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

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Abstract[1]

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 exaggerated 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 know more about the nature and form of the relationship between inflation and real GDP.

This study tries to shed more light on the concrete 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, the methods used allow for a quantification of the point of switch across the different regimes and 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 warranted.

1 First and third author: European Central Bank - The paper does not necessarily reflect the views of either the European Central Bank or of the Frankfurt School of Finance.

1. Introduction and Literature Review

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, being equivalent to a decline in the purchasing power of money, can be expected to reduce consumption, investment, the balance of payments and, thereby, also GDP growth. Taken together, it appears that GDP growth is negatively related to inflation.

This notwithstanding, the literature lists a variety of possible channels being at work and it is virtually impossible to summarise and to do justice to all of them.[2] As a consequence, we will restrict ourselves to a few selected papers that illustrate the main channels.[3]

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 and investment and, ultimately, spurring growth.[4] For instance, the Nobel prize winner James Tobin 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”.[5]

Later on, in his Nobel prize speech, Tobin argued further that a positive rate of inflation might, in light of the downward rigidity of wages, help to lower real wages and, thus, to 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".[6]

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.[7] 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

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2 It is fair to say that part of the debate centers on the “optimal level of inflation”. We refrain from any attempt to summarise this debate in this paper.

3 See Dholakia et al. (2021, p. 7) for a more detailed overview.

4 See, e.g., Mundell (1963, for instance p. 283).

5 See Tobin (1965, esp. p. 678). The Tobin effect could in essence be derived from a simple extension of Solow’s neoclassical growth model. Without going too far at this stage, it is worth mentioning that Tobin’s view was later challenged by Sidrausky (1967).

6 See Tobin (1972).

7 See Akerlof et al. (1996, esp. p. 20 ff and also the simulation results on p. 33 ff).

for investment, thereby lowering growth.[8] 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.[9]

Turning to the respective effects on consumption, several authors have supported the view that higher inflation necessarily lowers real balances and, therefore, also consumption expenditures and, ultimately, growth.[10]

Moreover, from the perspective of behavioural economics, it seems to be 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 becomes too high).[11]

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 the effective cost of capital as the main determinant of investment, thus hindering growth.[12] Finally, an additional role for relative prices has been advocated by arguing that inflation raises inflation uncertainty, increases risk premia and interest rates and via changes in relative prices lowers expected returns and, thereby, also growth.[13]

There are, however, also channels that seem to postulate 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, taken *per se*, would speak in favour of higher growth.[14] 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.[15]

More recently, the topic has clearly regained considerable popularity from a different perspective. In a widely cited paper, Blanchard et al. (2010) argue for increase of the inflation target from 2% to more than 3%, the main argument consisting of the empirical observation that low Inflation accompanying

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8 See Haslag (1995, 1997) or this reasoning.

9 See, for instance, Able (1980).

10 See Stockman (1981, p. 391).

11 See Akerlof et al. (2000, esp. p. 3). This is due to the fact that, for higher levels, the costs of ignoring inflation become too high.

12 See Friedman 1977, p. 279 ff).

13 See Dholakia (2020).

14 It is impossible to do justice to the extensive literature on Phillips Curves in this short study. To name just a few recent studies, tackling the issue of an (apparent) instability in such relationships, see Reichold et al. (2022), Passamani et al. (2022) and Nickel et al. (2019).

15 It is, however, fair to say that the literature is borderless and, as a consequence, it is impossible to do justice to all studies in this brief study.

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 bound prevents central banks from doing so.

As argued by the authors, one possible corollary of such a constellation lies in the need for more reliance on fiscal policy and, related to this, for larger deficits than would have been the case in the absence of the binding zero interest rate constraint. Another recipy, 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 to cut interest rates more. [16]

In a later study, Ball (2014) supports the notion that, against the background of the zero bound of 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 being 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.[17]

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 the medium and long-term growth (see Fischer, 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 at a low rate of inflation. However, it does not help in answering the question of how low the inflation target should be. Should the target inflation be 7%, 5%, or rather 0%?[18] Moreover, it does not help in answering another key question - can the negative relationship between inflation and real growth be described in terms of a purely monotonic function? Or is it rather 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), whereas at higher rates it will move into negative territory?

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

[16] See Blanchard (2010, p. 11).

[17] See Ball (2014).

[18] 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 an comprehensive summary of the considerations underlying the last ECB's monetary policy strategy review.

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 – do further damage to growth.

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 about some of these studies, their concrete set-up and the main results.

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

Table 1: Overview on selected studies quantifying threshold levels

Authors	Period	Sample	Threshold value
Sarel (1996)	1970-1990	90m countries	8%
Khan and Sehadji (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%
Akguel and Oezdemir (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-industrialied countries
Omay and Kan (2010)	1972-2005	6 developed countries	2.52%
Nasir and Saima (2010)	1961-2008	Pakistan	Two thresholds (6% and 11%)

Vinayaga-thasan (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 (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.

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 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 at investigating 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, 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 on 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 of 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 which 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.[19]

As regards the euro area, there are only a few studies investigating the issue explicitly for it, 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.[20]

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 being above as well below the "threshold" level, but the effect above the "threshold" is almost three times as large.[21]

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19 See Dholakia (2021, p. 22).

20 See Baghli et al. (2006) for details.

21 See Tsionas and Christopoulos (2003) for details.

2. Methodology

The issue of (possible) regime shifts has a long tradition in empirical macro-economics 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.[22] 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 concrete methodology of a threshold regression can be described by the following equations:[23]

(2.1) $$y_i = \theta_1^{'} x_i + \varepsilon_i \quad \text{if} \quad q_t \leq \gamma$$

(2.2) $$y_i = \theta_2^{'} x_i + \varepsilon_i \quad \text{if} \quad q_t > \gamma$$

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 in two groups. The random variable ε_t represents a regression error.[24]

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

(2.3) $$d_i(\gamma) = I(q_i \leq \gamma)$$

where $I(.)$ represents the indicator function. When setting $x_i(\gamma) = x_i d_i(\gamma)$, equations (2.1) and (2.2) can be rearranged to take the following form:

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22 See Granger (2001) for an overview.

23 We deliberately follow closely the discussion in Hansen (2000), pp. 576 *ff.*

24 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).

(2.4) $y_i = \theta' x_i + \delta'_n x_i(\gamma) + \varepsilon_i$

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 $t = 1,....i$.

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.[25] 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:

(2.5) H_0: $m = l$

H_A: $m = l + 1$

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 concrete 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.[26]

More concretely, 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

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25 See Hansen (2000) for details.

26 See, for instance, Zeileis et al. (2003, esp. p. 110 *ff*), who apply this methodology to oil prices (among other variables).

alternative hypothesis does a statistically significant 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:

$$(2.6)\quad F_T(l+1|l)=\frac{\left\{S_T(\hat{T}_1,\hat{T}_2,....,\hat{T}_l)-\min_{1<i<l}\inf_{\tau\in i\eta} S_T(\hat{T}_1,\hat{T}_2,....,\hat{T}_{l-1},\tau,\hat{T}_{i-1},\hat{T}_{i+1},....,\hat{T}_l\right\}}{\hat{\sigma}^2}$$

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

$$(2.7)\qquad \Lambda_{i\eta}=\left\{\tau;T_{i-1}+(T_i-T_{i-1})\eta\leq\tau\leq T_i+(T_i-T_{i-1})\eta\right\}$$

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:[27]

$$(2.8)\qquad y_t=\psi' z_t+\phi' z_t G(\gamma,c,s_t)+\mu_t$$

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.

27 See Teräsvirta (1994a) for details.

More concretely, the two extreme cases are mirrored in the expression $G(\gamma, c, s_t) = 0$, in which case the original equation exactly collapses to the linear case, and $G(\gamma, c, s_t) = 1$, which renders the original equation into a fully-fledged two-regime "Threshold Autoregression" model ("TAR") with a rather abrupt regime-switching behaviour. In case the transition function is characterised by $0 < G(\gamma, c, s_t) < 1$, the model in essence 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 for the overall approach. To begin with, the variable s_t represents the transition variable, whereas 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.[28] 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):[29]

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

This specific form of a 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.[30] Empirical evidence seems to show that the modelling of the two regimes in terms of a logistic function appears to be particularly suitable in case of small and large values of the transition variable s_t (relative to c).[31]

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

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

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28 More concretely, a $\gamma = 1$ can be seen as implying a rather slow transition, whereas a $\gamma = 10$ stands for rather fast change.

29 See van Dijk, Teräsvirta and Franses (2002) for a detailed discussion of the properties of various transition functions.

30 More precisely, the threshold value c determines the point at which the regimes are equally weighted.

31 See van Dijk, Teräsvirta and Franses (2002, p. 3ff) for these considerations.

Both functions have the property in common that they 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. [32]

The null hypothesis of linearity corresponds to a parameter constellation of $\gamma = 0$ in the equations (2.9) and (2.10). 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 to replace the transition function by a suitable Taylor series approximation and to test the null of all slope parameters equalling to 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.[33]

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 even to be of relevance during a possible transition period.

The aforementioned properties render STR models 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[34], in output and unemployment (as described in Okun's Law[35]), in

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32 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 of s in absolute deviations from the threshold value c. However, we will not make further use of this variant in this study.

33 See Luukkonen et al. (1988) and Granger and Teräsvirta (1993), especially the deliberations outlined in chapter 7.

34 See, for instance, Nickel et al. (2019) who 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). See also Passamani et al. (2022), who 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.

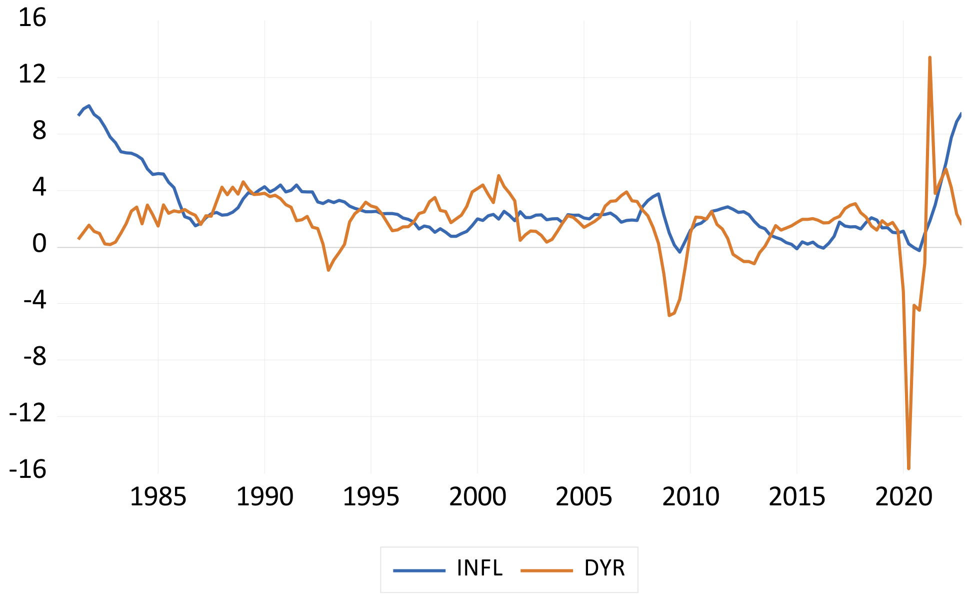
35 See, for instance, Christopoulos et al. (2019).

Phillips Curves[36], but also in exchange rates, oil prices[37] and other financial market prices.[38]

3. Data and Empirical Results

The chart below 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.[39] All euro area data are taken from the ECB's Statistical Data Warehouse and refer to the 19 member states.

Chart 1: Euro area inflation and real GDP growth in a time perspective



Note: annual percentage changes, the last data points for growth are provisional figures.

While visual inspection reveals a 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, with a standard deviation

36 See, for instance, the recent study by Reichold et al. (2022), who find evidence for nonlinearities and instabilities for the euro area as well as for 15 member states (i. e., all member states excluding Estonia, Ireland, Malta, Portugal and Croatia).

37 See, for instance, Zeileis et al. (2003).

38 See, for instance, Wang et al. (2019) for an application to exchange rates.

39 Quarterly data provided by the ECB database are used.

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 next proceed by spelling various alternative specifications that have been used in the literature in order to describe the aforementionend relationship between output growth and inflation. Among the many alternatives, five looks particularly promising in our view:

(2.11) $$\Delta y = \alpha_t + \beta_t \cdot \pi + \varepsilon$$

(2.12) $$\Delta y = \alpha_t + \beta_t \cdot \pi + \delta_1 \cdot \Delta e + \varepsilon$$

(2.13) $$\Delta y = \alpha_t + \beta_t \cdot \pi + \gamma_1 \cdot \Delta oil + \varepsilon$$

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

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

where y and π denote euro area real GDP and the euro area HICP inflation rate and e and oil stand for the euro area real effective exchange rate and oil prices (Brent crude oil in US-Dollar). Moreover, real M1 and the spread denote the annual changes in 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.[40] 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 which are shown in Table 3.

Table 3: Results of Bai and Perron Test Procedure

	α	**β**	**δ**	**γ_i**	**Threshold**	**Wald-test**
Eq. 2.11						
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)
Eq. 2.12						
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)
Eq. 2.13						
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)
Eq. 2.14						
Regime 1	-4.26 (0.00)	2.42 (0.00)		0.45 (0.00)		
Regiime 2	0.21 (0.55)	0.23 (0.08)		0.29 (0.00)	1.91	8.25 (0.00)
Eq. 2.15						
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.

[40] See Brand, Reimers and Seitz (2003) for the choice of the latter two variables and the respective lag structure.

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 that, however, 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.[41] This notwithstanding, it should be noted that the evidence for a break is not statistically significant for equations 2.12, 2.13 and 2.15 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 Lukkonen et al. (1988), which, in additon to estimating the linear regression models (2.11) to (2.15), also tests whether non-linear combinations of the fitted values of the right-hand variables help to explain the dependent variable.[42] 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 by 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
(2.11)	12.94 (0.00)	24.61 (0.00)
(2.12)	4.85 (0.01)	9.73 (0.01)
(2.13)	0.19 (0.82)	0.40 (0.82)
(2.14)	9.73 (0.00)	18.93 (0.00)
(2.15)	28.07 (0.00)	49.69 (0.00)

Note: p-values in brackets.[43]

It seems as if, with the exception of equation (2.13) (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

41 See ECB (1998, 2003, 2021).

42 A specific application of testing for non-linearities in the case of smooth transition regressions can be found in Luukkonen et al. (1988).

43 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)).

results of equation (2.13) can, at least partly, be attributed to the strong role of oil prices for the 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.

Table 5a: Results of Smooth Transition Regression Estimations

Equation	(2.11)	(2.12)	(2.13)	(2.14)	(2.15)
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)

Note: p-values in brackets.

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 being significant). Second, in case of the additional specification based on real M1 as 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-run the estimations using the normal transition function, which yields the results shown in Table 5b.

Table 5b: Results of Smooth Transition Regression Estimations

Equation	**(2.11)**	**(2.12)**	**(2.13)**	**(2.14)**	**(2.15)**
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 general, the results confirm the ones documented in the 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%. Seen from this perspective, the range of threshold values proves smaller. This notwithhanding, inflation rates higher than the threshold tend to lower real GDP growth.

4. 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 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.

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