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Investigating the Inflation–Output Nexus for the Euro Area: Old Questions and New Results

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Abstract: The relationship between inflation and real GDP growth is one of the most widely researched topics in macroeconomics. At the same time, it is certainly not an exaggeration to claim that this nexus also stands at the heart of monetary policy, given the fact that low inflation in combination with high and sustained output growth should be the central objective of any sound economic policy. The latter notion becomes even more obvious when taking account of the fact that many central banks all over the world have selected target levels for inflation and communicated them to the public. Against this background, it is of utmost importance for central banks to understand more about the nature and formation of the relationship between inflation and real GDP. This study attempts to shed more light on the specific shape of this relationship for the euro area and, more specifically, on the issue of possible regime shifts therein. The analysis provides strong evidence for non-linear effects in the euro area. As a by-product, and seemingly the novel contribution, of this paper, the methods used allow for the quantification of a switching point across the different regimes. It is found that this breakpoint closely matches the ECB's previous definitions of price stability and its new inflation target of 2%. While these results look encouraging, further research in this area seems to be warranted.

Keywords: monetary policy; inflation; euro area; threshold regression; smooth transition regressions

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Citation: Reimers, Hans-Eggert, Dieter Gerdesmeier, and Barbara Roffia. 2023. Investigating the Inflation–Output Nexus for the Euro Area: Old Questions and New Results. *Economies* 11: 265. https://doi.org/10.3390/economies11110265

Academic Editors: Angela Roman and Bruce Morley

Received: 23 August 2023
Revised: 6 October 2023
Accepted: 12 October 2023
Published: 24 October 2023

1. Introduction

When analysing the effects of inflation on output growth, macroeconomic textbooks generally refer to a number of possible transmission channels. At the most basic textbook level, inflation, as a decline in the purchasing power of money, can be expected to reduce consumption, investment, the balance of payments and, thereby, also reduce GDP growth. Taken together, it appears that GDP growth is negatively related to inflation.

This notwithstanding, the literature lists a variety of possible channels at work, and it is virtually impossible to summarise and do justice to all of them.[1] As a consequence, we will restrict ourselves to a few selected papers that illustrate the main channels (see Dholakia et al. (2021, p. 7) for a more detailed overview).

Earlier approaches have traditionally concentrated on the role of savings, postulating in essence that higher inflation triggers a decline in real wealth, hence incentivising individuals towards higher savings, investment and, ultimately, spurring growth (see, e.g., Mundell 1963, p. 283). For instance, the Nobel prize winner James Tobin (1965, esp. p. 678) argued that inflation could promote real growth by encouraging economic subjects to reduce their real balances and transfer their savings into capital accumulation, thereby fostering growth—an argument that became subsequently known as the "Tobin effect".

Later on, in his Nobel prize speech, Tobin (1972) argued further that a positive rate of inflation might, in light of the downward rigidity of wages, help to lower real wages and, thus, stabilise an economy after the emergence of an adverse shock. Therefore, in Tobin's view, a small amount of inflation could help "to grease the wheels of the labour market".

An alternative channel focuses on the role of investment in this process, claiming that rising inflation leads to a rise in the costs of investment, which via a reallocation of resources leads to higher growth for low levels of inflation, while at the same time, damping growth for higher levels of inflation (see Akerlof et al. (1996), esp. p. 20 ff and also the simulation results on p. 33 ff). In this context, some studies seem to demonstrate that financial factors could strengthen this assessment further as higher inflation is possibly followed by a decline in bank deposits, hence narrowing the space of financing opportunities for investment, and thereby lowering growth (see Haslag 1995, 1997). Other studies lend support to the idea that inflation distorts tax systems and discourages investment as it erodes the real value of historically based depreciation write-offs, thus rendering investment more costly and hindering growth (see Able 1980).

Turning to the respective effects on consumption, several authors have supported the view that higher inflation ultimately lowers real balances and, therefore, also consumption expenditures and, ultimately, growth (see Stockman 1981, p. 391).

Moreover, from the perspective of behavioural economics, it seems realistic to assume that economic subjects tend to ignore inflation when it remains at very low levels, while instead fully taking account of it when it reaches higher levels because the cost of ignoring it has become too high (see Akerlof et al. 2000, esp. p. 3).

When referring more explicitly to the role of uncertainty in general or inflation uncertainty in particular, it has been postulated that higher levels of inflation are generally accompanied by higher inflation uncertainty, thereby augmenting the effective cost of capital as the main determinant of investment, and thus hindering growth (see Friedman 1977). Finally, an additional role of relative prices has been advocated, arguing that inflation raises inflation uncertainty, which increases risk premia and interest rates and via changes in relative prices lowers expected returns and, thereby, also growth (see Dholakia 2020).

There are, however, also channels that seem to consider intuitively a positive relationship. For instance, a simple Phillips curve perspective might imply that high inflation rates are mirrored in low rates of unemployment which, if taken per se, would speak in favour of higher growth (see the discussion in Section 3). Taken together and judged from a purely theoretical perspective, previous studies do not seem fully conclusive about the relationship between economic growth and inflation, suggesting either neutrality, or a negative or a positive relationship.

More recently, the topic has clearly regained considerable popularity from a different perspective. In a widely cited paper, Blanchard et al. (2010) argue for an increase of the inflation target from 2% to more than 3%, the main argument consisting of the empirical observation that low inflation accompanying deflationary recessions substantially hampers the ability of monetary policy to sufficiently counteract such developments. The latter result can be attributed to the fact that the zero nominal interest rate constraint prevents central banks from doing so.

As argued by the authors, one possible corollary of such a constellation is the need for more reliance on fiscal policy and, related to this, for larger deficits than would have been present in the absence of the binding zero-interest-rate constraint. Another remedy, however, would consist of escaping the trap by obliging central banks to target higher inflation rates, thus allowing for higher nominal interest rates and, in this respect, the possibility of cutting interest rates more (see Blanchard et al. 2010, p. 11).

In a later study, Ball (2014) supports the notion that, against the background of the zero-bound interest rates and the related constraint on monetary policy (arising from the fact that nominal interest rates cannot be negative), a 2% inflation target is perceived as too low. In his view, it is not entirely clear what target is ideal, but 4% seems a reasonable guess, even more so as the United States have lived comfortably with that inflation rate in the past (see Ball 2014).

In today's world, where the negative consequences of inflation are well documented, a widespread consensus seems to have emerged that inflation has a negative effect on medium and long-term growth (see Fischer 1991, 1993). This in turn gives rise to a number of far-reaching questions that have an important bearing on monetary policy. To begin with, the results clearly support the conclusion that policymakers should aim for a low rate of inflation. However, it does not help to answer the question of how low the inflation target should be. Should the target inflation be 7%, 5%, or rather 0%?[2] Moreover, it does not help to answer another key question—can the negative relationship between inflation and real growth be described in terms of a purely monotonic function? Or is it instead of a non-linear nature? Expressed in other words: Can, at a specific (and rather low) rate of inflation, the relationship be characterised as positive (or maybe nonexistent), and at higher rates, move into negative territory?

And, if such a non-linear relationship can be shown to exist, is it possible to estimate the specific "inflection point" (or, alternatively, the "threshold" at which the sign of the relationship between the two variables would necessarily switch)?

It goes without saying that the results bear the potential to trigger serious policy implications. This is due to the fact that the threshold level of inflation is the value above which inflation significantly slows growth and—at the same time—it can be interpreted in terms of potential growth. As a consequence, a central bank that reacts too early to inflationary developments will never allow an economy to realise (full) potential growth. Vice versa, a central bank that reacts too late has already entered the zone where inflation hinders growth, and it can be expected that its anti-inflationary policy will—at least in the short run—cause further damage to growth.

The research topic underlying this paper is the question of whether a threshold level of inflation for the euro area exists, above which inflation can be found to negatively influence GDP growth. In line with this, we apply smooth transition regressions for different specifications over a sample period from 1980 to 2022. The estimated threshold values are in most cases close to 2%, which leads to the conclusion that higher inflation rates bear the risk of affecting growth in a negative way.

The paper is organised as follows. Section 2 proceeds with a review of the literature. Section 3 includes the description of the methodology. Section 4 presents the data and empirical results. The final section concludes.

2. Literature Review

A closer look at the empirical literature reveals that a wide variety of studies exist often investigating the inflation–growth nexus for a (possibly larger) panel of countries, sometimes even separating industrialised from non-industrialised countries. Table 1 provides an (non-exhaustive) overview of some of these studies, their specific set-up, and the main results.

Table 1. Overview on selected studies quantifying threshold levels.

Authors	Period	Sample	Threshold Value
Sarel (1996)	1970–1990	90 countries	8%
Khan and Senhadji (2001)	1960–1998	140 countries	3% developed countries, 12% developing countries, 9% all countries
Mubarik (2005)	1973–2000	Pakistan	9%
Munir et al. (2009)	1970–2005	Malaysia	3.89%
Hasanov (2011)	2001–2009	Azerbaijan	13%
Akgül and Özdemir (2012)	2003.01–2009.12	Turkey	1.26%
Kremer et al. (2013)	1950–2004	124 countries	2.53% for industrialized countries, 17.23% for non-industrialized countries
Omay and Kan (2010)	1972–2005	6 developed countries	2.52%

Table 1. *Cont.*

Authors	Period	Sample	Threshold Value
Nasir and Saima (2010)	1961–2008	Pakistan	Two thresholds (6% and 11%)
Vinayagathasan (2013)	1980–2009	32 Asian countries	5.43%
Tung and Thanh (2015)	1986–2013	Vietnam	7%
Thanh (2015)	1980–2011	Vietnam, Indonesia, Malaysia, Philippines, Thailand	7.84%
Aydin and Odabasioglu (2017)	1992–2013	Azerbaijan, Kyrgyzstan, Kazakhstan, Uzbekistan, Turkmenistan	7.97%
Nepal Rastra Bank (2017)	1978–2016	Nepal	6.25–6.40% depending on the estimation method
Dholakia et al. (2021)	1995–2018	58 countries	11% for the full sample, 4.1% for advanced economies, 24.8% for emerging economies

Sources: Ekinci et al. (2020, p. 9) and own additions.

One of the earliest studies in this area is by Sarel (1996). Using data for about 90 countries over a period from 1970 to 1990, the study found evidence for a threshold in the inflation rate at around 8%, above which inflation hampers economic growth in a statistically significant manner.

The study by Nasir and Saima (2010) relies on annual data from 1961 to 2008 for Pakistan and finds evidence in favour of a non-linear relationship with two thresholds (i.e., 6% and 11%). According to the findings, inflation links to economic growth positively, but in a statistically insignificant manner below the first threshold. In the area between the two threshold levels, inflation proves to impact on growth in a significant and strongly negative manner and in a statistically significant negative, albeit smaller, effect above the second threshold.

Somewhat related, Kremer et al. (2013) rely on a dynamic panel-threshold model to estimate inflation thresholds for long-term economic growth. The data set for their cross-country study encompasses 124 countries over a sample from 1950 to 2004. Interestingly enough, the threshold value seems to depend, to a considerable extent, on the state of the economy as the threshold value for developed economies is around 2.5%, whereas its equivalent for developing countries (i.e., the value that can be associated with lower economic growth) corresponds to around 17.2%.

In much the same vein, Kelikume (2018) aims to investigate the non-linear effects of inflation and the inflation thresholds for long-term economic growth in Africa. Based on a large panel data set of 41 African countries for the period 1960–2015, the study proceeds by separating 21 resource-rich countries from 20 non-resource-rich countries in order to validate whether any differences in the empirical linkage between inflation and long-term growth can be detected. Using a dynamic panel-threshold model, the study finds that for the full sample of African countries, there is evidence for a threshold of 11.1%, above which inflation hampers real economic growth. When going into more detail, further tests indicate threshold levels of 12.5% and 9.4% for resource-rich and non-resource-rich African countries, respectively. Taken together, the author finds evidence in favour of a growth-dampening effect of excessive inflation for Africa.

More recently, in their overview paper, Ekinci et al. (2020) summarise the evidence of threshold results regarding the relationship between price stability and economic growth from different studies for selected countries that rely on inflation targeting. In sum, they find that the threshold value is much lower in developed countries than in developing countries, the former lying in a range between 2% and 3%, while the latter ranges between 12% and 17%. When carrying out the analysis on a sample extended to 24 inflation-targeting countries, an inflation threshold of 4.2% can be found. The authors conclude by arguing in favour of a non-linear relationship prevailing between inflation and economic growth.

Another study that uses cross-country data is by Dholakia (2020), who relies on a cross-country data set of 58 countries for the sample period from 1995 to 2018. The study reports a threshold inflation rate of 11.0% for the full sample, while reporting some heterogeneity across economies, i.e., 4.1% for advanced economies, but a much higher threshold rate of inflation at 24.8% for emerging economies (see Dholakia et al. 2021, p. 22).

As regards the euro area, there are only a few studies investigating the issue explicitly, although most of them tackle the issue rather from the opposite point of view, i.e., from a Phillips curve perspective. For instance, the study by Baghli et al. (2006) doubts that the euro area inflation process can sufficiently be described in terms of a (traditional) linear Phillips curve and, instead, investigates, in a non-parametric framework, how inflation is sensitive to output growth. An asymmetric output-inflation trade-off is pointed out for the euro area at both aggregated and individual country levels (see Baghli et al. (2006) for details).

In a different study, Tsionas and Christopoulos (2003) start from the claim that the 2% inflation target set by the ECB implicitly assumes the existence of a non-linear relation between inflation and real GDP; in the sense that no effects of inflation materialise below a certain threshold, whereas there are significant negative effects above the threshold. Using threshold regressions and smooth transition models, the authors find significant evidence of non-linearities in the inflation–growth nexus and a threshold level of inflation of around 4.3%. The results also support the view of a negative relationship between inflation and growth for inflation rates that are above as well below the "threshold" level, but the effect above the "threshold" is almost three times as large.

3. Methodology

The issue of (possible) regime shifts has a long tradition in empirical macroeconomics, and it seems fair to say that non-linear models are relevant for a broad range of economic themes that could prove of high relevance for policy-making (see Granger (2001) for an overview). Among the most popular modelling approaches used in this field are the so-called "threshold regressions" and the so-called "smooth transition regressions".

Threshold-regression models represent one particular category of regime-switching models, in which the parameters are allowed to vary according to a regime-switching mechanism that, in turn, depends on a threshold variable. In this context, the threshold variable can be exogenous or endogenous by nature.

Threshold models have been successfully applied in many areas of empirical macroeconomics and for a variety of countries, as they constitute a suitable tool to test for the reliability of a previously detected relationship over different regimes. The specific methodology of a threshold regression can be described by the following equations (see Hansen 2000, esp. p. 576 ff):

$$y_i = \theta_1' x_i + \varepsilon_i \text{ if } q_t \leq \gamma \tag{1}$$

$$y_i = \theta_2' x_i + \varepsilon_i \text{ if } q_t > \gamma \tag{2}$$

where y_t and x_t denote the dependent and independent variable, and q_t stands for the threshold variable that can be used to split the sample into two groups. The random variable ε_t represents a regression error. It is worth noting already at this stage that the threshold variable can be a part of the dependent variables (see Hansen 2000, p. 577).

In order to transform the model into a single equation, we define a dummy variable:

$$d_i(\gamma) = I(q_i \leq \gamma) \tag{3}$$

where $I(.)$ represents the indicator function. When setting $x_i(\gamma) = x_i d_i(\gamma)$, Equations (1) and (2) can be rearranged to take the following form:

$$y_i = \theta' x_i + \delta'_n x_i(\gamma) + \varepsilon_i \tag{4}$$

where $\theta = \theta_2$ and $\delta_n = \theta_1 - \theta_2$. The latter equation then allows all regression parameters to differ between the two regimes. Following the results shown in Hansen (1992), an algorithm can be used that is based on sequential OLS estimation, which searches over all values $\gamma = q_i$ for $t = 1, \ldots . i$.

While it is well-known that the threshold estimates are super-consistent, the distribution theory for testing and inference remains challenging. In his study, Hansen (2000) suggests a heteroskedasticity-consistent *F*-test bootstrap procedure to test for the null hypothesis of linearity (see Hansen (2000) for details). However, given the fact that the threshold value is not identified under the null, the p-values must be computed by a fixed bootstrap method, which yields asymptotically correct p-values. If the null hypothesis of linearity is rejected, it seems advisable to split up the original sample according to the estimated threshold value(s).

A closely related issue is the determination of the exact number of break dates. In this respect, Bai and Perron (1998, 2003) have advocated an *F*-type test that is based on the following null hypothesis:

$$\begin{aligned} \mathrm{H_0}: \; m &= l \\ \mathrm{H_A}: \; m &= l + 1 \end{aligned} \tag{5}$$

Expressed in non-technical terms, the test splits the overall sample into individual segments, ranging from 1 up to $l + 1$ of the model under the null hypothesis. It is then tested whether a particular break date exists that can significantly reduce the sum of squared errors. In this context, use is made of a trimming parameter (η) that determines the minimum length that a segment must have if it is further broken up. It is not uncommon in the literature to set the trimming parameter equal to 0.15 (see, for instance, Zeileis et al. 2003, esp. p. 110 ff).

More specifically, if the test fails to reject the null hypothesis, the inclusion of a further break does not allow for a better econometric fit between the dependent and independent variables than the current set-up (under the null hypothesis). Should, however, the null hypothesis be rejected, the additional break under the alternative hypothesis does a statistically significantly better job of explaining the relationship between the variables.

In order to determine the optimal number of break dates, this test is repeated $l + 1$ times up to the moment where the null hypothesis is rejected. The break dates under the null hypothesis are selected in such a manner that they minimize the sum of squared residuals. The underlying *F*-test statistic can be expressed as follows:

$$F_T(l+1|l) = \frac{\left\{S_T(\hat{T}_1, \hat{T}_2, \ldots, \hat{T}_l) - \min_{1<i<l} \inf_{\tau \in i\eta} S_T(\hat{T}_1, \hat{T}_2, \ldots, \hat{T}_{l-1}, \tau, \hat{T}_{i-1}, \hat{T}_{i+1}, \ldots, \hat{T}_l)\right\}}{\hat{\sigma}^2} \tag{6}$$

where the set $\Lambda_{i\eta}$ is defined as

$$\Lambda_{i\eta} = \{\tau; T_{i-1} + (T_i - T_{i-1})\eta \leq \tau \leq T_i + (T_i - T_{i-1})\eta\} \tag{7}$$

In this context, $\hat{\sigma}^2$ is a consistent estimate of the residual variance under the null hypothesis of l breaks.

An alternative approach consists of the so-called "Smooth Transition Regression" model ("STR"). Originally advocated by Teräsvirta in the mid-1990s, STR models have, in the meantime, morphed into a popular tool to model non-linearities of the regime-switching type in many empirical applications. The basic specification and estimation framework of such an STR model generally takes the following form (see Teräsvirta (1994a) for details):

$$y_t = \psi' z_t + \phi' z_t G(\gamma, c, s_t) + \mu_t \tag{8}$$

where y_t represents a scalar, while z_t stands for the vector of explanatory variables, and ψ' and ϕ' denote the parameter vectors of the linear and non-linear part of the STR regression, respectively. Moreover, μ_t corresponds to a well-behaved error term with properties $N(0, {h_t}^2)$.

Probably the most interesting part of the equation is represented by the transition function $G(\gamma, c, s_t)$. The latter stands for a continuous transition function that is, in principle, bounded between zero and unity and thereby determines whether the economy is in the 'high regime', the 'low regime', or is transitioning between the two regimes. It is worth noting that exactly because of the latter property, the model is not only suitable to explain the two extreme states, but also a continuum of states that lie between those two extremes.

More specifically, the two extreme cases are mirrored in the expression $G(\gamma, c, s_t) = 0$, in which case the original equation specifically collapses to the linear case, and $G(\gamma, c, s_t) = 1$, which renders the original equation a fully-fledged two-regime "Threshold Autoregression" model ("TAR") with rather abrupt regime-switching behaviour. In the intermediate case, in which the transition function is characterised by $0 < G(\gamma, c, s_t) < 1$, the model consists of a weighted average of the "low regime" and the "high regime".

It is obvious that, in this context, the three variables of the transition function are of key relevance to the overall approach. To begin with, the variable s_t represents the transition variable; the slope parameter γ measures the smoothness of transition between the regimes; and the location parameter c denotes the threshold parameter that measures the location of the transition function. More specifically, $\gamma = 1$ can be seen as implying a rather slow transition, whereas $\gamma = 10$ stands for a rather fast change. It is not uncommon in the literature to specify the transition function according to the following logistic form (i.e., "logistic STR" model" or "LSTR" model, see van Dijk et al. (2002) for a detailed discussion of the properties of various transition functions):

$$G(\gamma, c, s_t) = 1 + \exp\left\{-\gamma \Pi_{K=1}^{K}(s_t - c)\right\}^{-1} \text{ with } \gamma > 0 \tag{9}$$

This specific form of transition function is characterised by a monotonic increase in s_t, whereby the slope parameter γ mirrors how rapid the transition from zero to unity materialises (as a function of s_t), while the location parameter c indicates where exactly the transition occurs. More precisely, the threshold value c determines the point at which the regimes are equally weighted. Empirical evidence seems to show that the modelling of the two regimes in terms of a logistic function appears to be particularly suitable in the case of small and large values of the transition variable s_t relative to c (see van Dijk et al. (2002, p. 3 ff) for these considerations).

Besides the logistic variant, the transition function is also often modelled in terms of a so-called "normal" transition function, as follows:

$$G(\gamma, c, s_t) = \int_{-\infty}^{\gamma(s-c)} \frac{1}{\sqrt{2\pi}} \exp\left(\frac{x^2}{2}\right) dx = \Phi(\gamma(s-c)) \tag{10}$$

Both functions are monotonically increasing in s_t, thus allowing for the interpretation of the two regimes as corresponding to high and low values of the threshold variable. It is worth mentioning at this point that another popular transition function in the literature consists of the so-called "exponential" transition function (hence the name "exponential STR model"), which can be characterised by an increase in s in absolute deviations from the threshold value c. However, we will not make further use of this variant in this study.

The null hypothesis of linearity corresponds to a parameter constellation of $\gamma = 0$ in the Equations (9) and (10). The latter condition, however, points to an identification problem as the model is identified under the alternative hypothesis but not under the null hypothesis. In order to overcome this problem, Luukkonen et al. (1988) have suggested replacing the transition function with a suitable Taylor series approximation and testing the null of all slope parameters equalling zero at the same time by means of a conventional

F-Test, whereby a rejection of the null hypothesis should be interpreted as evidence of non-linearity (see Luukkonen et al. (1988) and Granger and Teräsvirta (1993), especially the deliberations outlined in Chapter 7).

Taken together, STR models allow for a change in regime in the form of a continuous process that depends on a transition variable. Perhaps even more importantly, the regime-switching behaviour can also be evaluated in two important cases. Namely, first, when the exact timing of the regime change is not known with certainty, and second, when only a short transition period to a new regime exists. As a consequence, STR models prove to be of relevance even during a possible transition period.

The aforementioned properties render STR models as particularly useful tools in many economic fields, especially when it comes to the modelling of institutional structural breaks or asymmetries in the dynamics between variables. Popular examples include, for instance, asymmetries in the behaviour of wages and prices. For instance, Nickel et al. (2019) find that the weakness in wage growth can be mostly explained by cyclical drivers (captured by standard Phillips curve specifications), but also other factors (for instance, compositional effects, possible non-linear reactions of wage growth to cyclical improvements, and structural and institutional factors seem to play a role). Furthermore, Passamani et al. (2022) propose a newly specified Phillips curve model, in which expected inflation, instead of being treated as an exogenous explanatory variable of actual inflation, is endogenized. By contrast, Christopoulos et al. (2019) focus on the possible role of output and unemployment (as described in Okun's Law) in Phillips curves. A more recent study by Reichold et al. (2022) finds evidence for nonlinearities and instabilities of the euro area as well as for 15 member states (i.e., all member states excluding Estonia, Ireland, Malta, Portugal and Croatia). Zeileis et al. (2003) investigates possible nonlinearities in the context of exchange rates and oil prices, whereas Wang et al. (2019) focus on an application to exchange rates and other financial market prices.

It is worth mentioning, however, that the procedures described above rely on one crucial assumption, namely that the exogeneity of the independent variables is imposed. This represents a rather strong assumption as standard macroeconomic models generally postulate inflation and output growth to be endogenously, if not simultaneously, determined. In the latter case, a single equation framework could prove inappropriate and it could be advisable to apply a multivariate, endogenous (VAR-type) model, and to test for asymmetries and threshold effects within that framework (see Sims 1980). Promising steps in this direction are available (see, for instance, Hubrich and Teräsvirta 2013; Luetkepohl and Netsunajev 2017), but, at the current juncture, the issue of robustness seems to be a topic of ongoing research (see Li et al. 2020).

4. Data and Empirical Results

Figure 1 illustrates the time series behaviour of inflation (measured in terms of annual percentage changes in the Harmonised Index of Consumer Prices for the euro area, HICP henceforth) and real GDP growth for the euro area since the beginning of the 1980s (quarterly data, see for instance Gerdesmeier et al. 2012 (Annex 1) for details on the construction of the variables). All euro area data are taken from the ECB's Statistical Data Warehouse and refer to the 19 member states in 2022 (the nineteen member states being (in alphabetical order) Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Portugal, Slovakia, Slovenia, and Spain).

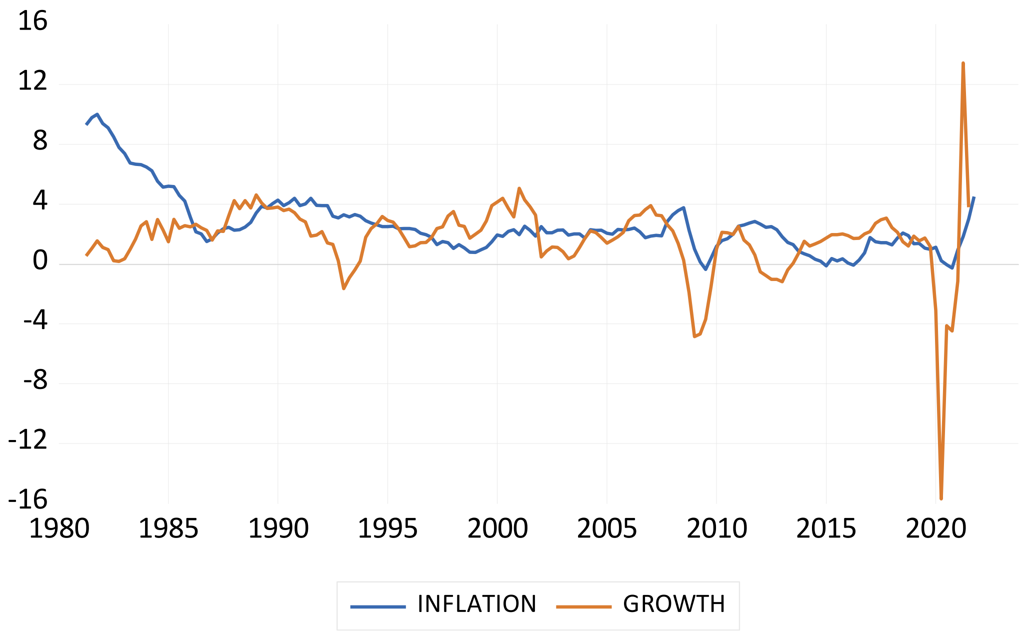

Figure 1. Euro area inflation and real GDP growth in a time perspective. Note: Annual percentage changes, and the last data points for growth are provisional figures.

While visual inspection reveals generally rather smooth behaviour of both series for most of the time, evidence for two considerable swings (in 2009 and, perhaps even more obviously, in 2020) can be detected. A deeper look into some descriptive statistical measures illustrates that euro area inflation has a mean value of 2.74% over the sample under consideration, which has a standard deviation of 2.16%. In addition, it is skewed to the upside with heavier tails as compared to the normal distribution.

By contrast, euro area GDP growth has a mean of 1.74% with a standard deviation of 2.42%. Moreover, it is heavily skewed to the downside and follows a leptokurtic distribution when compared to the normal distribution (see Table 2).

Table 2. Some descriptive statistics for inflation and growth.

Variable	Inflation	Real GDP Growth
Mean	2.74	1.74
Median	2.25	1.96
Maximum	10.00	13.44
Minimum	−0.37	−15.71
Std. Dev.	2.16	2.42
Skewness	1.57	−2.08
Kurtosis	5.40	21.30

Note: Figures rounded.

In the context of this study, we proceed by outlining various alternative specifications that have been used in the literature in order to describe the aforementioned relationship between output growth and inflation. Among the many alternatives, five look particularly promising in our view:

$$\Delta y = \alpha_t + \beta_t \cdot \pi + \varepsilon \tag{11}$$

$$\Delta y = \alpha_t + \beta_t \cdot \pi + \delta_1 \cdot \Delta e + \varepsilon \tag{12}$$

$$\Delta y = \alpha_t + \beta_t \cdot \pi + \gamma_1 \cdot \Delta oil + \varepsilon \tag{13}$$

$$\Delta y = \alpha_t + \beta_t \cdot \pi + \gamma_2 \cdot \Delta real(m1)_{t-i} + \varepsilon \tag{14}$$

$$\Delta y = \alpha_t + \beta_t \cdot \pi + \gamma_3 \cdot (spread)_{t-i} + \varepsilon \tag{15}$$

where y and π denote euro area real GDP and the euro area HICP inflation rate; e and oil stand for the euro area real effective exchange rate and oil prices (Brent crude oil in USD). Moreover, real M1 and its spread denote the annual changes in the real euro area M1 (nominal M1 deflated by HICP inflation), while the spread is measured as the difference between the long-term (ten-year government bond yield) and the short-term (three-month EURIBOR) nominal interest rates (see, for instance, Brand et al. (2003), who suggest the latter two variables and the respective lag structure). Furthermore, in line with large parts of the empirical literature, small letters denote logarithms.

We start by applying the Bai and Perron procedure to the equations mentioned above. This yields the results that are shown in Table 3.

Table 3. Results of Bai and Perron Test Procedure.

	α	β	δ	γ_i	**Threshold**	**Wald-Test**
Equation (11)						
Regime 1	−1.47 (0.01)	2.62 (0.00)	(-)	(-)		
Regime 2	2.18 (0.00)	−0.04 (0.67)	(-)	(-)	1.91	33.8 (0.00)
Equation (12)						
Regime 1	−1.49 (0.01)	2.44 (0.00)	−0.10 (0.08)	(-)		
Regime 2	0.83 (0.31)	0.38 (0.16)	−0.01 (0.87)	(-)	1.99	2.93 (0.09)
Equation (13)						
Regime 1	1.49 (0.09)	0.09 (0.94)		0.08 (0.00)		
Regime 2	2.30 (0.00)	−0.10 (0.22)		0.02 (0.01)	1.03	3.39 (0.07)
Equation (14)						
Regime 1	−4.26 (0.00)	2.42 (0.00)		0.45 (0.00)		
Regime 2	0.21 (0.55)	0.23 (0.08)		0.29 (0.00)	1.91	8.25 (0.00)
Equation (15)						
Regime 1	−3.33 (0.00)	1.85 (0.03)		1.78 (0.00)		
Regime 2	2.70 (0.00)	−0.12 (0.22)		−0.16 (0.35)	1.27	0.80 (0.37)

Note: The Wald-test refers to the test for equality of the slope parameters, p-values in brackets.

Surprisingly enough, we find evidence for two regimes in many equations, with the first one showing a positive effect of inflation on growth, whereas the effect becomes insignificant in the second regime. It is interesting to note, however, that in many cases the break in the regime is found to be slightly below the 2% inflation rate and, thus, fully in line with the "close but below two percent" postulated and advocated by the ECB decades ago (see ECB 1998, 2003, 2021). This notwithstanding, it should be noted that the evidence for a break is not statistically significant for Equations (12), (13), and (15) and, thus, the result is not very convincing.

As a consequence, as a next step, we proceed by specifying an alternative modelling approach, a so-called "smooth transition regression", and by taking a closer look into the linearity assumption. This can be done along the lines of the proposal by Luukkonen et al. (1988), which, in addition to estimating the linear regression models (11)–(15), also tests whether non-linear combinations of the fitted values of the right-hand variables help to explain the dependent variable (while Luukkonen originally suggested to make use of the χ^2 distribution, others have proposed to rather use an *F*-test, given its superior properties in small sample simulations (see, for instance, Teräsvirta 1994b). The general intuition behind the test consists of the notion that if non-linear combinations of the explanatory variables have any power in explaining the dependent variable, then the original model can be regarded as being misspecified in the sense that the data-generating process might be better approximated with a polynomial or another non-linear functional form. Table 4 below provides a summary of the results of the analysis.

Table 4. Results of Linearity Tests.

Equation	F-Statistic	LR-Ratio
(11)	12.94 (0.00)	24.61 (0.00)
(12)	4.85 (0.01)	9.73 (0.01)
(13)	0.19 (0.82)	0.40 (0.82)
(14)	9.73 (0.00)	18.93 (0.00)
(15)	28.07 (0.00)	49.69 (0.00)

Note: *p*-values in brackets.

It seems as if, with the exception of Equation (13) (i.e., the specification that includes the change in oil prices as additional variable), the (null) hypothesis of a linear specification can be rejected. In this context, it can be suspected that the results of Equation (13) can, at least partly, be attributed to the strong role of oil prices in euro area inflation.

We then proceed by specifying the so-called "smooth transition regression" (STR, henceforth) by estimating the coefficients of the aforementioned specifications using non-linear least squares. The estimation yields the results shown in Table 5a.

In referring to the empirical estimates of the STR model, we firstly note that, in the non-linear part, the inflation coefficient often changes sign from the positive into the negative territory (albeit not always significantly). Second, in case of the additional specification based on real M1 as the explanatory variable, the slope proves insignificant. Third, and perhaps more importantly, the inflation thresholds vary between 1.20% and 2.00% with a corresponding smoothing parameter varying between 0.93% and 2.17%, thus indicating that the transition between the lower and upper regime is relatively slow and only in one specification is more rapid. We also note that the thresholds prove in most cases to be very close to the ECB's definition of price stability of "below 2%" (announced in 1998), of "below, but close to 2%" (announced in 2003), and to the inflation target of 2% (announced in 2021). Seen from that perspective, the choice of the ECB seems to be fully justified on empirical grounds.

As a robustness check, we re-ran the estimations using the normal transition function, which yielded the results shown in Table 5b.

Table 5. (**a**) Results of Smooth Transition Regression Estimations (logistic transition function). (**b**) Results of Smooth Transition Regression Estimations (normal transition function).

(a)					
Equation	**(11)**	**(12)**	**(13)**	**(14)**	**(15)**
Linear part	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
α	−0.81 (0.16)	−3.77 (0.00)	−0.66 (0.19)	−3.19 (0.00)	−1.21 (0.04)
β	0.31 (0.02)	2.44 (0.00)	0.27 (0.02)	0.65 (0.00)	0.36 (0.00)
Non-linear part	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
α	4.87 (0.00)	5.65 (0.00)	4.82 (0.00)	4.57 (0.00)	4.76 (0.00)
β	−0.47 (0.07)	−2.25 (0.00)	−0.65 (0.01)	−0.43 (0.21)	−0.46 (0.06)
Non-threshold	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
δ		−0.01 (0.98)			
γ_1	(-)	(-)	0.03 (0.00)		
γ_2				0.33 (0.00)	
γ_3					0.28 (0.08)
Slope	0.93 (0.04)	1.08 (0.87)	2.17 (0.03)	1.37 (0.06)	1.75 (0.05)
Threshold	2.00 (0.00)	1.20 (0.00)	1.86 (0.00)	1.94 (0.00)	1.99 (0.00)
(b)					
Linear part	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
α	−0.81 (0.16)	(n.a.)	−0.61 (0.22)	−3.13 (0.00)	−1.17 (0.05)
β	0.31 (0.02)	(n.a.)	0.26 (0.02)	0.64 (0.00)	0.36 (0.00)
Non-linear part	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
α	4.87 (0.00)	(n.a.)	4.70 (0.00)	4.45 (0.00)	4.79 (0.00)
β	−0.47 (0.07)	(n.a.)	−0.63 (0.00)	−0.41 (0.21)	−0.47 (0.06)
Non-threshold	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
δ					
γ_1	(-)	(n.a.)	0.03 (0.00)		
γ_2				0.33 (0.00)	
γ_3					0.28 (0.08)
Slope	0.93 (0.04)	(n.a.)	1.38 (0.02)	0.86 (0.04)	1.02 (0.03)
Threshold	2.01 (0.00)	(n.a.)	1.87 (0.00)	1.95 (0.00)	2.04 (0.00)

Note: *p*-values in brackets, in case of (n.a.), the model did not converge.

In general, the results confirm the ones documented in previous paragraphs. More particularly, they show that while the smoothing parameters prove in all cases to be slightly smaller, hence indicating a slower and less abrupt transition between the regimes, the inflation thresholds continue to vary between 1.87% and 2.04%. Compared to the values in Table 1, the threshold is relatively low. Seen from this perspective, the range of threshold values proves smaller. This notwithstanding, inflation rates higher than the threshold tend to lower real GDP growth.

5. Conclusions

This paper focuses on the functional relationship between inflation and output growth for the euro area. The empirical approach is based on non-linear modelling approaches, which—based on the empirical evidence provided by some simple tests—seem to confirm the view that non-linear relationships are at work.

The study approaches the issue of (possible) non-linearities by use of two alternative modelling approaches, namely by applying the so-called "threshold regressions" and by estimating the so-called "smooth transition regressions". In contrast to the former discrete switching models that, in essence, test for the reliability of a previously detected relationship over different regimes, smooth transition regression (STR) models allow for changes in the dependent variable in the form of a continuous process dependent on the transition variable. This allows for incorporating regime-switching behaviour in real time, i.e., even during a possible transition period.

The empirical results show that, for most specifications, the existence of two regimes can be confirmed and that the estimated threshold values are very close to the ECB's inflation target of 2%. Inflation rates above the threshold value turn out to negatively affect real GDP growth in the euro area. The results can thus be interpreted as fully supporting the recent decisions taken by ECB's decision-makers to bring inflation down to the ECB's inflation target of 2%.

The caveats of this study mainly lie in its use of a single-equation approach. In further work we aim to apply multivariate approaches in order to take account of possible endogeneities. Moreover, it could be considered to better distinguish between inflation events caused by negative supply shocks and events stemming from the demand side.

Author Contributions: Conceptualization, D.G., B.R. and H.-E.R. Methodology, D.G., Validation, D.G., B.R. and H.-E.R. Writing, D.G. and B.R. Writing—Review & Editing, D.G., B.R. and H.-E.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Informed Consent Statement: All authors have consented to publish this manuscript.

Data Availability Statement: All data are available in the Statistical Data Warehouse of the European Central Bank.

Conflicts of Interest: No potential conflicts of interest were reported by the authors.

Notes

1 It is fair to say that part of the debate centres on the "optimal level of inflation". We refrain from any attempt to summarise this debate in this paper.

2 It is worth mentioning already at this stage that a number of studies have attempted to investigate the same question by focusing on the welfare costs of inflation. For a recent study see, for instance, Andrade et al. (2019). See also ECB (2021) for a comprehensive summary of the considerations underlying the last ECB's monetary policy strategy review.

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