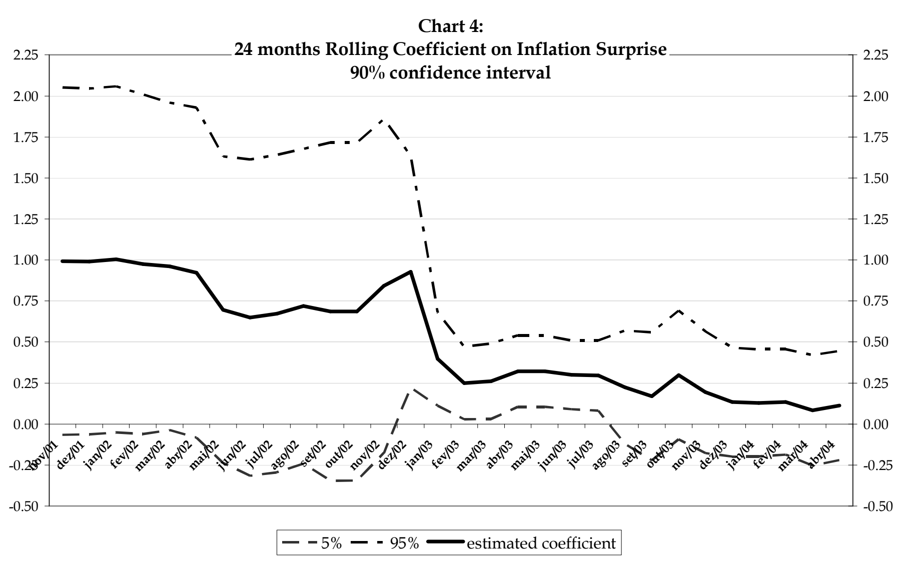
[6] This result is not robust to all sub-samples.

[7] In the sub-period regresions, we do include the control variables that didn't show up significant in the whole sample analysis because of the limited sample size.

OLS estimates	Dep Variable: Expected Deviation from Target = E(IPCA 12 month) - CB announced target 12 meses ahead							
	Eq. 1A	Eq. 1B	Eq. 2A	Eq. 2B	Eq. 3A	Eq. 3B	Eq. 4A	Eq. 4B
C	-0.010	-0.048	0.005	0.004	0.000	0.001	0.000	-0.001
	(0.879)	*(0.477)*	*(0.307)*	*(0.387)*	*(0.530)*	*(0.278)*	*(0.237)*	*(0.211)*
AR_1	0.665	0.488	0.233	0.225	0.996	0.998	0.909	0.898
	(0.000)	*(0.000)*	*(0.365)*	*(0.409)*	*0.000*	*0.000*	*0.000*	*0.000*
Surprise	**0.770**	-	**2.427**	-	**0.284**	-	-0.103	-
	(0.023)	-	***(0.019)***	-	***(0.022)***	-	*(0.510)*	-
Positive Surprise	-	**1.753**	-	**2.489**	-	-0.186	-	0.116
	-	***(0.002)***	-	***(0.032)***	-	*(0.677)*	-	*(0.762)*
Negative Surprise	-	-0.154	-	1.790	-	**0.389**	-	-0.229
	-	*(0.757)*	-	*(0.690)*	-	***(0.018)***	-	*(0.344)*
d(%XR(-1))	**0.068**	**0.072**	**0.098**	**0.095**	**0.051**	**0.044**	0.010	0.013
	(0.004)	***(0.002)***	***(0.039)***	***(0.066)***	***(0.008)***	***(0.027)***	*(0.303)*	*(0.237)*
d(%Commodities(-1))	0.011	0.017	-	-	-	-	-	-
	(0.771)	*(0.643)*	-	-	-	-	-	-
Capacity Utilization(-1)	0.000	0.001	-	-	-	-	-	-
	(0.857)	*(0.470)*	-	-	-	-	-	-
Adjusted R2	0.737	0.758	0.658	0.634	0.872	0.874	0.810	0.805
Durbin-Watson stat	1.704	1.479	1.465	1.412	1.857	1.811	1.521	1.620
AIC	-6.772	-6.840	-5.812	-5.708	-9.736	-9.716	-9.883	-9.823
Sample	Nov/01 - Oct/06	Nov/01 - Oct/06	Nov/01 - Jun/03	Nov/01 - Jun/03	Jul/03 - Dez/04	Jul/03 - Dez/04	Jan/05 - Out/06	Jan/05 - Out/06
N. Observations	*58*	*58*	*19*	*19*	*18*	*18*	*22*	*22*

P-values reported between parentheses

The choice of those 3 sub-periods was made in order to account for: (i) the pre and post electoral crises (Nov/01 - Jun/03), (ii) the re-built of the credibility under the new government (Jul/03 - Dec/04) and (iii) the present period (Jan/05 - Oct/06). Nonetheless, the choice of the specific dates for those periods was arbitrary. Hence, to better depict how this effect has been evolving over time, we also estimated 24 month rolling regression. The chart below present the results of the 90% confidence interval of the inflation surprise coefficient. Clearly, as previously noted, the effect of inflation surprise on deviation of inflation expectation over the target has diminished over time. Moreover, there seems to be 3 stable plateau levels for the coefficient: very high, lower but still significant and then low and insignificant.



To summarize, the overall evidence is that medium run inflation expectation was very sensitive to short run surprises in Brazil. More recently, apparently, this has not been a problem anymore. This does not mean, however, that it will not become again a problem in the future, as the Central Bank is not independent in Brazil yet.

For sake of comparison, we implement similar analysis with international data. Since we do not have the same disaggregation level available in international data[8] as we have in Brazil, the analysis is slightly different. Instead of using short run inflation surprises directly, we assume that the 1 month ahead inflation expectation is current month inflation, i.e., agents make projections as if monthly inflation were a random walk. We also modify the dependent variable, instead of using the expected deviation from the target we simply use the 12 month ahead inflation expectation, since some of the countries didn't have an announced target on our sample. We used market expectations survey and their sources are each country's central bank. We also run an instrumental variable regression where we use the lagged first difference of inflation as an instrument to the inflation surprise. The results are shown below:

OLS estimates — **Dep Variable: E(CPI 12 month/t) - E(CPI 12 month/t-1)**

	CHILE	BRAZIL	TURKEY	UK	MÉXICO	ISRAEL
C	0.000	0.037	-0.903	-0.004	-0.086	-0.164
	(0.992)	*(0.824)*	*(0.012)*	*(0.840)*	*(0.052)*	*(0.322)*
d(Monthly Inflation(-1))	0.063	0.521	-0.044	-0.002	-0.052	0.143
	(0.325)	*(0.022)*	*(0.866)*	*(0.935)*	*(0.420)*	*(0.492)*
d(%XR(-1))	2.141	3.428	8.830	-1.200	2.488	15.979
	(0.027)	*(0.108)*	*(0.059)*	*(0.128)*	*(0.158)*	*(0.029)*
d(%Commodities(-1))	-1.611	-1.760	-13.070	1.554	1.073	-3.590
	(0.020)	*(0.628)*	*(0.161)*	*(0.112)*	*(0.329)*	*(0.734)*
R2	0.256	0.189	0.166	0.101	0.105	0.083
Durbin-Watson stat	1.438	1.146	1.394	2.075	1.832	1.111
AIC	-0.662	2.252	3.697	-0.887	-0.443	2.739
Sample	Oct/2001 - Oct/2004	Jan/2002 - Mar/2005	Oct/2001 - Nov/2004	Oct/1997 - Dec/2003	Jun/2001 - Sep/2004	Feb/1992 - Jan/1996
N. Observations	*37*	*39*	*38*	*75*	*40*	*48*

P-values in parenthesis

OLS estimates — **Dep Variable: E(CPI 12 month/t) - E(CPI 12 month/t-1)**

	CHILE	BRAZIL	TURKEY	UK	MÉXICO	ISRAEL
C	0.000	0.024	-0.858	-0.006	-0.086	-0.139
	(0.990)	*(0.885)*	*(0.011)*	*(0.729)*	*(0.054)*	*(0.397)*
d(Monthly Inflation)	0.028	0.501	0.333	0.027	-0.016	-0.359
	(0.479)	*(0.062)*	*(0.084)*	*(0.416)*	*(0.846)*	*(0.061)*
d(%XR(-1))	2.583	2.701	8.221	-1.416	2.308	15.905
	(0.015)	*(0.136)*	*(0.072)*	*(0.178)*	*(0.200)*	*(0.012)*
d(%Commodities(-1))	-1.494	-0.790	-13.870	0.650	1.162	-7.472
	(0.041)	*(0.792)*	*(0.226)*	*(0.177)*	*(0.269)*	*(0.503)*
R2	0.219	0.178	0.219	0.064	0.096	0.123
Durbin-Watson stat	1.342	1.324	1.342	2.029	1.870	1.113
AIC	3.632	2.266	3.632	-0.846	-0.432	2.694
Sample	Oct/2001 - Oct/2004	Jan/2002 - Mar/2005	Oct/2001 - Nov/2004	Oct/1997 - Dec/2003	Jun/2001 - Sep/2004	Feb/1992 - Jan/1996
N. Observations	*37*	*39*	*38*	*75*	*40*	*48*

P-values in parenthesis

[8] We don't have 1 month ahead inflation to any country besides Brazil. Moreover, usually the data is for inflation expectaion for a given year, not for the following 12 months.

The results shown on the tables above suggest that in Brazil and Turkey[9] this effect is positive while in Chile, UK, Mexico and Israel there seems to be no effect at all.

Hence, the evidence so far is that short run inflation surprises induced a significant variation on medium run inflation expectation in Brazil (for the largest part of our sample), differently from most other countries. We conjectured that this phenomenon was happening for two (non mutually exclusive) reasons:

- Indexation of the economy.
- Lack of credibility of the Central Bank.

It is hard to argue that there is no remaining indexation in Brazil. A large part of the Brazilian CPI basket is composed of goods and services with managed prices. For instance, a quick look at public concession contracts such as telephony and energy services reveals that inflation indexation is quite alive: they are adjusted annually by the previous 12m inflation.

What we are interested in is in figuring out if, besides inflation inertia, the lack of credibility was also present. If this is the case, the benefit of an independent Central Bank would be clear. For the endeavor, what we propose in the next section is a methodology to identify if the phenomenon itself is somehow related to the lack of credibility of the Central Bank and then, in the fourth section, we apply it to the Brazilian data. The idea is to track *"Inflation Risk Premium"* movements.

3 The Model

Let us start by formally defining the "break even inflation" (also called "market inflation") and the "inflation risk premium":

- "Break Even Inflation" = (1+Nominal Rate)/(1+ Real Rate)-1
- Inflation Risk Premium = (Break Even Inflation) - (Expected inflation)

The main message of the model is the following: If the cause of the effect of short run inflation surprise on 12 month inflation expectation is solely indexation, there is no reason for an increase in the uncertainty when the economy is hit by a positive inflation shock: we know that the prices will be re-adjusted in the future with certainty. However, if there is lack of credibility on monetary policy, there will be an increase in the uncertainty on future responses to inflation, leading to an increase in the uncertainty on inflation itself. This will be captured by the inflation risk premium. We now formalize this argument.

[9] In Turkey the effect is not observed when we run the instrumental variable regression.

3.1 Asset Pricing and the Inflation Risk Premium

Define an economy with two assets: a nominal bond ($P_t^{\$}$) and a real bond ($P_t$). These bonds will be freely traded in the market. In order to price them, we will impose absence of arbitrage. This imply that there is a strictly positive stochastic discount factor M_{t+1} such that for any stochastic *nominal payoff* X_{t+1} to be observed in $t+1$, its time t price will be given by $P_t = E_t\left[M_{t+1}X_{t+1}\right]$. If markets were complete, the stochastic discount factor used to price any asset in this economy would be the same. We don't need that much, we can have incomplete markets since the M_{t+1} used to price the real bond can also be one of the stochastic discount factors used to price the nominal bond.

In this setting, if the *nominal payoff of the real bond is* Π_{t+1}, i.e., (1+inflation%), and the *nominal payoff of the nominal bond is* \$1, their prices will be:

- Real Bond: $P_t = E_t\left[M_{t+1}\Pi_{t+1}\right]$
- Nominal Bond: $P_t^{\$} = E_t\left[M_{t+1}\$1\right]$

If an investor buys a nominal bond he will not be hedged against inflation, so a nominal bond needs to compensate investors for inflation risk. Notice that if $E_t\Pi_{t+1} > 1$, then $P_t^{\$} < P_t$ or, in other words, the real rate will be smaller than the nominal rate.

The log real rate is $r_t \equiv -\ln P_t$ and the log-nominal rate is $r_t^{\$} \equiv -\ln P_t^{\$}$. We can specify the process of the short rate and the prices of risk which is equivalent to specifying a process for the stochastic discount factor. Our main hypothesis is that this short rate process is defined by the Central Bank and can be characterized by a state-dependent "Taylor rule". This is already usual in the recent Macro-Finance term structure literature and is also done in Ang & Piazzesi (2003), Rudebusch & Wu (2004) and Bonomo & Lowenkron (2006). Define the Taylor rule as:

$$r_t = \delta^0 + \delta_t^1 X_t \tag{1}$$

In (1) X_t are the state variables of the economy that affects the decision of the Central Bank, such as current inflation and output. Notice that we allow the Central Bank response to state variable shocks to be time-varying[10]. Let the dynamic of the state variables be driven by a VAR process:

$$X_t = \mu + \Phi X_{t-1} + \varepsilon_t$$

We also suppose that those sources of uncertainty on the economy are associated with a vector λ containing the prices of risk of each state variable of the economy. We follow Vasicek (1977) and suppose

[10] Think of that in an monetary policy framework where the Central Bank is not independent: there is a possibility that, for electoral reasons, the cuntry's president can change the staff of the Central Bank, generating a change in its Taylor rule.

that the prices of risk are not time varying[11]. To use the pricing formulas above, we must find the stochastic discount factor and the connection between the short rate and the stochastic discount factor is given by the Radon-Nikodym[12] derivative ξ_{t+1} that changes the probability measure to a martingale equivalent one:

$$\xi_{t+1} = \xi_t \exp\left(-\frac{1}{2}\lambda'\lambda - \lambda'\varepsilon_{t+1}\right) \tag{2}$$

Recall that ε_{t+1} is the vector of uncertainties affecting the state variables X_{t+1}.

The stochastic discount factor (or pricing kernel) will be given by:

$$M_{t+1} = \exp(-r_t)\frac{\xi_{t+1}}{\xi_t} \tag{3}$$

Substituting eq. (1) and eq. (2) in eq. (3), we get:

$$m_{t+1} \equiv \ln M_{t+1} = -\frac{1}{2}\lambda'\lambda - \delta^0 - \delta_t^{1'} X_t - \lambda'\varepsilon_{t+1} \tag{4}$$

Now we can calculate the prices of the relevant securities. Our task is to understand what affect the inflation risk premium, which is defined by the difference between the log "Break Even Inflation" ($\log \Pi_{t+1}^{BE}$), and the agent's log expected inflation ($\log E_t(\Pi_{t+1})$). The "break even inflation" is simply the inflation rate implicit on the financial securities, and it can be measured by the nominal forward rate minus the forward real rate $\log \Pi_{t+1}^{BE} = f_{t+1}^{\$} - f_{t+1}$. So, these are the securities that we are interested in to calculate the inflation risk premium.

Define $m_{t+1} \equiv \ln M_{t+1}$, $\pi_{t+1} \equiv \ln \Pi_{t+1}$ and suppose that M_t and Π_{t+1} are jointly lognormally distributed. In this setting, the price of the 1 period nominal bond will be given by:

$$p_t^{1\$} = E_t(m_{t+1}) + \frac{1}{2}Var_t(m_{t+1}) \tag{5}$$

And the price of the real bond will be given by:

$$p_t^1 = E_t(m_{t+1}) + E_t(\pi_{t+1}) + \frac{1}{2}Var_t(m_{t+1}) + \frac{1}{2}Var_t(\pi_{t+1}) + Cov_t(m_{t+1}, \pi_{t+1}) \tag{6}$$

In the same way, we can also calculate the price of the 2 period nominal and real bonds[13]. Using these formulas, we calculate the 1 period real forward rate, which is given by $f_t = p_t^1 - p_t^2$ and the 1 period nominal forward rate, given by $f_t^{\$} = p_t^{1,\$} - p_t^{2,\$}$:

$$f_t^{\$} = -E_t(m_{t+2}) - \frac{1}{2}Var_t(m_{t+2}) - Cov(m_{t+1}, m_{t+2}) \tag{7}$$

[11] Later, we will discuss what would be the implications of relaxing this hypothesis. We will argue that, for our purpuses, it wouldn't make much difference.

[12] Radon-Nikodym derivative changes the probability measure to a maringale equivalent one. However, to price assets, it is equivalent to work with the present value of the expected payoff under the martingale equivalent measure or the expected payoff multiplied by the stochastic discount factor.

[13] This calculation is shown in the appendix.

$$\begin{aligned} f_t &= -E_t\left(m_{t+2}\right) - E_t(\pi_{t+2}) - \frac{1}{2}Var_t\left(m_{t+2}\right) - \frac{1}{2}Var_t(\pi_{t+2}) - \\ &\quad -Cov(m_{t+1}, m_{t+2}) - Cov(\pi_{t+1}, \pi_{t+2}) - \\ &\quad -Cov_t(m_{t+1}, \pi_{t+2}) - Cov_t(m_{t+2}, \pi_{t+1}) - Cov_t(m_{t+2}, \pi_{t+2}) \end{aligned} \tag{8}$$

To calculate the inflation risk premium we also need the expected log inflation that under the log-normality assumption is given by:

$$\log E_t(\Pi_{t+1}) = E_t(\pi_{t+1}) + \frac{1}{2}Var_t(\pi_{t+1})$$

The formula of the 2 period inflation $\Pi_{t+2} = e^{\pi_{t+1}+\pi_{t+2}}$ is given by:

$$\log E_t(\Pi_{t+2}) = E_t(\pi_{t+2}) + E_t(\pi_{t+1}) + \frac{1}{2}Var_t(\pi_{t+1}) + \frac{1}{2}Var_t(\pi_{t+2}) + Cov(\pi_{t+1}, \pi_{t+2})$$

In turn, the expectation of the log 1 period inflation in $t+2$ will be:

$$\log E_t(\Pi_{t+2}/\Pi_{t+1}) = E_t(\pi_{t+2}) + \frac{1}{2}Var_t(\pi_{t+2}) + Cov(\pi_{t+1}, \pi_{t+2}) \tag{9}$$

Now we are ready to calculate the inflation risk premium substituting out the equations (7), (8) and (9) on the following definition:

$$\begin{aligned} \textit{Inflation Risk Premium}_t &\equiv \log \Pi^{BE}_{t+1} - \log E_t(\Pi_{t+2}/\Pi_{t+1}) \\ &= f^{\$}_t - f_t - E_t(\pi^f_{t+2}) \\ &= Cov_t(m_{t+1}, \pi_{t+2}) + Cov_t(m_{t+2}, \pi_{t+1}) + Cov_t(m_{t+2}, \pi_{t+2}) \end{aligned} \tag{10}$$

To relate the Taylor rule with inflation risk premium, we still need to substitute the s.d.f. equation (4). We also get rid of constant terms, that are irrelevant for the covariance, and arrive at:

$$\textit{Inflation Risk Premium}_t \equiv Cov_t(-\delta^{1'}_t X_t - \lambda' \varepsilon_{t+1}, \pi_{t+2}) + Cov_t(-\delta^{1'}_t X_{t+1} - \lambda' \varepsilon_{t+2}, \pi_{t+1}) + Cov_t(-\delta'_1 X_{t+1} - \lambda' \varepsilon_{t+2}, \pi_{t+2}) \tag{11}$$

In the next section we will impose some further restrictions to get a more tractable formula for the inflation risk premium.

3.2 Taylor Rule, Inflation Dynamics and the Inflation Risk Premium

Let us recall the main motivation of the paper. The empirical evidence presented in Section 2 was that short run inflation surprises induced a significant variation on medium run inflation expectation in Brazil, differently from most other countries. We conjecture that this phenomenon could be happening for two (non mutually exclusive) reasons:

- Indexation of the economy.
- Lack of credibility of the Central Bank.

As said before, it would be hard to argue that there is no remaining indexation in Brazil. What we are interested in is in figuring out if the lack of credibility is also present. The strategy that we are suggesting is to look at the effects of inflation surprises in inflation risk premium, which brings information about future responses to inflation shocks. In order to have more clear equation determining inflation risk premium, we will further parametrize and impose more structure in the model.

We start with the equation for inflation dynamic. A natural question that arises is: Can inflation inertia be the responsible for variations in inflation risk premium? For this reason, in the model we will allow inflation to have an inertia component. Assume that the log inflation has a certain degree of persistence, a long run average and that it is affected by monetary policy. The equation proposed is given by:

$$\pi_t = (1 - \phi_\pi)\mu_\pi + \phi_\pi \pi_{t-1} - \phi_r(r_{t-k} - \overline{r}) + \varepsilon_t^\pi \tag{12}$$

Where, μ_π is the long-run "natural inflation"; ϕ_π is the inflation inertia (degree of indexation of the economy); ϕ_r is the inflation sensitivity to monetary policy, $\varepsilon_t^\pi \sim N(0, \sigma)$ is the inflation shock at time t and; k is the lag with which the monetary policy affects the economy.

Now we turn to the Taylor rule. We permit for central bank's response to be time varying. Think of that as the possibility of changes in the board of the Central Bank. Without Central Bank independence, the government can appoint the CB board according to its will.

Since we already know that all that matters for inflation risk premium is the covariance of inflation with the stochastic discount factor, we just need to worry about the Central Bank responses to inflation shocks without any loss generality. Recall that ε_t^π is the unexpected inflation shock at time t. We will allow the central bank to respond to contemporaneous inflation shocks (ε_t^π) and/or any past inflation shocks ($\varepsilon_{t-j}^\pi,_{for\ j \geq 1}$), with different elasticities of response to each one of them. The idea is that with this formulation, we could account for as many kinds of monetary rules as possible. The state-dependent Taylor Rule will be given by:

$$r_t = \overline{r} + \delta_0^\theta \varepsilon_t^\pi + \delta_1^\theta \varepsilon_{t-1}^\pi + \delta_2^\theta \varepsilon_{t-2}^\pi + ... \tag{13}$$

Where $\overline{r}$ is the long run "natural" interest rate. δ_t^θ is the type θ monetary authority policy response[14] to inflation shock at time t.

[14] Should the monetary authority react to current inflation shocks ε_t^π raising interest rates if it wants to diminish inflation, i.e., should $\delta > 0$? If the $k = 0$ the answer is clearly yes. But it is also easy to see that even if the monetary policy affect the economy with some lag ($k > 0$), the central bank will want to have $\delta > 0$ if we have some inflation inertia ($\phi_\pi > 0$).

Now, we are ready to find a more simple expression for inflation risk premium expression (11) substituting in it the Taylor rule equation (13) and the inflation dynamics equation (12):

$$\begin{aligned} \textit{Inflation Risk Premium}_t &= [-\lambda - \delta_o]\,(1+\phi_r)\sigma^{\pi} \quad \text{if k=0} \\ &= (-\lambda - \delta_o)\sigma^{\pi} \qquad\qquad\quad \text{if k>0} \end{aligned} \tag{14}$$

This is enough to see that indexed economy does not provoke a positive relation between inflation surprises and inflation risk premium, since the indexation parameter ϕ_{π} does not appear in equation (14) neither in the more general equation (11)[15].

Would could cause variations in the inflation risk premium then? There are only 3 possible causes[16] of variations in inflation risk premium: (1) variations in the conditional expected volatility of future inflation σ^{π}_{t+1}; (2) variations in the price of risk of inflation λ; (3) variations in the expected central bank response to future inflation shocks δ^1_{t+1}. Notice that here we have even relaxed the hypothesis that market price of risks are constant. Therefore, these are the only three possibilities without imposing any further assumption[17].

On this paper, we will focus only on the third possible explanation: variations in the expected CB responses to inflation. The basic insight is already in equation (14): consider two types of Central Bank, a tougher one that responds aggressively to a contemporaneous inflation shock (high δ^1) and a second type, that has a loose monetary policy and do not respond so much to contemporaneous inflation shock (low δ^1). The tight monetary authority type will be associated with a lower inflation risk premium.

Suppose that there can be two types of Central Bank: (i) one more committed to fight inflation, i.e, with a higher interest rate response to inflation shock δ^H; and (ii) one less committed to fight inflation, i.e, with a lower interest rate response to inflation shock δ^L. Moreover, let p_t denote the conditional probability at time t of the type of monetary authority in $t+1$ being L and $(1-p_t)$ the the conditional probability at time t of the type of monetary authority in $t+1$ being H.

Now we can have a clearer expression to equations (10) and (11):

$$\begin{aligned} \textit{Inflation Risk Premium}_t &= \left[p_t(-\lambda-\delta^L_o) + (1-p_t)(-\lambda-\delta^H_o)\right](1+\phi_r)\sigma^{\pi} \quad \text{if k=0} \\ &= \left[p_t(-\lambda-\delta^L_o) + (1-p_t)(-\lambda-\delta^H_o)\right]\sigma^{\pi} \qquad\qquad\quad \text{if k>0} \end{aligned} \tag{15}$$

[15] If the indexation was time-varying then this term would be present in equation (14), thus this result is not robust to the that. However, we think that indexation of an economy is a very low frequency characteristc of an economy and, therefore, should not affect the result.

[16] Actually, if one go back to equation (11) will see that the relevant covariance is the one the state variables in the vector X_t. Inflation π_t is certainly one of them, but if there were contemporaneous covariance between π_t and other state variables to which the Central Bank react to through its Taylor rule, there would be other possibilities besides those 3.

[17] The only necessary hypothesis are: (i) absence of arbitrage, (ii) linear Taylor rule and (iii) linear price of risk and (iv) the contemporaneous covariance of inflation with other variables entering the Taylor rule is negligible.

According to our formulation, if we observe a positive relation between inflation surprises and inflation risk premium, what is happening is that a positive inflation shocks is inducing an increase in the perceived probability p_t that that the monetary policy next period will be more loose than the current one.

What could induce that perception? Recall that we supposed that we do not have Central Bank independence, so the chief of government (president) can choose to change the board according to his will. As an election approaches, if the economy is hit by negative shocks (such as negative shocks) there will be an increase in the probability in the change in the governing party. If moreover the new party have different preference concerning how hard should on fight inflation by increasing interest rates, a variation in risk premium will be observed.

Another possibility is strategic behavior by the incumbent government. Let us suppose that there is a short run trade off between inflation and output gap as in a Phillips curve. Suppose also that output gap affects voters evaluation of the incumbent government negatively and politicians care only about being elected as in an "opportunistic"[18] model in the spirit of Persson and Tabellini (1990) and Rogoff and Silbert (1988). These models have a non-observable competence term. The voters don't know if the better outcome was achieved by exploiting the Phillips curve or by a higher competence of the government so they vote for the incumbent when output is good (or at least not too bad). A positive relation between unexpected inflation shocks and inflation risk premium reflects financial agents expecting a change in the conduction of monetary policy towards a not so tight one, since the scenario is not so benign to the incumbent government. In turn, this happens because due to electoral concerns, the president can change the board of the Central Bank if the state of the nature (inflation shocks) is not in his favour. If Central Bank were independent, certainly this problem wouldn't happen.

To reconcile that last reasoning with our result that some agents are predicting a change in future responses to inflation shocks (change in the Taylor rule) we would need to introduce asymmetric information. Suppose that the agent who trades in the financial market and determine prices is not the *median voter*. This last hypothesis is done in Mankiw and Zeldes (1991): they observe that only a fraction of the families invest on the financial market in the USA and then use that to try to solve the equity premium puzzle[19]. We claim that it makes sense (and is also legitimized in the literature) to use different representative agents: one to price the assets and the other to elect the government. So think as our result under this political economy reasoning as if positive relation between unexpected inflation shocks and inflation risk premium reflects financial agents expectation, not the median voter expectation.

[18] Nordhaus (1975) and Lindbecck (1976) introduced this approach but in their model, voters are naïve and the agents do not have rational expectations.

[19] The volatitlity of consumption of equity investors is much higher than the average US resident, so in a CCAPM model the s.d.f. is more volatile, requiring a much smaller risk aversion to calibrate for the data on equity returns.

To conclude, in our formulation, if inflation risk premium is changing in the presence of positive unexpected inflation shocks agents are fearing that the "type" of the monetary policy can change. Precisely, agents are fearing a loosening of monetary policy $\delta^L < \delta^H$ when the economy is hit by a positive inflation shock, causing an increase in inflation risk premium[20]. This fact has a deleterious effect on economy since the inflation expectations should also increase in the presence of this shock, what makes monetary more costly in terms of output loss. It should be clear that we are not saying that lack of credibility of the monetary policy is the only factor: inflation indexation can be important too[21]. Thus, if the the empirical pattern indicate this positive relation this is an indication that there would room to reduce the cost of monetary policy by promoting Central Bank independence.

4 Inflation Risk Premium in Brazil

What could be causing the positive relation between short run inflation surprise and medium run inflation expectation as identified in Brazil in section 2? Does monetary policy credibility plays a role in that? The results from last section indicates that looking at the relation between inflation surprise and inflation risk premium helps to determine if the phenomenon is somehow related to the lack of credibility of the Central Bank. In this section we investigate if this is present in the Brazilian data.

The intuition of the model was that if the cause of the effect of short run inflation surprise on 12 month inflation expectation is solely indexation, there would be no reason for an increase in uncertainty when the economy is hit by a positive inflation shock: we know that the prices will be readjusted in the future with certainty. However, if there is lack of credibility on monetary policy, there would be an increase in the uncertainty on future responses to inflation which, in turn, would lead to an increase in the uncertainty on inflation itself. This will be capture by the inflation risk premium.

Now we look at the empirical relation between inflation risk premia and inflation surprises in Brazil. There was no liquid market for bonds indexed to IPCA until recently, so we had to resort to a different inflation index: IGPM[22]. All over the time frame analyzed, there was a liquid market for government bonds indexed to this inflation indexed, the NTN-Cs. The data used in the analysis is the interpolated 1 year real rate and 1 year nominal rate[23], both provided Brazil's Future and Mercatile Exchange (BM&F) and the survey of market expectation for IGPM 1 year inflation, which was obtained again in Brazilian

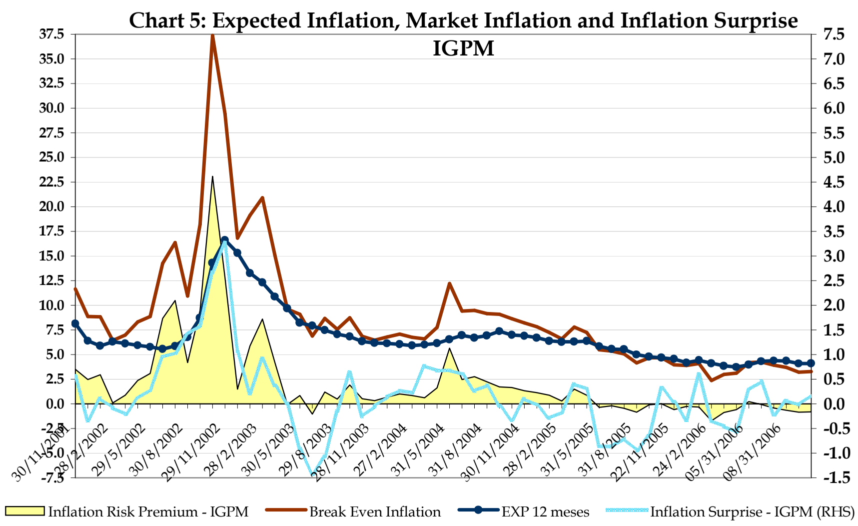
[20] An important observation made by Ilan Golfaijn is that the expected loosening of the monetary policy do not necessarily have to be associated with a lack of credibility of the monetary authority. If agents expect that during some period, supply shocks will be the dominant type of shocks, they can rationally expect a smaller interest rate response than before. And this response by the monetary authority is compatible with the optimal response, as in Woodford (2002).

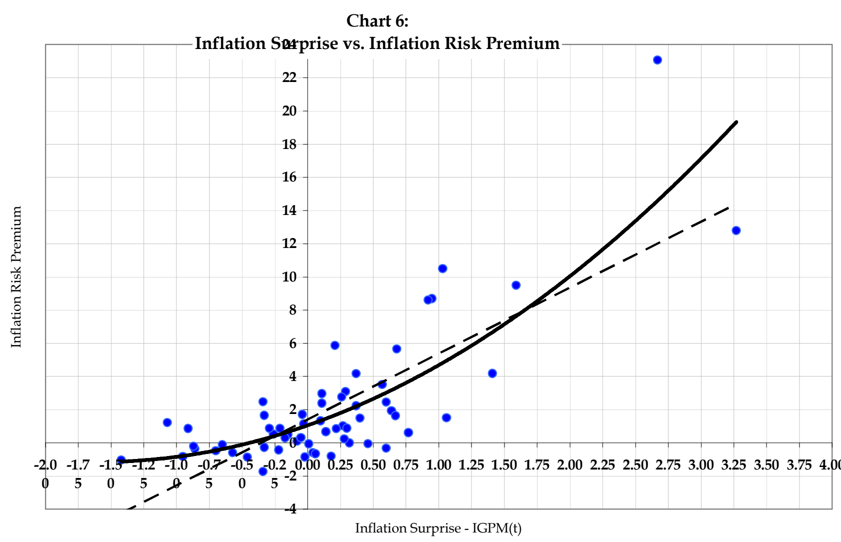
[21] And as said before, we think it is as the examples of the public services contracts such as telephones and energy points out.

[22] This is a general price index, basically an average of producer price index and consumer price index.

[23] Swap DI-pré 1 year.

Central Bank survey database. Below, we present graphs of the evolutions of these series. The brown line is the break even inflation, the dark blue line with circles is the 12 month expected inflation. The difference between these two is the Inflation risk premium, represented by the shaded area. The short run inflation IGPM surprise[24] is the light blue line. We also present scatter plot:





As in the case of expected deviation from the target analyzed in section 2, we also fin here a clear pattern of positive relation between inflation surprise and inflation risk premium. As stressed by our model, this indicates that the episode documented in section 2 is more likely to be associated with

[24] Calculated just like the the IPCA surprise.

expectation of more dovish monetary policy. As before, we continue our investigation with a series of regressions, which are presented below:

OLS estimation	**Dep Variable: IGPM Inflation Risk Premium**							
	Eq. 5A	Eq. 5B	Eq. 6A	Eq. 6B	Eq. 7A	Eq. 7B	Eq. 8A	Eq. 8B
C	-0.794	-1.199	3.444	3.154	0.436	0.813	-1.475	-1.407
	(0.17)	*(0.03)*	*(0.21)*	*(0.18)*	*(0.81)*	*(0.73)*	*(0.01)*	*(0.01)*
AR_1	-0.008	-0.152	-0.532	-0.755	0.211	0.221	0.329	0.374
	(0.95)	*(0.24)*	*(0.09)*	*(0.01)*	*(0.38)*	*(0.38)*	*(0.09)*	*(0.08)*
Surprise	**2.276**	-	**5.908**	-	**1.092**	-	**0.631**	-
	(0.00)	-	***(0.00)***	-	***(0.08)***	-	***(0.01)***	-
Positive Surprise	-	**4.116**	-	**8.207**	-	1.478	-	0.936
	-	-	-	***(0.00)***	-	*(0.36)*	-	*(0.13)*
Negative Surprise	-	0.336	-	2.765	-	0.714	-	0.427
	-	*(0.69)*	-	*(0.17)*	-	*(0.65)*	-	*(0.33)*
d%XR	12.475	10.191	6.728	2.205	12.412	13.626	**5.895**	**6.501**
	(0.10)	*(0.15)*	*(0.70)*	*(0.88)*	*(0.33)*	*(0.33)*	***(0.03)***	***(0.03)***
d%Commodities	-5.147	-7.920	-38.431	-44.023	-3.432	-2.591	**5.952**	**5.820**
	(0.61)	*(0.40)*	*(0.19)*	*(0.09)*	*(0.78)*	*(0.85)*	***(0.05)***	***(0.06)***
Embi+ Brazil	**0.372**	**0.329**	0.135	0.089	0.119	0.024	**0.423**	**3.000**
	(0.00)	***(0.00)***	*(0.57)*	*(0.66)*	*(0.68)*	*(0.96)*	***(0.01)***	***(0.04)***
Adjusted R2	*0.743*	*0.779*	*0.725*	*0.800*	*0.219*	*0.159*	*0.734*	*0.722*
D-W	*1.995*	*1.924*	*2.093*	*2.406*	*2.262*	*2.256*	*1.783*	*1.786*
AIC Criteria	*4.398*	*4.262*	*5.334*	*5.042*	*3.441*	*3.540*	*1.033*	*1.103*
Sample	**Nov/01 - Oct/06**	**Nov/01 - Oct/06**	**Nov/01 - Jun/03**	**Nov/01 - Jun/03**	**Jul/03 - Dez/04**	**Jul/03 - Dez/04**	**Jan/05 - Out/06**	**Jan/05 - Out/06**
N. Observations	*58*	*58*	*19*	*19*	*19*	*19*	*22*	*22*

P-values between brackets

The coefficient on inflation surprises is positive and significant in all specifications. In all of the estimated equations the magnitude is much greater than the ones in the inflation expectation regressions. On average a 1% inflation surprise increase inflation risk premium in 2.28% (Eq. 5A). Asymmetric effects are also present in the whole sample analysis (Eq. 5B) as a 1% positive surprises have 4.11% effect on inflation risk premium and a negative surprise have an insignificant effect .

Interestingly, the EMBI spread also have a positive effect in inflation risk premium but its inclusion don't change the significance of inflation surprises[25]. We could interpret that as accounting for variations in the risk aversion, the parameter λ in our model.

As on the previous analysis, the effect has clearly been diminishing in recent time. This can be seen by the evolution of the surprise coefficient in regressions. The effect of 1% inflation surprise in the first sample period was 5.9% (eq. 6A), became 1.0% in the second sample period (eq. 7A) and is right now very small, but still significant, at a 0.6% level (eq. 8A). The choice of the sample periods had the same objective as in section 2 but as they were arbitrary, we also plot the result of 24 month rolling regression in the Chart 7 below:

[25] Recall that earlier we said that one of the possible causes of the time variation in inflation risk premium is a time varying price of risk. Embi is the usually the best instrument for risk aversion in Brazil and its inclusion does not change the significance of short run inflation surprises. Thus, we believe that the effect that we are focusing in, namely the expected change in Taylor rule, is indeed present.

Chart 7:
24 months Rolling Coefficient on Inflation Risk Premium

So not only the expected deviation of the inflation from the targeting was responding to short run inflation surprises as we already knew from section 2 results. The evidence presented in this section is that at the same time, inflation risk premium was responding very strongly as well to those shocks. According to the model proposed in section 3, the interpretation to this fact is that agents did not believe that the same interest rate response to inflation shocks would continue in the following 12 months: a relaxation in the fight against inflation was expected. Possible reasons for that were already discussed.

Variations in the expected monetary authority response to future inflation shocks, i.e., the credibility of the ongoing policy, is certainly not the only possible explanation for the phenomenon we have documented here. Our general model also suggested that another possibility for time-varying inflation risk premium is the presence of heteroskedasticity in unexpected inflation shocks. But economically what would this mean? We believe that this could also be (but not necessarily would be) associated with lack of credibility in the monetary authority as big surprises would be followed by big surprises. And those surprises could be big precisely because of a confidence crisis as we had in 2002 in Brazil. The third and last possibility, also according to our general model, would be a time varying market price of risk for inflation λ. In the regressions we allowed the inflation risk premium to depend on the best proxy we found to a "price of risk", the EMBI+ Brazil spread. If that is a good measure of price of risk, its inclusion did not drive out the importance of inflation surprises. Therefore we conclude that variations in the expected monetary policy response to inflation shocks was important in Brazil during the time period analyzed. This is an indication that imperfect credibility in the monetary arrangement contributed to to clogging a transmission channel of the monetary policy, therefore imposing a higher equilibrium real rate than otherwise.

5 Conclusion

Short run inflation surprises has been affecting medium run inflation expectations in Brazil. This is a symptom of at least one of two problems: (i) Inflation inertia / indexation of the economy; and/or (ii) lack of credibility of the monetary authority. The remedy depends on the cause. For instance, if the reason is simply indexation, central bank independence would not help.

We presented a model arguing that movements in inflation risk premium can help to identify if credibility is one of the causes of this phenomenon. Empirical results indicate that in Brazil, inflation surprises have pushed expected inflation away from the target and have also driven inflation risk premium up for most of our sample. This is an indication that imperfect credibility in the monetary arrangement was clogging an important transmission channel of the monetary policy and, therefore, imposing a higher equilibrium real rate than otherwise. We conclude, therefore, that had central bank independence in place during this period, it would have helped monetary policy in Brazil to be significantly less costly. Other evidence that points in this direction is that bad news (positive inflation shocks) had more effect than good news on both medium run inflation expectation and inflation risk premium in our sample. Recently all of these effects of inflation surprise on inflation expectation and risk premium have diminished and eventually disappeared, what we interpret as an indication of improvement in monetary policy credibility - possibly being one of the responsibles for the lower real rate we are observing today. This does not mean, however, that it will not become again a problem in the future, as Central Bank is not independent in Brazil yet.

We conjecture that the lack of credibility can not be understood looking at the history of conservative decisions of the Brazilian central bank in our sample. As we put in our model, what we believe that harms the credibility is the fear of regime switch (peso problem). In line with political economy literature[26], the reasoning for goes as follows: bad news on inflation would require an even tougher monetary policy, reducing the chance of reelection of the incumbent party. In such a scenario, constantly arriving good news would be necessary to prevent a regime switch and that's why bad news would have such a deleterious effect.

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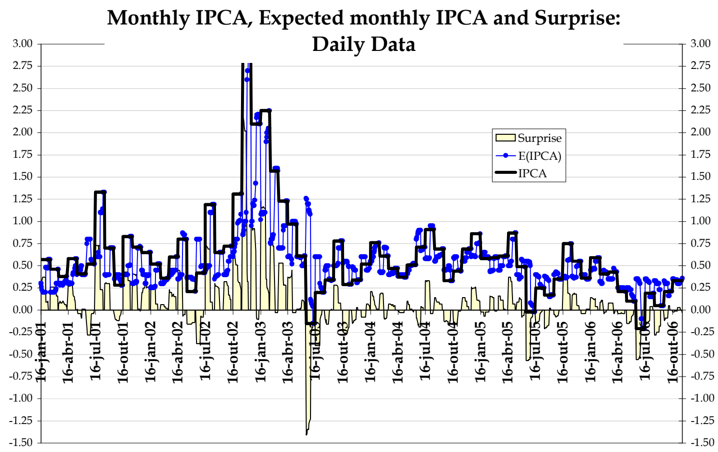
7 Appendix

7.1 Monthly IPCA surprise: daily data and methodology

The Chart below depicts the dynamic of the surprise on monthly IPCA. To better understand what is going on, it is useful to first discuss some methodological issues of the measures involved.



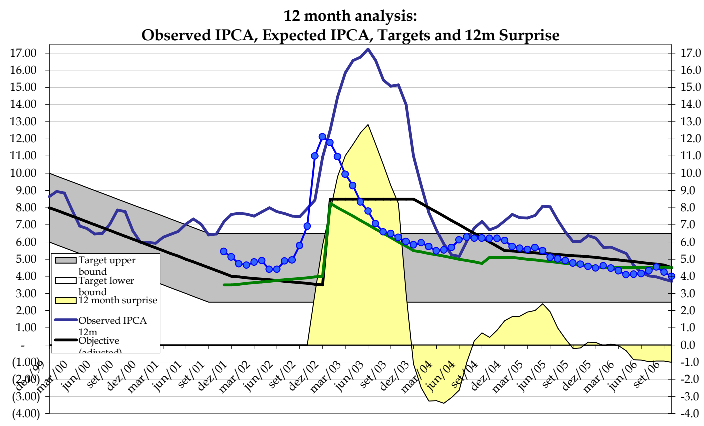
The month t IPCA is announced on the day 15th of month $t+1$ and refers to the inflation from the first to the last day of that previous month. On the first business day of each month, the same statistics office responsible for this inflation index, IBGE (Instituto Brasileiro de Geografia e Estatística), also report the IPCA-15 in which the basket of goods and services is the same one of the IPCA. The only difference between them is that IPCA-15 refers to the inflation from the day 15 form month t to day 15 from month $t+1$.

The black solid line in the chart represents the next monthly IPCA actually announced. For this reason, on the 16^{th} of each month, we observe a jump and it stay in the new level until the 16th of the following month. The blue line with circles are the market expectation for the next month IPCA. The surprise is the difference between the two measures and is represented by the filled area.

As one would expect, the measure of surprise diminishes we approach the announcement day. However, not surprisingly, the biggest change occurs around the 1st day of each month, when the IPCA-15 is announced. From the 16^{th} day to the 1^{st} day of each month, the change in the expected IPCA for that month is very smooth.

For those reasons and since we are working with monthly data, the measure of surprise we use in this paper is the point around the 16^{th} of each month.

7.2 Accumulated 12 month IPCA surprise



7.3 Pricing formula for 2 period bonds:

The price of a 2 period bonds:

$$p_t^{2\$} = E_t\left(m_{t+1}\right) + E_t\left(m_{t+2}\right) + \frac{1}{2}Var_t\left(m_{t+1}\right) + \frac{1}{2}Var_t\left(m_{t+2}\right) + Cov(m_{t+1}, m_{t+2})$$

$$\begin{aligned} P_t^2 \quad = \quad & E_t\left(m_{t+1}\right) + E_t(\pi_{t+1}) + E_t\left(m_{t+2}\right) + E_t(\pi_{t+2}) + \\ & + \frac{1}{2}Var_t\left(m_{t+1}\right) + \frac{1}{2}Var_t(\pi_{t+1}) + \frac{1}{2}Var_t\left(m_{t+2}\right) + \frac{1}{2}Var_t(\pi_{t+2}) + \\ & + Cov_t(m_{t+1}, m_{t+2}) + Cov_t(\pi_{t+1}, \pi_{t+2}) + \\ & + Cov_t(m_{t+1}, \pi_{t+1}) + Cov_t(m_{t+1}, \pi_{t+2}) + \\ & + Cov_t(m_{t+2}, \pi_{t+1}) + Cov_t(m_{t+2}, \pi_{t+2}) \end{aligned}$$

The 2 period forward rates are given by:

$$f_t = p_t^1 - p_t^2$$

$$f_t^{\$} = -E_t\left(m_{t+2}\right) - \frac{1}{2}Var_t\left(m_{t+2}\right) - Cov(m_{t+1}, m_{t+2})$$

$$\begin{aligned} f_t \quad = \quad & -E_t\left(m_{t+2}\right) - E_t(\pi_{t+2}) - \frac{1}{2}Var_t\left(m_{t+2}\right) - \frac{1}{2}Var_t(\pi_{t+2}) - \\ & - Cov(m_{t+1}, m_{t+2}) - Cov(\pi_{t+1}, \pi_{t+2}) - \\ & - Cov_t(m_{t+1}, \pi_{t+2}) - Cov_t(m_{t+2}, \pi_{t+1}) - Cov_t(m_{t+2}, \pi_{t+2}) \end{aligned}$$

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