Much of what we claim to know about the growth of nations and provinces comes from cross section regressions. But those familiar with regression analysis know that if one regresses y on x, one must determine what is y and what is x a priori: that is, one must already be fairly confident x causes y and not vice versa. In our case, y is either an income level or growth rate in the Solow-Swan or exogenous growth model or a growth in the endogenous growth model.[1] The independent variables "causing" growth might be education, trade or inequality for example. But how do we know that x causes y, or at the very least there is not some feedback from y to x. Take the familiar example of education (years of schooling per worker) as discussed in Hall and Jones (1999). The augmented-Solow model claims human capital education raises steady-state income levels and therefore creates a transitory (or permanent in Lucas (1988)) jump in the growth rate. However, we also know that higher income households tend to send their kids to school longer as they no longer need or want them to work in the family business. Therefore it is possible that higher incomes "cause" increase in schooling. This is precisely what Bils and Klenow (2000) argue though their findings have not discouraged anyone, almost, from thinking higher education leads to higher growth, up to a point.

The simplest way to deal with the causality issue by using lagged variables. Once something has happened, it becomes exogenous. No matter what happens today, the past will not change (unless we are traveling faster than the speed of light, of course). Take a standard cross section regression,

$$\Delta y_i = \beta_0 y_{io} + \beta_1 X_{ij} + \varepsilon_i \qquad \textbf{(1.1)}$$

where Δy_i is the average annual growth rate or log change in per capita GDP for country i and y_{io} is the initial income measured in comparable purchasing power parity or U.S. prices and X_i is a list of exogenous determinants of growth (see Barro (1997)). If the estimated β_0 is negative and significant this is interpreted as evidence of conditional convergence. Typically Δy_i and X_i are 20-30 year average GDP growth, life expectancy, human capital investment (years of schooling per person), tariff rates, etc. One obvious problem with these variables is that, apart from initial income which is at least pre-determined, there is generally causality running both ways. Higher per capita income leads to increased school enrollments, higher live expectancy etc.

Apart from using lagged or initial values, a second approach to making sure causality runs mainly from X to Y. One approach is to find suitable ***instrumental variables***. Basically this involves regressing X on some variables which are known to be exogenous and then using the predicted value of $X_i(Z_i)$ from a regression of X on Z to replace $\mathbf{X_i}$ in equation (1.0). Some famous instruments include the 19th century settler mortality rates (see AJR, 2001) the colonial legal system used by Beck, Levine and Loayza (2000) as an instrument for financial development or the proximity and size based "gravity" instrument for trade used by Frenkel and Romer (1999). In each case, a suitably exogenous or predetermined instrument is used to extract an exogenous component of financial development, trade or "institutions." Though clearly exogenous in most cases, these instruments may still be correlated with income and sometimes are open to different interpretations, as in Sachs (2003) who interprets settler mortality as a proxy for health and geography as opposed to institutions. Economists love instruments, but along "too much of a good thing"

[1] Note that technically we should not use an income level as a dependent variable if we are testing an endogenous growth model as y is not stationary: with endogenous growth y increases without bound, though the growth rate my be stationary, that is have a finite mean. This is an important distinction in many econometric models, but we mention it only in passing.

lines Roodman (2007) argues Beck, Levine and Loayza (2000) and Forbes (2000) use "too many" instruments. Unfortunately, if correct Roodman's arguments call into question a some solid evidence amassed by Levine and coauthors regarding the strong causality running from financial development (banks and stock markets) to growth (see *Carovic and Levine 2001 for example).*

A third approach to discerning causality is taking advantage of the simple fact that if X causes Y changes in X will tend to precede changes in Y. This is the idea underlying ***Granger causality*** tests and Vector-Auto-Regressions and VARs.

$$\Delta y_t = \beta_1 \Delta y_{t-1} + \beta_2 \Delta x_{t-1} + \varepsilon_i$$

$$\Delta x_t = \beta_3 \Delta y_{t-1} + \beta_4 \Delta x_{t-1} + \varepsilon_i \qquad (1.2)$$

If β_2 is significant and β_3 is not we have evidence that changes in x cause changes in y and not vice versa. In general one tests to sum of all significant lagged values of both variables. Adding conditioning variables or creating a larger system of variables create a VAR system, which adds more structure to the model by also makes this simple causality test harder to replicate. Of course it is possible that both β_2 and β_3 or that neither are significant in which case the test is not conclusive. Granger causality of course does prove causality, rather it provides some circumstance

Dynamic panel estimation is a third approach to dealing with causality that incorporates elements of all three previous approaches (pre-determined values, instrumental variables and Granger causality). Starting with standard panel regression,

$$\Delta y_{it} = \beta_0 \Delta y_{it-1} + \beta' X_{it} + \mu_i + \eta_t + \varepsilon_i \qquad (1.3)$$

where Δy_{it} now represents growth rates and X_{it} the determinants of growth for i = 1, …, N countries and t = 1,…,T periods. Typically the t periods are not years or quarters, rather they are 3-10 year averages of the relevant variables (as opposed to the 20-30 year averages typical of cross-section growth equations represented in equation 1.1 above). A significant addition is the unobserved "fixed" effects: μ_i represents an estimate across T periods of all the country "i" specific unobserved fixed effects, while η_t is a time period fixed effect of some worldwide phenomenon affecting all countries at date "t". Note that these are referred to as crossed section or period "fixed effects" as they are constant for each country over all time periods or for each time period across all countries. Note that initial income is similar to any other fixed effect, and that the lagged dependent variable plays a role in capturing the partial adjustment of growth to changes in the determinants of growth which may take longer that five years (school enrollments for example). Note also the similarity of 1.3 to the "auto-regressive" setup of the Granger causality or VAR systems discussed above.

Unfortunately, due to the presence of the lagged endogenous variable estimates of equation 1.3 are biased as the country fixed effects are correlated with the X variables. Differencing 1.3 eliminates the fixed effects but at the cost of losing a considerable amount of historical (level) information. However, there are some hybrid panel methods with restore some level information (see Bond and Blundell (1998) and Baltagi (2005) chapter 8 for a good discussion of these techniques). Another key advantage of dynamic panel methods is that we can test a key assumption of instrumental variables estimation: that the instruments are strictly orthogonal or independent of the error term (this often referred to as a Sargan test).

$$\Delta y_{it} = \beta_0 \Delta y_{it-1} + \beta' X_{it} + \mu_i + \eta_t + \varepsilon_i \quad (1.3)$$

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