

## Inflation and growth: Explaining a negative effect

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**Abstract.** The paper presents a monetary model of endogenous growth and specifies an econometric model consistent with it. The economic model suggests a negative inflation-growth effect, and one that is stronger at lower levels of inflation. Empirical evaluation of the model is based on a large panel of OECD and APEC member countries over the years 1961–1997. The hypothesized negative inflation effect is found comprehensively for the OECD countries to be significant and, as in the theory, to increase marginally as the inflation rate falls. For APEC countries, the results from using instrumental variables also show significant evidence of a similar behavior. The nature of the inflation-growth profile and differences in this between the regions are interpreted with the credit production technology of the model in a way not possible with a standard cash-only economy.

**Key words:** Endogenous growth, panel data, inflation, non-linearity

**JEL classification:** O42, C23, C51, E13

### 1. Introduction

Kormendi and McGuire (1985) document a negative effect of inflation on economic growth for a cross-section of 47 countries during the period 1950–1977. Recent panel evidence such as Barro's (2001) strengthens the support

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for such a negative effect. In qualification, Khan and Senhadji (2001), Ghosh and Phillips (1998), and Judson and Orphanides (1996) all find a significant negative inflation-growth effect above a certain “threshold” value of the inflation rate, and no significant effect below the threshold value, without using instrumental variables and with differences found between less and more developed country samples. Further the above-threshold negative effect that they find is significantly non-linear whereby the marginal effect is stronger at lower inflation rates than at higher ones; see also Fischer (1993).

Linking such evidence with a theoretical model has been somewhat tenuous. The Tobin (1965) paper concerns the induced increase in the capital stock within a Solow exogenous growth model. Stockman (1981) demonstrates a reverse Tobin effect of inflation on capital by applying Lucas’s (1980) Clower constraint to investment as well as consumption purchases, but does not explicitly deal with the balanced-growth rate of output.<sup>1</sup> Sidrauski’s (1967) money-in-the-utility function model and Ireland’s (1994) AK model derive only a transitional effect of inflation on the growth rate. Dotsey and Sarte (2000) use an AK-type model, apply the Clower constraint to investment as in Stockman (1981), add uncertainty, and calibrate a negligibly small negative effect of inflation on the balanced-growth rate. Chari, Jones and Manuelli (1996) calibrate, in an endogenous growth model with human capital, a negative effect of inflation on the balanced-growth rate, but one of a magnitude far below what they consider to be within the estimated range found in empirical studies.

However, it has sometimes been overlooked that Gomme’s (1993) endogenous growth framework, with a somewhat extended model relative to Chari et al. (1996), uses a Lucas (1988) type production function for human capital investment and produces a significant negative calibrated effect of inflation on growth. Because this model produces effects that are within the range of the significant negative effects found in recent panel estimates (see Gillman and Kejak 2002), it is a plausible candidate for a theory of the inflation-growth effect.

The contribution of the paper here is that we extend a Gomme (1993)-type model, and apply the extension to guide and interpret the estimation of the inflation-growth effect in a comprehensive way. This produces a simple way to understand the effect of inflation on growth, and a linked way to estimate this effect that is not inconsistent with previous work. However, the empirical results differ somewhat in that the effect of inflation is found to be significant and negative at all positive levels of the inflation rate, when using instrumental variables for both developed and less developed country samples. Together with the model this offers a novel combination of a fully supported theory of the inflation-growth effect.

The extension made to the Gomme (1993)-type model concerns the exchange technology. Instead of a cash-only economy, here as in Gillman and Kejak (2002) both money and credit can be used to buy the consumption good. The credit production function is specified explicitly in an additional layer of “micro-foundations”. This allows interpretation of different results

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<sup>1</sup> However the Stockman (1981) model can produce a negative effect on inflation on the balanced-growth path for the special case of an “AK” production function; see also Haslag (1998) who uses a Stockman-related approach with growth effects.

between OECD and APEC samples using differences in the credit technology, or in the “financial development”.

The model-based explanation is that inflation lowers the rate of return on capital, both human and physical. Ever since the Ramsey-Cass-Koopmans theory endogenized the savings rate of the Solow model by using utility optimization, the growth rate has depended on one variable: the rate of return to capital. Taxes that decrease that rate of return decrease the growth rate. Models that explain growth endogenously, with a Lucas (1988) human capital accumulation, further develop the theory by implying that the growth rate depends on the rate of return to human capital as well as physical capital, whereby the rate of return on all forms of capital must be equal in the balanced-growth equilibrium.<sup>2</sup> A tax on either form of capital induces a lower return in equilibrium on all forms of capital. When such endogenous growth models are set within a monetary exchange framework, such as those of Lucas (1980), Lucas and Stokey (1987), or McCallum and Goodfriend (1987), the inflation tax also will affect the rate of return on capital. In particular, as Chari et al. (1996) discuss, the inflation tax induces goods to leisure substitution that lowers the return to human capital, and the growth rate.

With a parsimonious empirical theory, the paper here explains growth through factors that reflect the return to physical and human capital in terms of easily measurable variables. The real interest rate, a measure of the return to physical capital, is proxied with the investment rate in a way suggested by the theory. Any further changes across countries to this real rate, for example as caused by differing tax regimes, are accounted for via use of fixed country specific effects within the econometric model. This is important in that the model implies (see King and Rebelo 1990), that a tax on capital income directly reduces the growth rate; a tax on labor income can also affect the growth rate for example if there is any kind of tax or subsidy to the human capital investment sector. The inflation rate enters the econometric specification as the one systematic, easily measured, tax on human capital within each country that is suggested by the theory.

Another aspect of the empirical work here is that time effects are conditioned upon, as fixed parameters in the econometric model, and interpreted as being related to unexpected international changes in the inflation rate.

The model also includes a variable designed to capture transitional dynamics. There are several potential sources of transitional dynamics in the model. For one, note that in the Lucas (1988) human capital model, without the assumption of a human capital externality, the human capital index acts to explain endogenously the original Solow exogenous technological change, or “total factor productivity” shift parameter. Further, Solow-like transitional dynamics exist when the model includes physical capital in the production of human capital, as in King and Rebelo (1990) and as in this paper. Thus there are the Solow-like transitional dynamics whereby a below-balanced-path-equilibrium amount of capital, now human as well as physical,

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<sup>2</sup> In contrast the balanced-growth path return on capital is fixed at  $A$  in AK models, and inflation effects this return and the growth rate only through devices that somehow put capital under the cash-in-advance constraint, such as in Stockman (1981), Haslag (1998) and Dotsey and Sarte (2000); but then these have non-empirically consistent reverse-Tobin type effects whereby inflation causes substitution away from capital because inflation lowers its return directly.

leads to increases in capital and income levels on the transition towards the stationary state. Applying this representative agent model to a panel suggests that countries within an interlinked group, or “growth club”, will converge to the same balanced-growth path, as in Barro (1997) for example. Therefore including the ratio of income in each country relative to that of the balanced-path “leader”, for example the US, can capture the effect of the transitional dynamics on the growth rate.

Second, Einarsson and Marquis (1999) present transitional dynamics for a Gomme (1993)–type model and indicate how the income variable moves transitionally with changes in the inflation rate, as a result of changes in the exogenous rate of money supply growth. This suggests that should the leader of a growth club have an influence on the inflation rates of the other countries in the club, the other countries in the club would have transitional effects on income that would be relative to the leader to some extent. For these two sources of transitional dynamics, and assuming the US as the lead country, we follow the older exogenous Solow-growth literature (Kormendi and Meguire 1985), and the new endogenous growth literature (Barro 2001), and include as a variable the ratio of the level of income in the US to the level of income in each other country.

Instrumental variables (IV’s), to test for possible endogeneity of the inflation and growth rates, are little used in the literature cited above. We test for such endogeneity and report results for all samples using an instrument suggested directly by the theoretical model. The paper follows the model’s implication that the money supply is exogenous and largely determines the inflation rate along the balanced growth rate. Further, there is evidence that finds that the money supply growth rate Granger-causes the inflation rate, while the inflation rate in turn Granger causes the output growth rate, such as in Nakov and Gillman (2002). This suggests the use of money as an instrument for the inflation rate in a way consistent with the model.

Also, note that the theoretical model predicts a non-linearity in the inflation-growth effect, whereby the effect is marginally stronger at lower inflation rates than at higher ones, but negative everywhere. So at the Friedman optimum of a zero nominal interest rate the effect is marginally the strongest, and monotonically weaker thereafter. This non-linearity is explored using alternative specifications, these being the natural logarithm, quadratic, and spline functions.

Finally, it is noted that the optimization model does not dismiss the Tobin (1965) effect, but rather re-states it in general equilibrium terms. Here, in contrast to Stockman (1981), there is a positive Tobin-type effect. The endogenous growth, cash-in-advance, setting implies that the inflation tax reduces the return on human capital, and that the return on physical capital must adjust downwards in equilibrium. This adjustment requires an increased investment and an increased capital/labor usage across all sectors. This input realignment slightly mitigates the degree to which the return on human capital and physical capital must fall as a result of an increase in the inflation rate. Thus the Tobin effect here is the more efficient use of inputs given the higher tax on labor relative to leisure that results from an inflation rate increase. It means a higher physical capital usage relative to effective labor, and a slightly smaller decline in the balanced-path growth rate. However, the effect of inflation on the balanced-growth rate is still negative, in contrast to

the exogenous growth, monetary, model of Tobin, or related models reviewed by Ahmed and Rogers (2000).

## 2. Endogenous growth monetary framework

The representative agent works in a constant-returns-to-scale (CRS) goods sector that employs physical capital and effective labor. Effective labor is defined as raw labor factored by the human capital (quality indexed). The agent also devotes resources to two additional, implicit price, sectors. These are the CRS human capital production that involves the investment of capital and effective labor, and a credit services sector that involves only effective labor in a diminishing returns technology. The agent faces four constraints on the maximization of utility over goods and leisure in terms of the flow of human capital; the flow of financial capital that is comprised of money and physical capital; the stock of financial capital; and the exchange technology. The technology of the credit services sector is built into the cash-in-advance constraint.

At time  $t$ , denote the real quantities of output and consumption goods by  $y_t$  and  $c_t$ , and the fraction of time spent in leisure, in credit services production, and in goods production by  $x_t$ ,  $l_{Ft}$ , and  $l_{Gt}$ . The share of physical capital in goods production is given by  $s_{Gt}$ . The stocks of physical and human capital and their depreciation rates are given by  $k_t$ ,  $h_t$ ,  $\delta_k$ , and  $\delta_h$  respectively. Denote the input prices of capital and effective labor by  $r_t$ , the real interest rate, and  $w_t$ , the real wage. The positive shift parameters of the production functions of goods, credit services, and human capital are  $A_G$ ,  $A_F$ , and  $A_H$ . Nominal variables are the price of goods  $P_t$ , the stock of nominal financial capital  $Q_t$ , the stock of money  $M_t$ , and the lump sum government transfer of cash  $V_t$  that is a constant fraction  $\sigma$  of the money stock. In addition denote by  $d_t$  the amount of real credit used in making purchases. Given parameters  $\rho$ ,  $\beta$ ,  $\varepsilon$ , and  $\gamma$  are in the  $(0,1)$  interval, and  $\alpha > 0$ , and  $\theta > 0$ .

### 2.1. The goods producer

Let the output of goods be produced by the function

$$y_t = A_G(s_{Gt}k_t)^{1-\beta}(l_{Gt}h_t)^\beta. \quad (1)$$

The firm's first-order conditions set the market's real interest rate and real wage equal to the marginal products:

$$r_t = (1 - \beta)A_G[(s_{Gt}k_t)/(l_{Gt}h_t)]^{-\beta}, \quad (2)$$

$$w_t = \beta A_G[(s_{Gt}k_t)/(l_{Gt}h_t)]^{1-\beta}. \quad (3)$$

### 2.2. The consumer problem

The consumer's current period utility function is given by

$$u(c_t, x_t) = c_t^{1-\theta} x_t^{\alpha(1-\theta)} / (1 - \theta). \quad (4)$$

### 2.2.1. Income and human capital constraints

The nominal financial capital constraint is

$$Q_t = M_t + P_t k_t. \quad (5)$$

The nominal income constraint derives from setting the change in financial capital to zero. This sets income of  $r_t P_t s_{Gt} k_t + w_t P_t l_{Gt} h_t + V_t + \dot{P}_t k_t$  minus expenditure of  $P_t c_t + \delta_K P_t k_t$  equal to zero:

$$\dot{Q}_t = r_t P_t s_{Gt} k_t + w_t P_t l_{Gt} h_t + V_t + \dot{P}_t k_t - \delta_K P_t k_t - P_t c_t = 0. \quad (6)$$

Human capital is CRS produced, with capital not used in goods production  $(1 - s_{Gt})k_t$  and time not used in leisure, credit services production, or goods production  $(1 - x_t - l_{Gt} - l_{Ft})$ . The investment in human capital is given by

$$\dot{h} = A_H (1 - x_t - l_{Gt} - l_{Ft})^\delta h_t (1 - s_{Gt})^{1-\delta} k_t - \delta_h h_t. \quad (7)$$

### 2.2.2. Exchange technology

Money and credit are perfect substitutes in purchasing the consumption good. This can be expressed by equating the sum of real money balances and total real credit to the aggregate consumption:

$$(M_t/P_t) + d_t = c_t. \quad (8)$$

Define by  $a_t \in (0, 1)$  the fraction of purchases made with cash, so that

$$[(M_t/P_t)/c_t] + (d_t/c_t) \equiv a_t + (d_t/c_t) = 1. \quad (9)$$

This makes the so-called cash-in-advance, Lucas's (1980) "Clower constraint", merely a part of the description of the perfect substitutability of money and credit:

$$M_t = a_t P_t c_t. \quad (10)$$

The money supply progresses through the government transfer, which is assumed to be made at a constant rate  $\sigma$ :

$$M_{t+1} = M_t + V_t = M_t(1 + \sigma). \quad (11)$$

From Eq. (9), it is clear that the share of purchases made by credit is given by  $1 - a_t$ . Or the total amount of credit used can be expressed as

$$d_t = (1 - a_t)c_t. \quad (12)$$

Consider specifying the production of this credit using an effective-labor only technology, with diminishing returns, whereby  $\tilde{A}_F$  is a function that depends on the level of consumption  $c_t$ :

$$d_t = \tilde{A}_F[c_t](l_{Ft} h_t)^\gamma. \quad (13)$$

With the shift parameter containing this dependence upon  $c_t$ , the function  $\tilde{A}_F$  is specified as  $\tilde{A}_F = A_F c_t^{1-\gamma}$ , and the credit production function is Cobb-Douglas in  $l_{Ft} h_t$  and  $c_t$ :

$$d_t = A_F (l_{Ft} h_t)^\gamma c_t^{1-\gamma}, \quad (14)$$

which can be written using equation (12) as

$$(1 - a_t)c_t = A_F (l_{Ft} h_t)^\gamma c_t^{1-\gamma}. \quad (15)$$

The rationale of the introduction of  $c_t$  into the total productivity factor is that the credit supplier, which in a decentralized framework can be thought of as a hypothetical firm similar to American Express, must take total economic activity as a given. The credit supplier can only hope to increase its share of the total activity that is being exchanged with credit.<sup>3</sup>

The nature of the externality is chosen by restricting the consumption velocity of money to be stable on the balanced growth path, as evidence suggests allowing for shifts due to financial innovation. Rewriting the Eq. (15) as

$$1/a_t = 1/[1 - A_F(l_{Ft}h_t/c_t)^{\gamma}], \quad (16)$$

velocity  $1/a_t$  is stationary because  $l_{Ft}$  and  $c_t/h_t$  are each stationary. Balanced-path changes in velocity, such as increases that result from deregulation and innovation in the Finance sector, are captured when  $A_F$  exogenously increases.<sup>4</sup>

Solving for  $a_t$  from Eq. (16), and substituting into Eq. (10),

$$M_t = [1 - A_F(l_{Ft}h_t/c_t)^{\gamma}]P_t c_t, \quad (17)$$

gives the constraint that enters the consumer maximization problem, which can be found presented in full in the Appendix in Gillman et al. (2001).

Note that Eq. (17) can be solved for  $l_{Ft}$ , the total time devoted by the consumer in the role as credit producer. This “banking time” solution of the constraint presents an exchange constraint that can be viewed as being equivalent to a special case of the shopping-time economy, as for example in Lucas (2000). Except here the time spent in exchange activity is only that time that enters into the credit production function.<sup>5</sup> The advantage of this over the shopping time models is that those models are typically, as in Lucas (2000), calibrated so as to yield a constant interest elasticity of money. Here the interest elasticity rises in magnitude as the inflation rate goes up, as consistent with evidence (see Mark and Sul 2002); the rising elasticity constitutes the central feature used to explain the non-linear nature of the inflation-growth effect.

### 2.3. The effect of inflation on the balanced-growth path

The representative agent maximizes the discounted stream of the period utility of Eq. (4), subject to Eqs. (5), (6), (7), and (17).<sup>6</sup> The marginal rate of substitution between goods and leisure is

<sup>3</sup> Gillman and Yerokhin (2003) detail how this model is equivalent to an interpretation of an Beckerian household production economy with a production of exchange using the intermediate goods of money and credit; the exchange is itself also an intermediate good that is then combined with the goods output to yield the Beckerian household consumption good.

<sup>4</sup> See Gillman and Otto (2002) for an empirical investigation of velocity as given by this model.

<sup>5</sup> See Gillman and Yerokhin (2003) for a proof of the shopping-time/banking-time equivalence and for further discussion.

<sup>6</sup> Details of the equilibrium conditions for this economy are found in Gillman and Kejak (2002); existence and uniqueness of the equilibrium is proved in the case of no physical capital in Gillman et al. (1999).

$$\alpha c/xh = w/(1 + aR + wl_Fh/c), \quad (18)$$

where  $R$  is defined as the nominal interest rate. The marginal rate equals the shadow price of leisure  $w$  divided by the shadow price of goods,  $1 + aR + wl_Fh/c$ . The goods shadow price includes a goods price of 1 and a cost of exchange that is the sum of the average cash cost  $aR$ , and the average credit cost  $wl_Fh/c$ . This relation shows that an increase in the inflation rate, which increases  $R$  directly, goes in the direction of causing  $c/h$  to fall relative to leisure,  $x$ , by a first-order effect. There are second-order changes of lesser magnitude that go in the opposite direction. In particular,  $a$  falls and  $w$  rises as the inflation rate goes up, but calibrations in Gillman and Kejak (2002) show that the rise in  $R$  ends up being dominant for levels of the inflation rate below hyperinflation, as typically defined, and the substitution goes from goods (normalized by human capital) to leisure.<sup>7</sup>

The equilibrium balanced-path growth rate  $g$  is characterized by

$$g \equiv \dot{c}/c = \dot{k}/k = \dot{h}/h = [r - \rho]/\theta, \quad (19)$$

and by the equality of the return of physical capital in goods production to the return on effective labor in human capital production:

$$r = (1 - x)A_H\beta(s_Hk/l_Hh)^{1-\beta} - \delta_h. \quad (20)$$

Equations (19) and (20) suggest that an increase in leisure  $x$  may have a significant effect on decreasing  $r$  and the growth rate.<sup>8</sup> With Eq. (18), these equations show how inflation can cause a negative growth effect through the increase in leisure.

Calibrations in Gillman and Kejak (2002) show that this negative effect is very significant and robust. It occurs for a wide range of parameters around the baseline, which is set by using standard values from the literature. For the non-standard parameters, mainly  $\gamma \in (0, 1)$  of the credit production sector, the full range of values was experimented with and all yield the negative inflation-growth effect. For example, with  $\gamma = 0.2$  (the baseline value as based on evidence in Gillman and Otto, 2002), an increase in the inflation rate from 5 to 15% causes a decrease in the growth rate by 0.27%. The non-linear nature of the inflation-growth effect is illustrated by increasing the inflation rate further from 15 to 25%; this causes a smaller decrease in the growth rate of 0.22%. Such a decreasing magnitude continues to result with continued inflation rate increases.

The non-linearity implies that the inflation-growth effect falls towards zero at high inflation rates. Depending on the calibration, for standard parameters the inflation rate at which the growth rate decrease becomes zero is between 100 and 200%. This is effectively above any stationary (non-hyperinflation) rate of inflation likely to be experienced in any given country.

<sup>7</sup> See Gillman and Kejak (2000) for a human-capital only version of the model, which enables a closed-form solution, and details of how the inflation-growth effect turns positive only for rates of inflation above the level at which the magnitude of the interest elasticity equals one.

<sup>8</sup> Long run evidence presented in Ahmed and Rogers (2000) supports a decrease in the real interest rate as a result of an increase in the inflation rate.

### 2.3.1. Non-linearity of the inflation-growth effect

The intuition for the non-linearity derives from the exchange technology. When the inflation rate is at a low level, the consumer uses mainly money and just a little amount of credit. The theory implies that the interest elasticity of money demand is very low in absolute value, or “inelastic”, at low inflation rates, and that it becomes increasingly more elastic (more negative) as the inflation rate rises and the agent substitutes towards credit. With an inelastic money demand, the agent substitutes from goods to leisure, and a bit from money to credit when the inflation rate goes up. As the interest elasticity increases with increases in the inflation rate, the agent still substitutes from goods to leisure but increasingly substitutes towards the use of credit away from money. The rising interest elasticity, and the emergence of increasing substitution towards credit as the primary substitution channel, means that the agent relies less on the goods to leisure channel. Therefore leisure increases at a decreasing rate, and the growth rate falls by increasingly smaller amounts. The bigger increases in credit and the smaller increases in leisure, as the inflation rate rises, explains why the inflation-growth effect is of smaller magnitude at higher inflation rates.

However, note that if no credit is available, then  $a = 1$  in the model and the interest elasticity of money remains low in magnitude even as the inflation rate rises. This gives a more linear inflation-growth effect whereby the decrease in the growth rate from increased inflation remains large even at very high inflation rates. Below such a case is considered as an alternative for explaining the evidence

### 2.3.2. Tobin effect and the savings rate

The Tobin effect here is a general equilibrium one along the balanced growth path whereby an increase in the inflation rate causes an increase in the input price ratio,  $w/r$ , and in the capital to effective labor ratio in both goods and human capital production. Calibrations show that the inflation rate robustly causes a decrease in the return to capital,  $r$ , as the return on human capital is forced down, and an increase in the real wage  $w$ , as a result mainly of the consumer using more leisure. This induces substitution from effective labor to capital, and produces the model's Tobin-type increase in capital intensity, even while causing a decrease in the growth rate.

The savings rate is shown in this model, in Gillman et al. (2001), to depend on the input price ratio,  $w/r$ , on leisure, and on the nominal interest rate. The effect of an increase in the real interest rate  $r$  is to increase the savings rate. And in equilibrium the savings rate equals the investment rate. It is on this basis that we proxy the effect of the real interest rate on the growth rate through the use of the investment rate. This abstracts from other effects such as the real wage, and so makes the investment rate an imperfect proxy of the real interest rate.

### 2.3.3. Financial development

The credit production function depends primarily on the degree of diminishing returns parameter  $\gamma$ . Calibrations show that as  $\gamma$  decreases from its baseline value, the inflation-growth effect is less. With the interpretation that

less developed countries have a greater degree of such diminishing returns, then the inflation-growth effect is pivoted up for developing versus developed countries, as in Fig. 1 (see Sect. 6).

### 3. The data

Three panels of countries are examined. The first consists of 29 OECD countries; the second panel consists of 18 APEC members (six of them jointly belonging to the OECD); and the third panel includes all 41 countries.

The data are from *EconData* and *World Bank World Tables*. The data set comprises annual measures on the following four variables: Per capita GDP, 1995 \$US million; average annual growth rate of real GDP, percent per annum; GDP deflator, percent per annum inflation rate; and the proportion of gross domestic investment in GDP, percent (these series have the following names: PCGDP, GDPGR, GDPDEF, INVPGDP respectively). The money stock data series is that listed as “money” in the online International Financial Statistics, or as M1 for some countries with multiple monetary aggregate listings; these generally correspond to the M1 aggregate.

The original sample period is 1961–1997 for all countries, except the Czech Republic (1985–1997), Germany (1992–1997), Turkey (1969–1997), Poland (1985–1997), Russia (1990–1997) and Vietnam (1986–1997).

Data is smoothed by setting each 5-year period as one averaged observation, as for example in Ghosh and Phillips (1998).

There appears to be no one definitive measure of the variable that represents the “inflation rate” in the literature. For example, Barro (1995) uses the inflation rate level,  $\pi$ ; while Judson and Orphanides (1996) use the logarithm form,  $\log(1 + \pi)$ . Ghosh and Phillips (1998) use four measures:  $\pi$ ;  $\pi/(1 + \pi)$ ,  $\log(1 + \pi)$  and a non-monotonic transformation,  $(1/(1 - \gamma))\pi^{(1-\gamma)}$ ; Khan and Senhadji (2001) use  $\log(\pi)$ . In the raw data, inflation rates range from  $-11\%$  to over  $6,000\%$ . To avoid hyperinflation measures, the data alternatively is capped at an inflation rate of 50, 100, and 150%, whereby values with higher rates are dropped from the sample. Also the few negative observations are dropped. Examination of the distributions shows that substantial outliers are still heavily skewing the distribution of the level of the inflation rate, such that this may bias the estimated inflation effect. The  $\log(1 + \pi)$  has a more normal distribution of inflation rates.

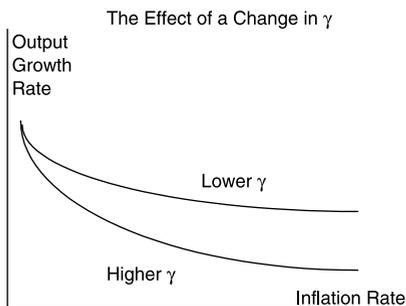


Fig. 1. Comparative statics of the credit production function

#### 4. The econometric model

The economic model derived in Sect. 2, leads to the following econometric specification

$$y_{it} = \alpha_i + \lambda_t + \beta_g g(\pi_{it}) + \beta_{I/y} \ln(I_{it}/y_{it}) + \beta_{y/y} \ln(y_{USA,t}/y_{it}) + u_{it} \quad (21)$$

where:  $y_{it}$  is the average annual growth rate (% pa) in GDP at constant prices, of country  $i$  in year  $t$ ;  $\underline{\beta}$  the vector of unknown coefficients;  $g(\pi_{it})$  a non-linear function of the annual rate of inflation;  $I_{it}/y_{it}$  the proportion of gross domestic investment in GDP (equal to the savings rate in the representative agent framework);  $y_{USA,t}/y_{it}$  the ratio of US output to country  $i$  output;  $\alpha_i$  the country specific, time invariant, effect which captures unobserved country heterogeneity, such as physical tax rates (conditioning on such, allows long-run growth rates to differ across countries, irrespective of their observed heterogeneity);  $\lambda_t$  the country invariant time effects, which account for any trend-deviation effects; and  $u_{it}$  the disturbance term. Signs on the investment/saving rate and on the ratio of incomes are predicted to be positive, while the inflation effect is predicted to be negative.

A fixed effects approach is followed in the estimations, as in Matyas and Sevestre (1996), to avoid any potential biases arising from correlations between the included variables and the unobserved effects.

##### 4.1. Modeling the inflation-growth non-linearity

Several variants of the non-linear relationship between  $\pi$  and growth,  $g(\pi_{it})$ , were estimated. First, as in Judson and Orphanides (1996) and Ghosh and Phillips (1998), the relation is specified as  $g(\pi_{it}) = \log(1 + \pi_{it})$ . In addition, a “tied” spline is constructed. For the log specification, the spline is  $g(\pi_{it}) = \sum_{j=1}^3 D_j \beta_j \log(1 + \pi_{it})$ , where  $D_j$  are three dummy variables, with  $D_1$  representing “low”,  $D_2$  “medium,” and  $D_3$  “high” inflation. Restrictions are imposed on the parameters to ensure that the spline functions are continuous at the spline knots. In addition to these two specifications for the logarithmic function, there is an instrumental variables estimation using the money stock as the instrument.<sup>9</sup>

##### 4.2. Robustness and endogeneity

Experiments were conducted regarding the robustness of the specification of the econometric model, the cut-off point for inflation rate outliers, and possible endogeneity bias from any simultaneity of growth and inflation. In terms of the robustness of the conditioning variables, the literature reports experiments with a variety of conditioning sets. That is, in addition to inflation, different sets of explanatory variables are included in the econometric speci-

<sup>9</sup> Extending the linear model, a quadratic form was also estimated whereby a squared term is included in  $\pi$ . Here  $g(\pi_{it}) = \sum_{j=1}^2 \beta_j \pi_{it}^j$  so that  $g(\pi_{it})$  is a quadratic in the level of inflation. For this, the spline specification is  $g(\pi_{it}) = \sum_{j=1}^3 D_j \beta_j \pi_{it}^j$ . The results did not improve upon the logarithmic specification and are not reported here but can be found in the working paper, Gillman et al. (2001).

fication (for example human capital variables). The different conditioning sets tend to be insignificant in terms of their effect on the inflation-growth relationship (see, for example, Khan and Senhadji 2001). While also experimented with here, such additional variables were not found to be significant and such results are not reported.

Negligible differences were found when using the different inflation rate truncation points of 50%, 100% and 150%. Given the traditional (Cagan 1956) hyperinflation definition of rates over 50%, the base specifications reported below use the 50% cut-off point.

The inflation rate enters the econometric model of Eq. (21) under the assumption that it is an exogenous variable relative to the output growth rate. To try to eliminate potential endogeneity bias, the model is re-estimated by the use of instrumental variables. Ghosh and Phillips (1998) use three alternatives: central bank independence, the exchange regime, and central bank governor turnover. They find a negative significant inflation-growth effect for the first two of these and insignificance for the latter. The approach here is to use current and lagged values of the money supply as instruments for inflation. This is suggested from the Sect. 2 model's balanced-growth equilibrium in which the money supply is exogenous and causes changes in the inflation rate.<sup>10</sup>

## 5. Results

The results reported in Table 1 are with data observations dropped from the sample if the inflation rates are above 50%. The table reports the results for the case when the inflation rate enters in the log form,  $\ln(1 + \pi_{it})$  (Specification A), for the IV version of the log specification (Specification B), and for the spline approximation of a non-linear relationship in the log function without IVs (Specification C). Figures 2–4 illustrate the results, with the “growth” label referring to Specification A, the “IVs” label to Specification B and the “Spline” label to Specification C.

Robust standard errors are reported in each case. In all specifications one rejects the null hypothesis that the individual and time effects are jointly zero. The direction and shape of the inflation effect in Table 1 is clear for Specifications A and B. A negative effect on the variable  $\log(1 + \pi)$  implies a non-linear negative relationship. For the spline, the results can be readily interpreted in terms of the implied inflation-growth profiles, in Figs. 2–4. Here the splines are represented according to their various implied marginal effects with all other variables evaluated at appropriate sample means.

For the OECD group of countries, there exists a striking amount of consensus of the non-linear negative inflation effect, irrespective of the estimation technique and the specification of the inflation effect in the estimated equation. Figure 2 shows that the marginal negative effect of inflation on growth is greatest at low levels of inflation – in particular at levels below

<sup>10</sup> As there were more missing values in these series, the IV versions generally have smaller sample size. Sargan-like tests for the appropriateness of such instruments are difficult to implement in fixed effects models, and are not reported for example in Ghosh and Phillips (1998) IV estimation (Table 5).

**Table 1.** Logarithm of inflation, logarithm of inflation – IVs and spline function in the logarithm of inflation

	OECD Coefficient	FULL Coefficient	APEC Coefficient
Specification A: <i>Within</i> Estimation; $g(\pi_{it}) = \ln(1 + \pi_{it})$			
$\ln(I_{it}/y_{it})$	0.260 (0.026)*	0.220 (0.020)*	0.232 (0.031)*
$\ln(y_{it}^{USA}/y_{it})$	3.059 (1.654)**	2.196 (1.185)**	3.168 (1.589)*
$\ln(1 + \pi_{it})$	-0.774 (0.132)*	-0.427 (0.123)*	-0.060 (0.218)
Constant	-1.717 (0.837)*	-1.180 (0.896)***	-2.668 (1.786)***
$\bar{R}^2$	47%	48%	43%
F-test	9.254*	8.598*	4.775*
NT	932	1,253	528
Hausman	3.813*	6.176*	5.162*
Specification B: IV <i>Within</i> Estimation; $g(\pi_{it}) = \ln(1 + \pi_{it})$			
$\ln(I_{it}/y_{it})$	2.255 (0.487)*	2.765 (0.428)*	3.289 (0.607)*
$\ln(y_{it}^{USA}/y_{it})$	-5.190 (1.541)*	-3.939 (1.146)*	-2.010 (1.585)***
$\ln(1 + \pi_{it})$	-0.922 (0.168)*	-0.617 (0.147)*	-0.448 (0.236)**
Constant	2.120 (0.944)*	1.720 (0.897)**	1.287 (1.435)
$\bar{R}^2$	44%	46%	46%
NT	835	1,086	458
Specification C: <i>Within</i> Estimation of the Spline Function; $g(\pi_{it}) = \sum_{j=1}^3 D_j \beta_j \log(1 + \pi_{it})$			
$\ln(I_{it}/y_{it})$	0.258 (0.026)*	0.213 (0.020)*	0.219 (0.031)*
$\ln(y_{it}^{USA}/y_{it})$	3.635 (1.674)*	2.532 (1.190)*	3.347 (1.590)*
$\pi_{it}$	-0.567 (0.164)*	-0.182 (0.155)	0.222 (0.272)
$(\ln[1 + \pi_{it}] - \ln[10]) \times 1(\pi_{it} > 10)$	-1.053 (0.565)**	-1.117 (0.544)*	-0.912 (0.971)
$(\ln[1 + \pi_{it}] - \ln[20]) \times 1(\pi_{it} > 20)$	0.589 (1.153)	0.297 (1.039)	-0.849 (1.767)
Constant	-2.037 (0.849)*	-1.431 (0.901)***	-2.827 (1.789)***
$\bar{R}^2$	47%	48%	43%
F-test	9.024*	8.588*	4.856*
NT	932	1,253	528

Notes: *p*-value of *F*-test for joint significance of all of the unobserved (fixed) effects (null model, are jointly zero); *Hausman* is the Hausman test for endogeneity of the inflation variable (null model is of exogeneity); robust standard errors in parentheses.

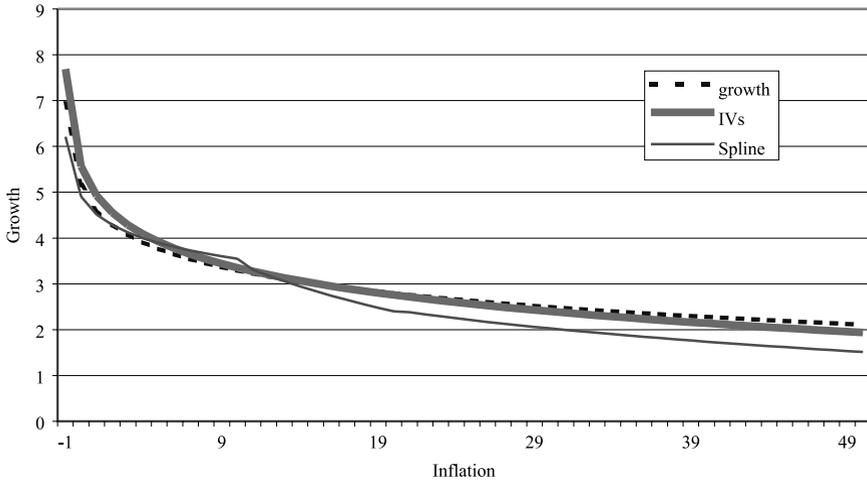
\* Reject (two-sided) null hypothesis at 5% size.

\*\* Reject (two-sided) null hypothesis at 10% size.

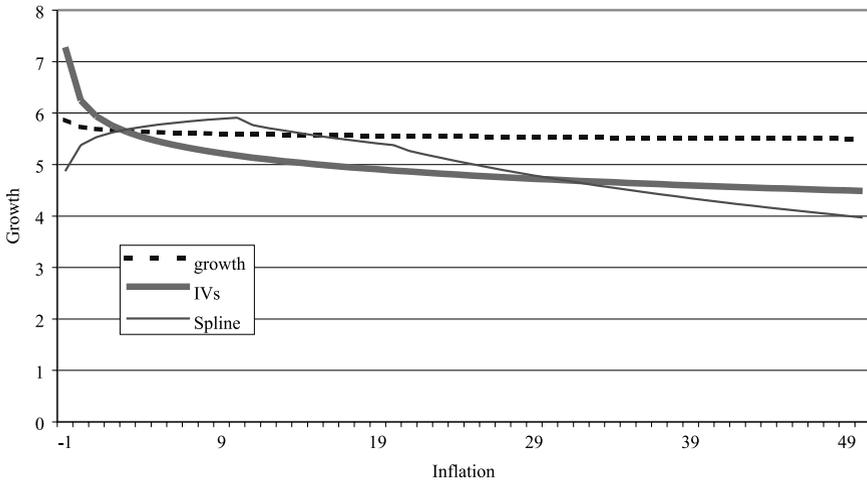
\*\*\* Reject (one-sided) null hypothesis at 10% size.

around 10%. Moreover, in each of the separate splines, the inflation effects are individually significant, at least at the 10% level, with one exception being the high inflation section of the spline function in the log specification. Instrumental variables estimation gives an almost identical result to those without instruments, suggesting little effect on the inflation rate coefficient of any endogeneity between inflation and growth.

When only APEC countries are considered, illustrated in Fig. 3, further reductions in significance levels are witnessed, and the expected non-linear relationship is only somewhat evident in the logarithm specification. The only



**Fig. 2.** Inflation-growth relationship, OECD, Inflation < 50%



**Fig. 3.** Inflation-growth relationship, APEC, Inflation < 50%

significant inflation effect comes with the IVs estimation, with a negative inflation-growth effect at all levels of the inflation rate. Here the coefficient is about half of that of the OECD inflation-growth effect. For the splines estimation, in Fig. 3, there is a positive but insignificant effect at low levels of inflation. This insignificant effect is increasingly negative at levels of inflation in excess of 10%.

The full sample results in Table 1 show a lower significance level than the OECD results, for the inflation variables, in one case. This is for the spline results in the range of the lowest inflation rates. It reflects the APEC positive but insignificant results in this range. Also, the full sample coefficient of the inflation effect in the IVs estimation is about halfway between the level of the OECD and APEC coefficients. These results can be summarized as saying that the OECD results show up in the entire sample, but with less robustness.

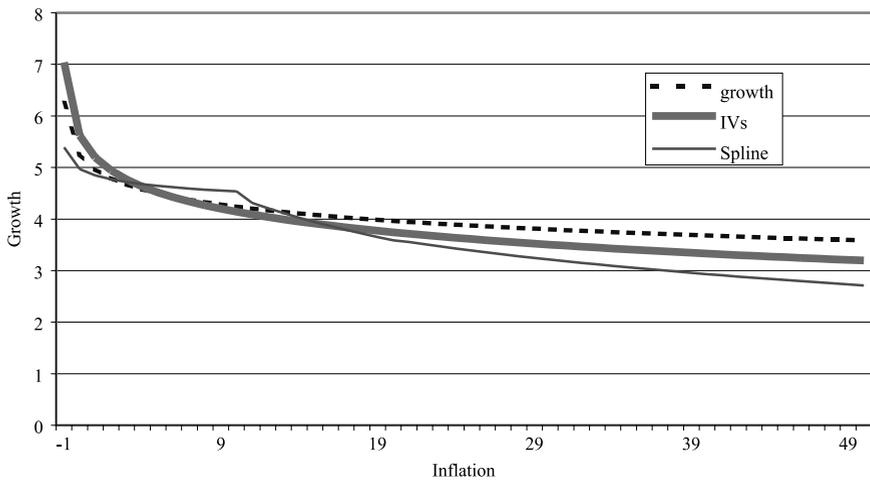


Fig. 4. Inflation-growth relationship, Full sample, Inflation < 50%

The non-linearity still emerges in all three specifications, as shown in Fig. 4, with it most pronounced in the logarithm specification.

Taken together, the results show the importance of separating out the OECD from the APEC countries, in the sense that the negative effect of the inflation rate is more robust and stronger in the separate OECD sample. However, instrumental variable estimation finds that the theoretically-predicted effect still is operative in the generally less financially-developed APEC group.

## 6. Discussion of results

### 6.1. Comparison

The results compare closely to those of Khan and Senhadji (2001), Judson and Orphanides (1996), and Ghosh and Phillips (1998). First, our use of the logarithm specification has support in Ghosh and Phillips (1998) who find this specification to have the best fit in non-linear models, while finding that the alternative linear specification is biased. Second, all of these studies above find significant negative inflation-growth results for rates above their chosen threshold values, for all samples. Third, for rates of inflation below the threshold values, using splines and no instrumental variables, all three report a positive but insignificant effect of inflation on growth for non-OECD (or lower income) samples, and a negative inflation-growth effect for OECD (or high income, or developed) country sub-samples.

Khan and Senhadji (2001) find an optimal threshold value inflation rate for developing nations sample of 11% with a positive and insignificant inflation-growth effect for rates below the threshold, without using instrumental variables. This corresponds to our spline results in Fig. 3, which show a somewhat positive but statistically insignificant effect of inflation for inflation rates 10% or below. Khan and Senhadji (2001) further find a

significant negative effect for all inflation rates above one percent for developed countries, similar to both our non-instrumented and instrumented results in Fig. 2. Judson and Orphanides (1996) use a 10% threshold value below which they find positive and insignificant effects for their non-OECD sub-samples, similar to our Fig. 3 spline results. And for the OECD at inflation rates below the threshold, they find a negative insignificant inflation-growth value; this compares to our Figure 2 spline except that our results are significant.<sup>11</sup>

Ghosh and Phillips (1998) pick a two and a half percent inflation rate as the threshold value and find a positive inflation-growth effect for lower income sub-samples of countries, and a negative inflation-growth effect for an upper income sub-sample; again these non-instrumented results compare directly to our APEC and OECD log specification splines. When they use exchange rate and central bank independence instrumental variables, they report significant negative inflation-growth effects for their full sample (sub-samples not reported); this compares to our negative IV effects in all log specifications.

### 6.2. Characterization

To interpret the results, first consider their characterization. Consider a comparison of any of the three alternative OECD log specifications in Fig. 2 relative to the APEC IV log specification in Fig. 3. The initial slope of the APEC profile, at the lowest inflation rate, is not as steep as the comparable OECD slope. And while both the APEC and OECD slopes show significant non-linearity, it can be seen that the slope of the APEC profile is flatter at all inflation rates. Thus the APEC profile is less non-linear and similar to a “pivoting up” of the OECD profile.

### 6.3. Interpretation

There are two dimensions of the credit model that aid in the interpretation of these results. First is the general extension of the cash-only model. To see this, consider an explanation 1) using the cash-only economy which is the special case of  $a = 1$ , and 2) the extended model of Sect. 2 with credit being produced. Calibrations in Gillman and Kejak (2002) show that the model with cash-only has a bigger inflation-growth effect but a substantially more linear one, unlike any of the profiles in Fig. 2. When the inflation rate rises, in the cash-only model the magnitude of the interest elasticity rises slightly, while with the provision of credit in the model the magnitude of the interest elasticity of money rises much more quickly, making the inflation-growth effect increasingly much smaller, as in Fig. 2. A simulated cash-only economy inflation-growth profile, as based on a calibration such as in Gillman and Kejak (2002), if superimposed on those profiles of Fig. 2, would “cross” the other lines at moderately high levels of the inflation rate because the growth rate would fall too quickly relative to the evidence. In contrast the credit

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<sup>11</sup> Khan and Senhadji (2001) note in their conclusions specifically that the inflation and output growth rates may be endogenous, so that non-instrumented results may entail biased estimate coefficients.

model simulation shows a profile that tapers out towards a zero inflation-growth effect, as in Fig. 2.

Second, the use of the credit production model has the additional advantage in that the nature of financial development within the economy can be described, and the interest elasticity determined, by the credit technology parameters. This allows differences in such parameters to be used to potentially explain differences in the inflation-growth profiles between the OECD and APEC results. Figure 1, showing two inflation-growth profiles with a different degree of the diminishing returns parameter,  $\gamma$ , corresponds well to the differences found between the OECD and APEC profiles with IV. Since  $\gamma = 1$  is the case of constant returns to scale, a smaller  $\gamma$  indicates a greater degree of diminishing returns. It is plausible that the less developed economies would have a greater degree of diminishing returns, which would suggest assigning a lower value of  $\gamma$  to APEC than to the OECD. Calibrations in Gillman and Kejak (2002) show that a smaller  $\gamma$  implies a higher level of the interest elasticity of money. So as the inflation rate rises from low levels, the initial decrease in growth would not be as severe. And as inflation continued to rise, the higher interest elasticity would make the profile for APEC have a flatter slope at all levels of the inflation rate, as in the IV estimation of Fig. 3.

## 7. Conclusion

Our results confirm findings in the literature of a significant negative inflation-growth effect. Further our non-instrumented results replicate the insignificant positive inflation growth effect at low inflation rates for developing countries. Use of instrumental variables is not common in literature. Ghosh and Phillips (1998) report the use of IVs for one sample and find significant negative inflation-growth effects, but do not distinguish between regions. Our results suggest that the instrumental variables make a difference for the APEC but not the OECD sample. And these instrumented results show a negative inflation-growth effect at all levels of the inflation rate in all samples.

The results indicate interesting differences between regions that we interpret through the use of the endogenous growth human capital economy, with credit production explicitly modeled. With the advantage of the additional credit sector microfoundations, the paper presents a way to explain comprehensively the inflation-growth empirical evidence with a theoretical model. In particular, the inflation tax causes substitution to leisure at a decreasing rate as the inflation rate rises and the magnitude of the interest elasticity of money likewise rises. This causes a decreasing negative inflation-growth effect, at all levels of the inflation rate, and causes its highly non-linear inflation-growth profile. This is a human capital driven growth model, as in Lucas (1988) and as used extensively in the macroeconomic literature, but the paper's contribution is to use it to generate and interpret the inflation-growth profile.

The theory is consistent with a positive realignment towards a higher capital to effective labor ratio as a result of inflation, what we consider to be a generalized Tobin effect. This occurs even while the growth rate goes down. Such realignment has found empirical support in Gillman and Nakov (2003), for the postwar US and UK; see also Ahmed and Rogers (2000) for additional long term US evidence in support of a Tobin effect. The growth

evidence of this paper, given its theoretical model, makes it a complement to the Tobin evidence.

The model also attributes a significant role to the leisure substitution away from employment as a result of inflation. While there is no unemployment *per se* in the model, the change in employment makes this relation similar in some ways to a reverse long-run Phillips curve. Further, there is evidence that is consistent with this. Ireland (1999) finds that inflation and unemployment are cointegrated, while testing a Barro-Gordon hypothesis that unemployment causes inflation. However he presents no evidence on causality and so these results equally support the model here in which inflation (really an increase in the money supply growth rate) causes a decrease in employment. Further, Shadman-Mehta (2001) finds similar inflation and unemployment cointegration, and also presents evidence that inflation Granger causes unemployment. This study uses long historical series for the UK including Phillips's original sample sub-period. Parallel to the growth and Tobin-type evidence, the employment aspect of the model could be further investigated for example by using the theory to give the structural VAR in Shadman-Mehta (2001) even more structure, and by also studying other countries ideally within a panel.

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