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Inflation and growth: new evidence from a dynamic panel threshold analysis

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Abstract We introduce a dynamic panel threshold model to estimate inflation thresholds for long-term economic growth. Advancing on Hansen (J Econom 93:345–368, 1999) and Caner and Hansen (Econom Theory 20:813–843, 2004), our model allows the estimation of threshold effects with panel data even in case of endogenous regressors. The empirical analysis is based on a large panel-dataset including 124 countries. For industrialized countries, our results confirm the inflation targets of about 2% set by many central banks. For non-industrialized countries, we estimate that inflation rates exceeding 17% are associated with lower economic growth. Below this threshold, however, the correlation remains insignificant.

Keywords Inflation thresholds · Inflation and growth · Dynamicpanel threshold model

JEL Classification C72 · C23 · O40

1 Introduction

Most economists would agree that inflation has distortional effects on long-term economic growth if it gets "too high". Yet how high is too high? In the aftermath

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of the recent financial crisis, the long-time consensus on inflation targets for industrialized countries centering around 2% has been put up for discussion. Following, e.g. Blanchard et al. (2010), the effects of inflation on growth are difficult to discern, so long as inflation remains in the single digits. As a consequence, they suggest that an inflation target of 4% might be more appropriate because it leaves more room for expansionary monetary policy in case of adverse shocks. For developing countries, the appropriate level of the inflation target is also unclear. Bruno and Easterly (1998), for example, showed in a cross-sectional setting that inflation has only a detrimental impact on long-term economic growth if inflation exceeds a critical level of 40%—a rather large value which may be only of limited relevance for monetary policy in many countries.[1]

The theoretical literature offers various channels through which inflation may distort or even foster economic growth, see Temple (2000). If these different channels overlap or offset each other, or unfold an economic meaningful impact only for certain ranges of inflation, then the relationship between inflation and economic growth might be characterized by inflation thresholds, see Vaona (2012).[2] A natural starting point for the empirical analysis of inflation thresholds is the panel threshold model introduced by Hansen (1999) which is designed to estimate threshold values instead of imposing them. Yet, the application of Hansen's threshold model to the empirical analysis of the inflation–growth nexus is not without problems. The most important limitation of Hansen's model is that all regressors are required to be exogenous. In growth regressions with panel data, the exogeneity assumption is particularly severe, because initial income as a crucial variable is endogenous by construction. Caselli et al. (1996) already demonstrated for linear panel models of economic growth that the endogeneity bias can be substantial. So far, dynamic versions of Hansen's panel threshold model have not been available. Therefore, with a view to the central role of initial income for the convergence debate of the economic growth literature, most empirical studies on growth-related thresholds applying the Hansen methodology decided to ignore the potential endogeneity bias (see Khan and Senhadji (2001), Cuaresma and Silgoner (2004), Foster (2006) and Bick (2010)). In contrast, Drukker et al. (2005) excluded initial income from their growth regressions to avoid the endogeneity problem. Both methods if applied to deal with the endogeneity of initial income can lead to biased estimates of the inflation thresholds and to misleading conclusions about the impact of inflation on growth in the corresponding inflation regimes.[3]

This article introduces a dynamic version of Hansen's panel threshold model to shed more light on the inflation–growth nexus. By applying the forward orthogonal

[1] For example, the Southern African Development Community (SADC) convergence criteria require a low single-digit inflation rate, see Regional Indicative Strategic Development Plan available at http://www.sadc.int/attachment/download/file/74. Recent empirical studies by Goncalves and Salles (2008) and Lin and Ye (2009) suggest that inflation targeting in developing countries can lead to significant improvements in terms of inflation and output volatility.

[2] Similar nonlinear effects of inflation have been documented by Bick and Nautz (2008) for relative price variability in the US and by Khan et al. (2006) for financial depth in a large cross-country panel dataset.

[3] Note that alternative approaches to estimate a nonlinear relationship between inflation and growth face the same problem: they either exclude initial income (Omay and Kan 2010) or do not control for its endogeneity (Burdekin et al. 2004; Hineline 2007; Vaona and Schiavo 2007).

deviations transformation suggested by Arellano and Bover (1995), we combine the instrumental variable estimation of the cross-sectional threshold model introduced by Caner and Hansen (2004) with the panel threshold model of Hansen (1999). In the dynamic model, the endogeneity of important control variables is no longer an issue. This permits us to estimate the critical level of inflation for economic growth for industrialized and non-industrialized countries despite the endogeneity problem of initial income.

Our empirical results strongly confirm earlier evidence in favor of inflation thresholds in the inflation–growth nexus. In accordance with Khan and Senhadji (2001), we find notable differences between the results obtained for industrialized and non-industrialized countries. For industrialized countries, the estimated inflation threshold is about 2.5% which provides strong support for the inflation targets of many central banks. In particular, inflation rates below/above 2.5% are associated with higher/lower long-term economic growth in industrialized countries. For developing countries, the estimated inflation threshold is 17.2%. Inflation rates exceeding this critical value, i.e. if it gets "too high," come along with significantly lower economic growth with a magnitude similar to industrialized countries. In contrast, there is no significant association between inflation and long-term economic growth in developing countries when inflation is below 17.2%.

Given the lack of a standard theory on the relationship between inflation and long-term economic growth, our empirical results on the inflation–growth nexus have to be interpreted with caution. Strictly speaking, our estimates may only reflect correlations and do not necessarily imply causality from inflation to growth. Yet, reduced form estimates may still serve as a benchmark and a first guideline for the discussion on the optimal level of inflation targets.

The rest of the article is organized as follows. In Sect. 2, we discuss the econometrics of the dynamic panel threshold model. Section 3 introduces the data and the control variables employed in our empirical application. In Sect. 4 the dynamic panel threshold model is applied to the inflation–growth nexus in industrialized and non-industrialized countries. Section 5 further compares the results from our setup with the original Hansen (1999) model via Monte-Carlo simulations and confirms the need for controlling for the endogeneity of initial income. Section 6 concludes.

2 A dynamic panel threshold model

2.1 The econometric model

This section develops a dynamic panel threshold model that extends Hansen (1999) original static setup to endogenous regressors. In our empirical application where we analyze the role of inflation thresholds in the relationship between inflation and economic growth ($y_{it} = dgdp_{it}$), the endogenous regressor will be initial income (gdp_{it-1}). Our model extension builds on the cross-sectional threshold model of Caner and Hansen (2004) where Generalized methods of moments (GMM) type estimators are used to allow for endogeneity. To this aim, consider the following panel threshold model:

$$y_{it} = \mu_i + \beta_1' z_{it} I(q_{it} \le \gamma) + \beta_2' z_{it} I(q_{it} > \gamma) + \varepsilon_{it}, \tag{1}$$

where subscripts $i = 1, \ldots, N$ represent the country and $t = 1, \ldots, T$ index the time. μ_i is the country-specific fixed effect, and the error term is $\varepsilon_{it} \overset{iid}{\sim} (0, \sigma^2)$. $I(\cdot)$ is the indicator function indicating the regime defined by the threshold variable q_{it}, and the threshold level γ. z_{it} is a m-dimensional vector of explanatory regressors which may include lagged values of y and other endogenous variables. The vector of explanatory variables is partitioned into a subset z_{1it} of exogenous variables uncorrelated with ε_{it}, and a subset of endogenous variables z_{2it}, correlated with ε_{it}. In addition to the structural equation (1), the model requires a suitable set of $k \ge m$ instrumental variables x_{it} including z_{1it}.

2.2 Fixed-effects elimination

In the first step of the estimation procedure, one has to eliminate the individual effects μ_i via a fixed-effects transformation. The main challenge is to transform the panel threshold model in a way that eliminates the country-specific fixed effects without violating the distributional assumptions underlying Hansen (1999) and Caner and Hansen (2004), see also Hansen (2000). In the dynamic model (1), the standard within transformation applied by Hansen (1999) leads to inconsistent estimates because the lagged dependent variable will always be correlated with the mean of the individual errors and thus all of the transformed individual errors. First-differencing of the dynamic equation (1), as usually done in the context of dynamic panels, implies negative serial correlation of the error terms such that the distribution theory developed by Hansen (1999) is not applicable anymore to panel data.[4]

In view of these problems, we consider the forward orthogonal deviations transformation suggested by Arellano and Bover (1995) to eliminate the fixed effects.[5] The distinguishing feature of the forward orthogonal deviations transformation is that serial correlation of the transformed error terms is avoided. Instead of subtracting the previous observation from the contemporaneous one (first-differencing) or the mean from each observation (within transformation), it subtracts the average of all future available observations of a variable. Thus, for the error term, the forward orthogonal deviations transformation is given by

$$\varepsilon_{it}^* = \sqrt{\frac{T-t}{T-t+1}} \left[\varepsilon_{it} - \frac{1}{T-t} (\varepsilon_{i(t+1)} + \ldots + \varepsilon_{iT}) \right]. \tag{2}$$

Therefore, the forward orthogonal deviation transformation maintains the uncorrelatedness of the error terms, i.e.,

[4] Note that in Hansen (1999) the within-transformation also implies negative serial correlation of the transformed error terms. However, this is not a problem because of the idempotency of the transformed error matrix, see Eq. A.12 Hansen (1999, p. 366).

[5] We are grateful to Jörg Breitung for this suggestion.

$$Var(\varepsilon_i) = \sigma^2 I_T \;\Rightarrow\; Var(\varepsilon_i^*) = \sigma^2 I_{T-1}.$$

In accordance with Hansen (2000), this ensures that the estimation procedure derived by Caner and Hansen (2004) for a cross-sectional model can be applied to the dynamic panel equation (1).

2.3 Estimation

Following Caner and Hansen (2004), we estimate a reduced form regression for the endogenous variables, z_{2it}, as a function of the instruments x_{it}. The endogenous variables, z_{2it}, are then replaced in the structural equation by the predicted values $\hat{z}_{2it}$. In step two, Eq. 1 is estimated via least squares for a fixed threshold γ where the z_{2i}s are replaced by their predicted values from the first-step regression. Denote the resulting sum of squared residuals by $S(\gamma)$. This step is repeated for a strict subset of the support of the threshold variable q from which, in a third step, the estimator of the threshold value γ is selected as the one associated with the smallest sum of squared residuals, i.e., $\hat{\gamma} = \underset{\gamma}{\text{argmin}}\; S_n(\gamma)$.

In accordance with Hansen (1999) and Caner and Hansen (2004), the critical values for determining the 95% confidence interval of the threshold value are given by

$$\Gamma = \{\gamma : LR(\gamma) \leq C(\alpha)\},$$

where $C(\alpha)$ is the 95% percentile of the asymptotic distribution of the likelihood ratio statistic $LR(\gamma)$. The underlying likelihood ratio has been adjusted to account for the number of time periods used for each cross section, see Hansen (1999). Once $\hat{\gamma}$ is determined, the slope coefficients can be estimated by the GMM for the previously used instruments and the previous estimated threshold $\hat{\gamma}$.

3 Data and Variables

Our empirical application of the dynamic panel threshold model to the inflation–growth nexus is based on an unbalanced panel-dataset of 124 countries. Industrialized and non-industrialized countries are identified in accordance with the International Financial Statistics (IFS) and shown in Tables 4 and 5 in the Appendix. Using data from 1950 to 2004, we extend the samples by Khan and Senhadji (2001) (1960–1998) and Drukker et al. (2005) (1950–2000). As a consequence, our sample contains more information about the growth effects of low inflation.

For each country, annual growth rates of real GDP per capita in constant 2000 prices ($dgdp$) are obtained from Penn World Table 6.2. Inflation is computed as the annual percentage change of the Consumer Price Index (π) collected from IFS. In line with the empirical growth literature, our results on the determinants of long-term economic growth will be based on 5 year averages which gives us 988 observations: 227 for industrialized and 761 for non-industrialized countries.

3.1 Control variables

Any empirical analysis of inflation's impact on economic growth has to control for the influence of other economic variables that are correlated with the rate of inflation. Following Khan and Senhadji (2001) and Drukker et al. (2005), we consider the percentage of GDP dedicated to investment ($igdp$), the population growth rate ($dpop$), the initial income level ($initial$)—measured as GDP per capita from the previous period—and openness ($open$)—measured as the logged share of exports plus imports in GDP. These variables are obtained from Penn World Table 6.2. The annual percentage change in the terms of trade ($dtot$) is measured as exports divided by imports. Export and import data are taken from Penn World Table 6.1 until 2000 and for the later years from the World Trade Organization (WTO) database. We also included the standard deviations of the terms of trade ($sdtot$) and of openness ($sdopen$). More information about the control variables is contained in Table 3 in the Appendix. All these variables passed the robustness tests of Levine and Renelt (1992) and Sala-i-Martin (1997).

3.2 Inflation

Inflation has been lower in industrialized countries with an average annual inflation rate over the sample period of 5.86% as opposed to 33.63% for non-industrialized countries. For both set of countries, the dispersion of inflation rates is considerable (see Figs. 1 and 3 in the Appendix A.2). In this case, Ghosh and Phillips (1998) strongly suggest the use of logged inflation rates to avoid the regression results being distorted by a few extreme inflation observations. Moreover, the use of logged inflation rates has the plausible implication that multiplicative, not additive, inflation shocks will have identical growth effects. Since our sample contains negative inflation rates, we follow Drukker et al. (2005) and Khan and Senhadji (2001) by employing a semi-log transformation of the inflation rate π_{it}:

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

where inflation rates below 1 are re-scaled for the sake of continuity.[6] In sharp contrast to the highly skewed and leptokurtic inflation data of industrialized and non-industrialized countries, the distributions of semi-logged inflation rates are much more symmetric and in line with the normal distribution (see Figs. 2 and 4 in Appendix A.2).

[6] Note that π is defined such that an inflation rate of, e.g., 5.86% enters the semi-log transformation with 5.86 and not 0.0586 implying a value of $\tilde{\pi} = 1.77$.

4 Inflation thresholds and growth

Let us now apply the dynamic panel threshold model to the analysis of the impact of inflation on long-term economic growth in industrialized and non-industrialized countries. To this aim, consider the following threshold model of the inflation–growth nexus:

$$dgdp_{it} = \mu_i + \beta_1 \tilde{\pi}_{it} I(\tilde{\pi}_{it} \leq \gamma) + \delta_1 I(\tilde{\pi}_{it} \leq \gamma) + \beta_2 \tilde{\pi}_{it} I(\tilde{\pi}_{it} > \gamma) + \phi z_{it} + \varepsilon_{it}. \tag{3}$$

In our application, inflation $\tilde{\pi}_{it}$ is both, the threshold variable and the regime-dependent regressor. z_{it} denotes the vector of partly endogenous control variables, where slope coefficients are assumed to be regime independent. Following Bick (2010), we allow for differences in the regime intercepts (δ_1).[7] Initial income is considered as endogenous variable, i.e. $z_{2it} = initial_{it} = gdp_{it-1}$, while z_{1it} contains the remaining control variables.[8]

Following Arellano and Bover (1995), we use lags of the dependent variable $(dgdp_{it-1}, \ldots, dgdp_{it-p})$ as instruments. Empirical results may depend on the number (p) of instruments (see Roodman (2009)). In particular, there is a bias/efficiency trade-off in finite samples. Therefore, we considered two empirical benchmark specifications. On the one hand, we use all the available lags of the instrument variable $(p = t)$ to increase efficiency (see Table 1). On the other hand, we reduced the instrument count to 1 $(p = 1)$ to avoid an overfit of instrumented variables that might lead to biased coefficient estimates. According to Table 6 in the Appendix, the choice of instruments has no important impact on our results.

Table 1 shows the results obtained for industrialized and non-industrialized countries. The upper part of the table displays the estimated inflation threshold and the corresponding 95% confidence interval. The middle part shows the regime-dependent coefficients of inflation on growth. Specifically, $\widehat{\beta_1}$ $(\widehat{\beta_2})$ denotes the marginal effect of inflation on growth in the low (high) inflation regime, i.e., when inflation is below (above) the estimated threshold value. The coefficients of the control variables are presented in the lower part of the table.

4.1 The inflation–growth nexus in industrialized countries

The results for the empirical relation between inflation and growth in industrialized countries based on the first benchmark specification are presented in the first column of Table 1. The estimated inflation threshold of 2.53% as well as the marginal effects of inflation on growth strongly support the prevailing inflation targets of many central banks. First, the 95% confidence interval ([1.94–2.76]) of the threshold value in-

7 Including time dummies in Eq. 3 will not change our main results.

8 The empirical model could be easily extended by allowing for the endogeneity of further control variables. In our application, however, standard Hausman tests indicate that the endogeneity of the remaining control variables is not an issue. Results of Hausman tests are not presented, but are available on request.

Table 1 Inflation thresholds and growth

	Industrialized countries	Non-industrialized countries
Threshold estimates		
$\widehat{\gamma}$	2.530%	17.228%
95% confidence interval	[1.94–2.76]	[12.85–19.11]
Impact of inflation		
$\widehat{\beta}_1$	1.374***	−0.121
	(0.436)	(0.117)
$\widehat{\beta}_2$	−0.391*	−0.434**
	(0.220)	(0.222)
Impact of covariates		
$initial_{it}$	−1.371	−1.800**
	(0.950)	(0.858)
$igdp_{it}$	0.107***	0.157***
	(0.036)	(0.045)
$dpop_{it}$	0.290	−0.503**
	(0.341)	(0.257)
$dtot_{it}$	−0.162***	−0.072***
	(0.036)	(0.025)
$sdtot_{it}$	−0.036	−0.007
	(0.041)	(0.020)
$open_{it}$	−0.882	0.768
	(1.080)	(0.640)
$sdopen_{it}$	0.426**	0.046
	(0.213)	(0.169)
$\widehat{\delta}_1$	−0.384	0.745
	(0.511)	(1.077)
Observations	227	761
N	23	101

This Table reports results for the dynamic panel threshold estimation as described in Sect. 2 using all available lags of the instrument variable, i.e. $\{dgdp_{it-1}, dgdp_{it-2}, \ldots, dgdp_{i0}\}$. Following Hansen (1999), each regime contains at least 5% of all observations. For industrialized countries, feasible inflation thresholds are, therefore, between 1.146 and 15.668% and for non-industrialized countries between 1.002 and 66.146%. Standard errors are given in parentheses

*/**/*** indicate significance at the 1/5/10% level

cludes 2% but does not contain 4%—the alternative inflation target recently suggested by Blanchard et al. (2010). Second, both regime-dependent coefficients of inflation are significant and plausibly signed. Inflation is positively correlated with economic growth in industrialized countries if it is less than the threshold ($\widehat{\beta}_1 = 1.37$), while the opposite is true for higher inflation ($\widehat{\beta}_2 = -0.391$). The absolute size of the inflation coefficients suggests that correlation between inflation and economic growth of industrialized countries is stronger when inflation is low. According to the 95% confidence intervals, this conclusion holds at least for inflation rates "below but close to 2%."

It is worth emphasizing that our results are robust with respect to the choice of instruments (see Table 6 in the Appendix). The only notable exception refers to the confidence interval of the inflation threshold. If the instrument count is reduced to 1, estimation is less efficient and the 95% confidence interval of the inflation threshold widens to [1.38–5.50]. As a consequence, the evidence on the long-run growth effects of inflation rates around 4% must be viewed with caution.

4.2 The inflation–growth nexus in non-industrialized countries

The results for non-industrialized countries are shown in the second column of Table 1. They differ from those obtained for industrialized countries in two important aspects. First, the estimated threshold level of inflation (17.2%) is definitely higher than in industrialized countries. The 95% confidence interval indicates that the critical value of inflation for non-industrialized countries is clearly lower than the 40% proposed by Bruno and Easterly (1998). According to our estimates, even inflation rates above 12.85% may already be seen as "too high." The higher inflation threshold for non-industrialized countries could be explained by the widespread use of indexation systems, which many non-industrialized countries have adopted because of a long history of inflation. These indexation systems may partially reduce the adverse effects of inflation. Following, e.g., Khan and Senhadji (2001), higher inflation thresholds in non-industrialized countries may also be related to a convergence process and the Balassa–Samuelson effect. The coefficient of inflation ($\widehat{\beta}_2 = -0.434$) is significant and plausibly signed, when inflation gets higher than its threshold. Therefore we find clear evidence suggesting that high inflation rates in non-industrialized countries come along with lower growth rates.[9]

The second important difference between the empirical results obtained for industrialized and non-industrialized countries refers to the correlation between growth and inflation when inflation is less than its threshold. While the inflation coefficient in industrial countries has been significant for low inflation rates and large in absolute terms relative to high inflation, this is not true for the low-inflation regime in developing countries. The corresponding estimate, $\widehat{\beta}_1 = -0.12$, is small and far from significant for non-industrialized countries.

For non-industrialized countries, the effect of the instrument variables on the estimated inflation thresholds is negligible, see Table 6. The reduction of the instrument count only affects the estimates for the control variables where the standard errors slightly increase.

Finally, it is worth noting that our results on the empirical inflation–growth nexus obtained from a dynamic panel threshold model broadly confirm earlier findings based on models that should have suffered from an endogeneity bias—compare with Khan and Senhadji (2001) and Bick (2010). Apparently, in our application accounting for the endogeneity of control variables does not have a major impact on the estimated thresholds. In other applications, however, avoiding the endogeneity bias in a panel threshold model may lead to very different conclusions. In the next section, this impression is confirmed by a Monte Carlo study based on our empirical data.

5 Monte carlo simulations

In this section, we conduct a Monte Carlo study to compare the performance of the dynamic panel threshold model proposed in this article with the traditional estimator introduced by Hansen (1999). Since the latter ignores the endogeneity of initial income, it should be outperformed by its GMM-type generalization in terms of both bias and root mean square error (RMSE). In order to demonstrate the effect of the number of time periods T, we run the simulation for $T = 5$ and $T = 10$. Following

[9] By contrast, Drukker et al. (2005) find significant inflation thresholds but no significant impact of inflation on growth in any regime.

Table 2 Monte Carlo simulations

$dgdp_{it} = \mu_i + 1.28\tilde{\pi}_{it} I(\tilde{\pi}_{it} \leq 0.928) - 0.531\tilde{\pi}_{it} I(\tilde{\pi}_{it} > 0.928)) - 3.543 gdp_{i,t-1} + 0.09 igdp_{it} + 0.15 dtot_{it} + \varepsilon_{it}$

	GMM			Hansen (1999)		
	Mean	Bias	RMSE	Mean	Bias	RMSE
$I = 21,\ T = 10$						
$\widehat{\gamma}^{a}$	0.915	−0.013	0.094	1.010	0.082	0.463
$\widehat{\beta}_1$	1.286	0.006	0.490	1.408	0.127	0.902
$\widehat{\beta}_2$	−0.531	−0.001	0.161	−0.559	−0.028	0.192
$\widehat{\phi}_1$	−3.580	−0.037	0.234	−3.758	−0.215	0.324
$I = 23,\ T = 5$						
$\widehat{\gamma}^{a}$	1.029	0.101	0.464	1.028	0.101	0.538
$\widehat{\beta}_1$	0.769	−0.511	1.425	1.942	0.662	3.321
$\widehat{\beta}_2$	−0.636	−0.105	0.389	−0.878	−0.347	0.554
$\widehat{\phi}_1$	−3.572	−0.028	0.663	−4.332	−0.789	1.029

This table reports simulation results for the dynamic panel threshold estimation as described in Sect. 2 using one lag of the instrument variable and the simulation results for the Hansen (1999) threshold model. The bias is the difference between the mean of the coefficient estimate and the corresponding true value of the coefficient

[a] The estimates for γ are displayed according to the estimated values with the log transformation

Hansen (1999), we had to restrict the analysis to a balanced panel for the Monte Carlo simulation. As a result, our empirical sample covers $I = 23$ countries for a shorter sample period $T = 5$, while the maximum of $T = 10$ periods is observed only for $I = 21$ countries. Each simulation is performed 1,000 times and based on the model proposed in Sect. 4 for industrialized countries:

$$dgdp_{it} = \mu_i + \beta_1 \tilde{\pi}_{it} I(\tilde{\pi}_{it} \leq \gamma) + \beta_2 \tilde{\pi}_{it} I(\tilde{\pi}_{it} > \gamma) + \phi_1 gdp_{i,t-1} + \phi_2 igdp_{it} + \phi_3 dtot_{it} + \varepsilon_{it}. \tag{4}$$

We perform the simulation with an instrument count of 1 as done in Table 6 and therefore include as covariates for the data-generating process other than initial income only those that were significantly different from zero in this specification.[10] We use the empirical data for the exogenous variables π, $igdp$, $dtot$, and the starting value of initial income, while the dependent variable $dgdp_{i,t}$ is generated according to Eq. 4. This also immediately generates the series of the lagged endogenous variable $gdp_{i,t-1}$ for $t > 1$. The coefficients in the data-generating process are based on the estimates presented in Table 6: the threshold is fixed at $\gamma = 0.928$, which corresponds to the inflation threshold of 2.53% before the log transformation, $\beta_1 = 1.28$, $\beta_2 = -0.531$, $\delta_1 = 0$, $\phi_2 = 0.09$, and $\phi_3 = 0.15$. In the same vein, ε is generated as iid random variable with zero mean and variance 1.4.

[10] Note that neither using all available lags as instruments (as done in the estimation shown in Table 1) nor including the insignificant covariates affects the qualitative results of the Monte Carlo simulations. For the sake of comparison with Hansen (1999), we estimate the model without accounting for a regime-specific intercept δ_1.

Table 2 shows the mean of the coefficient estimates from the 1000 simulations of the dynamic threshold model proposed in this article (labeled as GMM) and the original Hansen (1999) model along with the implied biases and RMSE for both samples ($T = 5, 10$). The results of the Monte Carlo simulation demonstrate that, accounting for the endogeneity of initial income generally improves the estimation in terms of RMSEs and bias. In particular, for $T = 10$ the estimates for the GMM approach are essentially unbiased as opposed to the original Hansen (1999) setup. In line with expectations, the bias increases and the precision decreases for both estimation strategies as T is reduced from 10 to 5. Apparently, the loss in observations along the time dimension cannot be compensated by adding two cross-sectional units.[11] The most significant improvements relative to the Hansen (1999) setup can be seen for the estimation of ϕ_1, the coefficient of the endogenous regressor initial income. Moreover, the estimates for β_1, the slope coefficient for inflation rates less than the threshold, are much more precise using the GMM approach.

6 Concluding remarks

This article provided new evidence on the nonlinear relationship between inflation and long-term economic growth. To this aim, we built on Hansen (1999) and Caner and Hansen (2004) and developed a dynamic threshold model that allows for endogenous regressors in a panel setup. Applying the forward orthogonal deviations transformation suggested by Arellano and Bover (1995) ensured that the original distribution theory of the threshold model applied to static panels as in Hansen (1999) is still valid in a dynamic context. Monte Carlo simulations show the superiority of the proposed dynamic model in the case of endogenous variables compared with the original Hansen (1999) setting.

Applying the dynamic panel threshold model to the analysis of thresholds in the inflation–growth nexus, confirmed the general consensus among economists. In particular, our empirical results suggest that inflation distorts economic growth provided it exceeds a certain critical value. However, there are important differences for industrialized and non-industrialized countries concerning both the level of the estimated inflation threshold and the impact of inflation in the various inflation regimes.

For industrialized countries, our results support the inflation targets of about 2% which are more or less explicitly announced by many central banks. Contributing to the recent discussion on the appropriate level of inflation targets stirred by Blanchard et al. (2010), we estimated that inflation rates exceeding a critical value of 2.5% are negatively correlated with economic growth, while the opposite is true below that level.

For non-industrialized countries, the estimated inflation threshold is much higher, about 17%. Inflation rates lesser than this threshold come along with significantly lower growth rates for non-industrialized countries, but not vice versa. Thus, our

[11] The results for $T = 5$ are virtually the same if the two cross-sections are dropped, for which less than $T = 10$ empirical observations are available.

results do not support growth-enhancing effects of moderate inflation rates below the threshold value. However, policy conclusions based on reduced form estimates have to be viewed with caution. In particular, the estimated inflation–growth nexus does not necessarily reflect causality but rather correlation. Yet, significant inflation thresholds in the empirical relationship between inflation and growth may provide a useful guideline for further research on the impact of inflation on growth.

The empirical setup of the current study controlled for the effect of further variables on growth but assumed that the level of the inflation threshold only depends on whether a country is industrialized or not. In particular for the very heterogenous group of non-industrialized countries, this assumption may be too restrictive. Lin and Ye (2009), for example, show that the performance of inflation targeting in developing countries can be affected by other country characteristics. Accordingly, inflation thresholds in developing countries and, thus, the appropriate level of the inflation target might be also country-specific. The identification of country-specific inflation thresholds in the inflation–growth nexus might provide useful information about the appropriate location and width of an inflation-targeting band. We leave this extension of our analysis for future research.

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A. Appendix

A.1 See Tables 3, 4, 5 and 6

A.2 See Figures 1, 2, 3, and 4

Table 3 List of variables

dgdp	Five-year average of the annual growth rate of real GDP per capita in constant 2000 prices
dpop	Five-year average of the annual growth rate of population
dtot	Five-year average of the annual percentage change in the terms of trade, where the terms of trade are measured as exports divided by imports
igdp	Five-year average of the annual percentage of GDP dedicated to investment
initial	Five-year average of GDP per capita in 2000 constant prices, from the previous period, in logs
open	Five-year average of log of openness, where openness is measured as the share of exports plus imports in the GDP
π	Five-year average of the annual percentage change of the CPI index
$\tilde{\pi}$	Semi-log transformed π
sdtot	Five-year standard deviation of the terms of trade
sdopen	Five-year standard deviation of openness
x	Vector of control variables: *initial*, *igdp*, *dpop*, *dtot*, *sdtot*, *open*, *sdopen*

Table 4 Sample industrialized countries

Country	t	π mean	*dgdp* mean
Australia	10	5.26	2.13
Austria	10	3.54	3.27
Belgium	10	3.73	2.65
Canada	10	4.14	2.22
Denmark	10	5.28	2.28
Finland	10	5.71	2.86
France	10	5.08	2.79
Germany	8	2.60	2.22
Greece	9	10.34	3.23
Iceland	10	17.84	2.83
Ireland	10	6.42	3.74
Italy	10	6.71	3.06
Japan	10	3.64	4.43
Luxembourg	10	3.49	3.18
The Netherlands	10	3.87	2.29
New Zealand	10	6.30	1.66
Norway	10	5.03	2.89
Portugal	10	9.42	3.71
Spain	10	8.07	3.52
Sweden	10	5.21	2.14
Switzerland	10	2.95	1.81
United Kingdom	10	5.97	2.22
United States	10	4.02	2.28

Average of annual inflation rates and average of annual growth rates of GDP in percent over the period 1955–2004. *Source* IFS, Penn World Table 6.2

Table 5 Sample non-industrialized countries

Country	T	π mean	*dgdp* mean	country	T	π mean	*dgdp* mean
Algeria	7	10.58	1.40	Malawi	7	18.82	1.35
Argentina	10	199.63	1.08	Malaysia	9	3.18	4.62
Bahamas	6	4.46	1.30	Mali	7	4.76	2.02
Bahrain	6	3.54	0.71	Malta	6	3.60	5.34
Barbados	7	6.99	1.24	Mauritania	5	6.94	0.24
Benin	2	4.19	2.11	Mauritius	9	8.08	3.12
Bolivia	10	291.40	4.04	Mexico	10	22.79	2.05
Botswana	6	10.43	5.44	Morocco	10	5.05	2.37
Brazil	7	346.25	2.10	Mozambique	4	40.12	3.23
Burkina Faso	8	4.78	1.29	Namibia	5	11.24	0.61
Burundi	8	9.81	0.91	Nepal	8	8.12	1.43
Cameroon	7	7.40	1.19	Netherlands Antilles	6	4.37	0.42
Cape Verde	5	7.33	4.28	Nicaragua	7	791.09	−1.53
Central African Republic	6	5.68	−0.13	Niger	8	5.33	0.84
Chad	7	3.12	0.98	Nigeria	10	15.83	0.96
Chile	9	52.03	2.40	Pakistan	9	.67	2.70
China	7	5.01	7.30	Panama	10	2.30	2.95
Colombia	10	16.83	1.66	Papua New Guinea	6	7.95	2.45
Congo	7	7.65	1.40	Paraguay	9	12.55	1.46
Costa Rica	10	12.41	1.66	Peru	10	266.10	1.10
Cote d‘Ivoire	8	6.94	0.66	Philippines	10	9.15	1.75

Table 5 continued

Country	T	π mean	$dgdp$ mean	country	T	π mean	$dgdp$ mean
Cyprus	6	4.82	5.09	Poland	6	46.97	2.03
Dominica	6	5.72	2.56	Romania	7	38.33	3.35
Dominican Republic	9	12.61	2.96	Rwanda	7	10.04	1.88
Ecuador	9	23.27	1.63	Samoa	6	8.45	0.96
Egypt	9	9.08	2.89	Saudi Arabia	6	2.99	−1.84
El Salvador	10	8.19	1.05	Senegal	7	6.22	0.15
Equatorial Guinea	5	12.60	10.96	Sierra Leone	6	39.54	−1.80
Ethiopia	8	6.22	1.68	Singapore	8	2.91	4.98
Fiji	6	5.83	1.10	Solomon Islands	6	10.35	−0.36
Gabon	8	5.78	0.30	South Africa	10	8.13	1.48
Gambia	8	9.56	1.02	Sri Lanka	10	7.59	3.27
Ghana	8	32.65	7.34	St, Lucia	6	5.26	2.68
Grenada	5	4.20	2.61	St,Vincent & Grenadines	6	4.795	4.21
Guatemala	10	7.96	1.07	Sudan	6	43.18	0.48
Guinea−Bissau	3	25.81	1.30	Suriname	6	43.03	3.76
Haiti	6	13.99	0.42	Swaziland	6	11.68	2.75
Honduras	10	8.81	0.89	Syria	8	10.35	1.85
Hong Kong	8	5.98	4.72	Tanzania	8	18.27	1.69
Hungary	6	12.46	2.27	Thailand	10	4.72	4.42
India	10	7.22	2.75	Togo	7	6.43	−1.46
Indonesia	8	53.61	3.53	Tonga	6	8.63	4.13
Iran	9	14.27	2.10	Trinidad &Tobago	10	7.23	3.55
Israel	9	39.92	2.75	Tunisia	7	4.73	3.27
Jamaica	9	15.29	0.80	Turkey	10	36.64	2.46
Jordan	7	6.81	−0.47	Uganda	5	48.62	1.63
Kenya	9	10.19	0.28	Uruguay	10	45.95	0.92
Korea	7	8.85	6.07	Venezuela	10	17.90	0.56
Kuwait	6	2.77	0.94	Zambia	7	35.67	0.21
Lesotho	6	12.93	3.25	Zimbabwe	8	37.10	0.54
Madagascar	8	12.46	−1.23				

Table 6 Inflation thresholds and growth: estimation with reduced instrument count

	Industrialized countries	Non-industrialized countries
Threshold estimates		
$\widehat{\gamma}$	2.530%	17.228%
95% confidence interval	[1.38–5.50]	[12.87–19.11]
Impact of inflation		
$\widehat{\beta}_1$	1.280***	−0.141
	(0.520)	(0.121)
$\widehat{\beta}_2$	−0.531*	−0.494**
	(0.312)	(0.221)
Impact of covariates		
$initial_{it}$	−3.543	−1.761
	(2.731)	(1.240)
$igdp_{it}$	0.093***	0.156***
	(0.030)	(0.048)

*/**/*** indicate significance at the 1/5/10% level

Table 6 continued

	Industrialized countries	Non-industrialized countries
$dpop_{it}$	0.101	−0.503
	(0.387)	(0.350)
$dtot_{it}$	−0.150***	−0.072***
	(0.043)	(0.028)
$sdtot_{it}$	−0.003	−0.006
	(0.057)	(0.023)
$open_{it}$	1.361	0.733
	(3.311)	(0.866)
$sdopen_{it}$	0.287	0.050
	(0.288)	(0.188)
$\widehat{\delta}_1$	−0.523	0.753
	(0.607)	(1.199)
Observations	227	761
N	23	101

Results for the dynamic panel threshold model (see Sect. 2) using only one instrument lag ($dgdp_{it-1}$). Each regime contains at least 5% of all observations. For industrialized countries, feasible inflation thresholds are, therefore, between 1.146 and 15.668%, and for non-industrialized countries, between 1.002 and 66.146%. Standard errors are given in parentheses

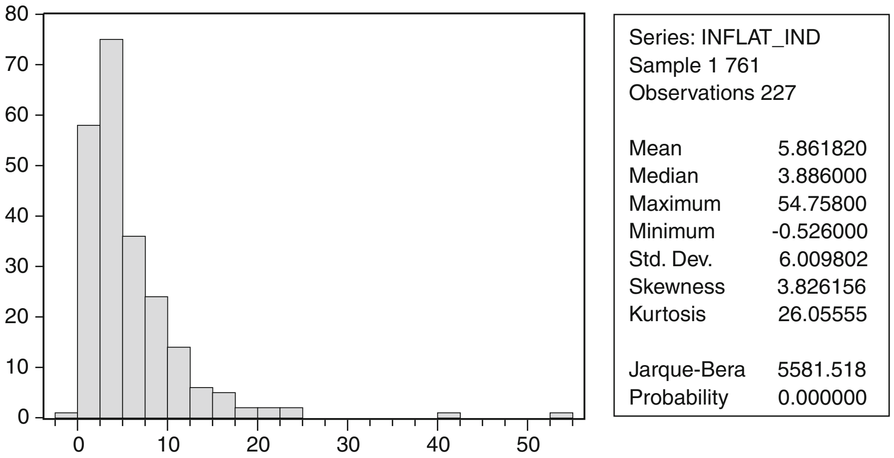

Fig. 1 Distribution of inflation rates: industrialized countries. *Notes* Five-year average of annual inflation rates (percentage points) for industrial countries, 1955–2004. *Source* IFS

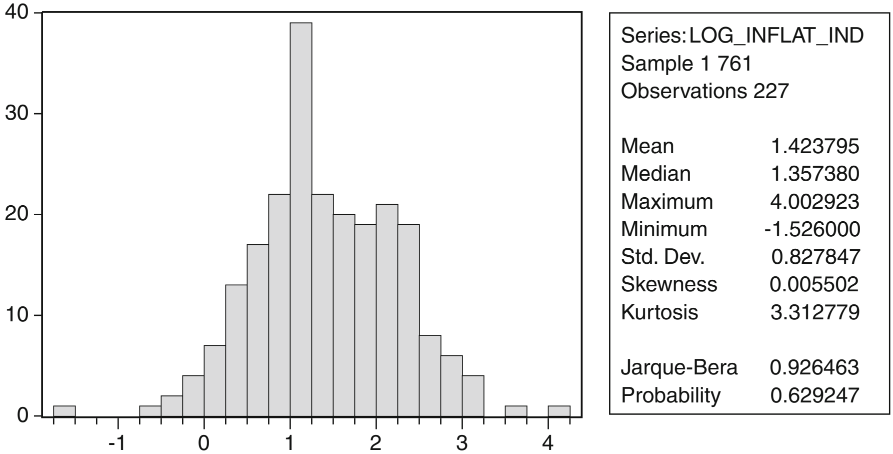

Fig. 2 Distribution of log inflation rates: industrialized countries. *Notes* Five-year average of annual inflation rates (percentage points) after the semi-log transformation for industrial countries, 1955–2004, see Sect. 2.1, (*Source* IFS)

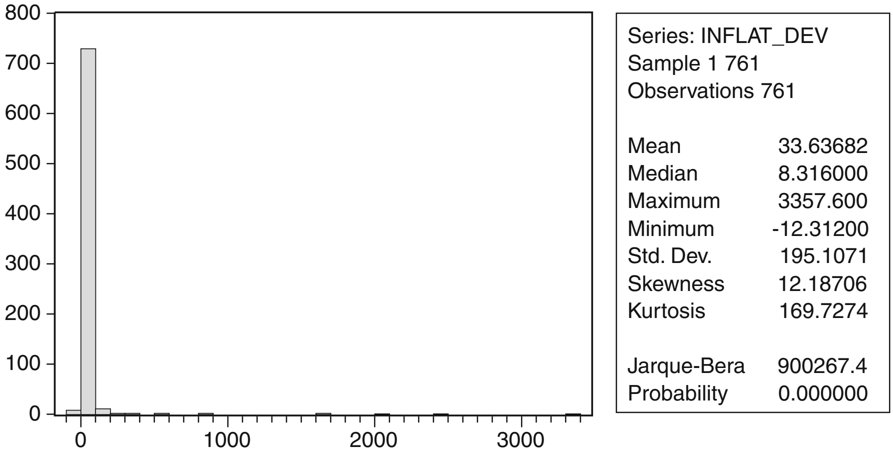

Fig. 3 Distribution of inflation rates: non-industrialized countries *Notes*: Five-year average of annual inflation rates (percentage points) for non-industrial countries, 1955–2004. *Source* IFS

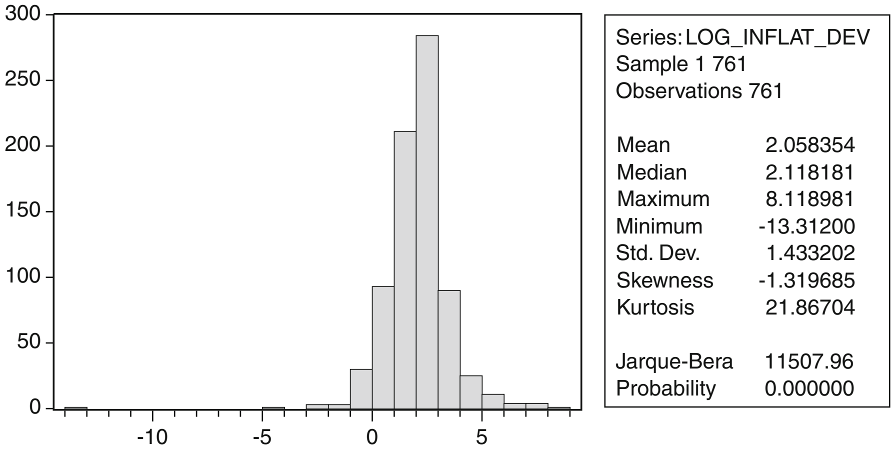

Fig. 4 Distribution of log inflation rates: non-industrialized countries. *Notes* Five-year average of annual inflation rates (percentage points) after the semi-log transformation for non-industrial countries, 1955–2004, see Sect. 2.1, (*Source* IFS)

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