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Nº 006 - 2011

Documento de trabajo

ISSN 1688-7565

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September 2011

Abstract

This paper studies the existence for a set of countries of an inflation threshold above which its effect on economic growth is negative, considering the speed of transition from one inflation regime to the other. Using a panel data set of above 120 countries for the period after the Second World War, we apply a panel smooth transition regression (PSTR) model with fixed effects. The estimated threshold of the inflation rate for industrialized countries is 4.1%, while for non-industrialized countries the threshold is 19.1%. The speed of transition is relatively smooth in the first group, but for developing economies inflation rapidly has negative effects on growth when it is near the threshold. In addition, we find that the inflation threshold falls to 7.9% by selecting a reduced group of developing countries, according to a measure associated with institutional quality. It is worth emphasizing that this reduced set of countries includes Uruguay.

Keywords: Inflation, economic growth, treshold effects, smooth transition.

JEL Classification: E31, O40, C33.

*This paper was prepared for the Central Bank of Uruguay and will appear in the working paper series of the Bank. We thank Ana Balsa, Fernando Borraz, Gerardo Licandro, and seminar participants at Universidad ORT Uruguay, Universidad del CEMA Argentina, and the XXVI Jornadas Anuales del Banco Central del Uruguay. The views on this paper correspond to the authors and do not necessarily reflect those of Banco de Mexico or Banco Central del Uruguay. Correspondence: Danilo Trupkin, Universidad de Montevideo, Prudencio de Pena 2440, 11600 Montevideo, Uruguay. E-mail: dtrupkin@um.edu.uy.

1 Introduction

The debate about the relationship between inflation and economic growth is important for the conduction of monetary policy. In the past years, central banks in several countries have adopted an inflation targeting regime. According to the studies by Barro (1991), Fischer (1983, 1993), and Bruno and Easterly (1998), inflation has a negative effect on economic growth, thus monetary policy should aim at achieving a low level of inflation. The important question is what should be the inflation target or, in other words, from what level inflation has a negative effect on economic growth.

Given the relevance of this topic, an important number of theoretic models in the macroeconomic literature analyze the impact of inflation on growth in the long run. In this sense, we can distinguish four relevant predictions in this literature:

1. Some theories find that there are no effects of inflation on growth (money is superneutral, for example Sidrauski, 1967).

2. Other theories such as Tobin (1965) assume that money is a substitute for capital, so inflation has a positive effect on growth.

3. Stockman (1981) proposes a model in which money is a complement to capital, so inflation generates negative effects on growth.

4. There is a new class of models in which inflation has a negative effect on growth, but only when it is above a certain threshold. In these models, high inflation rates exacerbate the frictions on financial markets, hampering efficiency and reducing economic growth.

The paper by Fisher (1993) is one of the first studies examining the possibility of nonlinearities in the relationship between inflation and growth. Using panel data for a set of developed and developing counties, Fisher finds a non-linear negative relationship between inflation and growth. However, an important limitation of this paper is that the sample is arbitrarily divided using breaks that represent the thresholds. In the time series literature, Bullard and Keating (1995) use structural VAR models to estimate the response of real output to permanent inflation shocks in each economy, for a sample containing 16 countries. They find that increases in long run inflation have positive (negative) effects on growth if the initial level of inflation is sufficiently low (high).

On the other hand, Khan and Senhadji (2001) estimate the inflation threshold in a panel based on five-year averages of the data. They find that the threshold level of annual inflation is between 1 and 3 percent for industrialized countries, and between 11 and 12 percent for developing countries.

Drukker et al. (2005) solve some of the limitations of Khan and Senhadji (2001) using the econometric methods developed by Hansen (1999, 2000) and Gonzalo and Pitarakis (2002) in order to estimate the number of thresholds, their values and the model coefficients. Using a non-dynamic, fixed-effects panel data model, Drukker et al. (2005) find two inflation thresholds in industrialized countries, 2.6% and 12.6%, and one threshold of 19.2% in non-industrialized economies. On the other hand, Vaona and Schiavo (2007) provide evidence about the nonlinear relationship between inflation and growth using non-parametric methods. In a recent paper, Kremer et al. (2009), introduce a dynamic panel model with threshold effects, finding results that are consistent with the existing literature. On the other hand, Espinoza et al. (2010) estimate the inflation-growth nexus using a smooth transition regression model, in order to investigate the speed at which inflation has a negative effect on growth. However, their results are difficult to interpret since their specification does not fit into the smooth transition regression model developed for panel data by González et al. (2005), which provides endogenous determination of the threshold levels.

The objective of this paper is to study the existence, for a set of countries, of an inflation threshold above which its effect on growth is negative. Moreover, we study the speed of transition from one to another regime. In particular, based on González et al (2005), we apply a panel smooth transition regression model (PSTR) with fixed effects. We use a panel data of over 120 countries, during the period after the Second World War. As it is standard in the empirical literature on economic growth, we use non-overlapping five-year averages of the data.

The estimated threshold for the group of industrialized countries is 4.1%, while that for non-industrialized countries is considerably higher: 19.1%. In both groups we observe that, once those thresholds are reached, the effect of inflation on growth is negative and statistically significant. However, if the inflation level is below the threshold, inflation has no significant effects on growth. The speed of transition is relatively smooth in the first group, while, for the second group, inflation quickly affects growth when it exceeds the threshold. We also find that the inflation threshold falls to 7.9% when the sample of developing countries is reduced to a group of economies (including Uruguay) satisfying a certain level of an exogenous measure for institutional quality, according to Acemoglu et al. (2001).

This paper is organized in the following way. Section 2 describes the data. Section 3 describes the econometric model. Sections 4 and 5 discuss the main findings. Finally, Section 6 presents concluding remarks.

2 Data

We use an unbalanced panel of 124 countries, for the period 1950-2007. Countries are classified as industrialized and non-industrialized, according to the *IMF* (see the lists of countries in Tables A.1 and A.2 in the Appendix). The growth rate of real per capita GDP at 2005 prices is obtained from the Penn World Table 6.3 data base, while inflation is obtained from the IMF's *International Financial Statistics* as the annual percent change of the consumer price index. Following the empirical growth literature (Temple, 2000), the time span is divided in five-year non-overlapped intervals. The growth rates for each interval are then calculated as five-year annual averages.

The control variables include the investment as the share of GDP, the rate of population growth, the initial level of income (measured as the real per capita GDP at the previous quinquennium), the degree of openness to trade (measured by adding exports and imports as the share of GDP) and the standard deviations of the terms of trade (calculated as the standard deviation within the five-year interval). Those variables were obtained from the Penn World Table.

Following Sarel (1996), we transform the inflation rate to logs in order to avoid that the extreme observations distort our regression results. In addition, such a change has the advantage that multiplicative shocks (instead of additive) have the same effects either in high or low-inflation economies. By applying this transformation, we obtain an almost symmetric inflation distribution, comparable to a Normal distribution (see Figures A.1 through A.4 in the Appendix). Moreover, Ghosh and Phillips (1998) find that the log function provides a reasonable characterization of the inflation-growth nexus.

Given that the logarithm is not defined for negative values and it approaches negative infinity for inflation levels near zero, we use a semi-logarithmic transformation as in Khan and Senhadji (2001). In particular, we consider the following transformation:

$$\tilde{\pi}_{it} = \begin{cases} \pi_{it} - 1 & \text{if} \quad \pi_{it} \leq 1 \\ \ln \pi_{it} & \text{if} \quad \pi_{it} > 1 \end{cases}$$

This function is linear for inflation rates less than unity, and logarithmic for rates larger than unity.

3 Model Specification

In order to estimate the effect of inflation on growth and, in particular, both the threshold as well as the speed of transition, we specify a *PSTR* model, following González et al. (2005). The growth rate of the real per capita GDP is the dependent variable, while the inflation rate and the control variables aforementioned in Section 2 are the independent variables. The two-regime PSTR model is defined as follows:[1]

$$dy_{it} = \mu_i + \beta_0' x_{it} + \beta_1' x_{it} G(\tilde{\pi}_{it}; \gamma, \tilde{\pi}^*) + u_{it}, \tag{1}$$

where $i = 1, \ldots, N$ represent countries and $t = 1, \ldots, T$, quinquennia. The variable dy_{it} is the growth rate of real per capita GDP, the vector x_{it} includes the transformed inflation rate ($\tilde{\pi}_{it}$) and the control variables: initial GDP ($igdp_{it}$), population growth rate (pop_{it}), investment/GDP (inv_{it}), openness to trade ($open_{it}$), the terms of trade standard deviations ($sdtot_{it}$), and an additional time dummy ($d70\text{-}84_{it}$) that captures the global effects of the OPEC's price-shocks (quinquennia 1970-1974, 1975-1979, 1980-1984), μ_i represents the individual fixed effects, and u_{it} are the errors.[2] The transition function $G(\tilde{\pi}_{it}; \gamma, \tilde{\pi}^*)$ is continuous in the observable transition variable, $\tilde{\pi}_{it}$. It is a normalized function that takes values between 0 and 1, and its extreme values are in turn associated with the regression coefficients β_0 and β_1. More generally, the value of $\tilde{\pi}_{it}$ determines the value of $G(\tilde{\pi}_{it}; \gamma, \tilde{\pi}^*)$ and thus the effects of inflation on growth, $\beta_0 + \beta_1 G(\tilde{\pi}_{it}; \gamma, \tilde{\pi}^*)$, for country i in period t. Notice that the estimated marginal effects on growth of each explanatory variable (included both the control variables and inflation) will be allowed to vary across time.[3] Additionally, a time dummy is introduced as a way to control for systemic time changes.

We specify G as the following logistic function:

$$G(\tilde{\pi}_{it}; \gamma, \tilde{\pi}^*) = \frac{1}{1 + \exp(-\gamma(\tilde{\pi}_{it} - \tilde{\pi}^*))}, \tag{2}$$

where the slope parameter of the logistic function, $\gamma > 0$, determines the speed of transition, and $\tilde{\pi}^*$ is the inflation threshold. For $\gamma \to \infty$, the logistic transition function approaches to an index function $I(\tilde{\pi}_{it} > \tilde{\pi}^*)$ that takes the value of 1 if $\tilde{\pi}_{it} > \tilde{\pi}^*$. For $\gamma \to 0$, the transition function approaches a constant and the model becomes homogenous or a linear panel regression model with fixed effects.

Notice that, for γ sufficiently high, the PSTR model reduces to a threshold model with

[1] In the next section, we show that the two-regime model is correctly specified by testing for the presence of non-linearities.

[2] We are aware that investment (used as control in the estimations) might be correlated with inflation. This would imply that the estimated effect of inflation on growth might be biased. We abstract from this potential issue in this work and leave it for future treatment.

[3] González et al (2005), propose a time varying PSTR where the regression coefficients are allowed to change as a function of time, which is suited for a relatively large time dimension T. Given our sample limitations, we estimate our PSTR model assuming that the threshold and gamma parameters are constant over time. However, as it is mentioned above, the regression coefficients are allowed to change over time according to the level of inflation. In other words, as the inflation rate in a particular country is changing over time, the country can fluctuate between high and low inflation regimes, and so the effect of inflation (as well as the other regressors) on growth.

two regimes as in Khan and Senhadji (2001). In such a case, the direct effect of inflation on real GDP growth will be given by β_0 for those countries with inflation less than or equal to π^*, and by $(\beta_0 + \beta_1)$ for those countries where inflation exceeds π^*.

3.1 Estimation and Specification Tests

The estimation procedure for the PSTR model consists of eliminating the individual effects μ_i by removing country-specific means and applying nonlinear least squares to the transformed model.[4] González et al. (2005) describe a testing procedure in order to test linearity against the PSTR model and determine the number r of transition functions. For the linearity test, the null hypothesis can be written as $H_0 : \gamma = 0$ or $H_0 : \beta_1 = 0$. However, in both cases the test is non-standard, since the PSTR model contains unidentified nuisance parameters under the null hypothesis. A possible solution is to replace the transition function $G(\tilde{\pi}_{it}; \gamma, \tilde{\pi}^*)$ by its first-order Taylor expansion around $\gamma = 0$ and to test an equivalent hypothesis based on the following auxiliary regression:

$$dy_{it} = \mu_i + \theta_0' x_{it} + \theta_1' x_{it} \tilde{\pi}_{it} + u_{it}^* \tag{3}$$

In this way, testing $H_0 : \gamma = 0$ in (1) is equivalent to testing the null hypothesis $H_0 : \theta_1 = 0$. Following Colletaz and Hurlin (2006), we can define the Wald, Fisher and Likelihood Ratio Tests. The Wald (LM) test can be written as:

$$LM = NT(SSR_0 - SSR_1)/SSR_0 \tag{4}$$

where SSR_0 is the panel sum of squared residuals under H_0 (linear panel model with individual effects) and SSR_1 is the panel sum of squared residuals under H_1 (PSTR model with two regimes). The Wald statistic is distributed as $\chi^2(K)$ under the null hypothesis. The Fisher (LM_F) test can be written as:

$$LM_F = [(SSR_0 - SSR_1)/K]/[SSR_0/(NT - N - K)] \tag{5}$$

where K is the number of explanatory variables, and it has an approximate $F(K, NT - N - k)$ distribution. Finally, the likelihood ratio test is defined as:

$$LRT = -2\left[\log(SSR_1) - \log(SSR_0)\right] \tag{6}$$

which follows a $\chi^2(K)$ under the null hypothesis.

To test the number of transition functions in the model, a similar logic is followed. In

[4] For more details about the estimation, see González et al. (2005).

particular, we test the null hypothesis of no remaining non-linearity in the transition function. For instance, suppose that we want to test whether there is one transition function, ($H_0 : r = 1$) versus there are at least two transition functions ($H_0 : r = 2$). Thus, consider the model:

$$dy_{it} = \mu_i + \beta_0' x_{it} + \beta_1' x_{it} G_1(\tilde{\pi}_{it}; \gamma_1, \tilde{\pi}_1^*) + \beta_2' x_{it} G_2(\tilde{\pi}_{it}; \gamma_2, \tilde{\pi}_2^*) + u_{it}, \tag{7}$$

The null hypothesis of no remaining heterogeneity can be formulated as $\gamma_2 = 0$. As before, the identification problem is solved by using a first order Taylor approximation of $G_2(\tilde{\pi}_{it}; \gamma_2, \tilde{\pi}_2^*)$, leading to the following auxiliary regression:

$$dy_{it} = \mu_i + \beta_0' x_{it} + \beta_1' x_{it} G_1(\tilde{\pi}_{it}; \gamma_1, \tilde{\pi}_1^*) + \theta_1' x_{it} \tilde{\pi}_{it} + u_{it}^*, \tag{8}$$

The null hypothesis of no remaining non-linearity can thus be defined as $H_0 : \theta_1 = 0$. The Wald, Fisher and Likelihood Ratio Tests can be computed as before. The testing procedure is as follows. Given a PSTR model, we test the null hypothesis that the model is linear. If the null is rejected, we estimate a two-regime PSTR model. Then, we test the null hypothesis of no remaining non-linearity in this model. If it is rejected, estimate a three regime model. The testing procedure continues until the first acceptance of the null hypothesis of no remaining heterogeneity. At each step of the sequential procedure, the significance level must be reduced by a factor $0 < \tau < 1$ to avoid excessively large models.

4 Results

Table 1 shows the linearity tests for industrialized and non-industrialized countries. For the industrialized countries, the null hypothesis that the model is linear is rejected at the 1% level in two of the three tests. For the non-industrialized economies, the results are less strong, but we still observe that linearity is rejected at the 10% level in all cases.

Table 1: Linearity Tests

	Industrialized		**Non Industrialized**	
Tests	**Statistic**	**pvalue**	**Statistic**	**pvalue**
Wald Test	19.5	0.007	14.7	0.040
Fisher Test	2.7	0.012	1.8	0.075
Likelihood Ratio Test	20.3	0.000	14.8	0.000

H_0: Linear Model. H_1:PSTR Model with at least one threshold.

Table 2 shows the tests to investigate whether there is remaining non-linearity after assuming a two regime model. The null hypothesis indicates that the PSTAR model has only one threshold, while under the alternative the model contains at least two thresholds. From the results we observe that the null hypothesis cannot be rejected, indicating that one threshold properly captures the non-linearity in the model. This type of models requires a sufficiently high value of the test statistic to select a higher number of thresholds. That is, selection criteria penalize the cost of increasing the number of thresholds associated with the curse of dimensionality.

Table 2: Tests of No Remaining Non-linearity: Tests for the Number of Regimes

	Industrialized		**Non Industrialized**	
Tests	**Statistic**	**pvalue**	**Statistic**	**pvalue**
Wald Test	11.0	0.139	2.6	0.920
Fisher Test	1.3	0.229	0.3	0.947
Likelihood Ratio Test	11.2	0.128	2.6	0.920

H_0: PSTR with one threshold. H_1:PSTR with at least two thresholds.

Finally, Table 3 shows the model parameters estimated for both samples. As expected, the thresholds exhibit the important differences that exist between both groups: 4.1% for the industrialized countries and 19.1% for the developing countries. These results are similar as those of Drukker et al. (2004), but higher than those of Khan and Senhadji (2001). The high threshold for the non-industrialized countries can be explained, in part, by the adoption of indexation systems which reduce the negative effects of inflation on growth. That is, those countries have showed high inflation rates without experiencing adverse effects on growth, since their relative prices did not present large changes.

The estimate of γ for industrialized countries is such that the transition from the lower regime to the upper regime is smooth but relatively rapid. Figure 1 shows the transition function for this group, plotted against the inflation rate.[5] It shows that the negative effect of inflation on growth occurs when inflation is close to the threshold, and not necessarily above it. Notice that most observations lie in either one of the extreme regimes, but there is also a number of them located in-between. For the case of non-industrialized economies, the slope of the transition function is extremely high, showing that the change in the effect of inflation on growth is abrupt when inflation is close to the threshold (see Figure 2). However, note that, for both sets of countries, while the estimated coefficient of β_0 is negative, it is not statistically significant. On the other hand, consistent with the theory the estimated β_1 is negative and statistically significant, at the 1% in the group of developed

[5]We removed outliers from the figure to have a better view of the slope of the transition function near the threshold.

Table 3: PSTR Model Estimation with Two Regimes

	Industrialized		**Non Industrialized**	
Threshold: π^*	4.1%		19.1%	
Slope: γ	31.4		27,943.0	
Variable	β_0	β_1	β_0	β_1
$\tilde{\pi}_{it}$	-0.0961	-1.5241***	-0.1120	-0.4377**
	(0.2376)	(0.4075)	(0.1347)	(0.2112)
$igdp_{it}$	-0.0001***	-0.0001***	-0.0002***	-0.0001
	(0.0000)	(0.0000)	(0.0001)	(0.0001)
pop_{it}	-0.2582	-0.1401	-0.6056***	-0.1283
	(0.3366)	(0.4070)	(0.1723)	(0.2661)
inv_{it}	-0.0194	0.1544***	0.0607***	0.0664**
	(0.0404)	(0.0320)	(0.0211)	(0.0391)
$open_{it}$	0.0427***	-0.0103*	0.0218***	-0.0244**
	(0.0108)	(0.0066)	(0.0066)	(0.0108)
$sdtot_{it}$	-23.4442	34.4556	-1.8718	13.6202
	(28.1468)	(31.2865)	(5.0142)	(11.1737)
$d70\text{-}84_{it}$	-2.5232***	2.7297***	0.2403	-1.2789**
	(0.5571)	(0.6510)	(0.3065)	(0.6660)

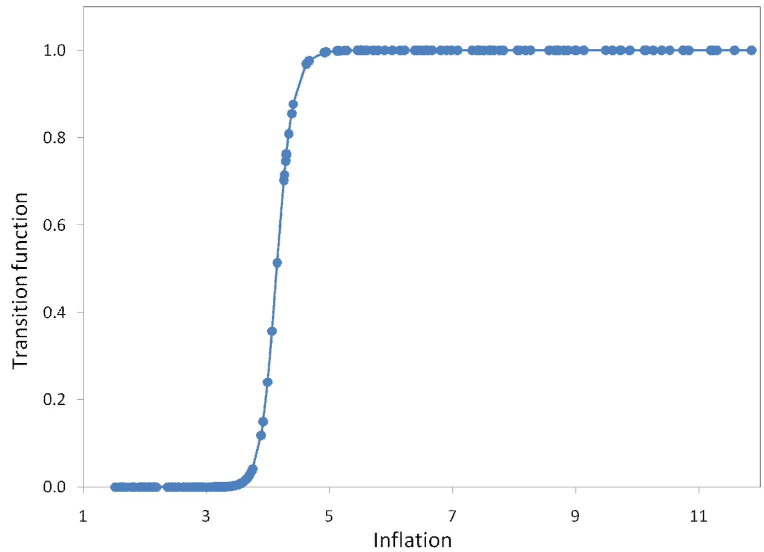
Significance levels: (*) 10%, (**) 5%, (***) 1%.
Values in parentheses are standard errors corrected for heteroskedasticity.

countries and 5% in the set of emerging economies. This means that the effects of inflation on growth are not statistically significant when inflation is below the threshold but become significant when it is above the threshold.

Regarding the control variables, we can see that the results are consistent both with the theory and with the empirical literature on economic growth in both groups of countries; see for example Levine and Renelt (1992) and Sala-i-Martin (1997). For industrialized countries, the coefficient associated with initial income is negative and statistically significant at the 1% level in both regimes. The coefficient associated with the investment-output variable is positive and statistically significant at the 1% level in both regimes. On the other hand, higher openness is associated with higher growth in low inflation regimes, but its effect is lower in high inflation regimes, although this result is significant at the 10% level.

For developing countries, the coefficients are mostly statistically significant at low inflation regimes. Both the population growth rate and initial income are negatively related with economic growth. On the other hand, the investment-output ratio is positively related with growth at both regimes. The effect of openness on growth is significantly positive at low inflation regimes, but is offset at high inflation regimes. Note, once again, that the

Figure 1: Estimated Transition Function: Industrialized Countries



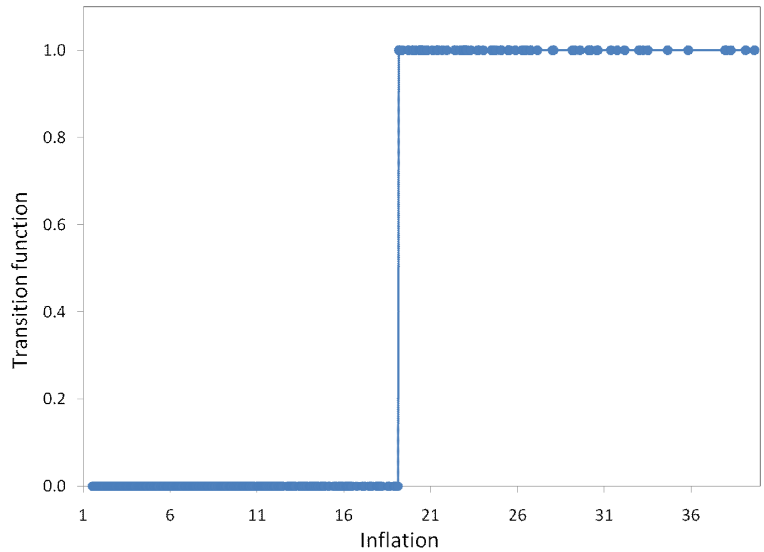
signs of the regression coefficients are consistent with the empirical literature on growth.

In order to check for the robustness of our estimations, we basically worked in two directions.[6] First, we aimed at reducing the degree of heterogeneity in the group of developing countries in order to have a threshold that identifies better the inflexion point, regarding inflation, of a particular economy. There are a number of ways to do that. One could endogenize the segmentation between industrialized and non-industrialized economies, for instance, by estimating the volatility of output shocks to each country, and then splitting the samples by the countries' relative degree of stability. Alternatively, one could control for a measure of institutional quality, so as to identify groups of countries with similar degrees of institutional development – a variable well known for its positive relationship with growth (e.g., Hall and Jones, 1999, and Acemoglu et al., 2001). We followed the second alternative, in particular based on Acemoglu et al. (2001). We provide a comprehensive study of this issue in the next section.

Second, we aimed at controlling for the potential effects on growth from financial depth. In this direction, we added a number of standard measures of financial development into our econometric model, following mostly King and Levine (1993). First, we introduced a proxy for the size of the financial system relative to the economy's total output (the ratio of liquid liabilities of the financial system, measured by series of both M3 and M2, to GDP). Second, we introduced a proxy for the fraction of domestic credit allocated to the private

[6]We also evaluated the sensitivity of our results to marginal changes either on the samples of countries or the variables included in the regressions. Additionally, we checked for sensitivity to the exclusion of outliers, in particular regarding the extremely high inflation rates displayed by some developing countries. None of these changes altered the main conclusions of our baseline estimations.

Figure 2: Estimated Transition Function: Non Industrialized Countries



sector (measured by the ratio of claims on the nonfinancial private sector to total domestic credit). Finally, we added a third measure, which is as the second, but normalized by GDP instead of total domestic credit.[7] As a result of this second robustness check, the bottom line is that the main conclusions remain. In particular, the thresholds, the speeds of transition and the signs of the estimated coefficients accompanying the control variables are found to be similar to those in baseline model.

We not only used financial data to add control variables into our econometric model, but we also applied these data to identify groups of countries ranked by financial development. None of the estimations in this direction proved to be insightful though. Especially, the estimated thresholds over the groups of countries formed by the financial orderings proved to be highly sensitive to the cut-offs applied. We also introduced lags of these variables, as controls, in order to capture potential long-run effects of financial development on growth. Yet, it proved not to be a useful direction to follow as well. Both the β_0 and the β_1 coefficients accompanying the financial series were not significant in most of the estimations.

5 Inflation, Institutions, and the Case of Uruguay

In this Section, we reduce the sample of non-industrialized economies according to a proxy for institutional characteristics, following Acemoglu et al. (2001). The proxy relates to the mortality rates faced by European settlers in the colonial origins, which then determined, as is shown, the colonization policies and the institutions created. Moreover, those institutions

[7] All these measures were taken from the *IFS* database of the IMF.

have persisted and prevail nowadays.

The use of this measure helps us in several ways. First, we can employ historical information linked to the institutional quality in a group of countries as a control variable in our estimations. Second, since this information refers to a point in time only, it serves to segment the sample by countries with similar characteristics. Finally, the settler mortality rates serve as an instrument for institutional quality, exogenous to growth, as opposed to the widely used endogenous institutional variables.

The procedure for splitting the sample is as follows. First, from the 101 countries that comprise our sample of non-industrialized economies, we take those that match with Acemoglu et al. (2001)'s sample, for which we are left with 56 countries. Second, in order to group countries with similar characteristics, we ranked the merged sample according to the mortality rates appearing in the data.[8] Finally, we selected those countries that had a settler mortality rate less than 250 in 1,000 per year (see Acemoglu et al., 2001, for a detailed description of this measure).[9] We have chosen a conservative cut-off that left us with the 75% of Acemoglu et al. (2001)'s sample, including Uruguay. Although the criterion for choosing the cut-off was arbitrary, the results were robust to changes on it.

Table 4 shows the estimated coefficients for the selected group of countries.[10] Notice that the inflation threshold falls considerably to 7.9%, compared to the threshold of 19.1% found in Section 4 for the original sample of developing countries. Thus, the inflation threshold gets closer to values mostly identified with developed economies. But we also note that the speed of transition from one regime to the other still results significantly high. Additionally, it is worth noting that, if we consider the total of 56 developing countries that match Acemoglu et al. (2001)'s sample with ours, the estimations provide an inflation threshold of 18.4%, i.e., almost as high as the one found in Section 4. This would indicate that the significant fall in the threshold for the institutionally-controlled group does not depend on the particular sample initially appearing in Acemoglu et al. (2001). Specially, we believe that there are no reasons to expect a selection bias.

Notice now that the coefficient β_0 for the inflation rate is positive and statistically significant at the 5% level, which shows that inflation is positively related with growth when its rate is sufficiently low. By contrast, the estimated coefficient β_1 turns out to be

[8] We used the information listed in Table A2 from Acemoglu et al. (2001)'s Appendix.

[9] The countries included in the sample were: Algeria, Argentina, Bahamas, Bangladesh, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, Egypt, El Salvador, Ethiopia, Guatemala, Haiti, Honduras, Hong Kong, India, Indonesia, Jamaica, Kenya, Malaysia, Malta, Mexico, Morocco, Nicaragua, Pakistan, Panama, Paraguay, Peru, Senegal, Singapore, South Africa, Sri Lanka, Sudan, Tanzania, Trinidad Tobago, Tunisia, Uruguay, and Venezuela.

[10] In the Appendix, Tables A.3 and A.4 show both the non-linearity test and the no-remaining-non-linearity test (to establish the number of regimes) applied to the controlled sample. These indicate the presence of non-linearities in the inflation-growth relationship, and do not allow us to significantly reject the specification that includes two regimes only.

Table 4: PSTR Model Estimation - Developing Countries, Control Institutions

Threshold: π^*	7.9%	
Slope: γ	22,198	
Variable	β_0	β_1
$\tilde{\pi}_{it}$	0.4104**	-0.7999***
	(0.2067)	(0.2482)
$igdp_{it}$	-0.0003***	-0.0004***
	(0.0001)	(0.0001)
pop_{it}	-0.9247***	0.4319**
	(0.2583)	(0.2463)
inv_{it}	0.0124	0.0674**
	(0.0301)	(0.0298)
$open_{it}$	0.0294***	0.0050
	(0.0084)	(0.0079)
$sdtot_{it}$	2.6367	-13.2963
	(10.7244)	(14.1708)
$d70\text{-}84_{it}$	-0.9205	0.9628
	(0.5277)	(0.6260)

Significance levels: (*) 10%, (**) 5%, (***) 1%.
Values in parentheses are standard errors corrected for heteroskedasticity.

negative and significant at the 1% level, similarly as in Section 4. This suggests that, for high inflation levels, increasing its rate is harmful to growth.

With respect to the control variables, we observe that the results are in general consistent with the literature. The initial income coefficient is negative and significant at the 1% level in both regimes. The one that corresponds to *investment/output* is positive and significant at 5%, though at high-inflation regimes only; whereas the coefficient that accompanies the population growth rate is negative and significant at the 1% level, only at low-inflation regimes. Finally, openness to trade is statistically significant and positively related with growth at low-inflation regimes, while we cannot observe a definite nexus between the two in periods of high inflation.

Finally, our model estimation results allowed us to calculate an average inflation-growth elasticity for the case of Uruguay. This elasticity was obtained by taking an average over all estimated coefficients accompanying each inflation observation for Uruguay across time.[11] Notice that we scaled each of the estimated coefficients, by the average economic growth rate, in order to express our estimate in terms of an elasticity. The resulting average inflation-growth for the case of Uruguay is of -0.22. That is, a 1% increase in the average

[11] As mentioned before, the estimated marginal effects of inflation, i.e., $\beta_0 + \beta_1 G(\tilde{\pi}_{it}; \gamma, \tilde{\pi}^*)$, are time varying, since their values depend on the regime in which inflation is found.

inflation rate of Uruguay, is expected to lower the rate of economic growth in about 0.22%. As a brief comparison with other countries in the region, the estimated average inflation-growth elasticities for Argentina and Brazil were -0.20 and -0.18, i.e., close to the elasticity found for Uruguay, while the one estimated for Chile was almost zero (-0.06).

6 Concluding Remarks

Motivated by the increase in the number of central banks that have adopted an inflation targeting regime in the last years, we revisit the nexus between inflation and economic growth by applying a smooth transition regression model for panel data (PSTR). Using a panel of 124 countries for the period 1950-2007, we estimate not only the threshold above which inflation is harmful for growth, but also the slope of the function that connects one regime to the other. In addition, for both regimes we estimated the effect on growth from the control variables that are standard in growth models: initial per capita income, population growth, the investment-output ratio, openness to trade, and the standard deviations of terms of trade.

Using a test for non-linearity, we provide evidence that the relationship between inflation and growth is non-linear. Therefore, a PSTR model is used to estimate that relationship. According to the test used to estimate the number of thresholds, we find that the model with one threshold (two regimes) adequately captures this relationship. An important advantage of the PSTR over the alternative models that have been used to estimate the inflation-growth nexus, including that of Khan and Senhadji (2001), is that the estimation of the thresholds is endogenous. The estimated threshold for the inflation rate for industrialized countries is 4.1%, while for non-industrialized countries it is 19.1%. The estimated thresholds are statistically significant at the conventional levels. The speed of transition is relatively smooth in the first group, while in the second group inflation is rapidly harmful for values of the inflation rate near the threshold. This suggests that central banks in developing countries should act fast when inflation is near or above the estimated threshold. We also find that the estimated coefficients associated with the control variables used in the model are consistent with the literature.

Finally, the inflation threshold falls considerably to 7.9% if the group of developing countries contains only those that have a certain level of institutional quality, according to Acemoglu et al. (2001). Following this criterion to find a proxy for "good institutions,"Uruguay was introduced into this reduced sample. The econometric model also allowed us to estimate an average inflation-growth elasticity for Uruguay of -0.22.

Further work includes sensitivity analysis to the variables, the sample and the presence of outliers. It would also be interesting, for a future work, to study the effect of additional control variables such as the presence (or absence) of indexation and dollarization schemes, particularly relevant for developing countries.

The results presented in this paper must be interpreted with caution, since the model used here has some limitations. The estimation results appear to be sensitive, particularly the parameter measuring the smoothness of transition. Moreover, the investment variable could be correlated with inflation, thus the associated coefficient could be biased.

In summary, the results suggest that central banks could improve economic growth by reducing inflation when it is above or near the estimated thresholds. Such results can be considered, therefore, as consistent with the adoption of inflation targeting regimes.

References

[1] Acemoglu, D., Johnson, S., Robinson, J.A., 2001, The Colonial Origins of Comparative Development: An Empirical Investigation, American Economic Review 91(5): 1369-1401.

[2] Barro, R., 1991, Economic Growth in a Cross-Section of Countries, Quarterly Journal of Economics 106(2): 407–43.

[3] Bullard, J., Keating, J. W., 1995, The long-run relationship between inflation and output in postwar economies, Journal of Monetary Economics 36(3): 477–496.

[4] Bruno, M., Easterly, W., 1998, Inflation Crises and Long-Run Growth, Journal of Monetary Economics 41(1): 3–26.

[5] Caner, M., Hansen, B. E., 2004, Instrumental Variable Estimation of a Threshold Model, Econometric Theory 20(5): 813–843.

[6] Colletaz, G., Hurlin, C., 2006, Threshold Effects in the Public Capital Productivity: An International Panel Smooth Transition Approach, University of Orléans Working Paper.

[7] Drukker, D., Gomis-Porqueras, P., Hernandez-Verme, P., 2005, Threshold Effects in the Relationship Between Inflation and Growth: A New Panel-Data Approach, Working Paper.

[8] Espinoza, R., Leon, H., Prasad, A., 2010, Estimating the Inflation-Growth Nexus –A smooth Transition Model, IMF Working Paper 10/76.

[9] Fischer, S., 1983, Inflation and Growth, NBER Working Paper No. 1235 (Cambridge, Massachusetts: National Bureau of Economic Research).

[10] Fischer, S., 1993, The Role of Macroeconomic Factors in Growth, Journal of Monetary Economics 32(3): 485–512.

[11] Ghosh, A., Phillips, S., 1998, Warning: Inflation May Be Harmful to Your Growth, IMF Staff Papers 45(4): 672–710.

[12] González, A., Teräsvirta, T., van Dijk, D., 2005, Panel Smooth Transition Regression Models, SSE/EFI Working Paper Series in Economics and Finance, No. 604.

[13] Gonzalo, J., Pitarakis, J.-Y, 2002, Estimation and Model Selection Based Inference in Single and Multiple Threshold Methods, Journal of Econometrics 110(2): 319–352.

[14] Hansen, B., 1999, Threshold Effects in Non-dynamic Panels: Estimation, Testing and Inference, Journal of Econometrics 93(2): 345–368.

[15] Hansen, B., 2000, Sample Splitting and Threshold Estimation, Econometrica 68(3): 575–603.

[16] Hall, R.E., Jones, C.I., 1999, "Why Do Some Countries Produce So Much More Output Per Worker Than Others?," Quarterly Journal of Economics, 114(1): 83–116.

[17] Khan, M., Senhadji, A., 2001, Threshold Effects in the Relationship Between Inflation and Growth, IMF Staff Papers 48(1): 1–21.

[18] King, R., Levine, R., 1993, "Finance and Growth: Schumpeter Might Be Right," Quarterly Journal of Economics, 108(3): 717–737.

[19] Kremer, S., Bick, A., Nautz, D., 2009, Inflation and Growth: New Evidence from a Dynamic Panel threshold Analysis, SFB 649 Discussion Paper, Humboldt University, Berlin, Germany.

[20] Levine, R., Renelt, D., 1992, "A sensitivity Analysis of Cross-Country Growth Regressions," American Economic Review 82(4): 942-963.

[21] Sala-i-Martin, X., 1997, "I Just Ran Two Million Regressions," American Economic Review 87(2): 173–183.

[22] Sarel, M., 1996, Nonlinear Effects of Inflation on Economic Growth, IMF Staff Papers 43(1): 199–215.

[23] Sidrauski, M., 1967, Rational Choice and Patterns of Growth in a Monetary Economy, American Economic Review 57(2): 534–544.

[24] Stockman, A. C., 1981, Anticipated Inflation and the Capital Stock in a Cash-in-Advance Economy, Journal of Monetary Economics 8(3): 387–393.

[25] Temple, J., 2000, Inflation and Growth: Stories Short and Tall, Journal of Economic Surveys 14(4): 395–426.

[26] Tobin, J., 1965, Money and Economic Growth, Econometrica 33(4): 671–684.

[27] Vaona, A., Schiavo, S., 2007, Nonparametric and semiparametric evidence on the long-run effects of inflation on growth, Economics Letters 94(3): 452–458.

A Appendix

Table A.1: List of Industrialized Countries

Australia	Japan
Austria	Luxembourg
Belgium	Netherlands
Canada	New Zealand
Denmark	Norway
Finland	Portugal
France	Spain
Germany	Sweden
Greece	Switzerland
Iceland	United Kingdom
Ireland	United States
Italy	

Table A.2: List of Non-Industrialized Countries

Algeria	Guinea-Bissau	Poland
Argentina	Haiti	Qatar
Bahamas	Honduras	Rwanda
Bahrain	Hong Kong	Samoa
Bangladesh	Hungary	Saudi Arabia
Barbados	India	Senegal
Belize	Indonesia	Seychelles
Benin	Iran	Sierra Leone
Bolivia	Israel	Singapore
Botswana	Jamaica	Solomon Islands
Brazil	Jordan	South Africa
Burkina Faso	Kenya	Sri Lanka
Burundi	Kuwait	St. Kitts & Nevis
Cameroon	Lesotho	St. Lucia
Cape Verde	Madagascar	St.Vincent & Grenadines
Chad	Malawi	Sudan
Chile	Malaysia	Suriname
Colombia	Maldives	Swaziland
Congo, Republic of	Mali	Syria
Costa Rica	Malta	Tanzania
Cote d`Ivoire	Mauritania	Thailand
Cyprus	Mauritius	Togo
Dominica	Mexico	Tonga
Dominican Republic	Morocco	Trinidad &Tobago
Ecuador	Mozambique	Tunisia
Egypt	Nepal	Turkey
El Salvador	Nicaragua	Uganda
Ethiopia	Niger	Uruguay
Fiji	Nigeria	Vanuatu
Gabon	Pakistan	Venezuela
Gambia, The	Panama	Zimbabwe
Ghana	Papua New Guinea	
Grenada	Paraguay	
Guatemala	Peru	
Guinea	Philippines	

Table A.3: Linearity Tests - Developing Countries, Control Institutions

Tests	**Statistic**	**pvalue**
Wald Test	13.8	0.056
Fisher Test	1.8	0.090
Likelihood Ratio Test	14.0	0.000

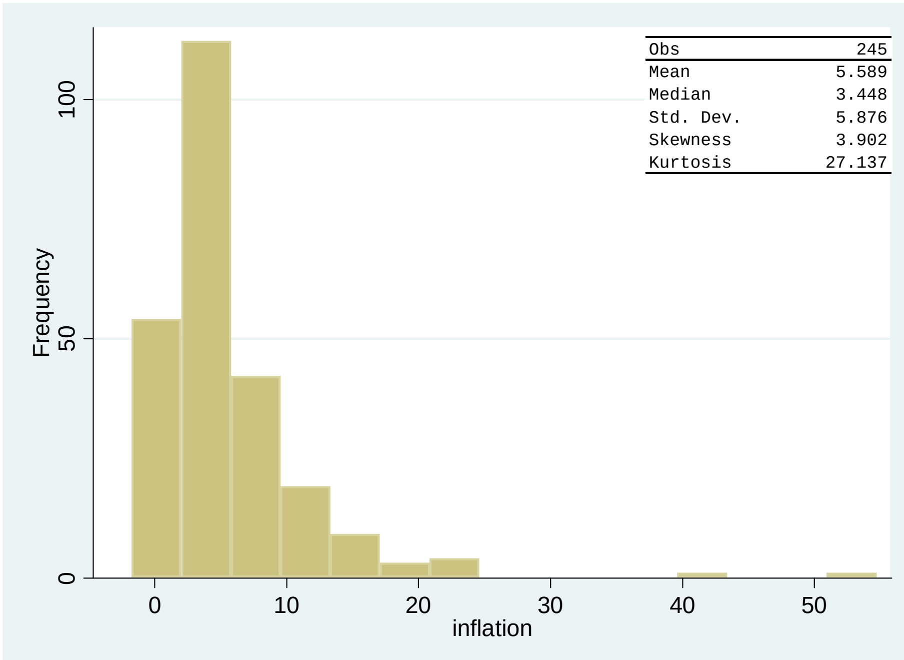
H_0: Linear Model. H_1:PSTR Model with at least one threshold.

Tests	**Statistic**	**pvalue**
Wald Test	13.9	0.052
Fisher Test	1.7	0.101
Likelihood Ratio Test	14.2	0.048

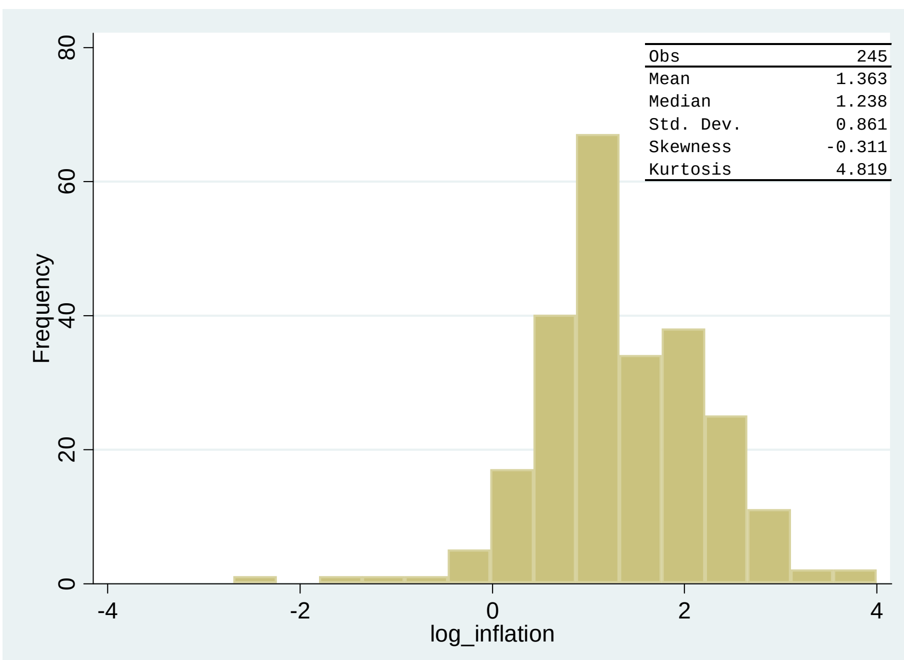
H_0: PSTR Model with one threshold. H_1:PSTR with at least two thresholds.

Table A.4: Tests for the Number of Regimes - Developing Countries, Control Institutions

Figure A.1: Inflation Distribution - Industrialized Countries



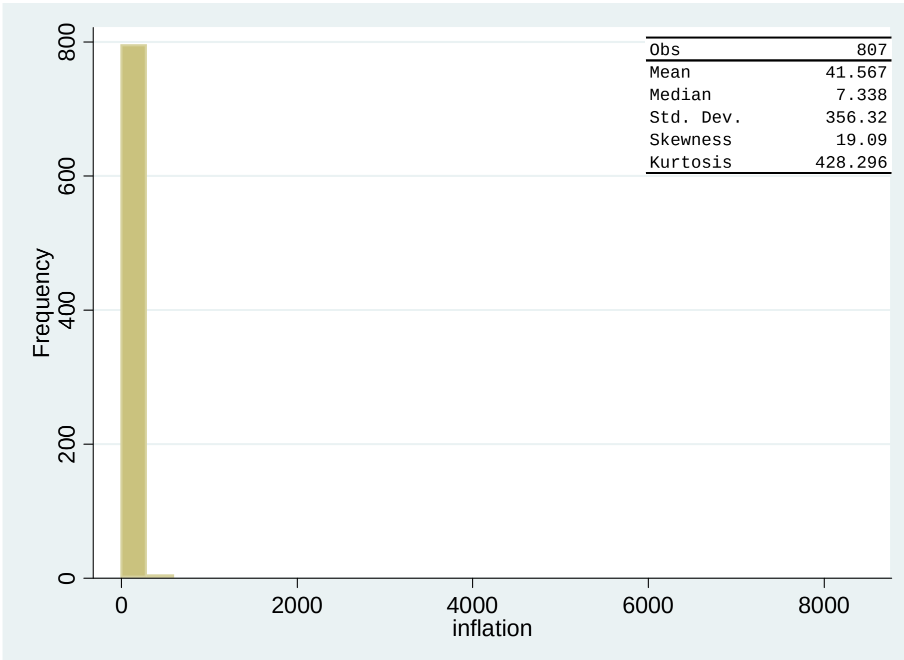
Note: Five-year average of annual inflation, in percentage points, 1955-2007. Source: IFS, IMF.



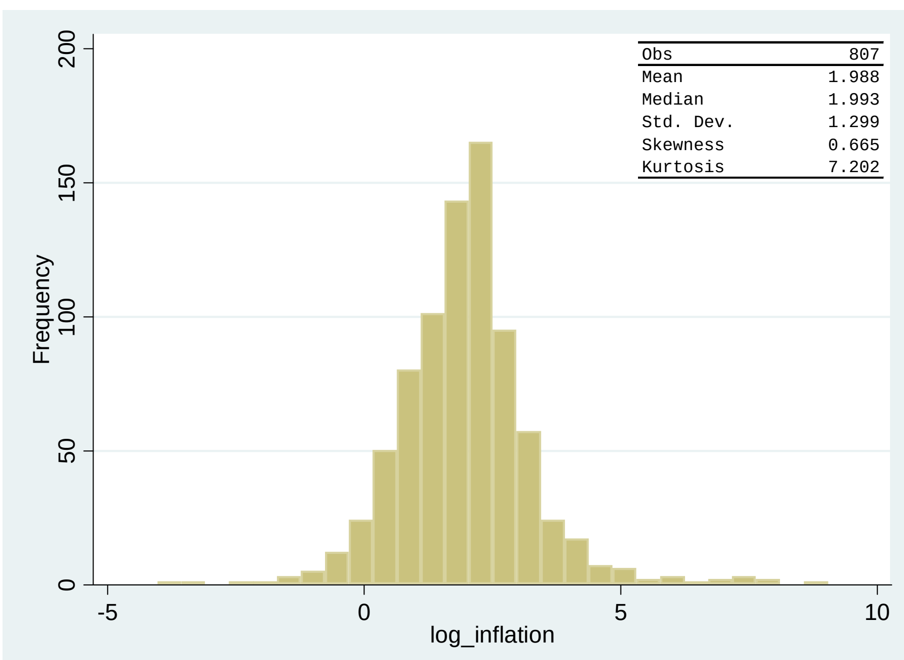
Note: Five-year average of annual inflation, semi-log transformation, 1955-2007. Source: IFS, IMF.

Figure A.2: *Transformed* Inflation Distribution - Industrialized Countries

Figure A.3: Inflation Distribution - Non Industrialized Countries



Note: Five-year average of annual inflation, in percentage points, 1955-2007. Source: IFS, IMF.



Note: Five-year average of annual inflation, semi-log transformation, 1955-2007. Source: IFS, IMF.

Figure A.4: *Transformed* Inflation Distribution - Non Industrialized Countries