Inflation and Relative Price Variability in the Euro Area: Evidence from a Panel Threshold Model

Dieter Nautz and Juliane Scharff∗

February 27, 2007

Abstract

The impact of inflation on relative price variability (RPV) generates an important channel for real effects of inflation. This paper provides first evidence on the empirical relation between inflation and RPV in the Euro area. Stirred by the widespread use of inflation caps or target bands in monetary policy practice, we are particularly interested in threshold effects of inflation. We find that expected inflation significantly increases RPV if inflation is either very low (below -1.38% p.a.) or very high (above 5.94% p.a.). In the intermediate regime, however, expected inflation has no effects supporting price stability as an outcome of optimal monetary policy.

Keywords: Inflation, Relative Price Variability, Panel Threshold Models

JEL classification: E31, C23

∗Department of Money and Macroeconomics, Mertonstr. 17, D-60054 Frankfurt am Main, Germany. e-mail: nautz@wiwi.uni-frankfurt.de. We thank Alexander Bick, Matei Demetrescu, Jörg Döpke, Bruce Hansen, Uwe Hassler, Heinz Herrmann, Johannes Hoffmann, and Julio Rotemberg for many helpful comments and suggestions. The research for this paper was partly conducted while Juliane Scharff was visiting the Economic Research Centre of the Deutsche Bundesbank. Financial support by the Monetary Stability Foundation is gratefully acknowledged.
1 Introduction

The impact of inflation on relative price variability (RPV) generates an important channel for real effects of inflation. Typically, macroeconomic theory emphasizes the distorting impact of inflation on relative prices. In particular, standard new Keynesian dynamic general equilibrium models support price stability as an outcome of optimal monetary policy mainly because inflation increases relative price variability (RPV) beyond its efficient level, see e.g. Woodford (2003). In spite of the crucial role of inflation’s impact on RPV, the empirical relevance of this relation is not very well researched. This paper contributes to the literature by providing new evidence on the relation between inflation and relative price variability in the European Monetary Union (EMU).

Since the influential paper by Parks (1978), several studies have provided evidence in favor of a significant impact of inflation on RPV for the US (see e.g. Parsley (1996), Debelle and Lamont (1997), Jaramillo (1999)), as well as for various European countries for the pre-EMU period (Fielding and Mizen (2000), Silver and Ioannidis (2001), Konieczny and Skrzypacz (2005), Nautz and Scharff (2005)). While some allow for a specific role of expected and unexpected inflation, a common feature of all these contributions is that they restrict the attention to linear relationships implying that the marginal impact of inflation on RPV does not depend on the inflation level.

However, a linear impact of inflation on the economy seem to be at odds with the non-linear behavior and strategies of many central banks. The ECB, for example, defines price stability as an inflation rate ”below but close to 2%”. As a consequence, the central bank’s reaction to an increase in the inflation rate from, say, 1% to 1.5%, may be qualitatively very different from an increase from 2% to 2.5%. Similar non-linear

---

1 Reducing the information content of nominal prices, inflation drives a wedge between marginal rates of transformation and substitution. Therefore, as Green (2005, p.132) put it, price dispersion is ”the root of all evil” caused by inflation in standard New Keynesian-style models. Note, however, that in the presence of e.g. nominal wage rigidities, inflation-induced increases in RPV can be also welfare improving by greasing the wheels of the economy, see e.g. Fielding and Mizon (2000).
policy responses may be observed for inflation reductions if inflation is already close to zero. Therefore, advancing on simple linear relationships, the use of threshold models seems a plausible first step for a deeper analysis of the relation between inflation and RPV.

A first attempt to model a non-linear relation between inflation and RPV can be found in Caglayan and Filiztekin (2003) who consider the inflation-RPV nexus for Turkish provinces. In Turkey there has been an obvious break in the inflation process around 1976. Therefore, Caglayan and Filiztekin (2003) simply divide the sample in a high and a low inflation period and estimate the RPV equation for the two periods separately. Obviously, this approach should not be applied to recent Euro area data where neither the number of inflation thresholds nor the threshold levels are clear.

A natural candidate for the analysis of the non-linear impact of inflation on RPV in the Euro area is the panel threshold model introduced by Hansen (1999, 2000). This model enables us to test for the number of inflation regimes and to estimate both the threshold levels as well as the marginal impact of inflation on RPV in the various regimes. As an additional feature, the threshold model allows different Euro area countries to be in different inflation regimes.²

Our empirical results show that threshold effects of inflation can be confirmed for the inflation-RPV nexus in the Euro area. Specifically, there is strong evidence in favor of a hump-shaped effect of expected inflation. The strongest marginal impact on RPV is estimated for inflation rates below zero while the effect is negligible if inflation is small and positive. If, however, inflation exceeds an upper threshold level ranging between 3% and 6% p.a., RPV increases again. Therefore, from the perspective of New Keynesian-style models, the non-response of RPV in low inflation regime supports that price stability should be the outcome of optimal monetary policy. Moreover, the estimated

² Note that inflation differentials have been considerable in the Euro area. Therefore, although Euro area countries are always in the same monetary policy regime, the assumption that all countries are always in the same inflation regime would be far too restrictive.
inflation thresholds may provide a further rationale for the widespread use of inflation
caps (Athey et al. 2005) or inflation target bands (Mishkin and Westelius 2006) in
monetary policy practice.

The paper is organized as follows: Section 2 introduces the data and the RPV measure
based on the harmonized index of consumer prices and provides first evidence on the
linear relation between inflation and RPV in the Euro area. We discuss the role of
expected versus unexpected inflation and determine core inflation as the relevant infla-
tion measure. Section 3 briefly reviews the econometrics of the panel threshold model
by Hansen (1999, 2000). The empirical results of the panel threshold analysis for the
Euro area are presented in Section 4. Section 5 offers some conclusions.

2 The linear relation between inflation and RPV in the
Euro area

2.1 Data

The following empirical analysis of the link between inflation and RPV in the Euro area
employs monthly data for various subcategories of the harmonized index of consumer
prices (HICP) provided by the Eurostat database. In the member states of the Euro-
pean Monetary Union, the harmonized indices of consumer prices provide a complete
set of comparable and high-quality consumer price indices. Moreover, the ECB uses the
HICP to assess price stability. Therefore, the HICP is a natural choice for analyzing
the inflation-RPV link for EMU members in a panel context. The data set contains
seasonally adjusted data of twelve HICP subcategories for the EMU members Austria,
Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, and Spain.3
The data are available since 1995 and our sample ends in December 2003.

3 The HICP subcategories are food and non-alcoholic beverages; alcoholic beverages, tobacco and nar-
cotics; clothing and footwear; housing, water, electricity, gas and other fuels; furnishings, household
equipment and routine maintenance of the house; health; transport; communication; recreation and
culture; education; restaurants and hotels; miscellaneous goods and services. The sample does not
contain Belgium and Luxembourg due to restricted data availability.
Following the empirical literature (see e.g. Jaramillo (1999), Parsley (1996), Fielding and Mizen (2000)), the variability of relative price changes for country $i$ in period $t$ ($RPV_{it}$) is defined as the square root of the weighted sum of squared deviations of subcategory-inflation $\pi_{ijt}$ around the average inflation for country $i$ ($\pi_{it}$), i.e.

$$RPV_{it} = \sqrt{\sum_{j=1}^{12} w_{ijt}(\pi_{ijt} - \pi_{it})^2}$$

where $\pi_{ijt} = \Delta \ln P_{ijt}$ and $P_{ijt}$ is the price index of the $j$th subcategory in country $i$ in period $t$. $w_{ijt}$ denotes the country-specific weight of the $j$th subcategory in the aggregate index so that $P_{it} = \sum_{j=1}^{12} w_{ijt}P_{ijt}$ gives the aggregate price level in country $i$ and the inflation rate $\pi_{it}$ is $\Delta \ln P_{it}$. Note that the country-specific weights are not time invariant but are adjusted on a yearly basis by Eurostat.
Since the mid-nineties, Euro area inflation has been at a very moderate level but there were also countries with negative or relatively high inflation rates. Illustrating the significance of inflation differentials in the Euro area, Figure 1 displays the minimum and the maximum of country-specific inflation rates. The histogram in Figure 2 shows that 25% of national inflation rates in the Euro area were below 0.68% p.a. and above 3.88% p.a., respectively. Interestingly, more than half of the national inflation rates exceed the 2% level.

The inflation-RPV relation might be distorted by supply shocks which jointly determine headline inflation and relative price variability. For example, if there is a positive supply shock in a product market then there is a fluctuation in that product price. This will lead to an increase in both average inflation and in the RPV measure. Consequently, there is correlation between headline inflation and the error term in the regression implying that the aggregate inflation can no longer be regarded as exoge-

---

4 Note that Euro area inflation is closer to the minimum of national rates mainly because inflation in Germany, the largest country in the Euro area, has been relatively low. National inflation rates and RPV measures are displayed in Figure 3, see Appendix.
nous. A possible solution to this endogeneity bias is the application of core inflation as
explanatory variable, see e.g. Jaramillo (1999) or Bomberger and Makinen (1993).

Core inflation for the Euro area is published by Eurostat and available from February
1996 onwards. It is defined as aggregate inflation without food and energy prices, i.e.
prices that are particularly driven by supply side shocks. This inflation measure is also
regularly monitored by the ECB, see e.g. ECB (2005). Apart from a view outliers,
headline and core inflation show a concurrent pattern and their difference is small in
most periods, compare Figures 4, 5 and 6 shown in the Appendix.

Preamounted relative price changes increase RPV but are likely to be less distorting
for the information content of prices. Therefore, we account for all ascertainable an-
ticipated effects like e.g. the introduction of a tuition fee in Austria in October 2001.
Additionally, we capture major institutional changes like e.g. the introduction of the
Euro in January 1999 or the entrance of Greece to the European Monetary Union in
January 2001 by including dummy variables in the following regressions.

The degree of persistence of the Euro area inflation process is still under debate, see
inflation, core inflation, and RPV clearly indicate that these time series have no indi-
vidual or common unit root. In line with the evidence provided by e.g. Lünnemann
and Mathá (2004), inflation persistence in the Euro area may have declined since the
mid-nineties.

2.2 Inflation and RPV: the basic relationship

Following Parsley’s (1996) and Debelle and Lamont’s (1997) analysis of the inflation-
RPV link for US cities, let us begin with a simple least squares panel regression of RPV

\footnote{Results of unit root tests are not presented but are available on request.}
Table 1: The linear relation between inflation and RPV

\[ RPV_{it} = \alpha_i + \beta|\pi_{it}| + \varepsilon_{it} \]

<table>
<thead>
<tr>
<th>Term</th>
<th>headline inflation</th>
<th>core inflation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \hat{\beta} )</td>
<td>0.46**</td>
<td>0.59**</td>
</tr>
<tr>
<td>(0.05)</td>
<td>(0.05)</td>
<td></td>
</tr>
<tr>
<td>Exogeneity test (F-statistic)</td>
<td>8.01</td>
<td>1.01</td>
</tr>
<tr>
<td>[0.00]</td>
<td>[0.32]</td>
<td></td>
</tr>
<tr>
<td>( \bar{R}^2 )</td>
<td>0.24</td>
<td>0.24</td>
</tr>
<tr>
<td>Observations</td>
<td>1070</td>
<td>950</td>
</tr>
<tr>
<td>Countries</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

Notes: ** indicate significance at the 1% level. Standard errors are given in parentheses, p-values in brackets. The exogeneity test is a test of exogeneity for a panel regression estimated via instrumental variables. The null hypothesis states that an ordinary least squares (OLS) estimator of the same equation would yield consistent estimates.

on the absolute value of aggregate inflation with country-specific fixed effects \( \alpha_i \).

\[ RPV_{it} = \alpha_i + \beta|\pi_{it}| + \varepsilon_{it}. \]  

(1)

The results for the fixed-effects estimation (1) for the two alternative inflation measures are reported in Table 1. In both cases, inflation has a significant and positive impact on RPV.

However, the estimates based on headline inflation have to be interpreted with caution. In particular, the Davidson-MacKinnon exogeneity test rejects the null hypothesis of exogeneity of headline inflation at the 1% level. In contrast, the Davidson-McKinnon

---

6 Parsley (1996) and Debelle and Lamont (1997) also include time dummies to control for shocks that hit all cities in a uniform manner. Since inclusion of time dummies does not alter our results qualitatively, we only present results referring to estimations without time dummies. The regressions of Equation (1) assume neither cross-section heteroskedasticity which allows for a different residual variance for each cross-section nor contemporaneous correlation between the cross-section residuals. If we allow for cross-section heteroskedasticity and contemporaneous correlation, the results do not change substantially.

7 The Davidson-MacKinnon test computes a test of exogeneity for a fixed-effect regression estimated via instrumental variables, see Davidson and MacKinnon (1993). A rejection of the null hypothesis indicates that endogenous regressors’ effects on the estimates are meaningful, and instrumental variables techniques are required.
test shows that there is no endogeneity bias if we use the absolute value of core inflation. Accordingly, the core inflation rate is the appropriate inflation measure for the following empirical investigations.

2.3 Expected inflation versus unexpected inflation

The empirical results presented in the previous subsection showed that relative price variability in Europe increases in inflation. According to the simple linear specification (1), the impact of inflation on RPV does not depend on inflation expectations. However, a different role of expected and unexpected inflation is not only found empirically (Aarstol (1999), Nautz and Scharff (2005)) but also suggested by various theories explaining the inflation-RPV link.

Menu cost models by Sheshinski and Weiss (1977) or Rotemberg (1983) emphasize a positive relationship between RPV and expected inflation. If there are fixed costs of price changes and firm-specific shocks, staggered price setting will be generated and higher expected inflation will amplify the dispersion of prices. In contrast, only unexpected inflation has an impact on RPV in signal-extraction models introduced by Barro (1976) or Hercowitz (1981). In these models, individuals have difficulties distinguishing between relative and aggregate price changes. Since inflation uncertainty hampers the distinction between relevant idiosyncratic and irrelevant aggregate demand shocks, it becomes optimal for firms to adjust output less in response to all shocks. As a consequence of the implied misperceptions, prices have to move more in each market to equate quantity demanded with the less variable quantity supplied. If price elasticities of supply differ across firms, then RPV will respond to the magnitude of unexpected inflation.

An obvious extension of the basic inflation-RPV relationship is, therefore, to allow for different coefficients on expected ($\pi_e$) and unexpected ($\pi_U - \pi_e$) inflation:

\[
RPV_{it} = \alpha_i + \beta_1|\pi_{ei}| + \beta_2|\pi_{Uit} - \pi_{ei}| + \varepsilon_{it},
\]  

(2)
Table 2: The effects of expected and unexpected inflation on RPV

|                    | $RPV_{it} = \alpha_{it} + \beta_1 |\pi_{it}'| + \beta_2 |\pi_{it} - \pi_{it}'| + \varepsilon_{it}$ | $RPV_{it} = \alpha_{it} + \beta_1 |\pi_{it}'| + \beta_2 (\pi_{it} - \pi_{it}')^+ + \beta_3 (|\pi_{it} - \pi_{it}'| - |\pi_{it} - \pi_{it}'|)^+ + \varepsilon_{it}$ |
|--------------------|-----------------------------------|--------------------------------------------------|
| $\hat{\beta}_1$   | 0.26** (0.09)                     | 0.27** (0.09)                                    |
| $\hat{\beta}_2$   | 1.13** (0.07)                     | 1.06** (0.09)                                    |
| $\hat{\beta}_3$   |                                   | 1.20** (0.09)                                    |
| $F(\hat{\beta}_1 = \hat{\beta}_2)$ | 50.88 [0.00]                      |                                                 |
| $F(\hat{\beta}_2 = \hat{\beta}_3)$ |                                   | 1.85 [0.17]                                     |
| $\bar{R}^2$       | 0.34                              | 0.34                                             |
| Obs.               | 830                               | 830                                              |
| Countries          | 10                                | 10                                               |

Notes: Expected and unexpected inflation are based on a AR(12) forecast of core inflation. ** indicate significance at the 1% level. Standard errors are given in parentheses, p-values in brackets. $F(\hat{\beta}_1 = \hat{\beta}_2)$ indicates the F-statistic testing $H_0: \hat{\beta}_1 = \hat{\beta}_2$. 

where $\alpha_{it}$ are again the fixed effects for each country. Typically, the empirical literature uses simple autoregressive time series representations to estimate inflation forecasts. Following e.g. Bomberger and Makinen (1993), Silver and Ioannidis (2001), Konieczny and Skrzypacz (2005), we estimate expected and unexpected inflation in Equation (2) using an AR(12) core inflation forecast for each country.

The first column of Table 2 shows the results for the fixed effects estimation of Equation (2). In line with the findings for Germany obtained by Nautz and Scharff (2005), the impact of unexpected inflation is much stronger in the Euro area. An F-Test of the null hypothesis that the coefficients on expected and unexpected inflation are equal indicates rejection at the 1% level. Nautz and Scharff (2005) argue that the influence of expected inflation in Germany disappears because a credible monetary policy stabilized inflationary expectations on a low level. In fact, Konieczny and Skrzypacz (2005) establish a more pronounced effect of expected inflation during the transition of Poland from a planned to a market economy when inflation expectations were relatively high.
For the US, Aarstol (1999) finds that the effect of inflation on RPV is more pronounced when inflation is unexpectedly high, i.e. when unexpected inflation is positive. Following this approach, we regress RPV on expected as well as positive and negative unexpected inflation:

\[
RPV_{it} = \alpha_i + \beta_1|\pi_{it}^e| + \beta_2(\pi_{it} - \pi_{it}^e)^+ + \beta_3(\pi_{it} - \pi_{it}^e)^- + \varepsilon_{it}, \tag{3}
\]

where \((\pi_{it} - \pi_{it}^e)^+ = (\pi_{it} - \pi_{it}^e)\) if \((\pi_{it} - \pi_{it}^e) \geq 0\) and \((\pi_{it} - \pi_{it}^e)^- = (\pi_{it} - \pi_{it}^e)\) if \((\pi_{it} - \pi_{it}^e) \leq 0\) (zero otherwise). The fixed effects estimation of Equation (3) is reported in the second column of Table 2. The results indicate no rejection of the null hypothesis that the coefficients of positive and negative unexpected inflation are equal. Thus, there is no evidence for an asymmetric impact of unexpected inflation on RPV in Europe. As a consequence, Equation (2) shall be regarded as a starting point for the analysis of threshold effects in the inflation-RPV relationship.

The panel threshold model is an obvious first step to analyze potential non-linearities in the impact of inflation on RPV in Europe. Hansen (1999, 2000) provides tests for the number of thresholds and estimates the threshold values, i.e. the critical inflation levels where the impact of inflation on RPV changes. In the next section, we recall how to estimate and evaluate single and multiple panel threshold models.

3 The Panel-Threshold-Model

3.1 The single threshold model

Consider the following single threshold model

\[
y_{it} = \alpha_i + \beta_1'x_{it}I(q_{it} \leq \gamma) + \beta_2'x_{it}I(q_{it} > \gamma) + \varepsilon_{it}, \tag{4}
\]

for a balanced panel where the subscript \(i\) stands for the cross-sections with \(1 \leq i \leq N\) and \(t\) indexes time \((1 \leq t \leq T)\). \(I(\cdot)\) is an indicator function and the error term \(\varepsilon_{it}\) is independent and identically distributed with zero mean and finite variance \(\sigma^2\). The
dependent variable $y_{it}$ and the threshold variable $q_{it}$ are scalar, the regressor $x_{it}$ is a $k$-dimensional vector of exogenous variables. $x_{it}$ and $y_{it}$ are assumed to be stationary variables. $x_{it}$ may contain variables with slope coefficients constrained to be the same in the two regimes which have no effect on the following distribution theory. If the threshold variable $q_{it}$ is below or above a certain value of $q_{it}$, namely $\gamma$, then the regressor $x_{it}$ has a different impact on $y_{it}$ represented by coefficients $\beta_1 \neq \beta_2$. The threshold variable $q_{it}$ may be an element of $x_{it}$ but this is not necessarily the case. In our application $y_{it}$ is RPV and a natural choice of $q_{it}$ is a measure of inflation. $x_{it}$ contains expected and unexpected inflation.

Hansen (1999, 2000) chooses a fixed effects approach to estimate Equation (4). For given $\gamma$, the slope coefficient $\beta$ can be estimated by ordinary least squares in a first step. In a second step, the estimator for the threshold $\hat{\gamma}$ is achieved by minimizing the sum of squared errors, i.e. $\hat{\gamma} = \arg\min_\gamma S_1(\gamma)$, and the estimate for the slope coefficient is obtained by $\hat{\beta} = \hat{\beta}(\hat{\gamma})$.

Having estimated the threshold $\hat{\gamma}$, it is important to check whether it is in fact statistically significant. Obviously, the null hypothesis "no threshold effect in Equation (4)" is equivalent to $H_0 : \beta_1 = \beta_2$. However, standard tests have non-standard distributions since the threshold is not identified under $H_0$. Therefore, Hansen (1996) suggests a bootstrap method to simulate the asymptotic distribution of the likelihood ratio test.

The bootstrap procedure is applied by Hansen (1999) to a large number of cross sections ($N$) but only a few time periods. In our application, the bootstrap procedure has to be modified because the number of countries is only ten while $T$ is large.\footnote{Hansen (1999) groups the regression residuals by individual $\varepsilon_{it}^* = \{\varepsilon_{i1}^*, \varepsilon_{i2}^*, \ldots, \varepsilon_{iT}^*\}$ and takes the sample $\{\varepsilon_{1}^*, \varepsilon_{2}^*, \ldots, \varepsilon_{N}^*\}$ with size $N$ as the empirical distribution. Since $N$ is limited but $T$ is large in our empirical analysis, we treat the sample $\{\varepsilon_{11}^*, \varepsilon_{12}^*, \ldots, \varepsilon_{1T}^*, \varepsilon_{21}^*, \varepsilon_{22}^*, \ldots, \varepsilon_{NT}^*\}$ as the empirical distribution to be used for bootstrapping. For the bootstrap procedure, the variable $x_{it}$ and the threshold variable $q_{it}$ are given, i.e. their values are fixed in repeated bootstrap samples. We take with replacement a sample of size $NT$ from the empirical distribution and create a bootstrap sample under the null hypothesis of no threshold. This bootstrap sample is used to estimate the model under $H_0$ and $H_1$ and to calculate the bootstrap value of the likelihood ratio statistic. This procedure is frequently repeated – 1000 bootstrap replications in our application – and the bootstrap estimate of the asymptotic p-value under $H_0$ is the percentage of draws for which the simulated likelihood ratio statistic is greater than or equal to the observed statistic.}

\[11\]
(2000) uses the likelihood ratio statistic (denoted by $F_1$) for tests on $\gamma$ to form valid asymptotic confidence intervals for $\gamma$ ($T \to \infty$ or $N \to \infty$). Note that these confidence intervals for $\gamma$ can be highly asymmetric.

### 3.2 Multiple thresholds

In many applications, there may be more than only one threshold. For example, there are two thresholds accounting for non-linearities in the relationship between inflation and growth in Europe, see Cuaresma and Silgoner (2004). To recall the testing and estimation procedure in case of multiple thresholds, consider the double threshold model

$$y_{it} = \alpha_i + \beta'_1 x_{it} I(q_{it} \leq \gamma_1) + \beta'_2 x_{it} I(\gamma_1 < q_{it} \leq \gamma_2) + \beta'_3 x_{it} I(\gamma_2 < q_{it}) + \epsilon_{it}$$

(5)

with $\gamma_1 < \gamma_2$. The sum of squared residuals $S(\gamma_1, \gamma_2)$ can be calculated as in the single threshold model and the joint least squares estimates of $(\gamma_1, \gamma_2)$ are the values which jointly minimize $S(\gamma_1, \gamma_2)$. Since a grid search over $(\gamma_1, \gamma_2)$ requires approximately $(NT)^2$ regressions, it is important to note that sequential estimation is consistent, see e.g. Hansen (1999). These results can be easily generalized to higher order threshold models.

Bai (1997) develops a sequential testing procedure to determine the number of significant thresholds in a multiple threshold model. If $F_1$ implies that the null of no threshold has to be rejected, the likelihood ratio statistic $F_2$ discriminates between one and two thresholds using the difference between the minimized sum of squares obtained from the two competing threshold models. The bootstrap procedure to approximate the asymptotic p-value for this likelihood ratio test works as for the single-threshold case. The sequential testing sequence stops if – according to the likelihood ratio statistic $F_K$ – the null of a maximum number of $(K - 1)$ thresholds is rejected but the null of at most $K$ thresholds is not.\(^9\)

\(^9\) The GAUSS program underlying this analysis is based on the GAUSS code by Bruce Hansen which is available from his homepage (http://www.ssc.wisc.edu/~bhansen/).

---

\(^9\) The ratio statistic exceeds the actual statistic. The null hypothesis of no threshold effect is rejected if the p-value is smaller than the desired significance level.
According to Bai (1997), the threshold estimators in the multiple threshold model have the same asymptotic distributions as the threshold estimate in the single threshold model. Therefore, the confidence intervals for multiple threshold parameters are constructed in the same way as in the single threshold case.

4 Inflation thresholds and RPV: Empirical results for the Euro area

4.1 Model specification

Let us now apply the panel-threshold model to the analysis of the relationship between RPV and inflation in the Euro area. According to the evidence found in Section 2, we use the linear specification (2) that allows for a different impact of expected ($\pi_{it}^e$) and unexpected ($\pi_{it} - \pi_{it}^e$) core inflation on RPV as the starting point of our analysis. Thus, using the notation of the threshold model introduced in Section 3, we have $y_{it} = RPV_{it}$ and $x_{it} = (|\pi_{it}^e|, |\pi_{it} - \pi_{it}^e|)$.

In the next step, the threshold variable $q$ has to be determined. Section 2 provided clear evidence that core inflation is the relevant measure of inflation for RPV. Therefore, core inflation as threshold variable seems to be the most natural choice. In the following we will therefore concentrate on the results obtained for $q_{it} = \pi_{it}$. Yet, it is worth emphasizing that our major results are very robust with respect to alternative threshold variables like headline inflation or expected core inflation, see Tables 5 and 6 in the Appendix for detailed results.

Finally, we have to determine whether expected and/or unexpected inflation may have a non-linear-threshold impact on RPV. Table 7 in the Appendix shows that the relation between unexpected inflation and RPV is linear. In the following, we therefore focus on the influence of expected inflation on RPV. Therefore, the threshold model employed
in the following analysis is specified as follows:

$$RPV_{it} = \alpha_i + \sum_{k=0}^{K} \beta_{k+1} |\pi_{it}^c| I(\gamma_k < \pi_{it} \leq \gamma_{k+1}) + \delta |\pi_{it} - \pi_{it}^e| + \varepsilon_{it},$$

(6)

where $\gamma_0 = -\infty$, $\gamma_{K+1} = \infty$, $K$ is the number of thresholds and, thus, $(K + 1)$ the number of inflation regimes.

4.2 The number of inflation thresholds

In order to determine the number of thresholds, the distinct values of the threshold variable core inflation are sorted. To ensure a minimum number of observations in each threshold regime, we restrict the search to values of monthly core inflation such that not less than 5% of the observations, i.e. at least 41 observations, lie in each regime, see e.g. Hansen (1999). The remaining values of monthly core inflation (beginning with $-0.1149$ and ending with $0.5112$) constitute the values of $\gamma$ which can be searched for $\hat{\gamma}$.

The likelihood ratio statistics $F_1$, $F_2$, and $F_3$ together with their asymptotic bootstrap p-values are shown in Table 3. According to the p-value associated to $F_1$, the null of no threshold effects can be rejected at the 1% level. The test statistic for a double threshold $F_2$ is also highly significant with a bootstrap p-value of 0.01. However, the test statistic for a third threshold ($F_3$) is far from being statistically significant. Therefore, the sequential test procedure implies two thresholds and, thus, three inflation regimes in the inflation-RPV relation for the Euro area.

4.3 Estimating the inflation thresholds and the slope coefficients

The estimated thresholds and the 95% confidence intervals are reported in the upper part of Table 4. The point estimates of the two thresholds for monthly core inflation are $-0.1149$ and $0.4948$. Note that $-0.1149$ is the smallest feasible threshold value having restricted the search for thresholds to values of $\gamma$ such that 5% of the observations lie in
Table 3: Test procedure establishing the number of thresholds

\[ RPV_{it} = \alpha_i + \sum_{k=0}^{K} \beta_{k+1} |\pi_{it}^e| I(\gamma_k < \pi_{it} \leq \gamma_{k+1}) + \delta |\pi_{it} - \pi_{it}^e| + \varepsilon_{it} \]

**H₀: no threshold (K=0)**

<table>
<thead>
<tr>
<th>F₀</th>
<th>p-value</th>
<th>(10%, 5%, 1% critical values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>34.82</td>
<td>0.00</td>
<td>(8.12, 9.85, 15.07)</td>
</tr>
</tbody>
</table>

**H₀: at most one threshold (K=1)**

<table>
<thead>
<tr>
<th>F₁</th>
<th>p-value</th>
<th>(10%, 5%, 1% critical values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.94</td>
<td>0.01</td>
<td>(7.88, 9.42, 13.19)</td>
</tr>
</tbody>
</table>

**H₀: at most two thresholds (K=2)**

<table>
<thead>
<tr>
<th>F₂</th>
<th>p-value</th>
<th>(10%, 5%, 1% critical values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.34</td>
<td>0.59</td>
<td>(6.95, 8.28, 11.68)</td>
</tr>
</tbody>
</table>

Notes: The threshold variable \( \pi_{it} \) is monthly core inflation. \( \gamma_0 = -\infty, \gamma_{K+1} = \infty \). The sequential test procedure indicates that the number of thresholds is \( K = 2 \). 1000 bootstrap replications were used to obtain the p-values.

Each regime. As a result, the regime \( \pi_{it} \leq \hat{\gamma}_1 \) contains exactly 41 observations and the lower bound of the 95% confidence interval is the threshold value itself. By contrast, the second threshold lies strictly within the confidence interval.

The different estimates (\( \hat{\beta}_1, \hat{\beta}_2, \hat{\beta}_3 \)) for the marginal impact of expected inflation in the three inflation regimes can be found in the lower part of Table 4. The coefficient of unexpected core inflation (\( \hat{\delta} \)) - the variable not switching between the regimes - on RPV is positive and highly significant. In contrast, the significant linear relation between expected inflation and RPV presented in Section 2 is attributed to the positive impact of expected inflation if inflation is either very high or very low. Specifically, the expected inflation coefficients on the regimes ‘very low inflation’ and ‘very high inflation’ are highly significant while the coefficient on the intermediate regime (\( \hat{\beta}_2 \)) is not significantly different from zero. RPV reacts positively (\( \hat{\beta}_3 = 0.5 \)) to expected
Table 4: A double threshold model for the inflation-RPV link

\[ RPV_{it} = \alpha_i + \beta_1 |\pi_{it}| I(\pi_{it} \leq \gamma_1) + \beta_2 |\pi_{it}| I(\gamma_1 < \pi_{it} \leq \gamma_2) + \beta_3 |\pi_{it}| I(\gamma_2 < \pi_{it}) + \delta |\pi_{it} - \pi_{it}^e| + \varepsilon_{it} \]

### Threshold estimates

<table>
<thead>
<tr>
<th>( \hat{\gamma}_1 )</th>
<th>-0.1149</th>
</tr>
</thead>
<tbody>
<tr>
<td>95% confidence interval</td>
<td>[-0.1149, -0.0996]</td>
</tr>
<tr>
<td>( \hat{\gamma}_2 )</td>
<td>0.4948</td>
</tr>
<tr>
<td>95% confidence interval</td>
<td>[0.2401, 0.5112]</td>
</tr>
</tbody>
</table>

### Regression estimates

<table>
<thead>
<tr>
<th>( \hat{\beta}_1 )</th>
<th>1.38** <em>(0.20)</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>( \hat{\beta}_2 )</td>
<td>0.05 <em>(0.10)</em></td>
</tr>
<tr>
<td>( \hat{\beta}_3 )</td>
<td>0.50** <em>(0.12)</em></td>
</tr>
<tr>
<td>( \hat{\delta} )</td>
<td>0.86** <em>(0.08)</em></td>
</tr>
<tr>
<td>SSR</td>
<td>48.74</td>
</tr>
<tr>
<td>Observations in regime 1</td>
<td>41</td>
</tr>
<tr>
<td>Observations in regime 2</td>
<td>739</td>
</tr>
<tr>
<td>Observations in regime 3</td>
<td>50</td>
</tr>
</tbody>
</table>

Notes: The threshold variable \( \pi_{it} \) is monthly core inflation. Standard errors are given in parentheses, p-values in brackets. ** indicate significance at the 1% level.

Inflation if monthly core inflation exceeds 0.4948%, i.e. if annualized core inflation is higher than 5.94%. As the 95% confidence interval for monthly inflation indicates, the estimated value of this upper inflation threshold exceeds 2.88% p.a. Expected inflation has the strongest marginal impact on RPV (\( \hat{\beta}_1 = 1.38 \)) if core inflation is lower than -0.1149%, i.e. -1.38% p.a.\(^{10}\) A linear specification underestimates the role of expected inflation for RPV in case of very high and very low inflation levels.

It is worth emphasizing that our results are robust with respect to the choice of the threshold variable. For example, as Tables 5 and 6 in the Appendix show, there are also

\(^{10}\) Confirming the importance of the pronounced low-inflation-effect, the threshold \( \hat{\gamma}_1 \) is the first threshold determined by the sequential test procedure. In fact, there is only evidence for a single low inflation threshold if each regime has to contain at least 10% of all observations.
two thresholds if the threshold variable is expected core inflation or headline inflation. In all these variants of the threshold model, the general conclusion remains: there is only a significant impact of expected inflation on RPV if inflation is either very low or very high.

5 Concluding Remarks

The effects of inflation on the economy are manifold. According to the recent macroeconomic literature, inflation-induced increases in relative price variability (RPV) are of particular importance. If inflation drives RPV above its efficient level, the information content of nominal prices is reduced impeding an efficient allocation of resources. This paper examined the empirical relationship between inflation and RPV in the Euro area focusing on threshold effects of inflation.

Employing the panel threshold model proposed by Hansen (1999, 2000), we found that RPV increases in expected inflation only if core inflation gets either too high ($\geq 5.94\%$ p.a.) or too low ($\leq -1.38\%$ p.a.). In the intermediate low inflation regime, however, there is no significant impact of expected inflation supporting price stability as an outcome of optimal monetary policy.

Threshold effects of inflation on RPV are not a straightforward implication of standard theories. The functional relationship between inflation and RPV depends on the assumptions made about firms’ price setting behavior. For example, deriving a linear relation between expected inflation and RPV from menu cost models requires simplifying assumptions about both, the costs of adjusting prices and the costs of keeping prices fix. However, recent evidence on price setting practices at the micro level (see e.g. Alvarez et al. (2006) ) suggests that firms’ pricing strategies might be much more complex.
Threshold models have already been applied in the empirical literature on the link between inflation and long-term growth. A general conclusion of this literature is that the costs of inflation are particularly significant if inflation exceeds a certain threshold. For example, Bruno and Easterly (1998) define inflation rates as high when they exceed 40% p.a. For European countries, Cuaresma and Silgoner (2004) estimate the upper threshold of inflation to be around 16% p.a. Obviously, this evidence is not very helpful for understanding current monetary policy. In particular, upper threshold levels of about 16% can hardly explain why current inflation targets in industrial countries center around 2%. Therefore, it is worth noting that our estimates for the upper threshold level of European core inflation range between 2.9% and 6.1% p.a.

Many central banks, including the ECB and the Bank of England, communicate their monetary policy strategy by use of inflation caps or target bands. Recently, various approaches have been proposed to explain the implied non-linearity in the behavior of central banks. For example, Athey, Atkeson and Kehoe (2005) and Mishkin and Westelius (2006) show that inflation target bands can solve the time-consistency problem of optimal monetary policy. Orphanides and Wieland (2000) derive inflation band targeting as optimal policy when the structure of the economy exhibits zone-linearity.

The current paper presented new evidence pointing to a non-linear impact of inflation on the economy. The significant thresholds found for inflation’s impact on relative price variability might provide a further rationale for the announcement of inflation target bands. Further research is needed to assess whether the estimated inflation thresholds could even serve as guidelines for the determination of the width and the location of the optimal inflation band.
References


A Appendix

A.1 Data figures

Figure 3: Headline inflation and RPV

Figure 4: Headline inflation and core inflation

Figure 5: Distribution of national core inflation rates in the Euro area

![Bar chart showing distribution of national core inflation rates in the Euro area](chart.png)

**Annualized Core Inflation**

Sample 1996.02-2003.12
(Observations 950)

- Minimum: -10.79
- Maximum: 23.26
- Mean: 2.17
- Median: 2.02
- Lower Quartile: 0.86
- Upper Quartile: 3.38
- Std. Dev.: 2.64
- Skewness: 0.53
- Kurtosis: 10.38


Figure 6: Minimum and maximum of core inflation

![Line chart showing minimum and maximum of core inflation](chart2.png)

### A.1.1 Expected core inflation and headline inflation as threshold variable

Table 5: Test for the number of thresholds with alternative threshold variables

\[ RPV_{it} = \alpha_i + \sum_{k=0}^{K} \beta_{k+1} |\pi_{it}^e| I(\gamma_k < x_{it} \leq \gamma_{k+1}) + \delta |\pi_{it} - \pi_{it}^e| + \varepsilon_{it} \]

<table>
<thead>
<tr>
<th>( H_0 ): no threshold (K=0)</th>
<th>expected core inflation</th>
<th>headline inflation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_1 )</td>
<td>71.56</td>
<td>84.05</td>
</tr>
<tr>
<td>p-value</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>(10%, 5%, 1% critical values)</td>
<td>(7.77, 9.94, 16.09)</td>
<td>(7.93, 9.66, 15.03)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( H_0 ): at most one threshold (K=1)</th>
<th>expected core inflation</th>
<th>headline inflation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_2 )</td>
<td>12.80</td>
<td>61.09</td>
</tr>
<tr>
<td>p-value</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>(10%, 5%, 1% critical values)</td>
<td>(8.45, 9.71, 12.43)</td>
<td>(8.15, 9.63, 13.98)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( H_0 ): at most two thresholds (K=2)</th>
<th>expected core inflation</th>
<th>headline inflation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_3 )</td>
<td>5.28</td>
<td>2.66</td>
</tr>
<tr>
<td>p-value</td>
<td>0.54</td>
<td>0.73</td>
</tr>
<tr>
<td>(10%, 5%, 1% critical values)</td>
<td>(9.12, 10.75, 13.78)</td>
<td>(7.59, 9.03, 13.40)</td>
</tr>
</tbody>
</table>

Notes: The threshold variable \( x_{it} \) is monthly expected core inflation or monthly headline inflation. 1000 bootstrap replications were used to obtain the p-values. \( \gamma_0 = -\infty, \gamma_{K+1} = \infty \). The sequential test procedure indicates that the number of thresholds for both expected core inflation and headline inflation is \( K = 2 \).
Table 6: A double threshold model with alternative threshold variables

\[ \text{RPV}_{it} = \alpha_i + \beta_1 |\pi_{it}^e|I(x_{it} \leq \gamma_1) + \beta_2 |\pi_{it}^e|I(\gamma_1 < x_{it} \leq \gamma_2) + \beta_3 |\pi_{it}^e|I(\gamma_2 < x_{it}) + \delta |\pi_{it}^e - \pi_{it}^c| + \varepsilon_{it} \]

<table>
<thead>
<tr>
<th>Threshold estimates</th>
<th>expected core inflation</th>
<th>headline inflation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\hat{\gamma}_1$</td>
<td>0.0441</td>
<td>-0.0887</td>
</tr>
<tr>
<td>95% confidence interval</td>
<td>[0.0047, 0.0541]</td>
<td>[-0.0972, -0.0777]</td>
</tr>
<tr>
<td>$\hat{\gamma}_2$</td>
<td>0.3671</td>
<td>0.4687</td>
</tr>
<tr>
<td>95% confidence interval</td>
<td>[0.1662, 0.3854]</td>
<td>[0.4655, 0.4694]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regression estimates</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\hat{\beta}_1$</td>
<td>1.86**</td>
<td>1.60**</td>
</tr>
<tr>
<td></td>
<td>(0.22)</td>
<td>(0.17)</td>
</tr>
<tr>
<td>$\hat{\beta}_2$</td>
<td>-0.09</td>
<td>-0.08</td>
</tr>
<tr>
<td></td>
<td>(0.11)</td>
<td>(0.09)</td>
</tr>
<tr>
<td>$\hat{\beta}_3$</td>
<td>0.26**</td>
<td>0.66**</td>
</tr>
<tr>
<td></td>
<td>(0.09)</td>
<td>(0.11)</td>
</tr>
<tr>
<td>$\hat{\delta}$</td>
<td>1.04**</td>
<td>0.97**</td>
</tr>
<tr>
<td></td>
<td>(0.07)</td>
<td>(0.07)</td>
</tr>
<tr>
<td>SSR</td>
<td>46.79</td>
<td>43.62</td>
</tr>
</tbody>
</table>

Observations in regime 1: 81
Observations in regime 2: 697
Observations in regime 3: 52

Notes: The threshold variable $x_{it}$ is monthly expected core inflation or monthly headline inflation. Standard errors are given in parentheses, p-values in brackets. ** indicate significance at the 1% level.
### A.1.2 No threshold effects of unexpected inflation

Table 7: Test procedure establishing the number of thresholds for unexpected inflation

\[
RPV_{it} = \alpha_i + \beta_1 |\pi_{it}^e| I(\pi_{it} \leq -0.11) + \beta_2 |\pi_{it}^e| I(-0.11 < \pi_{it} \leq 0.49) + \beta_3 |\pi_{it}^e| I(0.49 < \pi_{it}) \\
+ \sum_{k=0}^{K} \delta_{k+1} |\pi_{it} - \pi_{it}^e| I(\gamma_k < (\pi_{it} - \pi_{it}^e) \leq \gamma_{k+1}) + \varepsilon_{it}
\]

<table>
<thead>
<tr>
<th>$H_0$: no threshold (K=0)</th>
<th>$F_1$</th>
<th>3.39</th>
</tr>
</thead>
<tbody>
<tr>
<td>p-value</td>
<td></td>
<td>0.27</td>
</tr>
<tr>
<td>(10%, 5%, 1% critical values)</td>
<td></td>
<td>(5.64, 7.27, 10.49)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$H_0$: at most one threshold (K=1)</th>
<th>$F_2$</th>
<th>4.72</th>
</tr>
</thead>
<tbody>
<tr>
<td>p-value</td>
<td></td>
<td>0.47</td>
</tr>
<tr>
<td>(10%, 5%, 1% critical values)</td>
<td></td>
<td>(9.63, 11.60, 16.03)</td>
</tr>
</tbody>
</table>

Notes: The threshold variable is unexpected inflation. The sequential test procedure indicates that there is no threshold ($K = 0$) for unexpected inflation. The thresholds assumed for expected inflation are taken from the double threshold model shown in Table 4. A linear effect of unexpected inflation on RPV is also obtained for alternative threshold variables and for specifications assuming a linear relationship between RPV and expected inflation.