Growth and Inflation: A Cross-Country Study

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This paper examines the effect of inflation on real growth in a Solow growth model using data from a cross section of countries over a 30-year period. The advantage of using a theoretical model is that it reduces the risk that the results will reflect data-mining. The results suggest that the 5 percentage point reduction in inflation from the 1970s to the 1980s would increase the growth rate of real GDP per head by between 0.1 and 0.5 percentage point. This effect would be worth between 15 percent and 140 percent of one year's income. Even the lower of these projections would be larger than most estimates of the costs of bringing inflation down.

Since the beginning of the 1980s, the Federal Reserve has stressed its long-run commitment to achieving and maintaining low inflation. A number of other central banks have espoused a similar objective, and many have adopted (or had imposed on them by their governments) numerical targets for inflation and have followed monetary policies designed to achieve them.[1] There have been a number of proposals that the Federal Reserve also should focus its attention on keeping inflation low and refrain from policies that are primarily intended to affect output or employment.[2]

The argument that the Federal Reserve should emphasize holding down inflation comes from the twin beliefs that inflation imposes costs that reduce economic welfare and that monetary policy can lower inflation but cannot have a permanent effect on real aggregate demand. This paper focuses on the first of these points and examines the argument that persistent inflation leads in the long run to a reduced growth rate of real GDP. Since a policy to reduce inflation is likely to slow economic activity in the short run, it is useful to estimate its benefits through higher long-run output growth.

In the short run, faster real growth may be associated with more rapid inflation. Often, this is because strong growth is the result of a rise in aggregate demand that causes real output to increase at the same time as it bids up prices.[3] To reduce inflation, the central bank must curb aggregate demand, and this may lower output and employment temporarily. This is why resisting inflation often is unpopular. However, this paper is concerned with the long-run relation between inflation and real growth rather than with the

1. For example, Canada, New Zealand, and several European countries have specified targets for inflation either as single values or as ranges.

2. This policy emphasis on keeping inflation *low* rather than keeping employment or output *high* has come during a period of rising output and employment and declining inflation both in the U.S. and in many countries abroad. Whether it would continue if the world were confronted with a deep recession is unclear. My judgment is that most central banks would try to end a depression even if it were not part of their official job description.

3. However, because of differing lags in the response of output and prices to demand shocks, the observed *contemporaneous* correlations between real growth and inflation are not necessarily positive (Judd and Trehan 1995).

short-run dynamics. If inflation has a long-run influence on output (in levels or growth rates), it is probably because it affects aggregate supply rather than demand.

Inflation might affect aggregate supply in several ways.[4] First, inflation may make it more difficult for households and firms to make correct decisions in response to market signals. When most prices are rising, economic agents may find it more difficult to distinguish between changes in relative prices and changes in the overall price level. This difficulty may interfere with the efficient operation of the price system and so slow growth.

Second, inflation imposes various costs that would disappear if average prices were stable. Familiar examples are the menu costs of changing prices and wage rates frequently, the search costs imposed on buyers and sellers when prices change often, and the costs of economizing on holdings of non-interest-bearing money. In addition, Feldstein (1996) has suggested that even relatively low inflation imposes significant deadweight losses on the economy when the tax system is not fully indexed. In addition to these *pecuniary* costs, inflation also has *social* costs because it has differing effects on economic agents, with some benefitting and others being harmed. These differential effects add to the uncertainties that agents face, which may be undesirable even for those who turn out to benefit. Moreover, private actions taken to avoid these effects may hurt the overall economy but yield no overall benefits. For example, in an inflationary economy, talented persons may devote their energies to mitigating the effects of inflation rather than to developing products and processes that would raise overall living standards. Unfortunately, these activities often are included in measured GDP, which may make it difficult to identify the negative effects of inflation.

Finally, inflation may affect saving and investment decisions, reducing the proportion of GDP devoted to investment and so causing the economy to accumulate less human or physical capital. For example, when inflation is high, it often is more variable, thus harder to forecast. This may make it more difficult to deduce the real returns on investments from available market information and may cause savers and investors to be less willing to make long-term nominal contracts or to invest in long-term projects. The resulting reduced stocks of productive capital may, in turn, imply lower levels of future GDP.[5]

These arguments suggest that there are a number of reasons why persistent inflation might tend to reduce the level and/or growth rate of GDP in the long run. A cursory look at the data suggests that they are consistent with these predictions. Using a sample of 58 countries with reasonably high quality data,[6] the raw correlation between average inflation and real per capita GDP growth between 1960 and 1990 is –0.25, which is significant at the 5 percent probability level. Barro (1991), Cozier and Selody (1992), and Fischer (1993) also conclude that countries with higher rates of inflation tend to have lower rates of real growth in the long run.

However, Levine and Renelt (1992) and Levine and Zervos (1993) argue that cross-section regression estimates of the relation between GDP growth and a variety of potential causal variables—including the inflation rate—tend to be "fragile" in the sense that the results are sensitive to the precise set of variables included in the equation. Thus, they argue that this research is unusually subject to the dangers of data-mining. This paper tries to deal with this problem by basing the empirical analysis on a well-established theoretical model of economic growth, by making use of the restrictions the model implies, and by avoiding the inclusion of other variables. This approach may provide more precise estimates of relevant parameters and, perhaps more important, guard against the dangers of data-mining emphasized by Levine and his co-authors. This paper concludes that lowering inflation by 5 percentage points (roughly equal to the decline in inflation in the U.S. from the 1970s to the 1980s) would raise *average annual real growth* by at least 0.1 percentage point and perhaps by as much as 0.5 percentage point. The effect is larger than most estimates of the short-run costs of lowering inflation.

The plan of the paper is as follows. Section I briefly discusses the Mankiw, Romer, and Weil (1992) extensions to the standard Solow growth model to incorporate two kinds of capital—tangible and human—and to show how the economy will evolve when it is away from its long-run equilibrium path. This section then extends the model further to allow inflation to influence the rate of technical change, which determines the growth rate of per capita GDP in steady state equilibrium. Sections II and III describe the methodology and data for the empirical analysis that follows in Section IV. A brief discussion of the *quantitative*

4. For a fuller discussion of the costs of inflation, see Peter Howitt (1990).

5. This negative effect of inflation on capital formation might be offset by the so-called Mundell-Tobin effect. Mundell (1963) and Tobin (1965) each argued that although inflation makes *financial* assets less attractive, it might *increase* the willingness of investors to hold *tangible* assets because these may act as a hedge against inflation. The resulting greater accumulation of tangible capital could result in an increase rather than a decrease in the capital-labor ratio in an inflationary environment.

6. This sample is discussed in more detail in Section III.

significance of the results comprises Section V, and the conclusions are summarized in the concluding Section VI.

I. Neoclassical Growth

This paper takes off from Solow's neoclassical growth model (Solow 1956) and, in particular, from the paper by Mankiw, Romer, and Weil (1992) (MRW) that showed that a direct application of the Solow model could explain a large proportion of the cross-country variation in long-run GDP growth rates. I extend the MRW results by allowing for the possibility that inflation tends to reduce the rate of technical change.

In the Solow growth model, the *level* of output per worker depends on the stock of capital per worker, which in long-run equilibrium depends on the supply of saving per worker. An increase in the supply of saving allows the economy to adjust toward a larger stock of capital and hence a higher level of output. The model assumes that technical change is *Harrod neutral,* i.e., technical progress is analogous to increasing the supply of workers. The supply of labor is measured in "effective workers" and can be raised either by increasing the number of workers or by making those workers more effective through technical change.

When the economy reaches long-run equilibrium, the capital stock (and hence the level of output) per *effective* worker is constant. This means that the *equilibrium growth rate* of GDP per *actual* worker depends *only* on the rate of technical change. Hence, any effect of inflation on steady state growth must occur through influencing the pace of technical change.[7]

MRW extend the Solow growth model by assuming that total output, Y, depends on inputs of labor, L, and of both tangible and human capital, K and H. Assuming a constant-returns-to-scale Cobb-Douglas production function (with parameters α and β) and using lower-case letters to refer to quantities per worker, real income and real income per worker may be written[8]

$$(1)\qquad Y_t = K_t^{\alpha} H_t^{\beta} (A_t L_t)^{1-\alpha-\beta}$$

$$y_t = A_t^{1-\alpha-\beta} k_t^{\alpha} h_t^{\beta}.$$

MRW show that in the long run the economy converges to a moving equilibrium in which output is given by

$$(2)\quad \ln y_t^* = \ln A_t - \frac{\alpha+\beta}{1-\alpha-\beta}\ln(n+g+\delta) + \frac{\alpha}{1-\alpha-\beta}\ln s_K + \frac{\beta}{1-\alpha-\beta}\ln s_H$$

$$= \ln A_0 + gt + \gamma_1 \ln(n+g+\delta) + \gamma_2 \ln s_K + \gamma_3 \ln s_H\ ,$$

where y_t^* = $(Y/L)_t^*$ = real income per worker in steady state
A_t = level of technology in period t
n = growth rate of labor force
g = growth rate of technical change
t = time
δ = depreciation rate for tangible and human capital
s_K = investment in tangible capital as share of GDP
s_H = investment in human capital as share of GDP.

Since gt is the only term that changes over time, equation (2) implies that equilibrium real income per worker, y_t^*, grows at rate g, the pace of Harrod-neutral technological change. Constant returns implies that

$$\gamma_1 < 0,\ \gamma_2 > 0,\ \gamma_3 > 0, \text{ and } \gamma_2 + \gamma_3 = -\gamma_1.$$

This means that more investment (larger s_K or larger s_H) enables the economy to reach a higher level of tangible or human capital in equilibrium and hence more output per head. Conversely, a higher depreciation rate (δ) or faster growth in the effective labor force[9] ($n + g$) means that the economy will converge to a lower ratio of capital to effective labor in equilibrium and so to lower output per head.

At any point in time, an economy may not be in steady state, especially since reasonable parameter values suggest that convergence to long-run equilibrium may take several decades.[10] Hence the growth rate over the short to medium run depends not only on the factors that influence steady state growth, but also on the current level of output (relative to the equilibrium output) and the rate of convergence. MRW show that when the economy is away from its steady state, the level and growth of output may be written[11]

$$(3)\quad \ln y_t - \ln y_0 = gt + (1 - e^{-\lambda t})[\ln A_0 + \gamma_1 \ln(n + g + \delta) + \gamma_2 \ln s_K + \gamma_3 \ln s_H - \ln y_0]$$

7. Solow assumed that labor force growth depends only on demographics and ignored the role of changes in labor force participation. This means that the model makes no distinction between the population and the labor force. I adopt this assumption.

8. Throughout the equations in the paper, lowercase letters refer to quantities per worker. Thus, Y refers to total output and y to output per worker. Note that MRW use lowercase letters to refer to quantities per *effective* worker.

9. Since the stock of labor grows at rate n and technical progress occurs at rate g, the *effective* labor force grows at rate $n + g$.

10. MRW estimate that it would take 35 years for half of the adjustment to steady state to occur (p. 423). This estimate is close to one made by Sato (1966).

11. This equation differs slightly from the corresponding MRW equation because it refers to the growth of output per worker rather than per *effective* worker. It is derived by differentiating equation (2) with respect to equilibrium GDP and using a Taylor approximation.

with the same parameter definitions and restrictions as in equation (2). In addition, MRW show that the convergence parameter λ depends on the other parameters of the model:[12]

$$\lambda = (n + g + \delta)(1 - \alpha - \beta) \,. \tag{4}$$

To the extent that inflation interferes with the efficiency of markets, it might tend to reduce the growth rate of labor productivity, g, which is taken as constant in the above equations. In this case, the growth rate of output per worker would be reduced both in the steady state and during the period of convergence. If inflation were to cause uncertainty and make savers and investors less willing to undertake long-term projects, it might lower the rates of investment in tangible and human capital, s_K and s_H. A reduction in investment would lower the steady state capital-labor ratios (including both tangible and human capital) and hence reduce the level of output per worker in long-run equilibrium. In this case, the growth rate of output would be affected during the transition to the steady state equilibrium, but not after the economy reaches its long-run equilibrium path. Since this transition might take several decades, however, a lower level of equilibrium GDP relative to current GDP will imply slower growth for a very long time.

Thus in this simple neoclassical framework, inflation might influence real GDP growth by affecting either the growth rate of productivity or the rates of investment in human or tangible capital. In this paper, I focus on the first of these channels and assume that the rates of investment in human and tangible capital are exogenous and independent of inflation.

If inflation slows technical progress, this implies that

$$g_t = g(\pi_t), \text{ where } \frac{\partial g}{\partial \pi} \leq 0 \,, \tag{5}$$

where g_t and π_t are the rates of technical progress and of inflation at time t. Thus, the level of technology at time t depends on the history of inflation up to that time:

$$A_t = A_0 e^{\int_0^t g(\pi_s)ds} \,, \tag{6}$$

which may be approximated as

$$A_t = A_0 e^{(g_0 + g_1 \bar{\pi})t} \,, \tag{7}$$

where $\bar{\pi}$ is average inflation between dates 0 and t, and g_1 is negative.[13]

When this model of technology growth is substituted into equation (3), the result is

$$\ln y_t - \ln y_0 = (g_0 + g_1\bar{\pi})t + [1 - e^{-\lambda t}] \times [\ln A_0 + \gamma_1 \ln(n + g_0 + g_1\bar{\pi} + \delta) + \gamma_2 \ln s_K + \gamma_3 \ln s_H - \ln y_0]. \tag{8}$$

Since g_1 is negative, the first term of this equation implies that higher inflation may lower the steady state growth rate of output per worker. However, the initial negative effect of inflation on growth may be smaller than the steady state effect because the adjustment to the new lower growth rate takes time and because the rate of convergence to the steady state is reduced.[14]

II. METHODOLOGY

Several studies have used either cross-section or time series data to examine the relation between inflation and growth. Cozier and Selody (1992), for example, estimate cross-section equations that are similar to equation (8), and Grimes (1991) estimates time series equations for a sample of advanced countries. In this paper, I use both time series and cross-section data. Initially, I estimate cross-section equations for five large samples of countries in which the variables represent averages over a long sample period (1960–1990). This is the procedure used by MRW and by Cozier and Selody. The results generally confirm the Cozier and Selody finding of a negative relation between long-run inflation and real growth.

A potential problem with this procedure is that the observed negative cross-section correlation between average inflation and average growth over a long period might be

12. It is difficult to find an intuitive explanation of this result, and MRW do not provide one.

13. Cozier and Selody (1992) assume that the *level* rather than the *growth rate* of technology is affected by inflation:

$$A_t = A_0 e^{gt} \bar{\pi}^{\theta} \tag{7a}$$

One problem with this formulation is that the influence of inflation on growth presumably would depend on how long it persists, so that θ should depend on t. Also, it implies that the marginal effect of inflation on output growth declines as the level of inflation rises, which seems counterintuitive. Finally, this formulation, taken literally, implies that the rate of technical change may not be defined if inflation is negative.

14. Equation (8) may be written in the form

$$\ln y_t - \ln y_0 = (g_0 + g_1\bar{\pi})t = (1 - e^{-\lambda t})(\ln y_0^* - \ln y_0). \tag{8a}$$

When this expression is differentiated with respect to t and then with respect to $\bar{\pi}$ we obtain

$$\frac{\partial^2 \ln y_t}{\partial t \partial \bar{\pi}} = g_1 + \lambda e^{-\lambda t} \frac{\partial \ln y_0^*}{\partial \bar{\pi}} + (1 - \lambda t)e^{-\lambda t}(\ln y_0^* - \ln y_0)\frac{\partial \lambda}{\partial \bar{\pi}} \,. \tag{8b}$$

Using the restriction that $\lambda = (n + g_0 + g_1\pi + \delta)(1 - \alpha - \beta)$, this derivative may be written as

$$\frac{\partial^2 y_t}{\partial t \partial \bar{\pi}} = g_1 - e^{-\lambda t}(\alpha + \beta)g_1 + e^{-\lambda t}(1 - \lambda t)(\ln y_0^* - \ln y_0)(1 - \alpha - \beta)g_1 \,. \tag{8c}$$

due to a few major supply shocks that had different effects on the *levels* of prices and of output in different countries. Suppose, for example, that an oil shock during the sample period permanently raised the level of prices and lowered the level of output in *some* countries but not in others. This would mean that, over the whole sample period, the *average* rate of inflation would be higher and the growth rate of real GDP would be lower in the countries affected by the oil-shock than in those that were not affected. In this case, a cross section might detect a negative correlation between average growth rates of prices and output over the whole sample period even if, in fact, there was *no* causal relationship between inflation and output growth.[15]

This possibility may be examined by estimating a *series* of cross sections over different (shorter) periods rather than a single cross section covering a longer span. Each different cross section is affected by different supply shocks. If we find a negative cross-section relation between inflation and real growth in *different* periods, this would be more consistent with a structural relation between *growth rates,* rather than the effect of supply shocks on the levels of prices and output. This is because supply shocks vary over time and are likely to affect different countries in a different way and so would influence each cross section in a unique way.

For this purpose, the data were divided into three separate cross sections, each covering a ten-year sample period: 1960–1970, 1970–1980, 1980–1990. These periods should be long enough to identify long-run relations. For each sample of countries, three cross-section equations were estimated, subject to the restriction that the coefficients on the non-inflation ("Solow") variables were constant between periods.[16] This pooled time series/cross-section estimation technique should avoid the "supply-shock" problem that arises when a single cross section is estimated, but it uses all the data to obtain single estimates of the coefficients on the Solow variables. I test whether the inflation coefficients are negative and also whether these inflation effects are constant over the three subperiods. This should provide evidence as to whether any negative relation between inflation and output growth over the full 30-year period is due to a persistent relation that appears in each subperiod rather than to supply shocks that affect some periods but not others.[17]

Real GDP growth rates might vary systematically among countries for reasons that are not captured by the variables emphasized by neoclassical theory.[18] As a result, growth in any particular country might be systematically higher or lower in each of the three cross sections. One way to allow for this possibility is to include additional variables that might capture such systematic differences among countries. However, since there is no obvious way of choosing what variables to add to the estimated equations, this approach raises the danger of data-mining and would be likely to lead to Levine's "fragility" problem. Hence this approach was not used in this paper.

Instead, the three cross-section equations were estimated by Zellner's (1962) seemingly-unrelated-regressions (GLS) technique. Applied to a set of cross sections, this estimation method assumes that each country's real growth rate in any subperiod is correlated with its growth rate in other subperiods, but is unrelated to growth in other countries. If a country experienced systematically higher than average (lower than average) growth for reasons that are not captured by the structural variables in equation (8)—and thus showed consistently positive (negative) errors in the cross sections—this estimation technique will allow for this across-time covariance.

III. DATA SOURCES

The data set used is the 1993 edition of the system of Real National Accounts constructed by Summers and Heston (1991). These accounts provide cross-country data on real GDP, the price level, the working-age population, and the share of tangible investment in GDP for the period from 1960 to 1990. In these accounts, the price level is defined relative to the U.S. price level. Summers and Heston describe this measure of prices as the "international price level." The inflation rate in the estimated equations is defined as

15. This effect would not occur if the oil shock had exactly the same effect on the levels of output and prices in all countries.

16. That is, the coefficients on ln s_K, ln s_H, and ln $(n + g_0 + g_1\bar{\pi} + \delta)$ are constrained to be the same for the three cross sections. As shown in equation (8), the intercept terms in these equations include the log of technology in the initial period, log(A_0). Hence, it is not appropriate to constrain these terms to be equal, because the initial period is different in each cross section.

17. Fischer (1993) estimates panel regressions that combine annual time series and cross-section data. The problem with this method—which Fischer recognizes—is that the annual time series will pick up demand-side as well as supply-side influences. By using only ten-year averages, the estimates in this paper should isolate supply-side effects.

18. For example, a stable political system might promote faster growth because it encourages firms to innovate without fear that new technologies will be misappropriated. Several studies have found that a variable measuring the number of coups and revolutions is negatively correlated with growth (see Barro 1991).

the annual log difference of this international price level plus the annual log difference in the U.S. GDP deflator.[19] Other research on the effects of inflation on growth frequently uses the consumer price indexes for various countries. The advantage of the Summers and Heston data is that the price and output indexes for all countries are taken from a single source and so are more likely to be consistently defined. The population growth rate is defined as the annual log difference of the working-age population. Following MRW, I assume a depreciation rate (δ) for both tangible and human capital of 0.03 and a growth rate of technology in the absence of inflation (g_0) of 0.02.

The equations were estimated for five samples of countries.[20] The first sample, "All Non-oil," comprises all 78 countries for which full 1960–1990 data are available. The second sample, "High Quality," excludes countries with populations in 1960 of less than one million or with primary data to which Summers and Heston assign a grade of "D"; it comprises 58 countries. The third sample, "OECD," comprises 21 OECD countries excluding Turkey, Iceland, and Luxembourg.[21] The fourth sample, "OECD+," enlarges the OECD sample by adding seven countries in the High Quality sample that have income levels above that of the poorest OECD country (Portugal). The countries added are Hong Kong, Israel, Mexico, Singapore, South Korea, Syria, and Venezuela. Finally, the fifth sample, "Rest of the World," comprises the countries in the High Quality sample that are not in OECD+.

I use a variable constructed by MRW to measure investment in human capital. This variable, which MRW call SCHOOL, is defined as the proportion of the working-age population that is in secondary school.[22] MRW argue that this proportion is a proxy for the share of GDP that is used for investment in human capital. Unfortunately, SCHOOL may be a poor proxy for differences in human capital investment among advanced countries, most of which provide high levels of education. I also estimated equations using a measure of the *stock* of human capital constructed by the World Bank (Nehru, et al., 1995). The results from these equations are similar to those presented below. In most cases, the estimates of the effect of these alternative measures of human capital on growth are not statistically significant.

IV. Empirical Results

In this section, I report the results of estimating equation (8) for various cross-section samples and various time periods, and under various theoretical restrictions.

30-Year Cross-Section Results

Table 1 shows the results of estimating cross-section regression equations over the full 30-year sample period. These regressions are similar to those estimated by MRW (MRW, Tables V and VI). I include these results to check that they are broadly similar to those estimated by MRW, who used an earlier version of the Heston-Summers data set covering a somewhat shorter time period (1960–1985). The equations in Table 1 impose the adding-up restriction that $\gamma_1 + \gamma_2 + \gamma_3 = 0$; in all cases, an F test indicates that this restriction cannot be rejected.[23] The equations are estimated by nonlinear regression to obtain estimates of α, β, and λ.[24] All the coefficients in these equations have the signs predicted by theory and are statistically significant in most cases.[25] Previous research suggests that α should be close to one-third, and MRW argue that β should be between one third and one half.[26] In the case of α, this prediction is roughly satisfied, but the estimates of β are lower and, in the case of the OECD and OECD+ samples, imprecise. This may be because SCHOOL is a less satisfactory proxy for human capital investment in advanced economies.

19. Note that the empirical work in this paper was completed before the revision of the U.S. national accounts in 1995.

20. Countries that are major producers of oil are excluded from all samples.

21. Luxembourg and Iceland are excluded because they are too small and Turkey because its GDP level is far below that of other OECD countries.

22. David Weil kindly provided me with quinquennial data on this variable. These data were converted to annual series by linear interpolation and then averaged over ten-year and thirty-year periods.

23. A table that does not impose the adding-up restriction is provided in an earlier version of this paper (Motley 1994).

24. The restriction that $\lambda = (n + g + \delta)(1 - \alpha - \beta)$ was not imposed. This restriction would imply that λ is a variable rather than a parameter since it depends on n, the population growth rate. However, the estimated values of $(1 - \alpha - \beta)$ are between 0.3 and 0.6, and the mean value of $n + g + \delta$ is between 0.06 and 0.07, which would imply a value of λ between 0.02 and 0.04.

25. The intercept terms are not statistically significant. Equation (8) shows that the intercept represents $gt + (1 - e^{\lambda t}) \ln A_0$, where $t = 30$. Since the (log) level of technology in the initial year ($\ln A_0$) is arbitrary, theory does not predict a value for this intercept. See footnote 16 above.

26. With a Cobb-Douglas production function and perfect competition, α and β represent the shares of total income going to tangible and human capital, respectively. In advanced countries, physical capital receives about one-third of total income ($\alpha = 1/3$) and labor about two-thirds. MRW suggest that 50 to 70 percent of labor income represents the return to human capital, implying that human capital receives between one-third and one-half of total income ($1/3 \leq \beta \leq 1/2$). See MRW (1992) p. 417.

For all samples, the estimated values of the convergence parameter, λ, range between 0.01 and 0.04 and are close both to those estimated by MRW and to the values predicted by theory.

Table 2 adds inflation terms to these equations. Again, the adding-up restriction that $\gamma_1 + \gamma_2 + \gamma_3 = 0$ could not be rejected (see F statistics), so only the equations that impose this restriction are reported. The coefficient on inflation is negative in all cases and is statistically significant in most samples.[27] Thus, the results generally support the expanded MRW model and confirm earlier findings that inflation reduces long-run growth.

To check that the regression estimates of the effects of inflation are not overly influenced by a few outlying observations, Figures 1–5 show scatter plots in which average annual inflation is plotted against the part of real growth that is not explained by the Solow variables.[28] These plots

27. In the OECD sample, for example, which includes the U.S., the p-value exceeds 97 percent. Only in the Rest of the World sample is the effect of inflation on growth statistically insignificant (p-value of 64 percent). In developing countries, it appears that inflation may make growth more difficult to achieve, but there are other considerations that are more important.

28. These Figures are based on the equation estimates in Table 2.

TABLE 1

RESTRICTED ESTIMATES OF MRW CONDITIONAL CONVERGENCE MODEL, 1960–1990
DEPENDENT VARIABLE: LOG DIFFERENCE GDP PER WORKER

SAMPLE	ALL NON-OIL	HIGH QUALITY	OECD	OECD+	REST OF THE WORLD
λ: CONVERGENCE PARAMETER	0.015	0.019	0.028	0.042	0.013
	(0.003)	(0.004)	(0.005)	(0.006)	(0.006)
α: OUTPUT ELASTICITY	0.296	0.387	0.360	0.296	0.342
WRT PHYSICAL CAPITAL	(0.064)	(0.105)	(0.130)	(0.099)	(0.228)
β: OUTPUT ELASTICITY	0.362	0.257	0.095	0.109	0.185
WRT HUMAN CAPITAL	(0.055)	(0.100)	(0.121)	(0.119)	(0.200)
F TEST OF ADDING-UP RESTRICTION	0.066	0.075	0.042	0.800	0.211
CRITICAL VALUE AT 5%	4.00	4.00	4.49	4.28	4.24

TABLE 2

RESTRICTED ESTIMATES OF MRW CONDITIONAL CONVERGENCE MODEL, 1960–1990, WITH INFLATION
DEPENDENT VARIABLE: LOG DIFFERENCE GDP PER WORKER

SAMPLE	ALL NON-OIL	HIGH QUALITY	OECD	OECD+	REST OF THE WORLD
λ: CONVERGENCE PARAMETER	0.015	0.019	0.036	0.043	0.011
	(0.003)	(0.004)	(0.007)	(0.006)	(0.006)
α: OUTPUT ELASTICITY	0.288	0.365	0.260	0.267	0.387
WRT PHYSICAL CAPITAL	(0.063)	(0.105)	(0.132)	(0.103)	(0.243)
β: OUTPUT ELASTICITY	0.371	0.274	0.093	0.095	0.192
WRT HUMAN CAPITAL	(0.054)	(0.099)	(0.112)	(0.123)	(0.207)
g_1: INFLATION EFFECT	–0.024	–0.026	–0.140	–0.031	–0.011
	(0.014)	(0.015)	(0.061)	(0.020)	(0.012)
F TEST OF ADDING-UP RESTRICTION	0.000	0.225	0.105	1.381	0.024
CRITICAL VALUE AT 5%	4.00	4.00	4.54	4.30	4.26

show that the regression equations do appear to have picked up a negative relation between inflation and growth that affects a large number of countries. Although it must be admitted that a large part of the variation in growth between countries remains unexplained, it is worth emphasizing that a negative relation is clearly observable in Figure 3, which refers to advanced countries like the U.S.

The coefficients on inflation in Table 2 imply that in long-run steady state a 10 percent inflation rate will reduce annual per capita growth in an average country by about 1/4 percentage point.[29] In the near-term, the effect on growth would be somewhat less because the economy adjusts toward its slower growth path gradually. For example, for the High Quality sample shown in Table 2, the effect of a 10 percent inflation is to reduce annual growth by 0.26 percentage point if maintained indefinitely, but by only 0.15 percentage point after ten years.[30] In the OECD sample, the estimated effect of inflation is much larger, with 10 percent inflation reducing annual growth by 1.4 percentage points in steady state (about 1 percentage point after ten years). This effect of inflation seems so large that it is natural to suspect that it may reflect the presence of a small number of outlying observations. However, Figure 3 suggests that this is not the case. Also note that Figure 4 suggests that the smaller estimated effect of inflation on growth in the OECD+ sample is due largely to the influence of two outlier countries (Mexico and Israel) that experienced much higher inflation rates than other OECD+ countries.[31] For other advanced countries outside the OECD, the effect of inflation appears to be of the same order of magnitude as for OECD countries.

Short-Sample Cross-Section Results

As discussed earlier, it is possible that the negative relation between average inflation and average growth over the full 30-year period reflects only the effects of a few supply-side shocks that raised the level of prices and reduced the level of real output in a few countries simultaneously. To check for this possibility, sets of three cross-section equations were estimated over shorter (ten-year) time periods.

FIGURE 1

Non-oil Sample

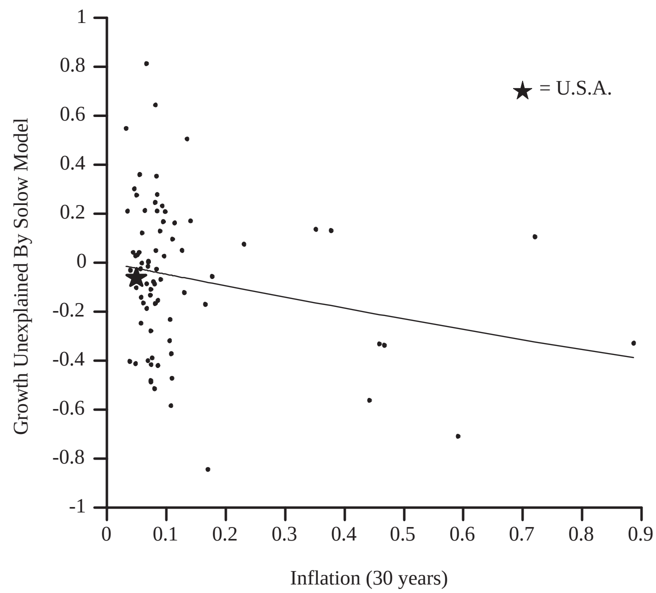


Table 3 shows the results of estimating three cross-section equations covering ten-year periods from 1960–1970, 1970–1980, and 1980–1990. These sets of cross-section equations were estimated as systems of “seemingly-unrelated” regressions, an estimation method that assumes that each country’s real growth rate in any decade is correlated with its growth rate in other decades but is unrelated to growth in other countries. For all five samples of countries, the adding-up constraint cannot be rejected, so this restriction is imposed. To focus on the effects of inflation, for each group of countries the three ten-year cross sections were estimated subject to the cross-equation restriction that the coefficients on the “Solow” variables were equal. The intercept terms were allowed to vary, since these terms include the logarithm of technology in the initial year of each decade.[32] The coefficients on inflation were allowed to vary across decades, but equations also were estimated with these coefficients constrained to be equal. For each set of equations reported in Table 3, the left column allows the inflation coefficients to vary among decades and the right column constrains these coefficients to be equal.

For the equations in which the inflation coefficients are not constrained, Table 3 shows that only one of these coefficients (that for the OECD countries from 1960–1970)

29. With steady growth of 2 percent (the assumed rate of Harrod-neutral technical change), per capita GDP will double in 35 years. If the growth rate were slowed to 1 3/4 percent, this doubling would take four more years.

30. These estimates are made under the assumption that the economy is in steady state equilibrium before the inflation rate rises.

31. Note that the scale of inflation in Figure 4 is smaller than it is in Figure 3.

32. See footnotes 16 and 25 above.

FIGURE 2

HIGH QUALITY SAMPLE

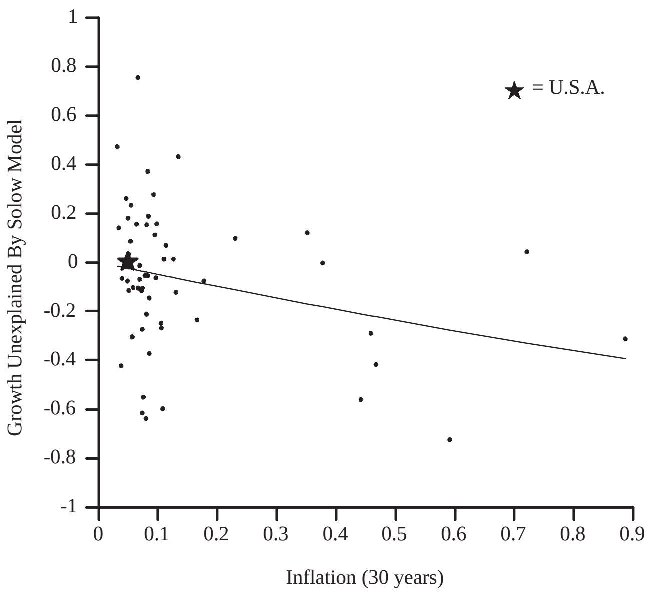


FIGURE 4

OECD+ SAMPLE

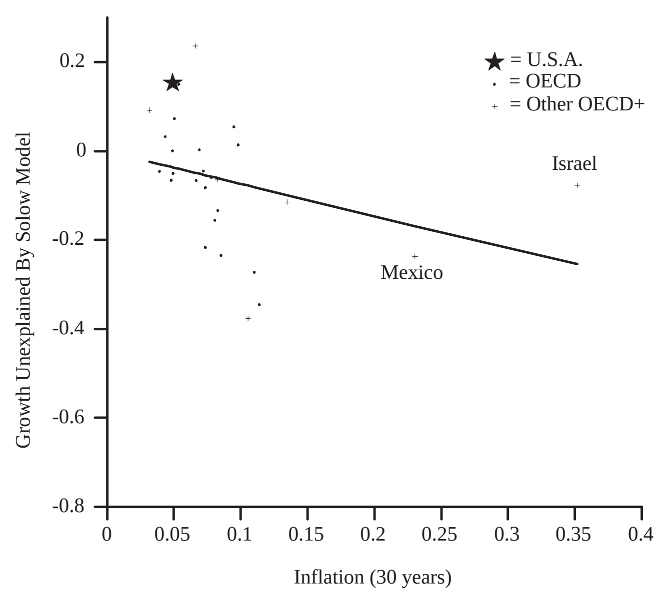


FIGURE 3

OECD SAMPLE

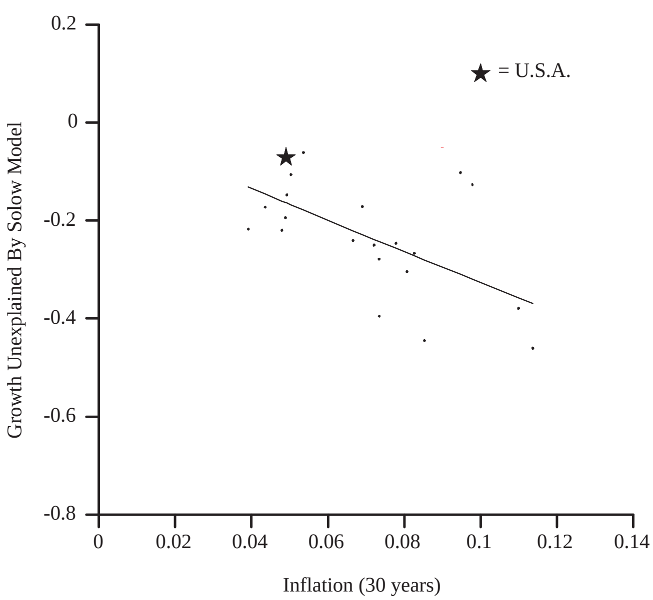
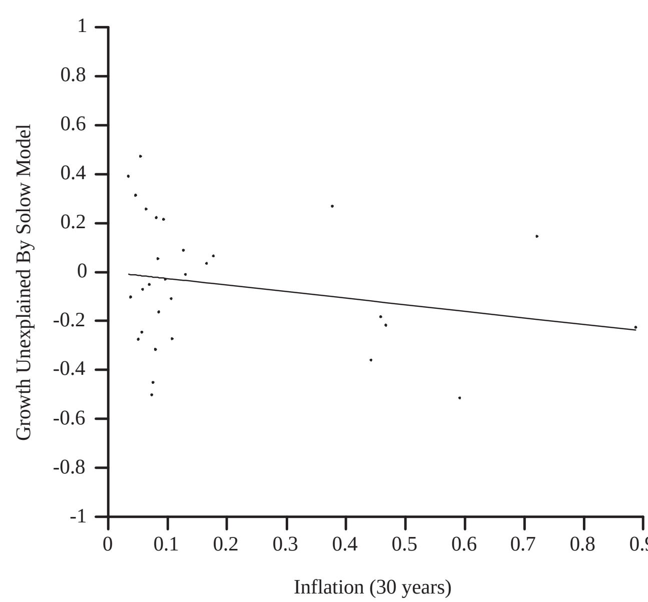


FIGURE 5

REST OF THE WORLD SAMPLE



is marginally and insignificantly positive, with the remainder being negative.[33] For most groups of countries, the measured impact of inflation on growth is weaker (and less significant) in the 1970–1980 decade. If the long-sample results in Table 2 were due primarily to the permanent effects of supply shocks on the levels of prices and output, one would expect that the apparent effects of inflation on growth would be *greater* during the 1970s, since that decade was dominated by the effects of two major oil shocks. Thus the short-sample results in Table 3 argue against this "supply shock" interpretation of the results. For all five groups of countries, the effect of inflation is significantly negative during the decade of the 1980s.

If the coefficients on inflation in these equations are constrained to be the same in each decade, they are significantly negative in all cases. These estimates of inflation's effect on growth are about the same as those from the 30-year cross sections; they indicate that 10 percent inflation would reduce annual real growth in steady state by about $^1/_4$ percentage point.[34] Again, the estimates of the inflation effect for the advanced countries appear rather high, but they are statistically significant.

Spline-Regression Results

The earlier discussion of the disruptions caused by inflation suggests that its negative effect on real growth would be greater at high than at low inflation rates. Fischer (1993) attempted to confirm this hypothesis by estimating "spline regressions." In a spline regression, the coefficient on inflation is allowed to vary with the inflation rate.[35] Fischer used annual panel data, with each observation representing annual real GDP growth in a given country and given year. A disadvantage of this procedure is that the short-run relation between inflation and output growth is likely to be dominated by demand-side effects or by temporary supply

33. In all groups of countries and all sample periods, the hypothesis that the inflation effect is negative cannot be rejected at standard probability levels. However, in about half of the equations, the hypothesis that the effect of inflation is zero also cannot be rejected.

34. These equations differ from those in Table 2 in that the intercepts (not reported) vary between decades, and the residuals for each country are correlated across decades. For all samples of countries, a chi-squared test of the restriction that the inflation coefficients are constant across the three decades is not rejected at the 5 percent probability level.

35. See Greene (1993) for a discussion of spline regressions.

TABLE 3

RESTRICTED ESTIMATES OF MRW CONDITIONAL CONVERGENCE MODEL, 1960–1970, 1970–1980, 1980–1990
DEPENDENT VARIABLE: LOG DIFFERENCE GDP PER WORKER

SAMPLE	ALL NON-OIL		HIGH QUALITY		OECD		OECD+		REST OF THE WORLD	
λ: CONVERGENCE PARAMETER	0.014 (0.003)	0.014 (0.003)	0.015 (0.003)	0.015 (0.003)	0.035 (0.005)	0.035 (0.005)	0.038 (0.003)	0.038 (0.003)	0.009 (0.004)	0.009 (0.004)
α: OUTPUT ELASTICITY WRT PHYSICAL CAPITAL	0.364 (0.059)	0.362 (0.058)	0.446 (0.093)	0.443 (0.090)	0.298 (0.095)	0.300 (0.089)	0.333 (0.079)	0.333 (0.079)	0.406 (0.178)	0.419 (0.182)
β: OUTPUT ELASTICITY WRT HUMAN CAPITAL	0.299 (0.049)	0.300 (0.048)	0.177 (0.087)	0.182 (0.084)	0.056 (0.089)	0.069 (0.083)	–0.023 (0.088)	–0.019 (0.085)	0.230 (0.153)	0.216 (0.154)
g_1: INFLATION EFFECT		–0.028 (0.009)		–0.028 (0.007)		–0.158 (0.066)		–0.110 (0.002)		–0.031 (0.007)
g_1: INFLATION EFFECT 1960–1970	–0.065 (0.024)		–0.058 (0.043)		0.001 (0.307)		–0.181 (0.099)		–0.051 (0.032)	
g_1: INFLATION EFFECT 1970–1980	–0.013 (0.027)		–0.014 (0.022)		–0.092 (0.072)		–0.019 (0.040)		–0.029 (0.024)	
g_1: INFLATION EFFECT 1980–1990	–0.028 (0.010)		–0.028 (0.008)		–0.159 (0.070)		–0.111 (0.002)		–0.029 (0.011)	
χ^2: TEST OF CONSTANT INFLATION COEFFICIENT	1.646		2.177		0.974		4.680		0.579	
CRITICAL VALUE AT 5%	5.99		5.99		5.99		5.99		5.99	

shocks rather than by the long-run effects of inflation on technology that this paper emphasizes.

Tables 4 and 5 report spline regressions in which each observation represents real GDP growth in a given country during a given decade. Again, Zellner's GLS estimation procedure for seemingly-unrelated regressions was employed. For the All Non-oil and High Quality samples, the data were divided into three groups with average inflation rates above 15 percent, between 5 and 15 percent and below 5 percent, respectively. For the OECD and OECD+ samples, a single "break point" of 5 percent inflation was chosen, since there were almost no observations with inflation rates above 15 percent. The coefficient on inflation is constrained to be constant between decades.[36]

36. This was necessary because there are insufficient high-inflation observations in any single decade cross section to permit estimation of meaningful spline regressions.

Table 5 suggests that in advanced economies (that is, OECD and OECD+), the effect of inflation on real growth is negligible at inflation rates of less than 5 percent but is much larger when inflation exceeds 5 percent. The inflation coefficients are not statistically significant at inflation rates below 5 percent, but are significantly negative when inflation exceeds 5 percent. However, the hypothesis that these coefficients do not change at 5 percent inflation cannot be rejected (see *t* statistics for spline). Figure 6 displays a scatter plot of the OECD sample which confirms that the estimates are not dominated by a few outlying observations.

For the OECD sample, the coefficient on inflation above 5 percent is the same order of magnitude as the coefficients estimated earlier in the 10- and 30-year cross sections. Figure 6 again shows that the regression equation is picking up a relationship that is not merely the result of the influence of a few extreme observations. For the OECD+ countries, the inflation coefficient is about the same as for the

TABLE 4

RESTRICTED ESTIMATES OF MRW CONDITIONAL CONVERGENCE MODEL, 1960–1990, SPLINE REGRESSIONS
DEPENDENT VARIABLE: LOG DIFFERENCE GDP PER WORKER

SAMPLE	ALL NON-OIL	HIGH QUALITY	REST OF THE WORLD
λ: CONVERGENCE PARAMETER	0.014	0.015	0.009
	(0.003)	(0.003)	(0.004)
α: OUTPUT ELASTICITY WRT PHYSICAL CAPITAL	0.351	0.422	0.421
	(0.061)	(0.093)	(0.194)
β: OUTPUT ELASTICITY WRT HUMAN CAPITAL	0.305	0.199	0.201
	(0.050)	(0.086)	(0.170)
g_1: INFLATION LESS THAN 5%	–0.290	–0.024	–0.207
	(0.178)	(0.145)	(0.181)
g_1: INFLATION BETWEEN 5% AND 15%	–0.116	–0.130	–0.040
	(0.088)	(0.065)	(0.080)
g_1: INFLATION GREATER THAN 15%	–0.012	–0.022	–0.025
	(0.017)	(0.012)	(0.010)
t TEST OF SPLINE AT 5% INFLATION	0.79	–0.87	0.72
t TEST OF SPLINE AT 15% INFLATION	1.08	1.53	0.18
NUMBER OF OBSERVATIONS WITH INFLATION LESS THAN 5%	93	58	27
NUMBER OF OBSERVATIONS WITH INFLATION BETWEEN 5% AND 15%	132	89	45
NUMBER OF OBSERVATIONS WITH INFLATION GREATER THAN 15%	44	35	26

TABLE 5

RESTRICTED ESTIMATES OF MRW CONDITIONAL CONVERGENCE MODEL, 1960–1990, SPLINE REGRESSIONS
DEPENDENT VARIABLE: LOG DIFFERENCE GDP PER WORKER

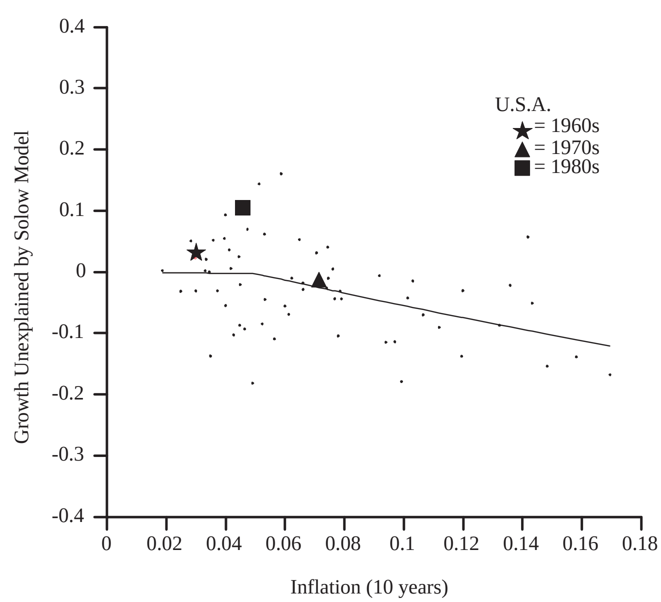
SAMPLE	OECD	OECD+
λ: CONVERGENCE PARAMETER	0.037 (0.005)	0.039 (0.004)
α: OUTPUT ELASTICITY WRT PHYSICAL CAPITAL	0.328 (0.084)	0.266 (0.079)
β: OUTPUT ELASTICITY WRT HUMAN CAPITAL	0.055 (0.081)	–0.013 (0.084)
g_1: INFLATION LESS THAN 5%	0.022 (0.130)	0.007 (0.139)
g_1: INFLATION GREATER THAN 5%	–0.200 (0.071)	–0.119 (0.012)
t TEST OF SPLINE	–1.49	–0.84
NUMBER OF OBSERVATIONS WITH INFLATION LESS THAN 5%	24	31
NUMBER OF OBSERVATIONS WITH INFLATION GREATER THAN 5%	39	53

OECD countries. For both the OECD and OECD+ samples, these results imply that at inflation rates above 5 percent, a 1 percentage point increase in inflation will reduce steady state growth by at least 0.1 percentage point.

For the All Non-oil, High Quality, and Rest of the World samples, the estimates are more puzzling since they seem to indicate that the marginal effect of inflation on real growth —although always negative—is *less* at high inflation rates than at low.[37] For all three samples in Table 4, the inflation coefficients are less negative for inflation rates of more than 15 percent than at lower inflation rates. A similar result was found by Fischer (1993). A possible explanation is that at high rates of inflation, institutions and activities develop that enable economic agents to reduce the consequences of inflation. There may be a measurement bias in the output data in that some activities that serve only to counter inflation may be included in the measured GDP of high-inflation countries. It is worth noting that the estimated inflation effect for High Quality countries with inflation rates below 15 percent is of the same order of magnitude as for OECD countries.

FIGURE 6

OECD PANEL WITH SPLINES



37. For the All Non-oil and Rest of the World samples, the marginal effect of inflation is implausibly large at inflation rates below 5 percent. However, for the High Quality sample, we cannot reject the hypothesis that the effect of inflation is the same for inflation rates below 5 percent as for inflation between 5 and 15 percent.

V. ARE THESE RESULTS QUANTITATIVELY IMPORTANT?

Between 1982 and 1992, inflation in the U.S. was about 5 percentage points lower than during the previous ten years. Inflation has come down even more during the 1990s. The empirical results reported in the preceding section imply that reducing average inflation by 5 percentage points should raise long-run growth in per capita GDP in a typical country by *at least* 0.1 percentage point. The results both for advanced countries and for countries with moderate inflation rates, which may be more relevant for judging the likely benefits of price stability in the U.S., yield higher estimates. Also the spline regressions indicate that the deleterious effects of inflation set in at quite low rates of inflation and are not confined to situations in which inflation is very high. Indeed, some of these regressions suggest that the marginal effect of inflation in slowing long-run growth may be greater at medium inflation rates than at very high rates. Moreover, for non-OECD countries with inflation rates in the same range as OECD countries, the effects are of the same order of magnitude. The overall conclusion from the results is that a 5 percentage point reduction in inflation could boost annual growth by between 0.1 and 0.5 percentage point.

The public and some politicians raise a number of concerns when a slowdown is proposed by the central bank to counter inflation pressures. Although the benefits of price stability accrue over the long run, the costs of moving to zero inflation are felt in the short run. Furthermore, an increase in growth of less than $\frac{1}{2}$ percentage point does not sound like much, even when those benefits are expected to accrue indefinitely. Finally, the impact of the reduction of inflation on the current generation is less than that indicated by the steady state results because the speed of convergence to a new steady state is slow.

In order to judge whether the move toward price stabilility in the past two decades will prove to have been worthwhile, we need to measure the *present value* of the long-run benefits in order to compare them with the upfront costs. This calculation is sensitive to the interest rate used to discount future benefits, but rough calculations suggest that the benefits exceed the costs by a wide margin. For example, with a 40-year working life, a 3 percent real discount rate, and a convergence parameter of $2\frac{1}{2}$ percent ($\lambda = 0.025$), a reduction in inflation that would yield a 0.1 percentage point boost to steady state growth would increase the discounted lifetime income of a typical worker by an amount equal to about 15 percent of one year's income, while a 0.5 percentage point boost to steady state growth would be worth almost 140 percent of one year's income. These estimates of the benefits of lower inflation appear to exceed the costs of bringing inflation down, which have been estimated as amounting to at most 12–15 percent of one year's GDP for a 5 percentage point reduction in inflation (Ball 1993, Mankiw 1992, p. 309).

VI. SUMMARY AND CONCLUSIONS

The results of this study generally confirm those reported elsewhere. Looking across a wide cross section of countries, I find a systematic tendency for higher rates of inflation to be associated with slower real growth. I have estimated the model over a range of different samples and different time periods. In almost all cases, inflation has a negative impact on real growth. Although standard tests imply that in some samples, the estimated coefficient on inflation is not statistically significant at conventional levels, the cumulative evidence generally supports the hypothesis. To guard against data mining, the data have been analyzed using a theoretical model of economic growth. No additional variables have been added to this model.

The scatter plots shown in Figures 1–6 indicate that, although the model leaves a lot of the intercountry variation in rates of growth unexplained, inflation has a negative effect on real growth that is economically and in many cases statistically significant. Thus, although one cannot claim that inflation is a major source of differences in rates of growth between countries, it does appear to be a systematic factor explaining at least part of these differences. Moreover, the results imply that it is a factor influencing growth in both advanced and less developed countries. Finally, a rough calculation suggests that the benefits from getting inflation down—although they will accrue only slowly and over a long period—may exceed the short-run costs of doing so. Much of the cost of bringing inflation down was borne in the early 1980s. If low inflation is to continue, future increases in inflation will have to be resisted. The results of this paper suggest that the short-run costs of such resistance probably will be worth bearing.

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