Growth effects of inflation in Europe: How low is too low, how high is too high?*

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Abstract

This paper reassesses the impact of inflation on long-term growth for a panel of 14 EU countries. While previous research focuses on a linear nexus or allows for a piecewise linear relationship with one single threshold we take account of a more complex relationship. We use a theoretical framework that allows for an explicit distinction between level and growth effects of inflation. The empirical estimates confirm the theory-based hypothesis that the relationship between inflation and growth is positive for very low inflation rates (i.e. below an estimate of 1.6%), insignificant thereafter and negative for high, two-digit inflation levels. While the growth effect model explains the data marginally better then the level effect, non-nested model testing does not give evidence of the superiority of one of the two explanations of the nature of the inflation-growth link.

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1 Introduction

Today there seem to be some facts about inflation that most economists and politicians would accept without further arguing: (a) Very high inflation rates are bad for economic growth. (b) Deflation, defined as a continuous fall of the overall price level over a sustained period of time, can be harmful for the economy. (c) Between these two extreme cases there is something like an optimal level or an optimal range of inflation. (d) An independent central bank together with a clear mandate to maintain price stability is commonly accepted as best suited to keep inflation within this optimal range of inflation.

As a consequence almost all independent central banks pursue either direct inflation targeting or have an explicit definition of price stability as a central part of their monetary policy strategy. The mandate for European Central Bank for example is defined in Article 105(1) of the Treaty as: “The primary objective of the [Eurosystem] shall be to maintain price stability”. The ECB specified that “price stability shall be defined as a year-on-year increase in the HICP for the euro area of below 2%. Price stability is to be maintained over the medium term.” In its press statement of May 18, 2003 the ECB reformulated this definition in order to explicitly take account of the risks of deflation: “... aim to maintain inflation rates close to 2% over the medium term.”

Direct inflation targets or definitions of price stability vary in the targeted measure of inflation, in the time horizon to achieve the goal and in the explicit formulation of the target (point target or range of desired inflation, symmetric or asymmetric definition). Since 1992 the Bank of England pursues direct inflation targeting with a symmetric target of 2.5% for an underlying inflation rate excluding mortgage interest payments (RPIX). Sweden aims since 1993 at keeping consumer price inflation within a band of 1-3%. The Bank of Canada aims at keeping headline inflation at the 2% target, the midpoint of the 1% to 3% inflation-control target range. Similarly the Reserve Bank of New Zealand since 2002 defines price stability as annual increases in the CPI of between 1% and 3% on average over the medium term; prior to 2002, price stability was deemed to be 0% to 3%. Other examples can be easily found.

While the exact definition of price stability varies considerably from country to country, they all fit very well within the picture given by the inital four propositions: Central banks should aim at avoiding too high as well as too low inflation rates. The targeted inflation bands or point targets furthermore remain within a fairly narrow range between 1 and 3 percent. Obviously it is common understanding that keeping inflation within this range is best suited to avoid sustained periods of deflation as well as the emergence of excessive inflation rates.

The purpose of this paper is to reassess the impact of inflation on long-term growth putting special emphasis on the theoretical arguments that point at the growth harming effects of very high as well as very low (or negative) inflation rates. It is these kind of arguments that can be considered as the basis for any definition of an optimal range or level of inflation.

Obviously the rationale behind explicit inflation targets or definitions of price stability can be manifold, the growth aspect being only one of many possible objectives. The "Policy Targets Agreement 2002" of the Reserve Bank of New Zealand for example specifies: "The objective of the Government's economic policy is to promote sustainable and balanced economic development in order to create full employment, higher real incomes and a more equitable distribution of incomes. Price stability plays an important part in supporting the achievement of wider economic and social objectives." Assessing the validity of specific inflation targets purely on grounds of growth aspects is therefore certainly only a partial and oversimplistic approach. It is, however, a common characteristic of all central bank strategies that the most general objective is to support the creation of a favourable economic environment for which a sustainable path of high and sustainable growth is certainly a central precondition. We therefore believe that an empirical investigation of the inflation-growth nexus is of high importance for monetary policy even though the complexity of central bank strategies does not allow for explicit conclusions on the most appropriate numerical definition of price stability.

The existing empirical literature on the relationship between inflation and long-term growth is manifold and varies considerably with respect to the theoretical foundation or the econometric specification. Starting from simple linear models the focus shifted in recent years towards nonlinear specifications, acknowledging the more complex nature of the nexus. Section 2 provides an extensive overview on the theoretical arguments as well as the existing empirical literature. This paper reassesses the effects of inflation on growth in the light of possible non-linearities using data from fourteen European countries. As compared to the previous literature our study deviates in several substantial respects.

While most studies on the inflation-growth nexus base their estimation on ad hoc regressions, we explicitly make use of a fully specified theoretical framework. This approach responds to the common criticism vis-à-vis a somewhat arbitrary choice of explanatory factors for growth. It is especially relevant as Levine and Renelt (1992), Levine and Zervos (1993) and Sala-i-Martin (1997), for linear models, and Crespo Cuaresma (2002), for non-linear models, found the cross-section inflation-growth relationship to be exceptionally fragile. Basing our estimation on a theoretical framework therefore reduces the risk that the results reflect data-mining.

While earlier studies usually allow for a single breakpoint in the growth-inflation nexus this appears to us to be an oversimplification of the story. Based on the theoretical arguments summarized in Section 2 one could expect a parabolic or trapezoid shape of the curve: a positive link for deflation and very low levels of inflation, an insignificant relationship thereafter, followed by a negative impact of inflation on growth for excessively high inflation. In order to test for this hypothesis we will thus allow for more than one breakpoint in the relationship.

Usually studies abstract from the question, whether the impact of inflation on growth takes the form of a level or a growth effect. A negative growth effect implies that a permanently higher rate of inflation does also permanently dampen growth. A level effect, on the other hand, harms growth during a transition period while steady state growth is left unaffected. The implications in terms of interpretation are fundamentally different. We will therefore explicitly take this issue into account and test for the existence of level and growth effects on long-term growth.

The paper is organized as follows: Secion 2 provides an extensive overview on the theoretical arguments as well as the existing empirical literature on the inflation-growth relationship. Section 3 presents the theoretical framework. Section 4 reports about the empirical implementation of the model, starting with a linear framework and allowing then for non-linear effects of different form (quadratic specification and a spline model). Section 4.3 elaborates on the growth versus level effect issue in more detail. Section 5 concludes and give some policy implications. Details on the data can be found in the Annex.

2 The theory and empirics of the inflation-growth nexus

From the theoretical point of view one has to distinguish between the short run and the long run link between inflation and growth. In the short run faster economic growth may be associated with more rapid inflation when aggregate demand exceeds aggregate supply and output cannot fully adjust. In order to maintain price stability, central banks can then use monetary policy instruments to curb aggregate demand. Short-term inflation dynamics are therefore mostly associated with the demand side of the economy.

In the long-run, however, a significant influence of inflation on growth for high levels of inflation will most probably be related to supply side effects, more specifically to misallocations of resources that distort investment and consumption. Common arguments usually refer to either the average rate of inflation or to the variability and uncertainty of inflation: menu costs, search costs, transaction costs due to the declining information value of prices, the costs of economizing on holdings of non-interest-bearing money, the social costs of increased uncertainty, the vicious cycle of a wage-price spiral etc. Very high inflation rates tend to be also more volatile, making the real returns on investments harder to forecast with subsequent consequences for savings and investment decisions. With inflation increasing even further the widespread transition to indexation systems makes future disinflation more difficult. At some point, finally, money may lose its role as medium of exchange and store of value.[1]

While high inflation is obviously associated with considerable costs and risks, deflation can be at least as dangerous. The most common argument refers to inflation as the “grease of the economy”. Under wage and price rigidities only a certain level of inflation guarantees a smooth adjustment of relative prices. The other risk associated with sustained periods of deflation is known under “the zero lower bound constraint”: If deflation occurs while the economy is in a recession monetary authorities may find themselves in a situation where the key interest rates are (almost) zero while real interest rates are still positive. In such a situation the most powerful monetary policy instrument has lost its power. Finding the appropriate mix of the other available monetary and economic instruments is a tricky task, as the experience of Japan over the last decade showed.

To the extent that a very low inflation level is associated with an increased risk of subsequent

[1] For a literature survey see, e.g. Briault (1995).

deflationary periods one could therefore expect a positive relationship between inflation and growth also for positive, but small increases in the price level. But there are at least two more arguments pointing at a positive growth-inflation link for relatively low inflation levels. The Mundell-Tobin effect describes a situation when increases in inflation force agents to shift their portfolio allocation away from holdings of real balances and into capital investment, leading thereby to higher levels of economic activity. Stockmann (1981), on the other hand, advances models where money and capital are considered as complements.

Summarizing these theoretical arguments one could expect a positive impact of inflation on growth for lower levels of inflation, followed by a "grey area" with no significant effect whatsoever. For excessive inflation the effect can be expected to be significantly negative. A look at the empirical literature reveals that the evidence for these hypotheses has undergone several phases with significant changes.

During the 50s and 60s, when periods of excessive inflation where basically unknown within the group of industrialized countries, empirical tests on the growth hampering impact of inflation tended to fail to show any clear-cut effect. The relationship between long-term growth and inflation was found to be insignificant, in some cases even positive (see, e.g. Wai, 1959, Bhatia, 1960, or Dorrance, 1966). With the two first oil price shocks and the emergence of severe periods of high and persistent inflation rates in many countries the evidence shifted. The effect was now usually found to be significantly negative, although highly dependent on the inclusion of post-1970 and therefore high inflation observations.[2]

It was only in the second half of the 90s that the focus increasingly shifted to the issue of possible non-linearities in the growth-inflation nexus. Acknowledging the existence of a structural break in the relationship could explain the lack of evidence for a significant negative effect in earlier decades due to the lack of episodes with high inflation. Disregarding this break furthermore implies an underestimation of the growth hampering effect of very high inflation levels. An estimated breakpoint in the growth-inflation nexus finally suggests a specific policy advice, namely to keep inflation below the level where the breakpoint takes place. Or, stated the other way round: Every explicit inflation target implicitly assumes a nonlinear relation between inflation and the economic performance.

Summarizing the recent literature reveals two major findings: (a) The non-linearities in the effect of inflation on long-term growth are now widely acknowledged. (b) The estimates of the optimal level of inflation vary considerably between studies. To illustrate this last point consider the following literature overview (in chronological order): Sarel (1996), using a panel of 87 countries for the period 1970-90, finds that inflation rates below 8% do not have any or even a slightly positive effect on growth; above 8% the effect is found to be negative, significant and robust. Gosh and Phillips (1998), using a longer data sample and more countries, find a substantially lower threshold at 2.5%. Bruno and Easterly (1998) find a negative relationship between inflation and growth only for high-frequency data and only

[2] For a detailed study on this relationship see, e.g. Fischer (1993) or Barro (1995); for a model based estimation see Motley (1998); for more recent evidence on European countries see, e.g. Crespo Cuaresma et al. (2003). Temple (2000) offers an excellent critical survey on the empirical literature on the inflation-growth link.

for inflation rates above 40%, their lower bound definition of an inflation crisis. Christoffersen and Doyle (1998) estimate for a set of transition economies a threshold level of 13%.

With the development of more sophisticated econometric techniques, the breakpoints, in earlier studies fixed more or less on an ad hoc basis, can now explicitly be estimated. Khan and Senhadji (2001) use a panel of 140 countries and 39 years of data. Applying the threshold panel data estimation technique (based on the methodology developed by Hansen, 1999) they estimate the threshold level beyond which the negative impact of inflation on growth is significant at 1-3% for industrial countries and at 11-12% for developing countries. Below the thresholds the relationship is positive and only significant for the industrial countries. The higher estimates for developing countries are partially explained by the widespread use of indexation systems that reduce the adverse effects of inflation. Using a smooth transition model for a set of 15 EU countries Tsionas and Christopoulos (2003) find a negative relation between inflation and growth below and above an estimated threshold of 4.3%; the effect is, however, three times as large in the higher inflation regime.

Summarizing this evidence it seems to be a common finding that a robust negative impact of inflation on growth can only be found for inflation levels that significantly exceed the most common definitions of price stability, as formalized in monetary policy strategies worldwide. For very low levels of inflation or even deflation most studies fail to show any significant impact. This could be interpreted as evidence for a very wide range of inflation rates that are compatible with sustained growth prospects. It could, however, also be seen simply as being due to the fact that a sufficient amount of low inflation data is not available. Fischer et al. (2002) for example comment: "We find it quite plausible to believe that deflation is bad for growth, and thus would not be surprised if further research showed that inflation and growth are positively related for extremely low and negative inflation rates, for example up to 2 percent per annum." A more sophisticated model setting in combination with new econometric techniques may, however, allow to reconsider this issue.

3 The theoretical framework

This section presents a human capital-augmented Solow model (Solow, 1956) where inflation is assumed to have an effect on the level of productivity of the economy. In spite of its simplicity, the power of the Solow model in explaining the post-war growth experience in both developed and developing countries is widely documented in the literature dealing with the empirics of economic growth (see Mankiw et al, 1992, for instance).

We will consider a simple human capital-augmented Solow model with a production function as in Hall and Jones (1999). The production function is given by

$$Y(t) = K(t)^{\alpha} \left[A(t)H(t)\right]^{1-\alpha},$$

where $K(t)$ is the stock of physical capital, $H(t)$ denotes the human capital-augmented labour force and $A(t)$ is a measure of labour-augmenting productivity. The measure of human capital augmented labour is given by

$$H(t) = G(E(t))L(t),$$

where $G(E(t))$ is a function mapping years of education ($E(t)$) to human capital stock per worker. Following Hall and Jones (1999), let $G(E(t))$ be given by[3]

$$G(E(t)) = \exp\left[\rho E(t)\right],$$

for $\rho > 0$. Consider a specification of $A(t)$, where inflation may affect the level and the growth rate of productivity,

$$A(t,\pi(t)) = A(0)\exp\left\{\Psi(\pi(t)) + [g + \Theta(\pi(t))]t\right\}, \tag{1}$$

where $g > 0$ is a the growth of technology at zero inflation and $\Psi(\cdot)$ and $\Theta(\cdot)$ are arbitrary bounded functions. This specification nests those of Cozier and Selody (1994) (corresponding to $\Psi(\pi(t), \sigma_\pi(t)) = \mu_1\pi(t) + \mu_2\sigma_\pi(t)$, where $\sigma_\pi(t)$ is the volatility of inflation, and $\Theta(\pi(t)) = 0$), Motley (1998) (for $\Theta(\pi(t)) = \phi\pi(t)$ and $\Psi(\pi(t)) = 0$) and Andrés and Hernando (1997) (using both secifications above).

Assume as in the usual textbook Solow model that the dynamics of physical capital are given by

$$\dot{K}(t) = sY(t) - \delta K(t),$$

where $s \in (0,1)$ is the (constant) fraction of output devoted to investment and δ is the depreciation rate of physical capital. The equilibrium level of physical capital per unit of effective labour ($k(t) = K(t)/(A(t)H(t))$) for the model described above is given by

$$k^* = \left(\frac{s}{n + \dot{A}(t,\pi(t))/A(t,\pi(t)) + \delta}\right)^{1/(1-\alpha)}.$$

A fixed long-run level of inflation π^* will be assumed, so that the equilibrium can be written as

$$k^* = \left(\frac{s}{n + g + \Theta(\pi^*) + \delta}\right)^{1/(1-\alpha)}.$$

The adjustment to equilibrium for $y(t)$ (=$Y(t)/(A(t)H(t))$) is given by (see, e.g., Mankiw, Romer and Weil (1992))

$$d[\ln(y(t))]/dt = \lambda[\ln(y^*) - \ln(y(t))],$$

for $y^* = f(k^*) = (k^*)^\alpha$. The parameter λ captures the speed of convergence to the steady state. Consider the dynamic process for output per unit of effective labour from period t to period $t + \tau$,

$$\begin{aligned}\ln(y(t+\tau)) - \ln(y(t)) \;&=\; \left(1 - e^{-\lambda\tau}\right)\frac{\alpha}{1-\alpha}\ln(s) - \left(1 - e^{-\lambda\tau}\right)\frac{\alpha}{1-\alpha}\ln(n + g + \Theta(\pi^*) + \delta) \\ &\quad - \left(1 - e^{-\lambda\tau}\right)\ln(y(t)),\end{aligned}$$

[3] Based on empirical evidence on estimates of returns to schooling, Hall and Jones (1999) actually assume the exponent in $G(E(t))$ to be a piecewise linear function, with a kink located at $E(t) = 4$. Given that the education levels in our sample lie well above that value, we use a linear function for the exponent in $G(E(t))$.

which can be written in terms of growth of income per capita as[4]

$$\ln\left(\frac{Y(t+\tau)}{L(t+\tau)}\right)-\ln\left(\frac{Y(t)}{L(t)}\right)=\Psi(\pi(t+\tau))-e^{-\lambda\tau}\Psi(\pi(t))+[g+\Theta(\pi(t+\tau))](t+\tau)- \quad (2)$$
$$-e^{-\lambda\tau}[g+\Theta(\pi(t))]t+\rho E(t+\tau)-\rho e^{-\lambda\tau}E(t)+\left(1-e^{-\lambda\tau}\right)\frac{\alpha}{1-\alpha}\ln(s)-$$
$$-\left(1-e^{-\lambda\tau}\right)\frac{\alpha}{1-\alpha}\ln(n+g+\Theta(\pi^*)+\delta)-\left(1-e^{-\lambda\tau}\right)\ln\left(\frac{Y(t)}{L(t)}\right)+\left(1-e^{-\lambda\tau}\right)\ln(A(0)).$$

We will proceed by estimating (2) under the assumption of a growth effect of inflation (and no level effect, that is, $\Psi(\cdot)=0$), a level effect (and no growth effect, that is $\Theta(\cdot)=0$) or assuming that inflation can cause both types of effect.

4 Inflation and growth in Europe: An empirical analysis

4.1 First results: A linear growth-inflation link?

In this section we will proceed by estimating several versions of (2) under different assumptions concerning the functional form of the growth and level effect of inflation. All estimations are done for a panel comprising all current EU member countries except for Luxembourg. The data sources are presented in the appendix. We used data spanning the period 1960–1999, divided into subperiods of seven years. The growth variable on the left hand side of (2) is thus the growth rate of income per capita in the corresponding seven years. A relatively low variability is observed for the variable that proxies education attainment (average years of education for an adult over 25 years old) within the countries in our sample. In order to avoid multicollinearity we assume that the changes in $E(t)$ happen in a stepwise fashion, so that within a period $E(t+\tau)=E(t)$. For the empirical implementation of the model, the value will be set equal to the average educational attainment in the period.[5] The general specification which is estimated for different assumptions on the nature of $\Psi(\cdot)$ and $\Theta(\cdot)$ is

$$\ln\left(\frac{Y_{i,t+\tau}}{L_{i,t+\tau}}\right)-\ln\left(\frac{Y_{i,t}}{L_{i,t}}\right)=\Psi(\pi_{i,t+\tau})-e^{-\lambda\tau}\Psi(\pi_{i,t})+[g+\Theta(\pi_{i,t+\tau})](t+\tau)-$$
$$-e^{-\lambda\tau}[g+\Theta(\pi_{i,t})]t+\rho(1-e^{-\lambda\tau})\bar{E}_{i,t+\tau}+\left(1-e^{-\lambda\tau}\right)\frac{\alpha}{1-\alpha}\ln(\bar{s}_{i,t+\tau})- \quad (3)$$
$$-\left(1-e^{-\lambda\tau}\right)\frac{\alpha}{1-\alpha}\ln(\bar{n}_{i,t+\tau}+g+\Theta(\pi^*_{i,t+\tau})+\delta)-\left(1-e^{-\lambda\tau}\right)\ln\left(\frac{Y_{i,t}}{L_{i,t}}\right)+\varepsilon_{i,t},$$

where $\bar{E}_{i,t+\tau}$ refers to the average educational attainment for country i in the period ranging from t to $t+\tau$, $\bar{s}_{i,t+\tau}$ is the average investment share and $\bar{n}_{i,t+\tau}$ is the average population

[4]Notice that the existence of a constant level of inflation corresponding to the steady state in this augmented Solow model is not a necessary assumption for the stability of the solution. As long as the inflation rate is generated by an ergodic stochastic process, the growth rate of GDP per capita in the Solow steady state will remain in a bounded interval and the adjustment described above will take place towards a nonconstant equilibrium that depends on the inflation rate in the period considered.

[5]This assumption does not affect the results of the paper concerning the effect of inflation on long-run growth, and only has a relevant effect on the significance level of the estimate of ρ.

growth. The error term $\varepsilon_{i,t}$ is assumed to be composed of a country and a subperiod specific error, both treated as constant, and a general i.i.d. error process, such that $\varepsilon_{i,t} = \mu_i + \kappa_t + \nu_{i,t}$ with $\nu_{i,t} \sim \text{IID}(0, \sigma^2)$. Throughout the study δ, the depreciation rate, and g, the growth of technology corresponding to zero inflation, will be set equal to 3% and 2% respectively, following Mankiw et al. (1992).[6]

Equation (3) has been estimated assuming different effects of inflation on labour-augmenting productivity. The first results are presented in Table 1.[7] The first column presents the results without the effect of inflation, that is, the structural parameter estimates from (3) setting $\Theta(\cdot) = \Psi(\cdot) = 0$. The estimates of λ imply a convergence rate of approximately 8%, significantly higher than the estimates usually obtained in cross-country studies. The fixed effects panel setting allows for different steady states across economies, and the estimate of the convergence rate refers thus to the convergence towards the country-specific steady state.[8] The estimate of α is in the upper range of those reported by Mankiw et al. (1992), for example, and the estimate of ρ is positive although insignificant. This latter result is due to the low variability of education measures for the sample analyzed both across countries and through time.[9] Notice that this simple specification is extremely successful in accounting for the growth experience in Europe since 1960, with 66% of the variability in growth rates of GDP per capita being explained by the model.

In a next step we are going to let inflation affect the labour augmenting technology. Figure 1 shows a scatter plot of average inflation versus the average yearly growth rate of GDP per capita for the 14 EU countries and all subperiods. While there appears to be a negative relationship between these two variables, it is not possible to draw inference before taking into account the other variables in the structural model. The second and third column present the results when including a linear growth and level effect of inflation respectively. The $\Theta(\pi(t))$ and $\Psi(\pi(t))$ functions used were $\Theta(\pi(t)) = \theta\pi(t), \theta \in I\!R$, and $\Psi(\pi(t)) = \psi\pi(t), \psi \in I\!R$. For the growth effect specification the estimates reported approximate the long run inflation level for each country using the subperiod average inflation rate. Other different specifications for π^* have been tried, including the overall sample average, or exogenously set inflation rates ranging between 2% and 6%, without any qualitative change in the results. The estimates of λ, α and ρ are practically not affected by the inclusion of inflation in the specification. The results in columns 2 and 3 show no significant effect of inflation on growth, independently of whether a growth or a level effect is assumed a priori in the model.

A similar picture appears if a simultaneous growth and level effect is assumed. The results when including both effects simultaneously are very inconclusive for all the specifications in the paper and are therefore not reported. They are available from the authors upon

[6] Changing the value of these parameters inside economically sensible ranges does not qualitatively affect the results presented in the paper.

[7] Given the low within-country variability of the education measure, the size and significance of the estimate of ρ depends strongly on the inclusion of fixed subperiod effects. Results with and without time dummies are available from the authors upon request.

[8] The point estimate of the convergence rate using a common intercept is approximately 4%. However, the null of equality of fixed effects is strongly rejected when performing the corresponding F-test.

[9] The estimate of ρ corresponding to the model without time effects is 0.315, with a standard deviation of 0.038 and thus highly significant.

request. The main reason is that the identification of the structural parameters is basically done through the estimate of the growth effect (the part of the specification in logs), which requires nonlinear estimation methods. This identification issue, together with a high degree of multicollinearity, renders most of the inflation effects insignificant when the model is too parametrized, as is the case if the level and growth effects are simultaneously assumed.

For all models with and without inflation, the null of Gaussian distribution of the residuals is strongly rejected using the Jarque-Bera test. The deviation of normality in the residuals of the models estimated and presented in Table 1 is exclusively caused by the growth observation corresponding to the last subperiod in the sample for Ireland, which the model (with and without inflation) systematically tends to underpredict. Table 2 presents the results of the specifications described above and presented in Table 1 including a dummy for Ireland in the period 1992-1999. The estimated parameter for the dummy is positive and significant in all specifications. Throughout the point estimate of the convergence rate, λ, is higher than in the model without the dummy, and the estimates of α are more in line with those usually reported in the literature. For all cases the Jarque Bera test statistic does not give evidence of significant deviations from Gaussianity in the residuals, and a considerable increase in goodness of fit of the model is observable in terms of adjusted R^2. A negative effect of inflation on growth of GDP per capita appears now marginally significant in the specification which allows exclusively for a growth effect of inflation.

In order to account for the potential endogeneity of inflation in the specification given by (3), we also estimated the level effect specification instrumenting the inflation rate using the index of central bank independence in Hall and Franzese (1998) and money supply growth.[10] Using a specification such as (3) without the parameter constraints implied by the structural model, the Durbin-Wu-Hausman test gave clear evidence in favour of the use of least square estimation.

4.2 Allowing for nonlinear effects of inflation on growth

Assuming a linear effect of inflation on the level or growth rate of GDP per capita may, however, be a wrong modelling strategy. If the effect of inflation on growth is of the nonlinear type suggested by theoretical arguments as described in Section 2, linear models would tend to underestimate its magnitude for high levels of inflation.

Table 3 presents the results based on a quadratic specification of $\Theta(\pi(t))$ and $\Psi(\pi(t))$. The models with individual growth and level effects point towards a hump-shaped relationship between inflation and economic growth. The other structural parameters remain practically unchanged by the inclusion of a quadratic specification of the growth-inflation link.

Independently of the nature of the inflation effect on growth, the estimates presented in Table 3 result in an extremely high estimate of the optimal (in the sense of growth max-

[10] The unrestricted level specification was used due to the fact that it is linear in parameters and therefore the usual asymptotics for instrumental variable estimation hold. There is little guidance in the literature as to the properties of instrumental variables estimators with non-linearities such as the ones arising in the specification with a growth effect. For the linear level effect case, a Sargan test could not reject that the instruments used were valid for inflation at any sensible level of significance.

imizing) level of inflation. According to the results with a quadratic growth specification, the European experience would imply that increases in the inflation rate for levels below 9% (8.5% for the level specification) have been accompanied by rising long term growth rates of GDP per capita. However, this high estimate could be due to the symmetry preimpossed by the quadratic specification. If the inflation-growth link is positive for very low levels of price increase and negative for high levels but the slope associated to these links differ, the estimate of the optimal level of inflation based on a model with a symmetric relationship between inflation and growth would be distorted.

A way to overcome this limitation and allow for model asymmetry in the relationship between inflation and growth would be to let $\Theta(\pi(t))$ and $\Psi(\pi(t))$ be continuous piecewise functions (so called *splines*), where the parameter associated with the inflation rate is allowed to change discretely depending on the level of inflation. The theoretical discussion in the introduction ans Section 2 and the evidence from the quadratic specification would call for the inclusion of a function with two differentiability breakpoints, while preserving continuity. For the growth effect, the function is defined as

$$\Theta(\pi(t)) = \begin{cases} \theta_3\pi(t) & \text{if } \pi(t) > \mu_2 \\ \theta_2(\pi(t)-\mu_2)+\theta_3\mu_2 & \text{if } \mu_1 < \pi(t) \leq \mu_2 \\ \theta_1(\pi(t)-\mu_1)+\theta_2(\mu_1-\mu_2)+\theta_3\mu_2 & \text{if } \pi(t) \leq \mu_1 \end{cases} \tag{4}$$

and analogously for the level effect,

$$\Psi(\pi(t)) = \begin{cases} \psi_3\pi(t) & \text{if } \pi(t) > \eta_2 \\ \psi_2(\pi(t)-\eta_2)+\psi_3\eta_2 & \text{if } \eta_1 < \pi(t) \leq \eta_2 \\ \psi_1(\pi(t)-\eta_1)+\psi_2(\eta_1-\eta_2)+\psi_3\eta_2 & \text{if } \pi(t) \leq \eta_1 \end{cases} \tag{5}$$

The breakpoints, μ_1 and μ_2 (or, alternatively, η_1 and η_2) will be treated as unknown parameters and therefore estimated. Table 4 shows the estimates of the models where the growth and level effect of inflation are modelled by means of (4) and (5), respectively. The estimation of the breakpoints for the case of a growth effect of inflation was done by choosing the values

$$\hat{\hat{\mu}} = (\hat{\mu}_1, \hat{\mu}_2) = \text{argmin}_{\{\tilde{\mu}\in M\}} \sum_{t=0}^{T}\sum_{i=0}^{N}\left[\hat{\nu}_{i,t}\left(\hat{\lambda}(\tilde{\mu}), \hat{\alpha}(\tilde{\mu}), \hat{\rho}(\tilde{\mu}), \hat{\theta}_1(\tilde{\mu}), \hat{\theta}_2(\tilde{\mu}), \hat{\theta}_3(\tilde{\mu})\right)\right]^2,$$

where M is the set of those inflation rates actually realized in the sample. The estimates for (5) are obtained analogously. That is, the breakpoints where estimated as the inflation values that jointly minimize the sum of squared residuals among those realized in the inflation sample (the estimation was done after trimming 5% of the extremes of the distribution of inflation rates, and ensuring that at least 10% of the observations fall in the central regime).

The results of the estimation for the available data are presented in Table 4. For both cases, the basic structural parameters from the underlying augmented Solow model remain practically unchanged. The results for the individual specifications provide a very interesting insight to the relationship between inflation and growth in Europe for the period 1960-1999 . In both cases, the estimate of the first break is slightly higher than 1.5% (which corresponds approximately to the 10th percentile of the distribution of inflation in the pooled sample), and the second break is situated at 16.35%. Significant effects of inflation on GDP per capita growth appear only in the lowest and highest regime of inflation. For very low levels of inflation (up to around 1.6% for both estimates), increases in inflation appear in parallel with increases in the growth rate of GDP per capita. For these specifications, the negative effect of inflation is significant for the observations with inflation rates above 16.35% in the models estimated. As expected the absolute value of the parameter estimate for the negatively sloped part is much higher than the estimates implied by the linear estimates.[11]

The likelihood ratio test statistics and their associated bootstrap p-value presented in Table 4 correspond to the test for linearity computed following Hansen (1996). The null hypothesis corresponds to the restriction $\theta_1 = \theta_2 = \theta_3$ for the growth effect specification ($\psi_1 = \psi_2 = \psi_3$ for the level effect model). Under the null hypothesis of linearity the thresholds μ_1 and μ_2 (η_1 and η_2) are not identified, and standard test statistics therefore fail to converge to known asymptotic distributions. Finding optimal tests in this setting is an issue that has been widely studied in the econometric literature recently (see Andrews and Ploberger, 1994, and Hansen, 1996, for example). In order to compute the p-values presented in Table 4, we followed the bootstrap procedure proposed by Hansen (1996). Using the actual parameter estimates of the linear model corresponding to the null hypothesis and drawing randomly from the residuals of this model, samples of growth rates where computed. A linear and a nonlinear model with a spline effect of inflation on growth are fitted to the simulated data, and the corresponding likelihood ratio test statistic is computed. Repeating this procedure a large number of times allows us to obtain an estimate of the distribution of the test statistic under the null of linearity, and therefore an estimate of the p-value corresponding to the test statistic computed with actual data. For the results in Table 4, 500 replications of the procedure were employed. In all cases, there is evidence of a nonlinear effect of inflation on GDP per capita growth of the type modelled through the continuous piecewise linear functions defined above.

The existence of two inflation thresholds is motivated by the theoretical underpinnings pointed out in the introduction. We also estimated models with a single breakpoint in the spline specification. These models pick up exclusively the negative link for high inflation rates, with an insignificant parameter attached to lower inflation levels. The breakpoint estimate in these models is somewhat smaller than the one resulting from the three-regime specification (7.8% for the growth effect specification and 8.6% for the level effect specification). Bootstrap tests such as the one described above give clear evidence of the superiority of the specification with two breakpoints over the two-regime model.

We also computed confidence intervals for the thresholds using a generalization of the procedure put forward in Hansen (2000). Fixing one of the two estimated thresholds, a 90% confidence interval for the remaining threshold will be defined as the (not necessarily symmetric) neighbourhood around the threshold value for which the null of a two-regime model is rejected at 10% significance level against a three regime model. While Hansen (2000)

[11] The negatively sloped part of the relationship remains significant and higher than the linear estimate if μ_2 and η_2 are reduced down to values around 10%, and the parameter for low values of inflation remains significantly positive for values of μ_1 and η_1 up to 2.5%, approximately. The models minimizing the sum of squared residuals, however, are those presented in Table 4.

recommends to use the asymptotic critical values for the likelihood ratio test, as our threshold estimates tend to be close to the extremes of the empirical distribution of inflation, we will compute the confidence intervals using the bootstrap distribution of the likelihood ratio test, computed using 1000 replications. The alternative hypothesis in the computation of the bootstrap distribution used in each case is the one corresponding to the least square three-regime model. The resulting 90% confidence intervals for the lower threshold are [1.40%, 1.75%] for the level effect specification and [0.64%, 2.05%] for the growth level specification. The confidence intervals for the higher threshold are much larger, spanning all values of inflation higher than 12.85% which are realized in the sample for the level effect model and all values higher than 13.15% for the growth effect model.

To sum up, estimation results with nonlinear models support our hypothesis of a more complex structure of the inflation growth relationship. For very low inflation rates or even deflation there is a positive link so that further disinflation would have negative growth effects. The spline model specification furthermore suggests that there is a wide range of inflation levels consistent with a maximization of long term growth. Only for very high inflation rates do we find inflation to be a major threat to growth.

4.3 A level or a growth effect of inflation in Europe?

The results presented above give evidence that extremely low and extremely high levels of inflation are related to bad growth experiences for the analyzed sample of European countries. For the model with a spline function, the result emerges independently of whether a growth or a level effect of inflation is assumed in the underlying specification. Is there evidence, however, that one of these two specifications explains the growth experience in the EU better than the other? According to model selection criteria, the model with a growth effect performs marginally better than the model with a level effect. The adjusted R^2 of the model with a growth effect is 0.803 (and thus the highest of all estimated models), against a value of 0.800 for the level effect specification. Consequently, as both models have the same number of parameters, the AIC and Schwarz criterion of the model with a growth effect are marginally smaller than those of the model with a level effect of inflation. A scientist led by model selection criteria would then be inclined to choose the model with a positive *growth* effect of inflation occurring at very low levels of inflation and a negative *growth* effect for very high levels. If, however, we are interested in whether the explanation of the link between inflation and growth postulated by the model with a growth effect implies, for the data at hand, a *significant* improvement over the level effect model, conducting a proper statistical test would is warranted.

The models to be compared are not nested, so the usual likelihood ratio test statistic does not have the standard χ^2 asymptotic distribution. In order to obtain the distribution of the likelihood ratio test statistic under the null hypothesis, a nonpivotal bootstrapping method similar to the one explained above for the linearity test can be used (see Pesaran and Weeks, 2001). Samples of GDP per capita growth are generated from the fitted model corresponding to the null hypothesis using random draws from its residuals, both models corresponding to the null and the alternative hypothesis are estimated and the likelihood ratio test statistic is computed. This is repeated a large enough number of times, and by comparing the original test statistic with the empirical distribution of likelihood ratio test statistics resulting from the replications, a bootstrap estimate of the p-value can be obtained.

The model with a piecewise linear level effect of inflation can be considered more parsimonious than the model with a growth effect, and given that its explanatory power is marginally lower than that of the latter, it is the natural candidate for the null hypothesis. The likelihood ratio test statistic corresponding to the test of a level against a growth effect equals 1.09, and the estimated bootstrap p-value is 0.18, obtained with 500 replications. While the result of this test does not give significant support to the growth effect model, the test carried out with the growth effect as the null hypothesis does not significantly support the level model, either.

To sum up, the overall shape of the relationship between inflation and growth in the framework of the model presented does not depend on the assumption of a level or growth effect of inflation. Non-nested model testing methods do not prove capable of deciding for the superiority of one of the two specifications.

5 Conclusions

The paper reassesses the impact of inflation on long-term growth for a panel of 14 EU countries. While previous research focuses on a linear nexus or allows for a piecewise linear relationship with one single threshold we allow for a more complex relationship. Theoretical arguments point at a positive relationship between inflation and growth for very low negative levels of inflation, followed possibly by a range of no significant effect. For very high inflation rates the impact on growth can be expected to become negative. These arguments suggest hypothesizing a trapezoid type of relationship between inflation and long-term growth.

We present a simple theoretical framework – based on the basic human-capital augmented Solow model with a production function as in Hall and Jones (1999) – that allows for an explicit empirical distinction between level and growth effects of inflation. The superiority of one of these models can then be tested using non-nested model testing techniques.

The empirical estimates confirm the hypothesis that the relationship between inflation and growth is of nonlinear nature and that one threshold may not be enough to account for the nonlinearities. We find a significant positive slope for levels of inflation below an estimated value of around 1.6%, giving support to the "grease of the economy" and "zero lower bound constraint"- type of arguments as suggested in the literature. This is followed by a range of inflation rates where no significant effect on growth prevails. This interval is surprisingly wide, considering that around three quarters of the observations fall within this area. The second threshold is estimated at a level of inflation of around 16%, a value beyond which we observe the expected negative impact of inflation on growth. While this breakpoint estimate appears surprisingly high it should be noted that the corresponding confidence interval is rather wide as well so that lower two-digit threshold level would still support the trapezoid shape. As compared to the models that allow for only one single threshold our negative slope for high levels of inflation is significantly steeper. While the growth effect model explains the data marginally better then the level effect, non-nested model testing does not give evidence of the superiority of one of the models.

Our findings therefore support the intuition of the detrimental growth effects of very low (or negative) and excessively high rates of inflation. Such a relationship would typically be the foundation for any explicit inflation target or definition of price stability by central banks. This opens the question of how our findings relate to these numerical inflation targets. Obviously our estimates suggest a much wider range of acceptable levels of price increase as it is typically seen by national banks. Does this constitute a criticism against these central bank strategies? Apart from the typical reservations associated with any empirical approach and the wide confidence intervals, one has to emphasize the multi-dimensional foundation for central bank strategies. Growth aspects are obviously only one of the many relevant aspects central banks have in mind when formalizing their strategy. Other goals are related to exchange rate stability or the stabilisation of expectations. In this sense the findings of the present study cannot be related one to one to typical definitions of inflation targets.

Appendix: Data sources

- GDP per capita: Penn World Tables 6.1; Heston, Summers and Aten (2002).
- Share of investment over GDP: Penn World Tables 6.1; Heston, Summers and Aten (2002).
- Population growth: Penn World Tables 6.1; Heston, Summers and Aten (2002).
- Average years of education of an adult over 25 years old; corrected Barro and Lee (2001) data set by de la Fuente and Domenech (2002).
- Inflation rate: CPI inflation, averages from quarterly data, International Financial Statistics, IMF.
- Money supply growth; AMECO Database, European Commission.
- Central bank independence index; Hall and Franzese (1998).

References

[1] Andrés, Javier and Ignacio Hernando, 1997, Does inflation harm economic growth? Evidence for the OECD, *NBER Working Paper*, 6062, June 1997.

[2] Andrews, Donald W. and Werner Ploberger, 1994, Optimal tests when a nuisance parameter is present only under the alternative, *Econometrica*, 62, 1383-1414.

[3] Barro, R.J., 1995, Inflation and economic growth, NBER Working Paper Series, 5326.

[4] Barro, R.J. and J.W. Lee, 2001, International data on educational attainment: updates and implications, *Oxford Economic Papers*, 53, 541-563.

[5] Bhatia, Rattan J., 1960, Inflation, deflation, and economic development, *IMF Staff Papers*, 8(1), 101-14.

[6] Briault, Clive, 1995, The costs of inflation, *Bank of England Quarterly Bulletin*, 35, February, 33-45.

[7] Bruno Michael, and William Easterly, 1998, Inflation crises and long-run growth, *Journal of Monetary Economics*, 41 (February), 3-26.

[8] Christoffersen Peter F., and Peter Doyle, 1998, From inflation to growth: Eight years of transition, *IMF Working Paper*, 98/100.

[9] Cozier, Barry and Jack Selody, 1992, Inflation and macroeconomic performance: some cross-country evidence, Department of Monetary and Financial Analysis, *Bank of Canada Working Papers*, 92-6.

[10] Crespo Cuaresma, Jesús, 2002, Some million thresholds: Nonlinearity and cross-country growth regressions, *University of Vienna, Department of Economics Working Papers*, 0210, October 2002.

[11] Crespo Cuaresma, Jesús, Doris Ritzberger-Grünwald and Maria Antoinette Silgoner, 2003, The impact of European integration on growth: What can we learn for EU accession?, in: *Economic Convergence and Divergence in Europe – Growth and Regional Development in an Enlarged European Union*, Gertrude Tumpel-Gugerell and Peter Mooslechner (eds), Edward Elgar, UK.

[12] Dorrance, Graeme S., 1966, Inflation and growth: the statistical evidence, *IMF Staff Papers*, 13(1), 82-102.

[13] Fischer, Stanley, 1993, The role of macroeconomic factors in growth, *NBER Working Paper*, 4565.

[14] Fischer, Stanley, Ratna Sahay and Carlos A. Végh, 2002, Modern hyper- and high inflations, *NBER Working Paper*, 8930.

[15] de la Fuente, Angel and Rafael Domenech, 2002, Human capital in growth regressions: how much difference does data quality make? An update and further results, *mimeo,* University of Valencia.

[16] Gosh, Atish, and Steven Phillips, 1998, Warning: Inflation may be harmful to your growth, *IMF Staff Papers*, 45(4), 672-710.

[17] Hall, Peter and Robert J. Franzese, 1998, Mixed Signals: Central Bank Independence, Coordinated Wage-Bargaining, and European Monetary Union, *International Organization*, 52 (3), 505-535.

[18] Hall, Robert E. and Charles I. Jones, 1999, Why do some countries produce so much more output per worker than others?, *Quarterly Journal of Economics*, 114, 83-116.

[19] Hansen, Bruce E., 1996, Inference when a nuisance parameter is not identified under the null hypothesis, *Econometrica*, 64, 413-30.

[20] Hansen, Bruce E., 1999, Threshold effects in non-dynamic panels: Estimation, testing, and inference, *Journal of Econometrics*, 93, 345-68.

[21] Hansen, Bruce E., 2000, Sample splitting and threshold estimation, *Econometrica*, 68, 575-603.

[22] Heston, Alan, Summers, Robert and Bettina Aten, 2002, Penn World Table Version 6.1, *Center for International Comparisons at the University of Pennsylvania (CICUP),* October 2002.

[23] Khan, Mohsin S., and Abdelhak S. Senhadji, 2001, Threshold effects in the relationship between inflation and growth, *IMF Staff Papers*, 48(1), 1-21.

[24] Levine, Ross, and David Renelt, 1992, A sensitivity analysis of cross-country growth regressions, *American Economic Review*, September, 942-63.

[25] Levine, Ross, and Sara J. Zervos, 1993, What we have learned about policy and growth from cross-country regressions?, *American Economic Review*, May, 426-30.

[26] Mankiw, N. Gregory, Romer, David and David N. Weil, 1992, A contribution to the empirics of economic growth, *The Quarterly Journal of Economics*, 107, 407-37.

[27] Motley, Brian, 1998, Growth and Inflation: A cross-country study, *Federal Reserve Bank of San Francisco Economic Review*, 1998(1), 15-28.

[28] Pesaran, M. Hashem and Melvyn Weeks, 2001, Non-nested hypothesis testing: An overview, in (ed) Badi H Baltagi, *Companion to Theoretical Econometrics*, Basil Blackwell, Oxford.

[29] Sala-i-Martin, Xavier X., 1997, I Just Ran Two Million Regressions, *American Economic Review*, 87(2), 178-83.

[30] Sarel, Michael, 1996, Nonlinear effects of inflation on economic growth, *IMF Staff Papers*, 43(1), 199-215.

[31] Solow, R.M., 1956, A contribution to the theory of economic growth, *Quarterly Journal of Economics*, 70, 65-94.

[32] Stockman, Alan C., 1981, Anticipated inflation and the capital stock in a cash-in-advance economy, *Journal of Monetary Economics*, 8, 387-93.

[33] Temple, Jonathan, 2000, Inflation and growth: stories short and tall, *Journal of Economic Surveys*, 14(4), 395-426.

[34] Tsionas, Efthymios G., and Dimitris K. Christopoulos, 2003, Maastricht convergence and real convergence: European evidence from threshold and smooth transition regression models, *Journal of Policy Modeling*, 25, 43-52.

[35] Tun Wai, U, 1959, The relation between inflation and economic development: a statistical inductive study, *IMF Staff Paper*s, 7(2), 302-17.

Table 1: Linear growth and level effect of inflation

Parameter	No inflation effect	Growth effect $\Theta(\pi(t)) = \theta\pi(t)$	Level effect $\Psi(\pi(t)) = \psi\pi(t)$
λ	0.083*** (0.025)	0.081*** (0.025)	0.079*** (0.026)
α	0.503*** (0.098)	0.497*** (0.110)	0.494*** (0.110)
ρ	0.116 (0.095)	0.112 (0.104)	0.118 (0.106)
θ	–	-0.009 (0.011)	–
ψ	–	–	-0.236 (0.235)
Obs.	68	68	68
$\bar{R}^2$	0.66	0.66	0.66
JB test	14.62	18.98	18.23

***(**)[*] stands for 1% (5%) [10%] significant. White heteroskedasticity consistent standard errors in parenthesis. Least square dummy variable estimation used in all cases, and nonlinear least square dummy variable estimation used when a growth effect of inflation is parametrized. Sub-period dummies used if jointly significant. Estimates based on a panel of 7 year averages for the period 1960–1999.

Table 2: Linear growth and level effect of inflation: Estimates with dummy for Ireland 1992-1999

Parameter	No inflation effect	Growth effect $\Theta(\pi(t)) = \theta\pi(t)$	Level effect $\Psi(\pi(t)) = \psi\pi(t)$
λ	0.100*** (0.023)	0.094*** (0.026)	0.094*** (0.027)
α	0.403*** (0.067)	0.379*** (0.077)	0.379*** (0.078)
ρ	0.047 (0.056)	0.035 (0.079)	0.045 (0.079)
θ	–	-0.016* (0.009)	–
ψ	–	–	-0.324 (0.211)
IRL Dummy	0.306*** (0.064)	0.321*** (0.028)	0.314*** (0.028)
Obs.	68	68	68
$\bar{R}^2$	0.77	0.78	0.77
JB test	0.02	0.32	0.10

***(**)[*] stands for 1% (5%) [10%] significant. White heteroskedasticity consistent standard errors in parenthesis. Least square dummy variable estimation used in all cases, and nonlinear least square dummy variable estimation used when a growth effect of inflation is parametrized. Sub-period dummies used if jointly significant. Estimates based on a panel of 7 year averages for the period 1960–1999.

Table 3: Quadratic growth and level effect of inflation

Parameter	Growth effect $\Theta(\pi(t)) = \theta_1\pi(t) + \theta_2\pi(t)^2$	Level effect $\Psi(\pi(t)) = \psi_1\pi(t) + \psi_2\pi(t)^2$
λ	0.088*** (0.027)	0.089*** (0.028)
α	0.392*** (0.075)	0.383*** (0.075)
ρ	0.050 (0.071)	0.042 (0.070)
θ_1	0.030* (0.017)	–
θ_2	-0.165*** (0.058)	–
ψ_1	–	0.659 (0.481)
ψ_2	–	-3.505**(1.529)
Obs.	68	68
$\bar{R}^2$	0.79	0.79
JB test	1.41	1.82

***(**)[*] stands for 1% (5%) [10%] significant. White heteroskedasticity consistent standard errors in parenthesis. Least square dummy variable estimation used in all cases, and nonlinear least square dummy variable estimation used when a growth effect of inflation is parametrized. Sub-period dummies used if jointly significant. Estimates based on a panel of 7 year averages for the period 1960–1999. Dummy for Ireland in the period 1992-1999 included and highly significant in all cases.

Table 4: Growth and level effect of inflation: Spline specification

Parameter	Growth effect $\Theta(\pi(t))$ as in (4)	Level effect $\Psi(\pi(t))$ as in (5)
λ	0.092^{***} (0.027)	0.098^{***} (0.028)
α	0.366^{***} (0.071)	0.359^{***} (0.071)
ρ	0.055 (0.067)	0.047 (0.062)
θ_1	0.153^{***} (0.053)	–
θ_2	0.004 (0.011)	–
θ_3	-0.049^{**} (0.020)	–
ψ_1	–	4.754^{***} (2.039)
ψ_2	–	0.119 (0.287)
ψ_2	–	-1.052^{**}(0.441)
μ_1	1.64%	–
μ_2	16.35%	–
η_1	–	1.63%
η_2	–	16.35%
Obs.	68	68
$\bar{R}^2$	0.80	0.80
JB test	1.29	1.49
LR test	12.84	12.01
(p-value)	0.035	0.046

$^{***(**)[*]}$ stands for 1% (5%) [10%] significant. White heteroskedasticity consistent standard errors in parenthesis. Least square dummy variable estimation used in all cases, and nonlinear least square dummy variable estimation used when a growth effect of inflation is parametrized. Sub-period dummies used if jointly significant. Estimates based on a panel of 7 year averages for the period 1960–1999. Dummy for Ireland in the period 1992-1999 included and highly significant in all cases. The LR test statistic and its bootstrap p-value correspond to the linearity test proposed by Hansen (1996). The bootstrap was done using 500 replications.

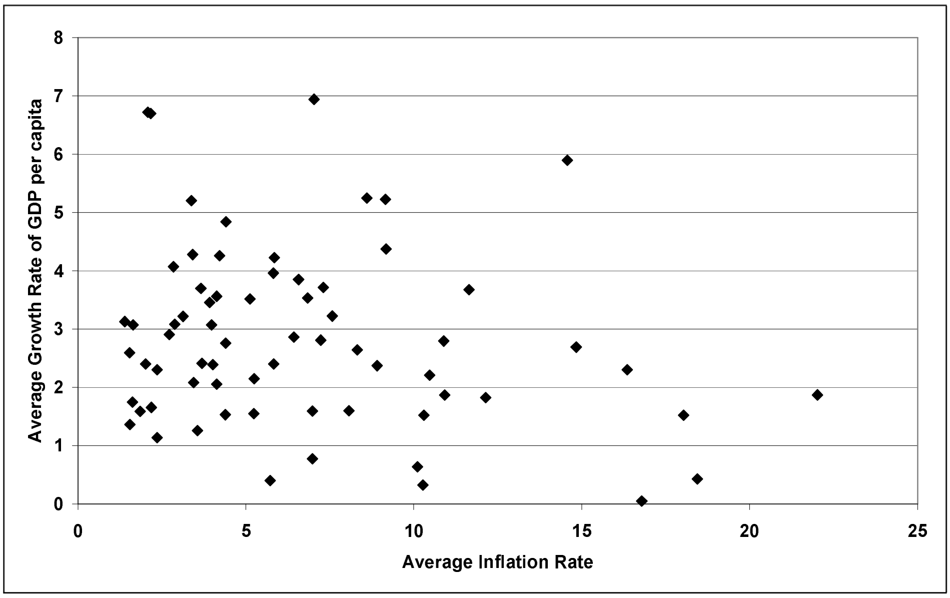

Figure 1: Average inflation rate versus average growth rate of GDP per capita: EU-15 countries (except Luxembourg) 1960-1999.