Christopher A. Sims is a member of the Economics Department at Yale University.

Commentary

Christopher A. Sims

Instrumental variables estimation on a single equation is used to estimate the causal effects of inflation on growth of output in this article by Robert J. Barro. He is certainly aware of the theoretical foundations of the equation he is estimating, and knows that justifying instrumental variables estimation requires at least informal discussion of the mechanisms that complete the system determining the endogenous variables. He does not discuss the theory underlying the equation much, however, and he gives only partial and informal indications of how he might complete the system. In this comment, I fill in these aspects of the analysis. The conclusion is that the coefficient on inflation that Barro estimates cannot reliably be interpreted as he seems to interpret it.

Barro also does not pay much attention to the fit of his model. That is, he does not ask how well it accords with the data compared with other models whose predictions of the effect of inflation on growth might be different. Though a comment does not provide enough space to do much along these lines, I make some remarks on this point, suggesting that theories that give no causal role to anti-inflation policy per se in promoting growth are apparently consistent with what we see in the data.

THE THEORY UNDERLYING THE EQUATION

If we postulate a Cobb-Douglas production function in physical capital *K* and human capital *H*, then

$$(1)\quad \dot{y} = \alpha\dot{k} + \beta\dot{h} + \dot{a},$$

where *Y* is output, *K* is physical capital, *H* is human capital, *A* is the productivity level, lower-case letters are logs of corresponding upper-case letters, and dots over letters indicate derivatives with respect to time *t*. Barro's approach is based on rewriting equation 1 to prevent the need for data on the level of *K*. This can be done by simply solving the production function for *K* and substituting, yielding:

$$(2)\quad \dot{y} = \alpha\frac{\dot{K}}{Y}\cdot Y^{1-\frac{1}{\alpha}}\cdot A^{\frac{1}{\alpha}}\cdot H^{\frac{\beta}{\alpha}} + \beta\frac{\dot{H}}{Y}\cdot\frac{Y}{H} + \dot{a}.$$

If we linearize equation 2, expanding in terms of deviations of:

$$\frac{\dot{K}}{Y},\ \frac{\dot{H}}{Y},\ y,\ h,\ a,\ \text{and}\ \dot{a}$$

from their values at a point near the center of the sample, we will have (with the *d* operator indicating deviations from the point of linearization):

$$(3)\quad d\hat{\dot{y}} = \theta_0 d\left(\frac{\dot{K}}{Y}\right) + \theta_1 dy + \theta_2 dh + \theta_3 d\left(\frac{\dot{H}}{Y}\right) + d\dot{a} + \bar{\dot{k}}\, da,$$

which is close to the equation Barro estimates, with the terms in a and $\dot{a}$ interpreted as making up the error term. The coefficients have the following interpretation:

$$(4)\quad \theta_0 = \alpha\left(\frac{\bar{Y}}{\bar{K}}\right),\ \theta_1 = (\alpha - 1)\bar{\dot{k}} + \beta\bar{\dot{h}},$$

$$\theta_2 = \beta\left(\bar{\dot{k}} - \bar{\dot{h}}\right),\ \theta_3 = \beta\frac{\bar{Y}}{\bar{H}}.$$

The relationships in equation 4 pose difficulties for Barro's interpretation of his regression. In the neighborhood of a steady state in which $\dot{k} = \dot{h}$, a balanced growth path, there is no effect of *h* on output growth and the effect of the level of *y* is also likely to be zero. The coefficient on y, θ_1, is $-(1 - \alpha - \beta)\quad g$, where g is the steady-state growth rate. If $\alpha + \beta < 1$, then $g = 0$. If $g > 0$, then $\alpha + \beta \geq 1$. This may seem to conflict with the prediction of neoclassical growth theory that economies will converge to a common level of income, except as their levels of A differ. But this prediction works entirely through the idea that $\dot{k}$ and $\dot{h}$ will depend systematically on the output level. In an equation, like the one Barro estimates, in which $\dot{K}/Y$ and $\dot{H}/Y$ both appear directly, convergence effects do not appear in the coefficients of the level variables h and y.

That the coefficients in this convergence equation no longer have anything to do with convergence once human and physical capital investment terms have been added does not directly raise problems for the use of the equation as a base for examining the effects of inflation on growth. However, that the estimated coefficients on h and y still emerge with values that might be expected from an actual convergence equation, without the $\dot{K}/Y$ and $\dot{H}/Y$ terms, does raise concerns. We need to know why this result has occurred. Is the theory simply wrong? Are there omitted productive factors of such importance that y is still proxying for their levels? Is there severe uncontrolled-for measurement error in some variables?

Suppose we could find an answer to these questions, so that we were still willing to interpret the equation as a technology equation. Additional variables like political instability measures, fertility, life expectancy, and inflation would then have to be interpreted as components of a or $\dot{a}$, or else their inclusion in the equation would undermine the interpretation of the original set of variables as reflecting the technology. To estimate the equation, Barro must be assuming that the parts of A and $\dot{a}$ not accounted for explicitly with additional variables are independent of the variables he uses as instruments. He may also have in mind that some variables are measured with error, and that such measurement errors can be absorbed into the equation disturbance term if they are uncorrelated with the instruments.

Barro labels this an output growth equation, but because he recognizes the endogeneity of the investment ratio, the schooling ratio, and some of the additional variables he introduces, it would be better just to call it the technology equation. What goes on the left side is arbitrary. The theory Barro is invoking to allow him to interpret the coefficients of his estimated equation is embodied in the classification of variables into *endogenous, predetermined included,* and *predetermined excluded,* which is explained in the footnote to his Table 2. I display it here in Table 1.

Note that, though we follow Barro's article in matching up many of the excluded predetermined variables with corresponding included endogenous variables, the model and estimation procedure do not make use of any such matching. In a multivariate equation with multiple instruments, one instrument is not logically an *instrument for* any particular variable in the equation. We do need to ensure that the number of instruments matches the number of included endogenous variables, less one, and that each endogenous variable is to some degree correlated with the whole vector of instruments. This accounts for the common practice of matching instruments to variables, but we should be careful not to be misled by it. In this article an index of central bank independence is dismissed as an instrument for inflation because it is not strongly correlated with inflation. It may be that it is not a good instrument, but its bivariate correlation with inflation does not in itself tell us that.

This is an equation drawn from a system of 12 jointly determined endogenous variables, any one of which could in principle be put on the left and serve to name the equation. In one case, this would not make sense. The level of gross domestic product (*GDP*) enters the equation with a lag relative to the dependent variable—it is the *GDP* at the beginning of the period over which the growth of output is calculated. The level of *GDP* is treated as endogenous apparently only because of concerns about its being measured imprecisely. That is, one equation in the full system is meant to be

$$(5)\quad \log(GDP) = \log(GDP^*) + v,$$

where GDP^* is correctly measured *GDP*, which is taken to be predetermined. Be-

Table 1

Barro's Classification of Variables

Endogenous	Predetermined Included	Predetermined Excluded
Output growth		
Output level		Lagged output level
	Male schooling level	
	Female schooling level	
	Life expectancy	
Log (*GDP*) * human capital		Log (GDP_{-1}) * human capital*
Fertility		Lagged fertility
Government C/Y		Lagged government C/Y
$\dot{H} / Y$†		Lagged $\dot{H} / Y$
Black-market premium		Lagged black-market premium
	Rule of law	
	Terms of trade	
$\dot{K} / Y$		Lagged $\dot{K} / Y$
Democracy		Lagged democracy
Democracy-squared		Lagged democracy-squared
Inflation‡	Inflation	Lagged inflation
Inflation standard deviation		Lagged inflation std. deviation
		Colonial status
		Latin America dummy

* This instrument is not listed explicitly in the draft of the paper presented at the conference.

† $\dot{H}$ is proxied by spending on public education.

‡ Inflation is in some estimations treated as exogenous and in others treated as endogenous. In the latter case, lagged inflation is introduced as an instrumental variable.

cause equation 5 has only one endogenous variable in it, it determines *GDP* and makes it unreasonable to regard the Barro equation as determining the level of *GDP*. But aside from this one, all the other endogenous variables are apparently so treated because it seems clear that there is a distinct possibility that they are not determined by mechanisms independent of the unobserved components of A and $\dot{a}$.

Barro describes his results as if the estimated coefficient on inflation describes the effects of policy-generated changes in inflation on output growth. But of course nothing in the specification of the equation tells us that we must hold every endogenous variable except output growth fixed while we contemplate changes in inflation. Indeed, to describe the effects of inflation on output growth accurately, we need the full set of equations describing the reaction of private-sector behavior to government policy aimed at altering the inflation rate. For example, the black-market premium, the terms of trade, and the investment ratio all seem likely to change after any policy change that affects the inflation rate. Another example is that, particularly in poor countries, inflation may be an important source of government revenue. A policy-induced inflation increase that holds public spending on education and government consumption constant therefore must, through the government budget constraint, entail increased government investment, increased transfer payments, decreases in taxes other than the inflation tax, or decreased budget deficits. Because we do not control directly for which of these fiscal offsets is chosen, the equation describes what happens when an *average* accompanying fiscal policy is used. But why would we be interested in a pattern of fiscal offsets that is average except that it keeps government consumption and public school spending fixed as proportions of output?

The conclusion from all these considerations is that the coefficient on inflation in the equation Barro presents to us represents, at best, a small piece of the story of how policy-induced changes in inflation influence output growth and at worst an uninterpretable hodgepodge.

THE THEORY UNDERLYING ESTIMATION

So far, we have assumed that we do have estimates of the technology equation 2 and raised questions about its interpretation. Now we turn to the stochastic specification. Note that, so long as we are considering data where the average growth rate of capital is nonzero, equation 2 includes the level of technology, A, as well as its rate of growth, $\dot{a}$. That is, in this specification, because Y is being used to proxy for the unavailable K, the *growth rate* of output depends on the *level* of the unobserved productivity factor. It is quite unlikely that A is serially uncorrelated, even though $\dot{a}$ might be. If there are large, persistent differences across countries in A, as most economists who take the neoclassical growth model seriously believe there are, then nearly every choice of predetermined instrument in the model is suspect. For example, male schooling levels, female schooling levels, and life expectancy are all likely to depend strongly on the level of a country's wealth through demand effects. Treating them as predetermined in equation 2 lets them absorb explanatory power through this passive correlation with components of A other than their own direct effect on technology. Not only will their estimated coefficients be too large, but treating them as predetermined may produce distortions in the coefficients of other variables in the estimated equation. Most of the instrumental variables that are not included in the equation are lagged values of variables included in the equation. Since the components of the error term determined by A are probably persistent, there are no grounds for concluding that these variables are actually predetermined.

Barro points out that the estimated disturbances are nearly serially uncorrelated. However, the equations contain variables correlated with A and are estimated using instruments correlated with A. Therefore even though the true residuals would contain a contribution from A, we expect that the estimated residuals will have little or none of A left in them. That the estimated residuals are not serially correlated thus does not provide much support for the claim that lagged variables can be taken as predetermined.

THE FIT

There are at least four mechanisms by which inflationary policies could be related to growth. The mechanism implicit in this article's formulation is a direct effect of inflation on productive efficiency. Details of the mechanism might be like those in the article by Robert G. King and Alexander L. Wolman in this issue, in which sticky prices allow inflation to distort allocations and shoe leather transactions costs rise with inflation. Mechanisms like these seem most likely to affect the level of total factor productivity more than its growth rate because investment is being held constant, but because a, as well as $\dot{a}$, enter equation 2, level effects can legitimately show up in the estimated equation.

A second mechanism, laid out in Narayana Kocherlakota's comment on Barro's article is a classical one, in which supply shocks, not totally offset by the monetary authority, create an inverse relationship between the price level and the output level. This level-to-level relationship is also of course a growth rate-to-growth rate relationship.

A third is the Keynesian/Monetarist mechanism, in which nominal aggregate demand changes produce output changes and price changes in the same direction.

And finally there is the possibility that inflation is a symptom of political, social, or bureaucratic problems that also hinder growth.

These mechanisms are not mutually exclusive theories; in principle all could be present simultaneously. Nonetheless, it is reasonable to consider the possibility that one dominates the others in importance, so the data behave largely as predicted by one of the theories. Barro's article does not articulate the comparative implications for the data of these alternatives, and I cannot do a thorough job of comparing their fits to the data here. From the results in both Barro's article and Michael Bruno and William Easterly's article, though, a few points do stand out.

If the first class of mechanisms—direct effects on efficiency—were mainly at work and if these were mainly just increased transactions costs, it is difficult to see how such large effects as Barro estimates could emerge. If the efficiency effects came from distorting allocation more generally, then the effects could be larger. But in this case it is difficult to understand why the level of inflation should be so much more important than its standard deviation. Nominal contracting schemes should be able to adapt to a steady high inflation to prevent distortions.

Bruno and Easterly show that the relationship of inflation to output growth around the times of inflation crises is more or less contemporaneous. This fits well with the classical view. It does not contradict the efficiency effect, but inflation effects on efficiency seem quite likely to show delays and nontrivial dynamics, so the absence of these in the data weighs in favor of a classical interpretation.

The identified vector autoregression (VAR) literature has been developing a detailed dynamic picture of determinants and effects of monetary policy in the United States and other advanced economies.[1] Though different articles on this topic reach different conclusions on some points, they almost entirely agree in allocating most of the explanation of observed correlated movements of interest rates, prices, and output to shocks originating outside the monetary authority. Most of the estimated variation looks like responses to supply shocks, in that, it involves inverse co-movements of prices and output. Thus there is support in these VAR studies for the view that monetary policy in a variety of countries behaves in such a way as to create an inverse pattern of co-movement between prices and output.

Though the timing of price and output movements fits the classical story fairly well, the relative magnitudes of inflation and output variation do not. Inflation rates vary across time and countries much more than do output growth rates. To explain the high volatility of inflation, a classical model will probably have to follow the identified VAR literature in introducing strong dynamic reactions of monetary policy to disturbances in the private sector. Even then, the high inflations that Bruno and Easterly find most strongly associated with output growth seem disproportionate to what one would expect from any systematic monetary policy reaction to the corresponding output growth declines. This tends to support the idea that, at least for the largest inflations, the best interpretation is that they are indicators of political or social crises with widespread economic effect.

The coefficient on inflation in Barro's equation is robust to whether inflation enters as a predetermined variable or instead lagged inflation is added to the list of instruments. Furthermore, a comparison of this article's estimates with those in Barro (1994) shows that no coefficients in the estimated equation change by more than about one standard error when inflation is added to the equation.[2] The lags here are fairly long—averages over the five years immediately preceding the sample being taken to correspond as instruments to endogenous variables averaged over the subsequent 10 years. Though it would take a more detailed analysis to be sure of this point, it seems that what Barro is turning up is quite a low-frequency phenomenon, with countries that tend to have high inflation over long spans tending also to have lower growth. If this is what the data show, it may be difficult to account for it with a classical interpretation. Of course none of this weakens the point that, be-

[1] Recent examples are Bernanke and Mihov (1995); Christiano, Eichenbaum, and Evans (1994); Gordon and Leeper (1995); and Sims and Zha (1995).

[2] The comparable equation in Barro (1994) appears to be that in column 5 of Table 1, which includes democracy and democracy-squared and excludes all regional dummies. This differs from columns 1 to 3 of my Table 1 only in the presence of inflation and inflation standard deviation in the latter's variable list.

cause the instruments are not plausibly predetermined relative to the endogenous variables in the technology equation, the results do not provide much support for a direct technological effect of inflation on output growth.

CONSTRUCTIVE COMMENTS

Though the tone of these remarks has been almost entirely critical and skeptical, I do not mean to be discouraging about the overall project in which Barro is engaged. Empirical work in economics inevitably entails trying simplified models to see which capture much of what is going on in the data. Such models can always be criticized as oversimple or as not fitting some aspect of the data. Barro and others following his research plan of exploring international panel data sets on growth are working at an important task. My view is not that they should give up or wait until they have complete, unassailable models fitted and tested by the most advanced techniques. I just think they could do better by being clearer about what theories are relevant to their data analysis and by keeping their equation specifications and estimation methods better aligned with the theories in play.

This project, to measure the effects of inflation on growth through its effects on technological efficiency only, seems too refined to me, given the current state of our knowledge. Single-equation methods, like those in this article, may seem attractively simple, but when the problem is inherently multivariate, they force us to consider partial effects, holding many things constant, that may be hard to interpret or of little practical use. If the objective is finding the effects of policy-induced inflation on the growth rate, the most useful first step is to find the effects in a multivariate model. In such a model both its effects through accumulation of H, K, and other possible unmeasured capital stocks and its direct effects on technological efficiency can be considered. To keep things simple at first, we might forgo separating direct effects of inflation on technology from indirect effects through accumulation rates. This would not free us from the need for multiple equation methods, as it would still be necessary to account for the joint determination of inflation policy and growth, but the number of variables handled at once could be kept smaller.

It also makes sense, as in the Bruno and Easterly article, to look at data at finer time intervals. Of course we would like to focus on determinants of long-term growth, not cyclical fluctuations. This is the reason that use of decade averages in the Barro equations are appealing. But since many of the determinants of inflation seem to operate on a year-to-year or shorter scale, there is a much better chance of identifying policy-induced shifts in inflation by working with data at more frequent intervals.

The analysis of error structure I have gone through in the preceding text suggests that trying to do without data on the level of K may be a mistake, error-ridden though such data may be. With a measure of K in hand, the residual in a technology equation like equation 2 would acquire a term in the measurement error for K, but would lose its dependence on A. This would make identification through assumptions about lags in causal chains much more plausible. Finding instrumental variables uncorrelated with measurement error in K seems a less daunting task than finding ones uncorrelated with unmeasured components of A.

REFERENCES

Barro, Robert. "Democracy and Growth," NBER Working Paper No. 4909, 1994.

Bernanke, Ben, and Ilian Mihov. *Working Papers in Applied Economic Theory 95-09*, Federal Reserve Bank of San Francisco (March 1995).

Christiano, L; M. Eichenbaum; and C. Evans. "The Effects of Monetary Policy Shocks: Some Evidence from the Flow of Funds," National Bureau of Economic Research Working Paper 4699 (April 1994).

Gordon, David, and Eric Leeper. "The Dynamic Impacts of Monetary Policy: An Exercise in Tentative Identification," *Journal of Political Economy* (December 1994), pp. 1, 228–47.

Sims, C. A., and T. Zha "Does Monetary Policy Generate Recessions?" Manuscript, Yale University, 1995.