

# IMF Working Paper

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## Estimating The Inflation-Growth Nexus— A Smooth Transition Model

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## IMF Working Paper

Middle East and Central Asia Department

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#### Abstract

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Motivated by the global inflation episode of 2007–08 and concern that high levels of inflation could undermine growth, this paper uses a panel of 165 countries and data for 1960–2007 to revisit the nexus between inflation and growth. We use a smooth transition model to investigate the speed at which inflation beyond a threshold becomes harmful to growth, an important consideration in the policy response to rising inflation as the world economy recovers. We estimate that for all country groups (except for advanced countries) inflation above a threshold of about 10 percent quickly becomes harmful to growth, suggesting the need for a prompt policy response to inflation at or above the relevant threshold. For the advanced economies, the threshold is much lower. For oil exporting countries, the estimates are less robust, possibly reflecting heterogeneity among oil producers, but the effect of higher inflation for oil producers is found to be stronger.

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## I. INTRODUCTION

Inflation emerged as a global phenomenon in mid-2007 in the face of high oil and food price shocks. There were concerns that inflation in many emerging market and developing economies were reaching high levels that, if uncontained, would undermine growth by raising inflationary expectations. Heading off inflationary pressures, while preserving growth, became a policy priority for many countries. Motivated by the risks that the next upturn in the business cycle will be accompanied by even higher inflation (spurred by highly accommodative monetary and fiscal policies around the world), this paper revisits the relationship between inflation and growth and estimates the speed at which inflation beyond a threshold becomes harmful to growth.

High output growth and low inflation are among the central objectives of macroeconomic policy. But can they coexist? Or is there a trade-off between lowering inflation and achieving higher growth? At the operational level, there is a recognition that the growth-inflation relationship depends on the level of inflation—at some low levels, inflation may be positively correlated with growth, by “greasing the wheels” of the economy or as a signal of overheating, but at higher levels inflation is likely to be harmful to growth. In the academic literature, this has been translated into the use of threshold models, which suggest that when inflation exceeds a certain level (the threshold) higher inflation becomes immediately very costly for growth, a result that would call for radical policy changes as soon as inflation exceeds the threshold.

This structural break in the relationship between inflation and growth is assumed to occur instantaneously, since the preferred model in the literature is a piecewise linear model (the Threshold (TAR) model). Considering the policy implications of the findings that inflation is quickly penalizing for growth, there is a need for a further analysis of the speed at which inflation becomes costly. Toward this objective, this study uses a Logistic Smooth Transition model (LSTR)—see Teräsvirta (1994, 1998) and van Dijk and others (2002)—to estimate the speed of transition from one regime (low effect of inflation on growth) to another (high effect of inflation on growth).

This study estimates a threshold of about 10 percent for most of the country groups (except for the advanced economies). This is in line with many of the estimates found in the literature, although several papers have suggested higher thresholds (around 20 percent for developing economies). We estimate a fairly high speed of transition, which implies that inflation is harmful to growth soon after it exceeds the threshold. The accuracy of the estimates is validated by using bootstrapping techniques—providing, to the best of our knowledge, new robustness checks in the inflation-growth literature—that explain the range of estimates found in the literature as inherent to the data process as much as the estimation technique. Indeed, although the bootstrapping exercises suggest that the value of the threshold is robust to outliers, the range of bootstrap estimates turns out to be almost as large as the range of estimates in the literature. For instance, looking at developing countries, for more than 90 percent of the bootstrapped sample, the estimated inflation threshold lies between 7 and 13 percent. Furthermore, the results indicate that that inflation is more costly

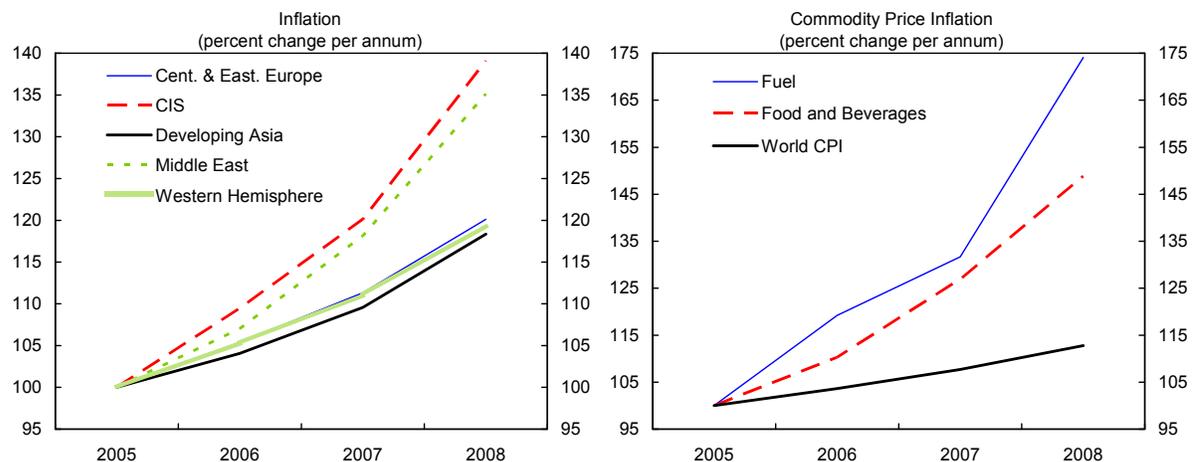
for oil-exporters than for the other country groups if the dependent variable is non-oil GDP growth (as opposed to total GDP growth).

Finally, Monte-Carlo experiments are run to investigate the performance of the LSTR model in estimating thresholds and speeds of transition. They reveal that although the LSTR provides some useful additional degree of freedom in the estimation, the distinction between the LSTR and a more standard TAR model is not crucial in this case.

Section II of the paper reviews the global environment in 2007/08 as the most recent period of high inflationary pressures, and the policy measures that were taken around the world to fight overheating. Section III reviews the related academic literature. The fourth section identifies a threshold level for the relationship between inflation and growth, as well as a speed of transition from one regime (low effect of inflation on growth) to another (high effect of inflation on growth). Section V concludes.

## II. THE BACKDROP

Although the previous rapid increase in headline inflation was driven mostly by food and energy prices, core inflation had started rising in many countries before 2007. Broadly speaking, three types of underlying inflationary challenges were facing the global economy. First, a number of countries—including several in emerging Europe—were facing a combination of strong capital inflows, rapid credit growth, tightening labor markets, and widening current account deficits, pointing to evidence of overheating. Second, many commodity-exporting countries, including the members of Gulf Cooperation Council (GCC) and Russia, were seeing rising export earnings, pushing up aggregate demand and facilitating domestic credit growth. In the GCC region, capacity constraints, especially in housing, and the limited availability of raw materials exacerbated the situation. Third, surging commodity (food) prices boosted inflation across the global economy. High food and fuel prices led to substantial increases in inflation, particularly in emerging markets and low-income countries. In advanced economies, headline inflation rose to 3.5 percent in May 2008 (year-on-year) while core inflation remained at 1.8 percent. In emerging and developing economies, headline and core inflation had risen to 8.6 percent and 4.2 percent, respectively.



Source: IMF (2008)

Countries used a combination of monetary, trade, and fiscal responses, involving difficult trade-offs, to counter inflationary pressures, depending on whether they were fuel (non-fuel) exporters or importers. Some governments resorted to price and quantity controls on imports and exports, and implemented administered prices, subsidies, and buffer-stock building. The responses to inflation also depended on the exchange rate regime. Countries with flexible exchange rate regimes used a combination of monetary and fiscal policies to combat inflation. Countries with pegged or relatively fixed exchange rate regimes depended more on fiscal policy, efforts to increase productive capacity, and prudential measures to rein in inflation.

Overall, the results of such policy efforts were mixed, and the lessons from the previous inflationary cycle are still being documented. Further, inflation remained high until the housing market issues brought down rents in some markets and until the crisis pulled down brutally commodity and asset prices.

### III. A REVIEW OF THE LITERATURE

Research on the inflation-growth nexus have addressed three key questions: (i) is there a robust negative relationship between inflation and growth? (ii) is there a “kink” in the relationship such that at very low levels of inflation the relationship is positive (perhaps due to Phillips curve effects), but at higher levels of inflation the relationship is negative? and (iii) does inflation have to reach some minimum “threshold” before the growth effects become serious?

A starting point to answering these questions is the identification of the threshold (optimal, tolerable) beyond which inflation has a negative effect on growth. Empirical studies have found a significant statistical relationship between inflation and growth, even after controlling for fiscal performance, wars, droughts, population growth, openness, and even human and physical capital, and allowing for simultaneity bias. Measuring the threshold level of inflation in a cross-country framework runs the risk of being influenced by extreme values since samples typically include countries with inflation as low as 1 per cent and as high as 200 per cent. Ideally, inflation thresholds should be estimated for each country separately, allowing the incorporation of country specific characteristics. Nevertheless, since the relationship between inflation and growth is likely to be stronger at low frequencies, and the data rarely cover more than 40 years, the literature has mostly relied on panel techniques.

Empirical studies have been conducted using both time series and panel estimates. Mubarik (2005) analyzed data on Pakistan for the period 1973–2005 and found that although inflation below 5 percent has a positive impact on economic growth; it depresses growth if above 9 percent. Rangarajan (1997), working with Indian data, suggested a range of 5 to 7 percent, a result that was confirmed by Samantaraya and Prasad (2001) who estimated the threshold at 6.5 percent.

Studies based on panel estimates have produced mixed results. Based on a cross-country regression (101 countries) over the period 1960–89, Fischer (1993) found that high inflation retards the growth of output by reducing investment and the rate of productivity growth. Barro (1995, 2001) and Bruno and Easterley (1996) noticed, using different panels, that the

negative effect of inflation on growth was significant only when high-inflation episodes were included in its sample. Using annual data for 87 countries for the period 1970–90, Sarel (1996) found evidence of a structural break occurring at a level of inflation of 8 percent— inflation and growth are positively correlated below 8 percent, but negatively correlated above that, suggesting that the omission of this non-linearity would result in a significant underestimation of the impact of inflation on growth.

Ghosh and Philips (1998) found that although inflation and growth are positively correlated at very low inflation rates (about 2 to 3 percent a year); the relationship is reversed at higher rates. Furthermore, the relationship is convex, so that the decline in growth associated with an increase in inflation from 10 to 20 percent is much larger than that associated with an increase from 40 to 50 percent. Khan and Senhadji (2001) reexamined this result and found a significant threshold effect that was different for industrial and developing countries. Their study, based on a panel of 140 countries over the period 1960–98, established that the threshold above which inflation significantly slows growth is between 1 and 3 percent for industrial countries and 7 and 11 percent for developing countries. Drukker, Gomis-Porqueras, and Hernandez-Verme (2005) confirmed the existence of a threshold using a panel of 138 countries, but they estimated its level to be higher, at about 19 percent. This level of the threshold, higher than usually estimated, was confirmed by Pollin and Zhu (2006) who also divided the sample by decades and suggested that the threshold would be around 15-18 percent. A much lower threshold was obtained by Burdekin et al (2004), who estimated a panel model on 72 countries using annual data and, allowing for multiple thresholds, found that for developing countries inflation is costly when it is higher than 3 percent. A second break was also identified at 50 percent, above which marginal growth costs decreases by 25 percent.

This study augments the literature by (i) extending the estimation period and increasing the number of countries, (ii) distinguishing emerging markets and oil exporters, (iii) estimating the speed of transition between low and high costs to inflation, and (iv) using bootstrap techniques to validate the precision of the estimates.

#### **IV. INFLATION AND GROWTH–THRESHOLD LEVEL**

##### **A. Estimating the LSTR Model**

We extend the Khan and Senhadji (2001) model by estimating the link between inflation and GDP growth using a panel of 165 countries covering the period 1960–2007 and allowing both for a smooth threshold model and a convex relationship above (and below) the threshold. Our explanatory variable is a logarithmic function of inflation: as a result, an increase from 10 percent to 20 percent inflation is modeled to have the same effect as an increase from 50 percent to 100 percent. In line with the growth literature, we averaged data over 5-year periods<sup>1</sup> to smooth out the business cycles fluctuations and controlled for the

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<sup>1</sup> The time dimension of the data is therefore 9 periods of 5-year averages. This prevents any moving average dynamics that would be generated by keeping annual data of 5-year averages.

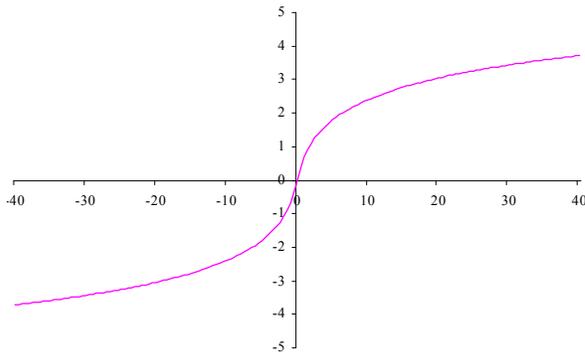
other determinants of growth: the ratio of investment to GDP, population growth, initial GDP, the rate of change in the terms of trade, and the variability of the terms of trade. We estimate the following LSTR model to test for the costs of inflation on activity:

$$\left\{ \begin{array}{l} \Delta y_{it} = \alpha_{iy} + \beta^{\text{low}} W^{\text{low}} (f(\pi_{it}) - f(c^*)) + \beta^{\text{high}} W^{\text{high}} (f(\pi_{it}) - f(c^*)) + \Theta \cdot \mathbf{X}_{it} + \varepsilon_{it} \\ f(\pi_{it}) = \begin{cases} \ln(1 + \pi_{it}) & \text{if } \pi_{it} \geq 0 \\ -\ln(1 - \pi_{it}) & \text{if } \pi_{it} < 0 \end{cases} \\ W^{\text{low}} = 1 - W^{\text{high}} \\ W^{\text{high}} = \frac{1}{1 + \exp(-\gamma \frac{f(\pi_{it}) - f(c^*)}{\text{st.dev}})} \end{array} \right. \quad (1)$$

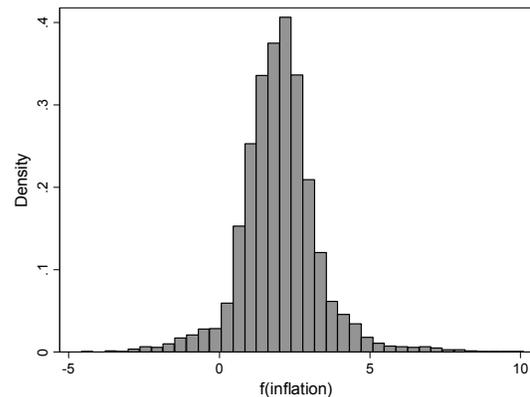
NB : st.dev is the standard deviation of  $f(\pi_{it}) - f(\pi^{*TAR})$  where  $\pi^{*TAR}$  is the threshold estimated in a discrete Threshold model

The function  $f(\pi)$  (see Figure 1) is used to model the effect of inflation on growth. The choice of a logarithmic function, as opposed to a linear function such as  $f(\pi) = \pi$ , allows us to capture the fact that multiplicative shocks in inflation have similar effects on growth, for any level of initial inflation. For instance, in a linear model, an increase in inflation from 10 percent to 20 percent would have the same effect on growth as an increase from 50 percent to 60 percent. In a multiplicative (i.e. logarithmic) model, an increase from 10 percent to 20 percent inflation would have the same effect as an increase from 50 percent to 100 percent. The constant 1 was added in the logarithmic function to smooth the distribution of  $f(\pi)$  around zero. The distribution for  $f(\pi)$  in the data also seems acceptable (see Figure 2).

**Figure 1 - Explanatory Variable  $f(\pi)$  as a Function of  $\pi$**

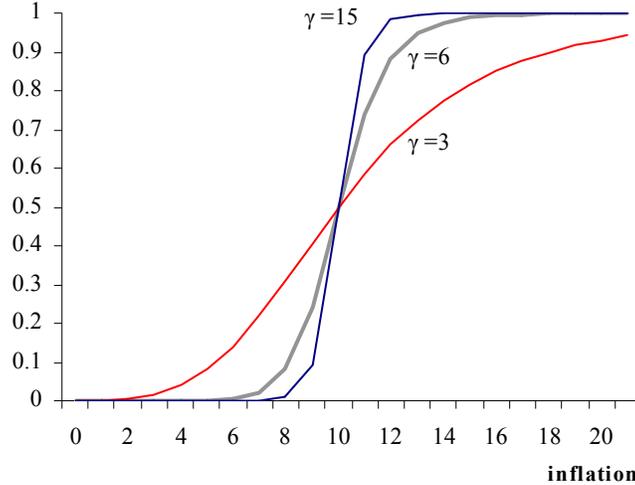


**Figure 2 - Distribution of  $f(\pi)$  in the Data**



The explanatory variable  $f(\pi)$  is represented by two variables— $W^{\text{low}} (f(\pi) - f(\pi^*))$  and  $W^{\text{high}} (f(\pi) - f(\pi^*))$ —to capture the possibility that a different  $\beta$  should be used for different levels of inflation:

**Figure 3: Weight on  $\beta^{\text{high}}$  (threshold = 10, st.dev = 0.5)**



- a) if inflation is very low, the effect of inflation on growth is represented by  $\beta^{\text{low}}$  only (since  $W^{\text{high}} = 0$  – see Figure 3 – and therefore  $W^{\text{low}} = 1$ ).
- b) if inflation is very high, the effect of inflation on growth will be represented by  $\beta^{\text{high}}$  mostly (since  $W^{\text{high}} = 1$  when inflation is high).
- c) when inflation is of a similar order to  $\pi^*$ , the actual effect of inflation on growth is given by a weighted average of  $\beta^{\text{low}}$  and  $\beta^{\text{high}}$ , where the weights are given by  $W^{\text{high}}$ , as plotted in Figure 3, and  $W^{\text{low}} = 1 - W^{\text{high}}$ . When inflation is equal to  $\pi^*$  there is no difference between the two explanatory variables and  $W^{\text{high}} = W^{\text{low}} = 1/2$ .

In addition, the parameter  $\gamma$  captures the speed of transition from one regime to another. When  $\gamma$  is low (e.g.  $\gamma = 3$  in Figure 3), even if inflation is above the threshold (say inflation is 13 percent and the estimated threshold is 10 percent), the effect of inflation on growth may not be strongly negative, since it will be captured by  $0.3 * \beta^{\text{low}} + 0.7 * \beta^{\text{high}}$ .<sup>2</sup> If  $\gamma = 15$ , the effect is instead  $0.003 * \beta^{\text{low}} + 0.997 * \beta^{\text{high}}$ .

The estimation of  $\gamma$  is important in the LSTR model: the policy implications of a high  $\gamma$  would be that inflation pressures have to be tackled on a priority basis as it becomes immediately costly. The standard Threshold models used in the literature assumed that  $\gamma \rightarrow \infty$  and, therefore, is unable to answer the question of how quickly one should worry about high inflation.

We estimated the LSTR model using several control variables as determinants of growth: the ratio of investment to GDP, population growth, initial GDP, the rate of change in terms of trade, and the variability of the terms of trade. Since investment is included in the list of explanatory variables, the total effect of inflation on growth could be biased by the correlation between inflation and investment. The effect of inflation on investment (and

<sup>2</sup> All the calculus and the graph above are computed with st.dev = 0.5.

indirectly on growth) is not investigated. Since we control for population growth as opposed to employment growth (because of data availability), the effect of inflation on labor force participation rates and structural unemployment is implicitly included in the costs of inflation we compute. We included time dummies to control for world business cycles and country dummies to capture country-specific characteristics. To smooth out short-term fluctuations, we averaged data over 5 years.<sup>3</sup>

We estimated the model for all the countries in the data set (Table 1 columns 1 to 3) and for several country groups (the list is presented in the Appendix), including advanced economies (columns 4 to 6), emerging markets (columns 7 to 9), a group of oil producers (columns 10 to 12), and all countries for which non-oil GDP data was available (columns 13 to 15). We excluded data for periods of severe recession—when losses were higher than 5 percent of GDP per year over 5 years. These episodes correspond to the fall of the Soviet Union (Azerbaijan, Belarus, Kazakhstan, Russia in the 1990–1994 period), the 1990–1994 years in Angola, and the 1960–1964 period in Argentina and Taiwan.

Our results identify a threshold inflation of about 9 percent for the entire sample of 165 countries. The coefficient  $\beta^{\text{high}}$  for the variable  $W^{\text{high}}(f(\pi) - f(\pi^*))$  is significant (the standard errors are built using 500 bootstrapping iterations that are conditioned on the value of the threshold found in the base estimation. More general bootstrapping results are discussed in section B). When inflation is above 9 percent, a doubling of inflation decreases GDP by 0.7 percentage point per year – see **Table 2**. The order of magnitude of our estimate is in line with that of Khan and Senhadji (2001), who use a discrete threshold model and the same control variables. We find that our full sample estimate is driven by the data in emerging and developing economies, which produces almost identical results to that of the full panel. Our results for advanced economies show a different pattern: inflation would be costly at much lower levels (the threshold is 1 percent)—however the costs of inflation would be smaller as well (almost three times smaller).

The estimates are very similar if one selects only the sub-sample of post-1990 data for all countries (see **Table 3**). We found that the threshold for this smaller sample is almost the same, at about 11 or 12 percent, and that the cost of inflation for growth is also of the same order of magnitude. For the advanced economies, the non-linearity in the relationship between inflation and growth seems however to have been reduced after 1990: there is no major difference in the cost of inflation below and above the threshold (both are negative), and this is why the threshold estimate is very high (at 14 percent). The precision of the estimate is however hampered by the relatively smaller size of the sample. The bootstrapping exercise nonetheless confirms that the 1 percent threshold is accurately estimated for the whole sample.

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<sup>3</sup> We also estimated the model on 3-year average data. The results were very similar (see Table 3).

For the group of oil-exporting countries, the threshold inflation is found to be 74 percent. This result is much higher than what would be found using the TAR model, according to which the threshold would be 10 percent. We show however that this result is not robust, and that it is useful to look at the modes of the bootstrapping distribution to form a better judgment on this threshold.

In particular, since GDP numbers may be contaminated by the importance of oil production in real GDP, we also estimated the model using non-oil GDP data, covering all countries for which this data is available. Interestingly, the results are stronger than that of our previous estimates: a doubling of inflation from higher than 13 percent decreases real non-oil GDP by 2.7 percent per year. Although we do not have the data to investigate the cause of this finding, we speculate that this could be either because the non-primary commodity sector tends to be more sensitive to inflation (since production in the primary sector tends to depend on other elements such as international prices and production capacity)—in which case the finding would be relevant to a varied range of countries— or because the structure of the countries for which we have data (countries from Africa, the Middle East, and Central Asia) is different.

The LSTR model provides estimates of  $\gamma$  that are fairly high. This implies that starting from a level of inflation of 10 percent, doubling inflation is more costly than if the speed of transition from one regime was much lower (see column (a) vs. column (b) in Table 2). The exception is for the group of oil producers, for which the LSTR estimate suggests a very low speed of transition and a very high threshold – however this result is not robust and is probably driven by outliers: indeed, the bootstrapping exercise (see section B) suggests that the data is also compatible with a high speed of transition and much lower threshold. Overall, the LSTR models confirm that inflation tends to be costly quickly, which means that inflation has to be tackled sooner rather than later. Since this result would suggest that the discrete TAR model may also be a good – albeit simplified – model of the relationship between inflation and growth, we also estimate TAR models as a check and find that the results are comparable.

All the models are identified using the assumption that over the medium-term (the variables are expressed as 5-year averages) the causality runs from inflation to growth, a common assumption in the growth-inflation literature (the OLS assumption). We checked for robustness of our results to endogeneity of inflation by regressing growth on lagged inflation (which is unlikely to be caused by future growth), as opposed to contemporaneous inflation. The lagged investment to GDP ratio was also used for the same reason. The dataset was averaged over 3 years for this exercise, in order to keep the relationship meaningful. The threshold estimates were again very similar (slightly higher for Emerging Markets) to what was found using contemporaneous inflation (see **Table 3**, columns 7 to 15), confirming that the estimation is robust to potential endogeneity of inflation. The effect of high inflation seems however to be stronger when using 5-year averages and contemporaneous inflation.

## B. Statistical Inference through Bootstrapping

Statistical inference was performed using a bootstrapping technique that takes into account the panel structure of the data and the non-linearities that are estimated. (The TAR estimates in **Tables 1 and 3** incorporate the analytical results in Chan and Tsay (1998) and Hansen (1999)).<sup>4</sup>

The bootstrapping exercises suggest that most of our results are robust (see **Figures 4 to 6**). The distribution of the thresholds is concentrated around the base estimates. For developing countries, the estimated inflation threshold lies between 7 and 13 percent for more than 90 percent of the bootstrapped sample. For advanced economies, although the mode of the distribution is at 1 percent, the inflation threshold is found to be lower than 5 (resp. 18) percent in only 43 (resp. 75) percent of the bootstrapped samples.

For oil exporters, the estimations (both TAR and LSTR) are not robust, as the histogram in **Figure 5** shows. Indeed, there seems to be two potential “modes” for the distribution of the threshold – the TAR mode estimate in the bootstrapping distribution is at 10 percent, but there is a cluster of simulations for which the estimated threshold would exceed 100 percent. This suggests that there are several outliers or, equivalently, that the country group oil exporters is not homogenous enough to conduct such an estimation. As a result, the estimated LSTR model in **Table 1** could be misleading<sup>5</sup> since the data is also compatible with a standard inflation threshold of around 10 percent and a  $\gamma$  higher than 10. For this group, the TAR model seems more robust than the LSTR, and its estimate is in line with that of the LSTR’s lower peak (and more reasonable threshold estimate) in the bootstrapping distribution. The heterogeneity in the relationship seems to be due to hydrocarbon GDP: when estimating the same model with non-oil GDP growth as a dependent variable, the threshold estimate is robust around 13 percent, in line with that found for the Emerging Market group. However, one should note that the effect of higher inflation on (non-oil) growth is stronger for oil producing countries than for the other emerging markets.

It is noteworthy that although the coefficients linking growth and inflation at low levels of inflation are not consistently different from zero, the link between growth and inflation at

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<sup>4</sup> Hansen (1999) suggests a LR statistics to test for the significance of the non-linearity. The LR test compares the likelihood of the OLS model against that of the TAR model. Since the statistic is not identified under the null hypothesis of absence of non-linearity, the significance level has to be estimated using bootstrapping. A bootstrap of residuals is used, where the entire time series of country residuals are sampled (with replacement). The sampling is performed by group of countries for which the same number of data (periods) is available (see Appendix 4 for a description of the bootstrapping technique). Chan and Tsay (1998) give analytical results on the distribution of the threshold and the coefficient estimates for continuous models such as the ones estimated here. We provide the standard error of the TAR threshold and the z-scores for the explanatory variables in column (ii) of our estimates. The standard errors for the threshold estimates are usually small, around 1 percentage point, which suggests that the TAR estimates are accurate – although less so than as estimated by Khan and Senhadji (2001).

<sup>5</sup> As a result, the very low  $\gamma$  is not robust either – there is a very strong negative correlation between  $\gamma$  and  $c$ .

high levels of inflation is almost always negative. This confirms the importance of nonlinearities and the negative relation between high inflation and growth.

### C. TAR or LSTR: a Monte-Carlo Analysis

We conducted Monte-Carlo experiments to analyze the difference between the LSTR model with a reasonably low  $\gamma$  ( $\gamma = 6$ ) and one with an infinite  $\gamma$  (i.e. a TAR model). The Monte-Carlo simulations consist in generating artificial data from the low- $\gamma$  LSTR model (equation 1) using the actual estimates of the parameters the model ( $\gamma$ ,  $c^*$ , and the standard error of the model) for the different groups, and then estimating a TAR model. The reverse experiment is also performed, i.e. artificial data is generated using the TAR model's parameters and used to estimate an LSTR model.

The results are presented in **Figure 7**. We find that the LSTR estimation procedure is good at capturing the value of the threshold as well as the negative sign of the  $\beta^{\text{high}}$  coefficient. However, the  $\beta^{\text{low}}$  coefficient is not statistically different from 0. Since this result matches that of the bootstrapping exercise, it suggests that with random errors in the data, it is difficult to obtain statistical significance for  $\beta^{\text{low}}$  even if  $\beta^{\text{low}}$  is different from zero in the data generation process. We also find that the LSTR often estimates  $\gamma$  to be lower than its true value: for a TAR, the estimate should be  $\gamma \rightarrow \infty$ , which we approximate by  $\gamma \geq 15$ , but this happens only 25 percent of the time.

For the converse exercise, i.e. an LSTR model simulated with a low  $\gamma$  and estimated as a TAR, we find that the TAR model does not bias significantly the threshold estimate. It is also able to obtain a significantly negative coefficient for  $\beta^{\text{high}}$ . Of course, the TAR does not allow us to evaluate the size of  $\gamma$ .

## V. CONCLUSION

Motivated by the global inflation episode of 2007–08 and the risk that the monetary policies during the global financial crisis could spur global inflation, this paper revisits the nexus between inflation and growth. We use a smooth transition model to investigate the speed at which inflation beyond a threshold becomes harmful to growth, an important consideration in the policy response to rising inflation as the world economy recovers. Using a panel of 165 countries covering the period 1960–2007, we estimate that for emerging market economies inflation above a threshold of about 10 percent quickly becomes harmful to growth, suggesting the need for a prompt policy response to inflation at or above that threshold. For the advanced economies, the threshold is much lower. For oil exporting countries, the estimates are less robust (there are two potential modes for the bootstrapping distribution, reflecting some heterogeneity among oil producers), but we estimate the threshold to be again about 10 percent. The effect of higher inflation for oil producers is also stronger than for the rest of the countries.

## APPENDIX A. COUNTRY GROUPS

*Oil producers:* Algeria, Azerbaijan, Rep. of, Bahrain, Kingdom of, Brunei Darussalam, Canada, Congo, Republic of, Ecuador, Equatorial Guinea, Gabon, Iran, I.R. of, Kazakhstan, Kuwait, Libya, Nigeria, Norway, Oman, Qatar, Russia, Saudi Arabia, Sudan, Syrian Arab Republic, Trinidad and Tobago, Turkmenistan, United Arab Emirates, Venezuela, Rep. Bol., Yemen, Republic of.

*Advanced economies:* Australia, Austria, Belgium, Canada, China,P.R.:Hong Kong, Cyprus, Denmark, Finland, France, Germany, Greece, Iceland, Israel, Italy, Japan, Korea, Luxembourg, Malta, Netherlands, New Zealand, Norway, Portugal, Singapore, Slovenia, Spain, Sweden, Switzerland, Taiwan Prov.of China, United Kingdom, United States.

*Emerging markets:* Albania, Algeria, Angola, Argentina, Armenia, Azerbaijan, Rep. of, Bahamas, The, Bahrain, Kingdom of, Bangladesh, Barbados, Belarus, Belize, Benin, Bhutan, Bolivia, Bosnia & Herzegovina, Botswana, Brazil, Bulgaria, Burkina Faso, Burundi, Cambodia, Cameroon, Cape Verde, Central African Rep., Chad, Chile, China,P.R.: Mainland, Colombia, Comoros, Congo, Republic of, Costa Rica, Côte d'Ivoire, Croatia, Czech Republic, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Eritrea, Estonia, Ethiopia, Gabon, Gambia, The, Georgia, Ghana, Grenada, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Hungary, India, Indonesia, Iran, I.R. of, Ireland, Jamaica, Jordan, Kazakhstan, Kenya, Kuwait, Kyrgyz Republic, Lao People's Dem.Rep, Latvia, Lebanon, Lesotho, Libya, Lithuania, Macedonia, FYR, Madagascar, Malawi, Malaysia, Maldives, Mali, Mauritania, Mauritius, Mexico, Moldova, Mongolia, Morocco, Mozambique, Myanmar, Namibia, Nicaragua, Niger, Nigeria, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Qatar, Romania, Russia, Rwanda, Saudi Arabia, Senegal, Serbia, Republic of, Seychelles, Sierra Leone, Slovak Republic, Solomon Islands, South Africa, Sri Lanka, St. Kitts and Nevis, St. Lucia, St. Vincent & Grens., Sudan, Suriname, Swaziland, Syrian Arab Republic, Tajikistan, Tanzania, Thailand, Togo, Trinidad and Tobago, Tunisia, Turkey, Uganda, Ukraine, United Arab Emirates, Uruguay, Uzbekistan, Venezuela, Rep. Bol., Vietnam, Yemen, Republic of, Zambia, Zimbabwe.

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**Table 1: OLS, LSTR, and TAR Results**

	All countries			Advanced economies			Emerging Markets			Oil producers			Oil producers - non oil GDP		
	(1) OLS	(2) LSTR	(3) TAR	(4) OLS	(5) LSTR	(6) TAR	(7) OLS	(8) LSTR	(9) TAR	(10) OLS	(11) LSTR	(12) TAR	(13) OLS	(14) LSTR	(15) TAR
	conditional bootstrap			conditional bootstrap			conditional bootstrap			conditional bootstrap			conditional bootstrap		
Investment/GDP	0.069	0.064	0.064	0.095	0.092	0.092	0.065	0.061	0.062	0.212	0.208	0.202	0.333	0.334	0.333
	[7.26]***	[1.74]*	[6.76]***	[4.00]***	[3.90]***	[3.92]***	[6.16]***	[1.66]*	[5.86]***	[5.47]***	[1.86]*	[5.24]***	[3.41]***	[3.21]***	[3.54]***
population growth	0.497	0.502	0.503	0.581	0.52	0.519	0.497	0.504	0.502	0.768	0.796	0.811	0.397	-0.193	-0.177
	[6.09]***	[3.36]***	[6.23]***	[3.16]***	[2.21]**	[2.82]***	[5.45]***	[3.13]***	[5.54]***	[4.64]***	[5.04]***	[4.94]***	[0.39]	[0.19]	[0.18]
initial GDP	-0.021	-0.021	-0.021	-0.037	-0.037	-0.037	-0.017	-0.016	-0.016	-0.023	-0.024	-0.023	0.204	0.206	0.206
	[7.55]***	[6.12]***	[7.36]***	[8.28]***	[5.53]***	[8.18]***	[4.82]***	[4.01]***	[4.79]***	[2.58]**	[3.12]***	[2.61]***	[6.44]***	[1.96]*	[6.78]***
terms of trade growth	0.057	0.053	0.053	0.061	0.057	0.057	0.055	0.052	0.052	0.076	0.064	0.065	0.156	0.123	0.122
	[4.41]***	[2.82]***	[4.13]***	[1.81]*	[1.38]	[1.69]*	[3.79]***	[2.69]***	[3.60]***	[1.81]*	[1.91]*	[1.56]	[1.51]	[1.02]	[1.23]
stdev of the terms of trade	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	[2.69]***	[0.62]	[2.60]***	[0.48]	[0.36]	[0.43]	[2.52]**	[0.64]	[2.46]**	[1.53]	[1.10]	[1.42]	[2.01]**	[0.36]	[1.79]*
$f(\text{inflation})$	<b>-0.005</b>			<b>-0.006</b>			<b>-0.005</b>			<b>-0.001</b>			<b>-0.007</b>		
	[4.75]***			[3.55]***			[4.37]***			[0.24]			[0.58]		
$f(\text{inflation})-f(\text{threshold})$ if inflation<threshold			<b>0.003</b>			<b>0.008</b>			<b>0.001</b>			<b>0.007</b>			<b>0.028</b>
			[1.53]			[1.23]			[0.36]			[1.51]			[1.98]**
$f(\text{inflation})-f(\text{threshold})$ if inflation>threshold			<b>-0.01</b>			<b>-0.008</b>			<b>-0.01</b>			<b>-0.019</b>			<b>-0.083</b>
			[7.04]***			[4.19]***			[5.72]***			[2.30]**			[3.61]***
$W^{\text{low}} * (f(\text{inflation})-f(c^*))$ if inflation<c*		<b>0.002</b>				<b>0.008</b>			<b>0.001</b>			<b>-0.006</b>			<b>0.028</b>
		[1.10]				[0.33]			[0.40]			[2.06]**			[2.06]**
$W^{\text{high}} * (f(\text{inflation})-f(c^*))$ if inflation>c*		<b>-0.01</b>				<b>-0.008</b>			<b>-0.01</b>			<b>-0.135</b>			<b>-0.082</b>
		[6.83]***				[2.69]***			[5.35]***			[3.38]***			[3.04]***
Constant	0.142	0.135	0.136	0.131	0.127	0.127	0.117	0.112	0.112	0.074	0.037	0.078	-0.873	-0.881	-0.88
	[6.60]***	[2.68]***	[6.49]***	[8.34]***	[1.30]	[8.23]***	[5.16]***	[1.89]*	[4.97]***	[1.67]*	[0.29]	[1.80]*	[5.05]***	[1.23]	[5.34]***
Observations	1304	1304	1304	259	259	259	1042	1042	1042	200	200	200	253	253	253
R-squared	0.41		0.43	0.75		0.76	0.39		0.4	0.5		0.52	0.64		0.67
Hansen F-test (H0: Pi*=0)			26.51			<b>5.41</b>			14.8			5.76			14.38
p-value			0			<b>0</b>			0			0.01			0
Threshold		<b>9</b>	<b>8</b>			<b>1</b>			<b>10</b>			<b>74</b>			<b>13</b>
Stdev threshold			<b>1.13</b>			<b>1.32</b>			<b>1.58</b>			<b>1.48</b>			<b>0.91</b>
z-score threshold			<b>-7.07</b>			-0.76			<b>-6.98</b>			<b>-6.73</b>			<b>-14.35</b>
Gamma		<b>6</b>				<b>13</b>			<b>6</b>			<b>1</b>			<b>11</b>

\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%

Coefficients for time and country dummy variables not shown

Absolute value of t statistics in square brackets

TABLE 2. EFFECT OF INFLATION ON GROWTH

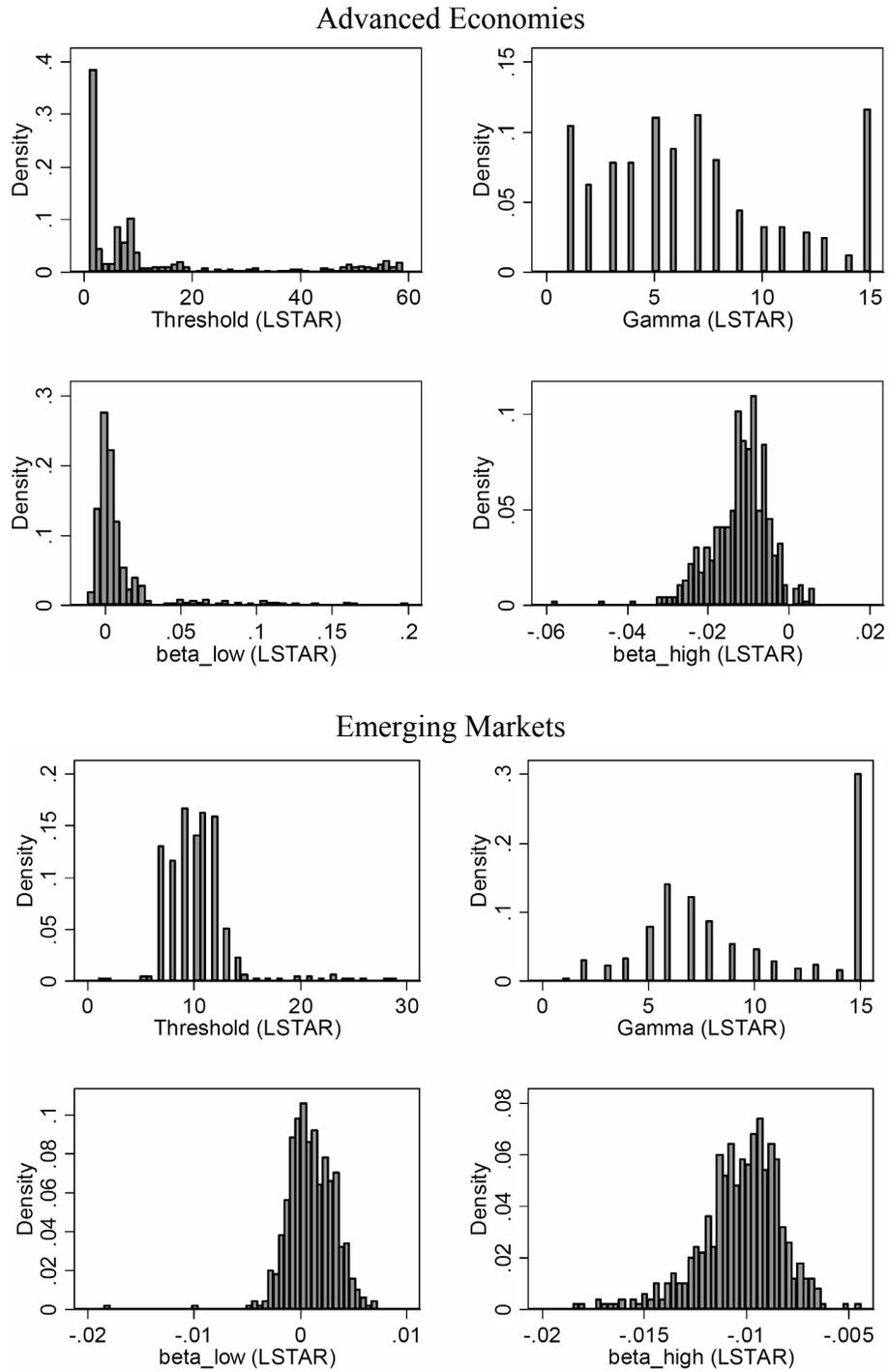
effect on annual GDP growth	All countries (a)	All countries (if gamma =1) (b)	All countries (if gamma =15) (c)	advanced economies (d)	emerging and developing economies (e)	effect on non- oil real GDP (f)
<b>threshold</b>	<b>9</b>	<b>9</b>	<b>9</b>	<b>1</b>	<b>10</b>	<b>13</b>
<b><math>\beta</math> low</b>	<b>0.002</b>	<b>0.002</b>	<b>0.002</b>	<b>0.008</b>	<b>0.001</b>	<b>0.028</b>
<b><math>\beta</math> high</b>	<b>-0.01</b>	<b>-0.01</b>	<b>-0.01</b>	<b>-0.008</b>	<b>-0.01</b>	<b>-0.082</b>
<b>gamma</b>	<b>6</b>	<b>1</b>	<b>15</b>	<b>13</b>	<b>6</b>	<b>11</b>
<i>(st.dev)</i>	1.08	1.08	1.08	0.84	1.12	0.98
<b>from initial inflation</b>	<b>1</b>					
to new inflation	1	0.00	0.00	0.00	0.00	0.00
	5	0.25	0.10	0.22	-0.88	0.13
	8	0.35	0.00	0.32	-1.20	0.21
	9	0.32	-0.04	0.32	-1.29	0.20
	10	0.27	-0.08	0.25	-1.36	0.17
	12	0.12	-0.16	0.07	-1.50	0.06
	15	-0.11	-0.28	-0.15	-1.66	-0.16
	20	-0.41	-0.48	-0.42	-1.88	-0.45
	30	-0.81	-0.81	-0.81	-2.19	-0.86
	45	-1.20	-1.20	-1.20	-2.51	-1.26
<b>from initial inflation</b>	<b>5</b>					
to new inflation	1	-0.25	-0.10	-0.22	0.88	-0.13
	5	0.00	0.00	0.00	0.00	0.00
	8	0.09	-0.09	0.10	-0.32	0.07
	9	0.07	-0.13	0.10	-0.41	0.07
	10	0.02	-0.17	0.03	-0.48	0.04
	12	-0.13	-0.26	-0.15	-0.62	-0.08
	15	-0.36	-0.38	-0.37	-0.78	-0.29
	20	-0.66	-0.58	-0.64	-1.00	-0.59
	30	-1.06	-0.91	-1.03	-1.31	-1.00
	45	-1.46	-1.30	-1.42	-1.63	-1.39
<b>from initial inflation</b>	<b>10</b>					
to new inflation	1	-0.27	0.08	-0.25	1.36	-0.17
	5	-0.02	0.17	-0.03	0.48	-0.04
	8	0.08	0.08	0.07	0.16	0.04
	9	0.05	0.04	0.07	0.08	0.03
	10	0.00	0.00	0.00	0.00	0.00
	12	-0.15	-0.08	-0.18	-0.13	-0.11
	15	-0.38	-0.21	-0.40	-0.30	-0.33
	20	-0.67	-0.40	-0.67	-0.52	-0.63
	30	-1.08	-0.74	-1.06	-0.83	-1.03
	45	-1.47	-1.13	-1.45	-1.14	-1.43
<b>from initial inflation</b>	<b>15</b>					
to new inflation	1	0.11	0.28	0.15	1.66	0.16
	5	0.36	0.38	0.37	0.78	0.29
	8	0.46	0.29	0.47	0.46	0.36
	9	0.43	0.25	0.47	0.38	0.36
	10	0.38	0.21	0.40	0.30	0.33
	12	0.23	0.12	0.21	0.17	0.21
	15	0.00	0.00	0.00	0.00	0.00
	20	-0.30	-0.20	-0.27	-0.22	-0.30
	30	-0.70	-0.53	-0.66	-0.53	-0.71
	45	-1.09	-0.92	-1.06	-0.84	-1.10

**Table 3. Robustness Checks**

	All Countries Post 1990			Advanced Economies Post 1990			All Countries (lagged infl. and investment; 3-year av.)			Emerg. Markets (lagged infl. and investment; 3-year av.)			Oil producers (lagged infl. and investment; 3-year av.)		
	(1) OLS	(2) LSTR	(3) TAR	(4) OLS	(5) LSTR	(6) TAR	(7) OLS	(8) LSTR	(9) TAR	(10) OLS	(11) LSTR	(12) TAR	(13) OLS	(14) LSTR	(15) TAR
	conditional bootstrap			conditional bootstrap			conditional bootstrap			conditional bootstrap			conditional bootstrap		
Investment/GDP	0.146 [6.21]***	0.139 [2.07]**	0.139 [2.09]**	0.159 [3.13]***	0.103 [1.01]	0.103 [1.03]	0.014 [1.39]	0.011 [0.65]	0.011 [0.62]	0.013 [1.15]	0.011 [0.63]	0.011 [0.64]	0.155 [3.68]***	0.143 [2.00]**	0.143 [3.43]***
population growth	0.353 [2.54]**	0.339 [1.51]	0.338 [1.44]	0.164 [0.39]	0.122 [0.19]	0.123 [0.19]	0.337 [4.10]***	0.339 [1.64]	0.34 [1.76]*	0.322 [3.48]***	0.324 [1.44]	0.325 [1.48]	0.385 [2.05]**	0.446 [1.28]	0.443 [2.38]**
initial GDP	-0.043 [6.52]***	-0.043 [3.74]***	-0.043 [3.45]***	-0.071 [3.59]***	-0.076 [4.86]***	-0.076 [4.65]***	-0.012 [3.69]***	-0.012 [2.89]***	-0.012 [2.89]***	-0.007 [1.76]*	-0.007 [1.55]	-0.007 [1.59]	-0.018 [1.70]*	-0.022 [2.19]**	-0.022 [2.06]**
terms of trade growth	0.02 [0.86]	0.008 [0.34]	0.009 [0.38]	0.022 [0.29]	0.006 [0.08]	0.007 [0.09]	0.049 [5.07]***	0.049 [2.55]**	0.049 [2.65]***	0.048 [4.44]***	0.047 [2.47]**	0.047 [2.43]**	0.132 [4.06]***	0.132 [3.07]***	0.132 [4.12]***
stdev of the terms of trade	0 [0.56]	0 [0.23]	0 [0.22]	-0.001 [0.85]	0 [0.13]	0 [0.14]	0 [0.46]	0 [0.11]	0 [0.10]	0 [0.52]	0 [0.14]	0 [0.13]	0.001 [2.67]***	0.001 [1.47]	0.001 [2.58]**
$f(\text{inflation})$	-0.009 [5.38]***			-0.007 [1.99]**			0.001 [1.08]			0.001 [1.32]			-0.0002 [0.06]		
$f(\text{inflation})-f(\text{threshold})$ if inflation<threshold			<b>0</b> [0.13]		<b>-0.001</b> [0.48]			<b>0.004</b> [2.51]**			<b>0.004</b> [2.75]***				<b>0.007</b> [1.68]*
$f(\text{inflation})-f(\text{threshold})$ if inflation>threshold			<b>-0.015</b> [3.94]***		<b>-0.021</b> [0.06]			<b>-0.004</b> [2.24]**			<b>-0.004</b> [1.74]*				<b>-0.02</b> [2.43]**
$W^{\text{low}} * (f(\text{inflation})-f(c^*))$ if inflation<c*		<b>0</b> [0.13]		<b>-0.001</b> [0.49]			<b>0.004</b> [2.53]***			<b>0.004</b> [2.62]***					<b>0.007</b> [1.31]
$W^{\text{high}} * (f(\text{inflation})-f(c^*))$ if inflation>c*		<b>-0.014</b> [4.09]***		<b>-0.021</b> [0.00]			<b>-0.004</b> [2.16]**			<b>-0.004</b> [1.79]*					<b>-0.018</b> [1.54]
Constant	0.229 [6.50]***	0.214 [1.87]*	0.213 [1.81]*	0.252 [3.50]***	0.27 [1.26]	0.27 [1.22]	0.118 [5.58]***	0.11 [1.72]*	0.11 [1.85]*	0.093 [3.68]***	0.103 [1.91]*	0.103 [2.05]**	0.11 [2.04]**	0.133 [1.06]	0.134 [2.47]**
Observations	616	616	616	116	116	116	1688	1688	1688	1326	1326	1326	252	252	252
R-squared	0.62			0.7			0.33			0.31			0.41		0.43
Hansen F-test (H0: Pi*=0)			13.04			6.69			12.34			9.13			6.75
p-value			0			0.02			0			0			0.14
Threshold		<b>11</b>	<b>12</b>		<b>14</b>	<b>14</b>		<b>9</b>	<b>11</b>		<b>15</b>	<b>13</b>		<b>10</b>	<b>11</b>
Stdev threshold			1.43			1.99			1.95			2.31			1.96
z-score threshold			8.37			7.02			5.65			5.63			5.62
Gamma		<b>5</b>			<b>15</b>			<b>15</b>			<b>7</b>			<b>15</b>	

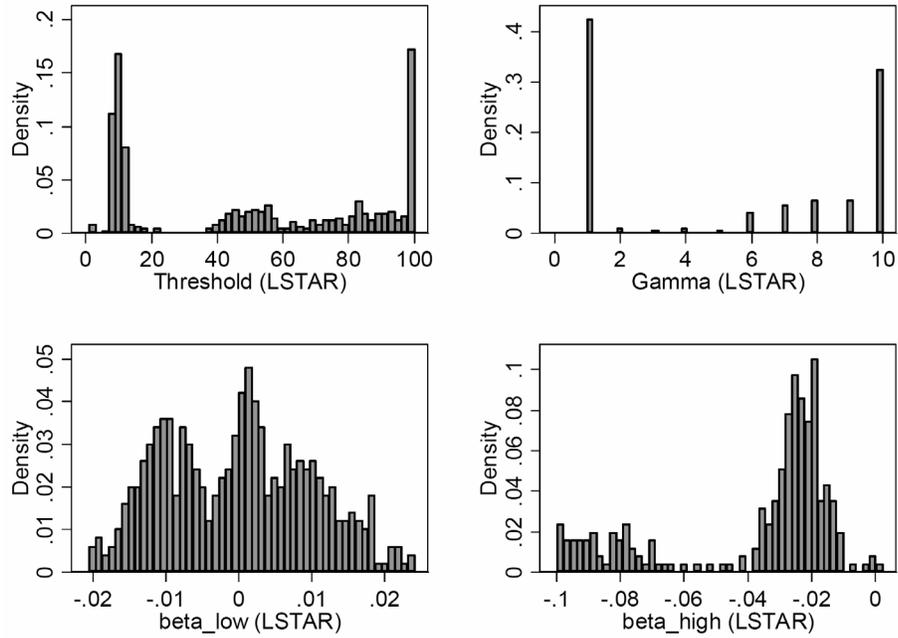
\* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%  
 Coefficients for time and country dummy variables not shown  
 Absolute value of t statistics in square brackets

**Figure 4. Bootstrapping Advanced Economies and Emerging Markets**

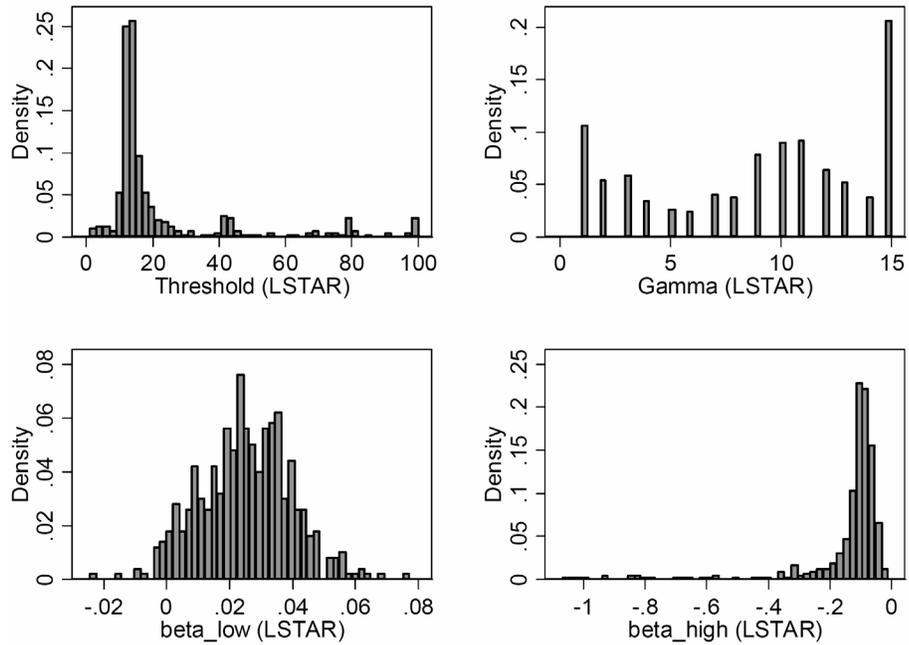


**Figure 5. Bootstrapping Oil Producers**

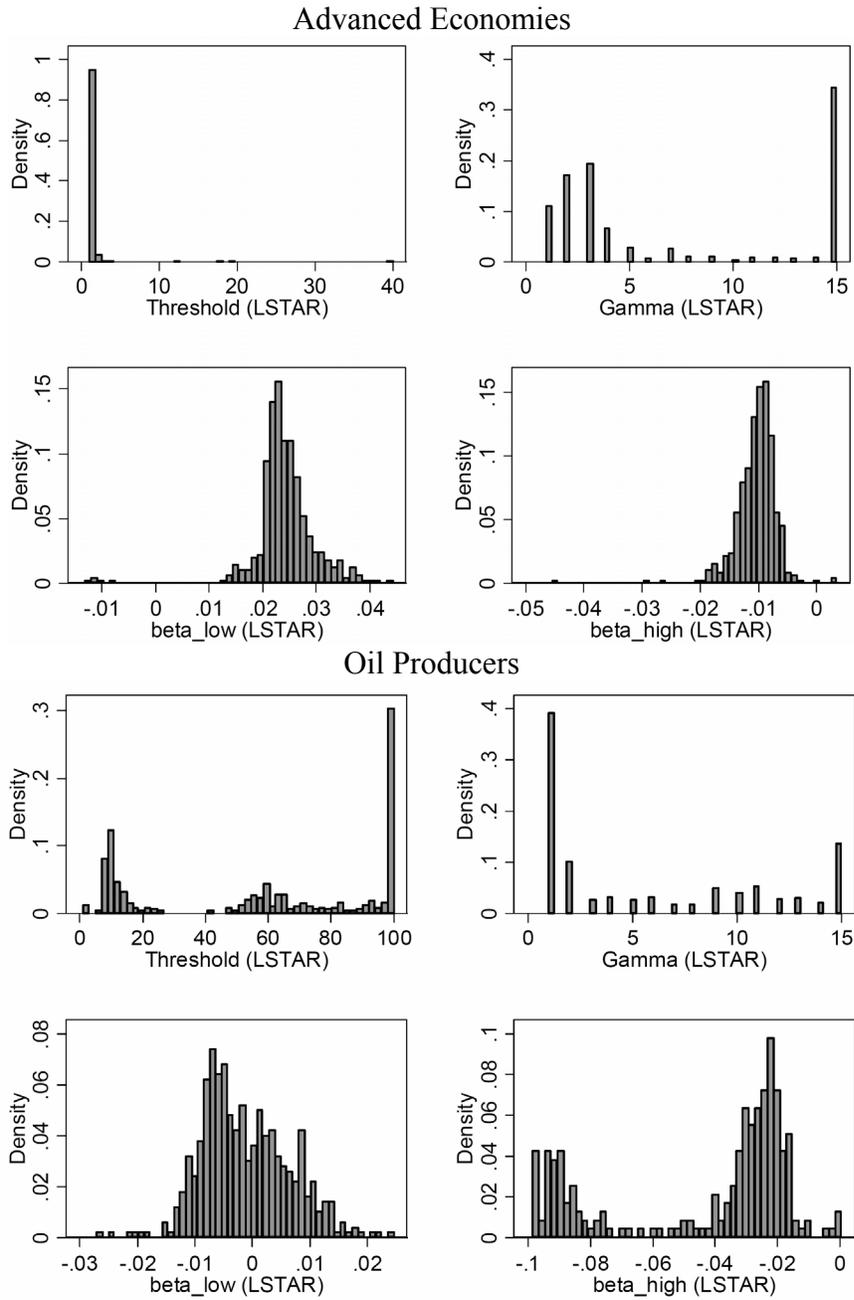
## Oil Producers, Total Real GDP



## Oil Producers, Non-Oil Real GDP (Africa, Middle East and Central Asia)



**Figure 6. Lagged Inflation and Lagged Investment**



**Figure 7. Monte-Carlo Simulations (DGPs are that Estimated for Emerging Markets)**

