Testing the Neoclassical Growth Model: A Causality Approach

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May, 1998

Abstract

In this paper we propose a time series test of augmented versions of the Solow growth model, analyzing the causality relationship from investment rates to income per capita. We claim that the convergence property of these exogenous growth models can be interpreted as an error correction mechanism which implies the existence of long run causality from accumulation rates to income. Using a sample of OECD countries from 1960 to 1995, our results overwhelmingly reject the null hypothesis of causality in a variety of model specifications, and the estimated impulse-response functions show a pattern that is clearly at odds with the theoretical ones we find in different Monte-Carlo experiments. These results provide evidence against the dynamics of income implied by these versions of the Solow growth model.

JEL number: O41

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This paper is part of the project "Growth, Convergence and Macroeconomic Performance" carried out at the Ministry of Economy and Finance of Spain and it has been supported by CICYT grant SEC96-1435. We wish to thank Angel de la Fuente and the participants at several seminars for helpful comments. J. Andrés acknowledges the hospitality of the Centre for Economic Performance at the LSE while working on this paper.

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1. Introduction

The empirical growth literature has recently flourished mainly around the convergence regression. As it stands, this approach relies crucially on the long run causality between savings and income per capita levels. In the Solow-Swan model or its further augmentations (Mankiw, Romer and Weil (1992), MRW hereafter, or Nonneman and Vanhoudt (1996)), the steady state income level is determined by the rates of accumulation in the different types of capital , as well as by the rate of growth of efficient labour plus some technological parameters. Indeed, the expected close association between these variables has been found to be a consistent empirical fact in cross-section regressions (MRW, Levine and Renelt (1992) or Andrés, Doménech and Molinas (1996) among others). This link is also dictated by common sense. It is difficult to imagine a growth mechanism that does not work through the increase of capital in one way or another.

Whereas the association between investment and growth is a property of most models of economic growth, causality from the former to the level of income is mainly an implication of the augmented versions of the Solow Model. We claim that the convergence property of these models can be interpreted as an error correction mechanism which implies the existence of long run causality from investment to income. In this case, accumulation rates should improve the forecast of future income levels, as compared with those based on a simple autorregressive specification. This surmise is corroborated by Monte-Carlo experiments based on a stochastic version of the MRW model. In this paper we test this causality implication, exploiting the time series dimension of the data instead of relying on cross-section regressions. Although the use of annual data in the empirical growth literauture is somehow controversial because of the business-cycle effects, their use can be justified on reasonable grounds. First, our approach is akin to some recent contributions in the growth literature, such as those of Jones (1995), Kocherlakota and Yi (1996) or Lee, Pesaran and Smith (1997), who propose time series tests of the empirical implications of growth models. Second, as King, Plosser and Rebelo (1988) have pointed out economic fluctuations can be just a manifestation of the underlying process of stochastic growth. Third, business cycle fluctuations could bias the convergence rate, as discussed by Canova and Marcet (1995), but there are no reasons to expect any influence upon the long run causality from investement to income.

The causality among physical capital accumulation and income per capita is investigated using a panel of OECD countries from 1960 to 1995. The OECD economies are characterized by well developed market structures and stable political systems, which make them good candidates to test the implications of growth models. Our results overwhelmingly reject the null hypothesis of causality in a variety of model specifications. In contrast, there is some evidence of causality from income growth to investment. Contrary to what some authors have suggested, the failure of investment to cause income does not undermine the crucial role of capital accumulation in the growth process. The lack of causality provides strong and robust evidence against the adjustment mechanism built in the augmented versions of the Solow model, and suggests that general equilibrium versions of this model with adjustment costs to investment or some endogenous growth models would be more appropriate to understand the long run experience of OECD countries during the sample period.

The rest of the paper is organized as follows. In section II, we discuss the relevant econometric issues involved in testing causality when regressors are non stationary and might be cointegrated. We also implement Monte-Carlo experiments to analyze the appropriateness of our test using data generated from quantitative model economies. In section III, we analyze the relationship between income per capita and investment using alternative estimation methods. Finally, section IV concludes with some final remarks.

2. Some econometric issues

2.1 Convergence equations and causality

The convergence regression, as derived by Barro and Sala i Martin (1992), is a log linear approximation of the adjustment process to the steady state:

$$\Delta y_t = \pi \left(y_{t-1} - \beta \mathbf{X}^*_{t-1} \right) + u_t \tag{1}$$

where y represents income per capita and, according to the augmented versions of the Solow model, $\mathbf{X}^*$ is a vector of accumulation rates (investment, schooling, accumulation of technological know-how and population growth) at their steady state levels. The main hypothesis to test in (1) is the sign and significance of π. Actually, a test of this kind in standard convergence equations is already provided in the coefficient of lagged income. However, the convergence hypothesis can also be viewed as the adjustment process around a cointegration relationship, and the convergence equation as a non-fully specified error correction model.[1] Equation (1) can be generalized to allow for adjustment costs and other lags as:

$$\Delta y_t = \pi \left(y_{t-1} - \beta \mathbf{X}^*_{t-1} \right) + \sum_i a_i \Delta y_{t-i} + \sum_i \beta_i \Delta \mathbf{X}^*_{t-i} + u_i \tag{1'}$$

According to this interpretation, the distinctive feature of the augmented Solow growth models is not that capital accumulation affects growth rates, but that current accumulation rates should improve the forecast of future income levels based on the past history of this variable, i.e. that there is long run causality from accumulation rates to income. The argument can be stated in very simple terms. Built in a constant returns growth model there is an adjustment mechanism. The level of accumulation rates drive the long run level of attainable income per capita, so that when income is off its long run path it tends towards it at a positive speed. To predict future income levels we need to know where the economy has been in the past as well as where it is heading towards in the future. According to this, past income levels are not enough to predict future ones, and the observed physical and human capital accumulation rates (to the extent that they proxy their long run value) should improve this forecast.

Therefore, an alternative way of testing the adjustment mechanism in augmented

1 Similarly, Quah (1994b) has suggested the interpretation of the absolute convergence regression as a unit root test in the process generating income per capita levels.

Solow growth models would be to find a cointegrating vector among income and the accumulation rates. However, tests of cointegration have low power, and we know very little about their behaviour in data fields as the one we deal with here. We will try a more general approach instead, testing the causality from $\mathbf{X}^*$ to income per capita. If causality is rejected we could safely conclude that variables in $\mathbf{X}^*$ do not help to predict future income levels so that there is not a long run equilibrium relationship as the one implied by the Solow-Swan model or its further augmentations.[2] Although what the model predicts is that the accumulation rates in different types of capital determine the steady state of the level of income, we shall consider in next sections only investment rates in physical capital. Nevertheless, in all cases we also report causality tests of this variable in models including other components of the $\mathbf{X}^*$ vector, such as human capital or investment in R&D.

For the sake of completeness, we might test the causality running from $\mathbf{X}^*$ to both the income level and its rate of growth. According to (1') the two alternatives should lead to the same results since the latter is merely a reparametrization of the former. Similarly we shall also look at causality in both directions because, even if there was a cointegrating vector between $\mathbf{X}^*$ and y, only causality running from accumulation rates to income levels would be compatible with augmented Solow growth models.

2.2 Causality tests with non stationary variables

A number of studies have recently tackled the issue of causality among growth and some other variables using multi-country data.[3] They all rely in one way or another on the notion of Granger causality, which tells us that we can improve the predictions of one variable y taking into account the p past values of another variable x ($x_{t-1}, ..., x_{t-p}$), which presumably causes y. When x and y are stationary, the F-test of the p restrictions converges asymptotically to a χ^2 with p degrees of freedom.

However, if the VAR system includes non stationary variables this test has a non standard asymptotic distribution, which depends on the existence of a cointegrating vector among the variables (Sims, Stock and Watson (1990)). In Figures 1 and 2 we depict respectively the coefficient of $\ln y_{t-1}$ and $\ln s_{k,t-1}$ (where y is per capita income and s_k the investment rate) estimated in standard augmented Dickey-Fuller regressions along with their confidence intervals for each OECD country from 1960 to 1995.[4] As we can

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[2] If variables X and y are cointegrated either X causes y or y causes X. See Engle and Granger (1987) and Banerjee *et al.* (1993).

[3] See Conte and Darrat (1988), LaCivita and Frederiksen (1991), Blömstrom, Lipsey and Zejan (1996) and Carrol and Weil (1994) among others.

[4] The confidence intervals in Figures 1 and 2 have been obtained using -3.95 and -3.33 respec-

see, both income per capita and investment rates are $I(1)$ variables since we can accept that the coefficients of $\ln y_{t-1}$ and $\ln s_{k,t-1}$ are non-significant.[5] Although unit root tests suffer from lack of power, given these results it seems appropriate to be cautious. Thus, we explore two alternative situations in our VAR system which depend on the presence of a cointegrating vector. We also present the procedure proposed by Dolado and Lütkepohl (1996) which leads to a Wald test with standard χ^2 asymptotic distribution without the specification of the cointegrating vector.[6]

Let us consider that x and y are integrated of order one, $I(1)$, with cointegrating vector $(1, \alpha)$. In this case, following Sims, Stock and Watson (1990), causality can be tested in the following model:

$$y_t = a_o + g_1(y_{t-1} - \alpha x_{t-1}) + \mu_1(1-L)y_{t-1} + ... + \mu_p(1-L)y_{t-p} +$$

$$\pi_1(1-L)x_{t-1} + ... + \pi_p(1-L)x_{t-p} + d_1 y_{t-1} + u_t \qquad (2)$$

Notice that now, most of the regressors included in (2) are $I(0)$. Hence, we can use the F-test for restrictions on the parameters g_1, $\pi_1, ..., \pi_p$ which has a standard asymptotic distribution. In particular, when we cannot reject g_1=0, i.e. the error correction mechanism is not significant, there is no *long run causality* from x to y.

If there is not a cointegrating vector, we can still rewrite equation in (2) in terms of $I(0)$ and $I(1)$ regressors:

$$y_t = a_o + (\alpha_1 + ... + \alpha_p)y_{t-1} - (\alpha_2 + ... + \alpha_p)\Delta y_{t-1} - ... + \alpha_p \Delta y_{t-p}$$

$$+ (\beta_1 + ... + \beta_p)x_{t-1} - (\beta_2 + ... + \beta_p)\Delta x_{t-1} - ... + \beta_p \Delta x_{t-p} + u_t, \qquad (3)$$

that can be reparametrized defining $\alpha_i^* = \sum_{i=j+1} \alpha_i$ and $\beta_i^* = \sum_{i=j+1} \beta_i$ to obtain:

$$y_t = a_o + \sum_i^p \alpha_i y_{t-1} + \sum_i^p \beta_i x_{t-1} - \sum_j \alpha_i^* \Delta y_{t-j} - \sum_j \beta_i^* \Delta x_{t-j} + u_t. \qquad (4)$$

However, while the β_i^*'s are coefficients of I(0) regressors and, therefore, the test of the joint significance of Δx_{t-1},...,Δx_{t-p} follows asymptotically a χ^2(p), testing the signifi-

tively as the critical values of the augmented Dickey-Fuller test.

5 The evidence of income per capita being a $I(1)$ process found in our data is compatible with the results of Jones (1995), where growth rates exhibit no large permanent movements.

6 As we show in the next section, causality results obtained using this approach in Monte-Carlo experiments are not crucially affected by per capita income and investment rates being I(1) or trend stationary.

cance of x_{t-1} implies a restriction on the coefficient of a $I(1)$ regressor so that the F-test has a non standard asymptotic distribution.

Recently, Dolado and Lütkepohl (1996) have put forward a procedure to avoid the specification of the cointegrating vector and still have an asymptotically standard distribution for the F-test. Their method implies the direct estimation of the VAR process by least squares, with the variable in levels, fitting a VAR whose order exceeds the true order of the process (i.e. adding an extra lag if variables are $I(1)$). Although there is a loss in efficiency since the system is overparametrized, tests based on the estimated coefficients have a standard χ^2 asymptotic distribution.

So far we have discussed the properties of causality tests taking only into consideration the time series properties of the data. However, the cross section structure of our multi-country data set must be carefully handled in order to avoid imposing too many restrictions. Pooling data, without taking into account the presence of country specific effects, is a usual procedure in the empirical growth literature that nonetheless can lead to misleading results. Indeed, there is some evidence that suggests that the correlation between growth, investment and schooling is not that strong, once country specific effects are allowed for (Andrés and Hernando (1997) and Cohen (1993)). Some authors have simply proposed to test causality for each individual country since the estimated parameters in the pooled sample are at most consistent estimates of the average across countries (Conte and Darrat (1988), LaCivita and Frederiksen (1991)). In this paper we assume homogeneous slopes across countries, allowing for country specific time invariant effects. Under these assumptions, the basic model can be written as

$$y_{it} = \alpha_o + \alpha_i + \alpha_1 y_{it-1} + ... + \alpha_p y_{it-p} + \beta_1 x_{it-1} + ... + \beta_p x_{it-p} + u_{it} \tag{5}$$

This equation includes a time invariant individual effect (α_i). If all the regressors were stationary, as long as time dimension is relatively large, we could estimate this equation including an individual dummy with the variable in levels. However, the properties of the tests for individual effects when the variables are non stationary are less well known. Quah (1994a) has explored the implication of the cross section variation upon the unit root regression, when individuals are independent among them. He concludes that the estimated coefficient has an asymptotic distribution which is neither the normal distribution nor the Dickey-Fuller one. In fact, for a given time dimension T, increasing N drives the distribution of the estimated coefficient towards the normal.[7] This suggests that the cross section variation mitigates the problem of non stationarity along the time

[7] According to the Monte Carlo results presented by Quah, when $N = T = 25$ the critical value for a probability no greater than 2.5% is -2.60, above the -1.96 for the normal distribution but below the Dickey-Fuller case.

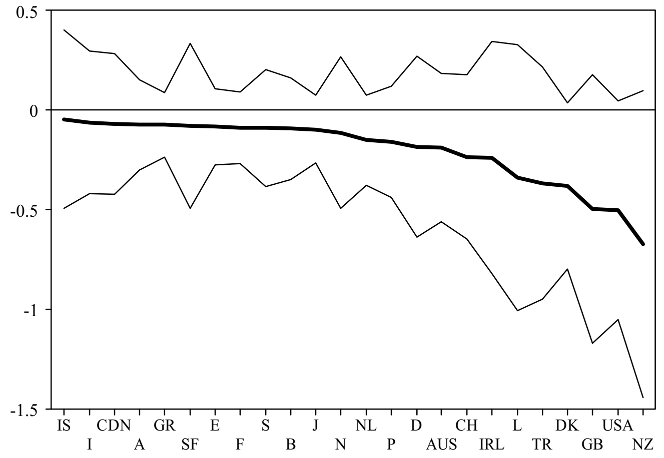

Figure 1: *Estimated coefficients of* $\ln y_{t-1}$ *in the augmented Dickey-Fuller regression for each country and their confidence intervals at the 95 per cent.*

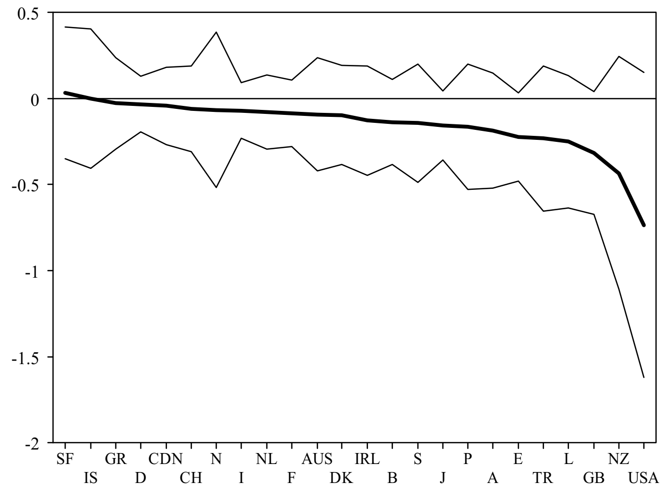

Figure 2: *Estimated coefficients of* $\ln s_{k,t-1}$ *in the augmented Dickey-Fuller regression for each country and their confidence intervals at the 95 per cent.*

series dimension. If both variables in equation (5) are $I(1)$, standard Wald tests based on the estimated coefficients presumably do not have a standard χ^2 asymptotic distribution, although now the problem will be less severe. Nevertheless, following Dolado and Lütkepohl (1996) we can estimate equation (5) in levels with an individual dummy as well as an additional lag for y and x.[8]

3. Monte-Carlo Experiments

Before testing causality from investment rates to income levels in our sample of OECD countries it is worth discussing further our approach to this issue, analyzing the power of the test proposed by Dolado and Lütkepohl in the standard neoclassical growth framework. To corroborate that the transitional dynamics of the MRW model implies causality and to asses how the modified Wald test can be altered by the omission of relevant variables such as human capital or investment in R&D, we have set up the following Monte-Carlo experiments.[9] The transitional dynamics of the Solow growth model can be described by the following expression:

$$\ln \widetilde{y}_{t+\tau} = (1 - e^{-\lambda\tau}) \ln \widetilde{y}^{*}_{t} + e^{-\lambda\tau} \ln \widetilde{y}_{t}, \tag{6}$$

where $\widetilde{y}$ is the income per worker in efficiency units, λ is the speed of convergence and $\widetilde{y}^{*}$ is the steady state to which the economy is converging, determined by its accumulation rates. Working with the human capital augmented version of the Solow model in terms of per capita income (y) when $\tau = 1$, equation (6) can be expressed as follows:

$$\begin{aligned} \ln y_{t+1} \;=\; & g(t+1) + (1 - e^{-\lambda}) \ln A_0 - e^{\lambda}(\ln y_t - g) + (1 - e^{-\lambda}) \\ & \left(\frac{\alpha}{1-\alpha-\beta} \ln s_{k,t} + \frac{\beta}{1-\alpha-\beta} \ln s_{h,t} - \frac{\alpha+\beta}{1-\alpha-\beta} \ln(n_t + g + \delta) \right), \end{aligned} \tag{7}$$

where g is the exogenous rate of technological progress, s_k and s_h the accumulation rate in physical and human capital, n the rate of growth of population, δ the depreciation rate, A_0 the initial stock of knowledge, and α and β the elasticities of output to physical and human capital respectively. Since we are interested in a stochastic version of this model we have made the following assumptions. First, we assume that A follows a

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[8] Another way of testing causality has been proposed by Holtz-Eakin, Newey and Rosen (1988), taking first differences in equation (5), using a variable set of instrumental variables. However, this method is only operative with the usual panel data structure in which only the cross-section dimension is large.

[9] See King and Rebelo (1993) for related quantitative experiments in other neoclassical models with intertemporally optimizing households.

stationary stochastic process:

$$\ln A_t = \ln A_0 + gt + \varepsilon_t^g.$$

Second, accumulations rates and population growth rates are also stochastic variables so that:

$$\ln s_{k,t} = \overline{\ln s_k} + (1-\rho_{sk})(\ln s_{k,t-1} - \overline{\ln s_k}) + \varepsilon_t^{sk},$$

$$\ln s_{h,t} = \overline{\ln s_h} + (1-\rho_{sh})(\ln s_{h,t-1} - \overline{\ln s_h}) + \varepsilon_t^{sh},$$

$$\ln(n_t+g+\delta) = \overline{\ln(n+g+\delta)} + (1-\rho_n)(\ln(n_t+g+\delta) - \overline{\ln(n+g+\delta)}) + \varepsilon_t^n.$$

Thus, if $\rho_{sk} = \rho_{sh} = \rho_n = 0$ then $\ln s_k$, $\ln s_h$ and $\ln(n_t + g + \delta)$ are integrated of order one. Finally, as our sample of OECD countries can present other sources of cross-sectional variance apart from the accumulation or the population growth rates, we allow for time invariant differences in the initial conditions so that:

$$\ln A_{0,i} = \ln A_0 + \varepsilon_i^a,$$

where subscript i denotes the different countries.

We have simulated equation (7) 1000 times for $t = 1, ..., 100$ and $i = 1, ..., 24$, and then, we have tested the causality from investment rates to per capita income levels for different values of λ, α, β and ρ.[10] As Mankiw, Romer and Weil (1992), we use an annual depreciation rate of 3 per cent and a rate of technological progress of 2 per cent. Additionally, ε^g, ε^{sk} and ε^n are drawn from normal distributions with standard deviations which reproduce the second moments of the variables in first differences we observe in our sample of OECD countries (see notes in Table 1).[11] Notice that the simulated series are obtained from a basic version of the human capital augmented Solow

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[10] In the human-capital augmented Solow model for closed economies, the rate of convergence is $\lambda = (1-\alpha-\beta)(n+g+\delta)$. Given the usual values of these parameters it is easy to obtain rates of convergence near the common 2 per cent of the empirical literature. However, as shown by Barro, Mankiw and Sala-i-Martín (1995), in open economies with partial capita mobility, the preceding expression should be modified, making possible to obtain higher rates of convergence. Thus, Caselli, Esquivel and Lefort (1996) have found rates of convergence of approximately 10 per cent that, for these authors, tend to support open economy versions of the neoclassical growth model.

[11] Given that the available human capital variables (for example, such as those included in the Barro and Lee (1996) data set) probably exhibit a different variance than the unobserved human capital accumulation rate considered in theoretical models, we have assumed equal ε^{sh} and ε^{sk} in our experiments.

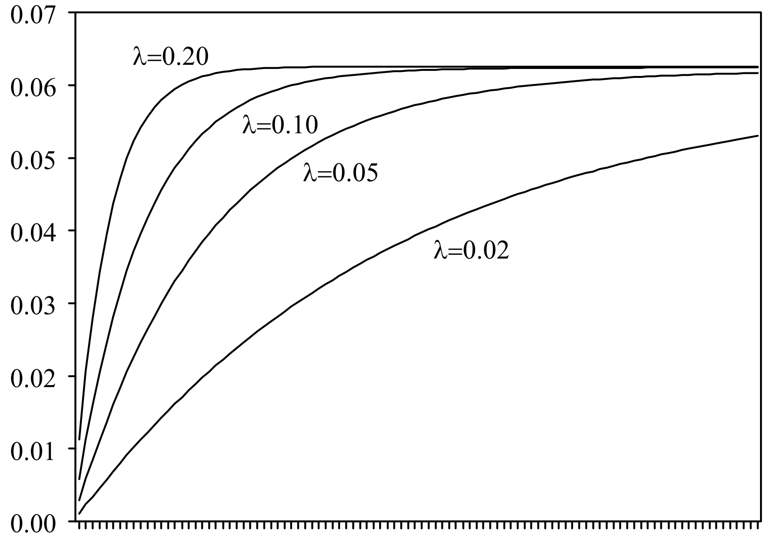

Figure 3: *Response of output per unit of effective labour in the simulated series to a permanent increase in the saving rate, depending on different convergence rates (λ).*

growth model where there are neither adjustment costs nor time-to-build; therefore as the true data gererating process (DGP) is a VAR(1) we have to estimate a VAR(2).

In Table 1 we present the $\chi^2(1)$ statistics of the null hypothesis of non causality for the 0.01 and 0.05 percentiles and the rejection rates depending on whether we include s_h or not.[12] Thus, we can analyze the performance of the test to the omission of a relevant variable (when $\beta = 0.33$), and to the inclusion of a non-relevant one (when $\beta = 0.0$). As we can see, for $\lambda \geq 0.02$ our test is quite powerful since it rejects the null hypothesis of non causality when is false. In fact, for $\lambda \geq 0.03$ we reject this hypothesis in all of the cases we include s_h, so the power of the test is equal to one. Notice also that for roots significantly below one ($1 - \rho_{sk} < 1$), the modified version of the Wald test also captures the relationship between the variables in the simulated economies. This is a very interesting result since, as we can see in the last two rows, the validity of our

[12] Although we simulate equation (7) with $t = 1, ..., 100$, we only take the last 36 observations to perform the causality test, making the sample size comparable with the sample used to obtain our emprirical results.

approach does not depend crucially on whether these variables are stationary or not.[13] Therefore, the procedure that we propose to test causality from saving to output per capita seems to be very robust to different stochastic assumptions and versions of the Solow growth model.

Finally, in Figure 3 we present the estimated response of output per unit of efficient labour to permanent changes in the saving rate using simulated series.[14] As we can see, consistent with the implications of the Solow model and with the causality tests in Table 1, such changes have a permanent effect on output per effective worker. Besides, these exercises show that the dynamic path of income following these shocks depends on the convergence rate.

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[13] These cases are considered for the sake of completeness. Although the unit roots in s_k and y cannot be rejected in a country by country analysis, the estimated roots in the pooled sample are below one (0.93 and 0.85 respectively). Unfortunately, the critical values of unit root tests in pooled samples, when the individuals are not independent, are not well known.

[14] According to the DGP of the variables in our simulations, the identifying restrictions are based on short run ones. Thus, ε_t^{sk} affects simultaneously $\ln y_t$ and $\ln s_t^k$, but the remaining shocks have no effects upon $\ln s_t^k$.

Table 1
Causality test with simulated series

	s_h excluded			s_h included		
	r	1%	5%	r	1%	5%
$\alpha = \beta = 0.33, \lambda = 0.00, \rho_{sk} = 0$	8.0	0.00	0.01	8.0	0.00	0.00
$\alpha = \beta = 0.33, \lambda = 0.02, \rho_{sk} = 0$	87.0	0.41	2.05	94.4	1.73	3.47
$\alpha = \beta = 0.33, \lambda = 0.05, \rho_{sk} = 0$	95.6	1.76	4.55	100	21.88	27.73
$\alpha = \beta = 0.33, \lambda = 0.10, \rho_{sk} = 0$	72.8	0.06	0.50	100	35.35	41.85
$\alpha = \beta = 0.33, \lambda = 0.20, \rho_{sk} = 0$	22.7	0.00	0.01	100	20.61	26.30
$\alpha = 0.33, \beta = 0.0, \lambda = 0.10, \rho_{sk} = 0$	100	31.65	40.54	100	32.10	40.79
$\alpha = \beta = 0.33, \lambda = 0.05, \rho_{sk} = 0.15$	99.5	4.61	7.83	100	15.77	20.17
$\alpha = \beta = 0.33, \lambda = 0.10, \rho_{sk} = 0.15$	91.1	1.13	2.76	100	25.44	31.16

Notes: the critical value of $\chi(1)$ at 5% of significance level is 3.84. Number of simulations=1000, t=36, n=24. r is the empirical rejection frequency. The variance-covariance matrix of shocks is given by:

$$\sum = \varepsilon'\varepsilon = \begin{pmatrix} 0.065^2 & & & & \\ & 0.05^2 & & & \\ & & 0.065^2 & & \\ & & & 0.14^2 & \\ & & & & 0.008^2 \end{pmatrix}$$

where

$$\varepsilon' = \begin{pmatrix} \varepsilon^{sk} & \varepsilon^{n} & \varepsilon^{sh} & \varepsilon^{a} & \varepsilon^{g} \end{pmatrix}$$

4. Empirical results

In this section we analyze the relationship between investment and income in OECD countries from 1960 to 1995, using alternative specifications.[15] Following Dolado and Lütkepohl (1996), we can estimate equation (7) with and without individual effects, augmented with additional lags of the variables. The problem with this approach is that we ignore the true order of the VAR process. In this case, the standard approach consists in testing different lag lengths until we obtain stationary and uncorrelated residuals. Once we know p, we have fitted a VAR($p+1$) to perform the modified Wald tests. Nevertheless, we have also estimated higher order VARs to be sure about our results in the case where adjustment costs are present, when more complex dynamics are probably needed.

Tests of causality running from investment to per capita GDP are presented in Table 2. As the optimal lag length is two, in accordance with the likelihood ratio test, we have included three lags in our regressions to implement the modified Wald test.[16] The $\chi^2(2)$ for the exclusion of β_1^k and β_2^k (see the estimated equation at the bottom of Table 2) ranges from 0.23 to 1.54 depending on the specification used, well below the critical value at the 5 per cent significance level. In accordance to Table 1, the probability of obtaining such values of the χ^2, if the model is well specified is almost zero.[17] Hence, the null hypothesis of non-causality cannot be rejected.[18] This is irrespective of whether individual effects are included or not (cols. 2 and 3 versus col. 1) and of the presence of other regressors such as the rate of human capital accumulation (as in col. 3) or the ratio of gross domestic expenditure on research and development to nominal GDP (col. 4).[19] Figure 4 displays the theoretical impulse-response functions corresponding to the

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[15] Most of the data used in this paper are described at length in Dabán, Doménech and Molinas (1997). The only exception are investment in R&D rates which have been taken from UNESCO *Statistical Yearbook*. We have observations of this ratio for all OECD countries, except Iceland, Luxembourg and Turkey, during 1964-1989. Data are available in the following URL address: HTTP:\??? (not provided here to guarantee anonymous text in this version).

[16] The likelihood ratio test for two lags versus three lags was $\chi^2(4) = 5.16$ (significance level equal to 27.5 per cent), whereas for one lag versus two lags was $\chi^2(4) = 48.2$ (significance level equal to 0.0 per cent). We have tried a higher number of lags without significant differences upon causality tests.

[17] It must be noticed that the probability of obtaining low χ^2 statistics increases somewhat if the model omits some relevant regressors. However, as Table 1 points out in the case when $\beta = 0$, the power of the test is not very much affected when non-relevant variables are included.

[18] In multivariate systems, as causality from $\ln s_k$ to $\ln y$ may work through other variables, we have also tested causality from $\ln s_h, \ln(n+g+\delta)$ and $\ln s_{I+D}$. In all the cases causality is comfortably rejected.

[19] Following the approach suggested by Lee, Pesaran and Smith (1997), country heterogeneity may extend to slope coefficients. The results (not presented here) confirm again the absence of

convergence rates of 10 and 5 per cent, and the estimated lines. Again the implications of the MRW model are clearly at odds with what we find in the data. For the OECD sample an unanticipated change in the investment rate seems to have at most a temporary impact on GDP per capita. Thus, the interpretation given to capital accumulation in convergence equations might be misleading.

Table 2

Causality tests from investment rates to income per capita

	(1)	(2)	(3)	(4)
Number of lags	3	3	3	3
Wald test on the exclusion of β_1^k and β_2^k	0.23	0.60	0.88	1.54
Significance level (%)	89.1	74.0	64.3	46.4
$\beta_1^k + \beta_2^k$	-0.008	-0.013	-0.016	-0.003
Implied convergence rate (%)	1.6	7.1	7.2	10.5
Individual effects	no	yes	yes	yes
$\ln(n+g+\delta)$	no	yes	yes	yes
$\ln s_h$	no	no	yes	yes
$\ln s_{I+D}$	no	no	no	yes
N. of observations	792	792	782	585

Note: estimated equation for income per capita (y) is:

$$\ln y_{it} = \alpha_i + \sum_{j=1}^{3} \alpha_j \ln y_{it-j} + \sum_{j=1}^{3} \beta_j^k \ln s_{k,it-j} + \sum_{j=1}^{3} \beta_j^h \ln s_{h,it-j} + \sum_{j=1}^{3} \beta_j^n \ln (n+g+\delta)_{it-j} + \sum_{j=1}^{3} \beta_j^{I+D} \ln s_{I+D,it-j} + dT + u_{it}$$

causality from investment rates to income.

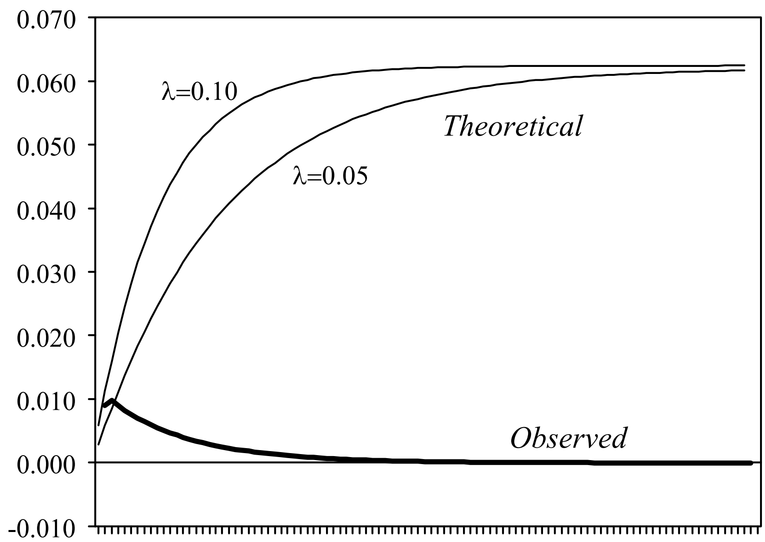

Figure 4: *Empirical and observed responses of output to a permanent increase in the saving rate.*

The picture that comes out of these results is disappointing for the so called 'mechanical link' between investment and income that is inherent to the exogenous growth model. Other authors report related results although with different econometric methods and a rather different economic interpretation. Blömstrom, Lipsey and Zejan (1996) find no evidence of causality from investment to growth in cross section and pooling regressions on five years averages, even after controlling for specific country effects.[20] In a related work Carroll and Weil (1994) find that savings do not cause growth for the OECD sample or, if they do, the coefficient of growth on lagged savings turns out to be negative.

These results are rather puzzling, since the investment rate appears as the single most relevant determinant of growth rates in the recent growth literature. In their comprehensive study, Levine and Renelt (1992) find a robust correlation between these two variables irrespective of the conditioning information set. How can we account for this correlation in the light of the lack of causality? One possibility is that the positive sign in regression models simply reflects a simultaneity bias. Accelerator models of investment can give rise to a positive causation running from income to investment. Similarly,

[20] They do so dividing the variables by their average over the sample period.

as Carroll and Weil (1994) claim, the life cycle theory of consumption would predict a negative impact of current income on the future savings rate (and hence investment) as a result of forward looking consumers feeling wealthier. These authors find in fact the opposite happening; current GDP causes future savings rates with a positive sign. Blömstrom, Lipsey and Zejan (1996) come up with similar results; the correlation between current growth and future investment rates is positive and stronger than the correlation with current and past investment. In Table 3 we have tested this direction of causality, from income to investment, applying the same econometric methods as in Table 2.[21] The corresponding χ^2 statistics show that the null of non causality can be safely rejected in most specifications at the 5 per cent level of significance. In all cases, the sign of the correlation between current growth (we can accept the restriction $\alpha_1 = -\alpha_2$) and future investment/GDP ratio is positive and quite strong.

This feedback from growth to investment implies that the positive correlation in conventional growth equations can be contaminated by a simultaneity bias, as the one detected by Caselli, Esquivel and Lefort (1996) in a sample of 97 countries. Although in our exercises, the causality hypothesis from investment rates to per capita income is rejected whether individual effects are include or not, it is interesting to note that the cross-section correlation could also be explained by the absence of individual effects in the standard convergence regressions. In fact, once the possibility of different intercepts is allowed for, investment is no longer significant in standard cross-section growth equations in our sample of OECD countries, as Andrés and Hernando (1997) find in convergence regressions augmented with the inflation rate. This interpretation is consistent with Cohen's results (1993) on the role of human capital accumulation in convergence regressions. Country specificities might explain why some countries save (and invest) more than others as well as why some countries grow faster than others.

[21] In this case, the likelihood ratio test for two lags versus three lags was $\chi^2(4) = 5.53$ (significance level equal to 26.7 per cent), whereas for one lag versus two lags was $\chi^2(4) = 78.9$ (significance level equal to 0.0 per cent).

Table 3

Causality tests from income per capita to investment rates

	(1)	(2)	(3)	(4)
Number of lags	3	3	3	3
Wald test on the exclusion of α_1 and α_2	37.4	25.3	26.4	35.3
Significance level (%)	0.0	0.0	0.0	0.0
α_1	0.69	0.57	0.56	0.65
Individual effects	no	yes	yes	yes
$\ln(n+g+\delta)$	no	yes	yes	yes
$\ln s_h$	no	no	yes	yes
$\ln s_{I+D}$	no	no	no	yes
N. of observations	792	792	782	525

Note: the estimated equation for investment rates (s_k) is:

$$\ln s_{k,it} = \alpha_i + \sum_{j=1}^{3} \alpha_j \ln y_{it-j} + \sum_{j=1}^{3} \beta_j^k \ln s_{k,it-j} + \sum_{j=1}^{3} \beta_j^h \ln s_{h,it-j} + \sum_{j=1}^{3} \beta_j^n \ln (n+g+\delta)_{it-j} + \sum_{j=1}^{3} \beta_j^{I+D} \ln s_{I+D,it-j} + dT + u_{it}$$

5. Conclusions and final remarks

The adjustment mechanism of income towards its steady state is a distinctive feature of the standard augmented Solow growth model with exogenous accumulation rates. According to this, accumulation rates should cause income in a statistical sense in the long run, since the past history of this variable is not enough to predict its future behaviour. In this paper we exploit this implication to carry out a test of the dynamic properties of augmented versions of the Solow growth model. We study the causality from capital accumulation to income, taking special care of the features of the data set we deal with, such as non-stationary regressors as well as the likely presence of a cointegrating vector among them. Also, we allow for country specific effects in the estimated equations.

We have reported a consistent and robust lack of causality from investment rates to income per capita. Thus, the forecast of income per capita cannot be improved on by taking current investment rates into account, irrespective of whether other regressors are included in the equation. This provides strong evidence against the error correction model implied by the dynamics of the augmented versions of the Solow growth model. These results are in sharp contrast with the standard interpretation of the correlation between income levels and current accumulation rates found in the empirical literature. If anything, we find signs of reverse causality running from income to investment, that may explain the cross section correlation among income per capita and average investment rates found in OECD countries.

Finally, we must emphasize that the lack of causality from investment to income found in this paper should not lead to conclude that investment is not crucial for growth. Indeed, it is hard to think of any growth mechanism that does not work, in one way or another, through the accumulation of these and other factors of production. All what these results tell us is that the evidence in favour of the adjustment mechanism of the Solow model, built in the convergence equations, is far less convincing than what is usually meant, since the property of convergence to steady state that characterizes this model implies long-run statistical causality running from investment to output. The link between investment and growth is more complicated than is generally assumed. At least, as far as the OECD is concerned, faster growing countries are also the ones with higher investments. Some economies grow faster and invest more than others because some idiosyncratic features encourage them to do so. These unknown factors (market organization, public sector efficiency, financial development, inflation control, etc.) are the ones we should look at before we can put forward any policy recommendations.

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