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ABSTRACT

In this paper, we analyse the relationship between productive physical investment and economic growth from a panel perspective for a sample of 61 countries spanning the period 1950-1992. The analysis can be thought of as two-fold. First, we test the empirical validity of AK models following the logic by Jones (1995). For that purpose, we determine the degree of persistence of physical investment rates and growth by employing recently developed panel unit roots tests which enable us to make more reliable inferences about the existence of stochastic trends in the series. Second, we estimate the long-run effect of physical investment on growth by using panel data techniques rather than cross-section regressions. Overall, our findings cast doubts on the rejection of the empirical validity of the AK model as suggested by Jones' analysis.

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Key Words: Panel Unit Root Tests, Endogenous Growth, Physical Investment.

1. Introduction

Since the seminal work of Jones (1995) there has been a long-standing debate over the empirical validity of endogenous growth models versus neoclassical growth models that follow the Solow (1956) tradition. Two main reasons are responsible for this interest in discriminating among both strands of the growth literature. Firstly, the different predictions of neoclassical growth theory and the endogenous growth models of Romer (1986, 1990) and Lucas (1988), among others, regarding the long-run impact of policy variables on growth. Accordingly, under the neoclassical paradigm diminishing returns to reproducible capital leads inevitably to only temporary growth effects along the transitional growth path. On the contrary, by assuming constant or increasing returns to reproducible capital, endogenous growth models can render genuine long-run growth effects from policy variables along the balanced growth path. Secondly, the increasing availability of cross-country datasets such the Penn World Table (Summers and Heston, 1991) has allowed the empirical analysis of these issues as well as international comparisons of economic performance over relatively long periods.[1]

Early empirical growth studies employed the cross-sectional approach following the work of Barro (1991) to determine whether a policy variable can affect long-run growth averages by entering significantly the growth regression. If that happens, there would be support for endogenous growth theory. However, given the high sensitivity of this approach to the set of control variables (Levine and Renelt, 1992), aggregation issues (Ericsson et al., 2001) and reverse causality problems, researchers have shifted the focus to test the different predictions of endogenous growth models against neoclassical models using time series data. Given the different implications of both paradigms, researchers have tried to see whether both growth and its determinants follow the same evolving pattern over time. If this is the case, it can be argued for the existence of a long-run link between the growth-determinant and economic growth as predicted by endogenous growth models. In contrast, if both series show different degrees of persistence, then support is found for

[1] For an authoritative review of the empirics of growth including the main studies in the field and the methodological as well as econometric problems, see Temple (1999).

the neoclassical paradigm where policy variables can only have level effects in the long-run.

In this study we focus on the link between physical investment and growth in the long run for a sample of 61 countries over the period 1950-1992. Our analysis will have two goals. First, by taking advantage of the time dimension of the data as well as the different implications that the relation between investment and growth have according to the neoclassical paradigm and endogenous growth models of the AK-type such as those developed by Romer (1986) and Rebelo (1990), we will be able to test the empirical validity of the AK model. The main difference between the AK model and the Solow model is that the former allows for the existence of constant returns to capital, which in turn enables investment to have a long-run impact on growth. Second, provided we do not reject the empirical validity of the AK paradigm when analysing the degree of persistence of investment rates and output growth, we aim at determining whether there is effectively a long-run impact of productive physical investment on growth using panel data techniques. Third, we employ the equation derived by Auerbach et al. (1993) to determine whether the long-run coefficients estimated for the investment rates are associated with rates of return to reproducible physical capital above those implied by the Solow model. Overall, our findings do not permit a clear rejection of the empirical validity of AK growth models.

Recently, research on non-stationary panels has developed panel techniques to analyse the stationary character of macroeconomic series. These techniques improve on their time series counterparts, since by increasing the number of observations through the panel structure, important gains in terms of power to reject a false null are achieved. Therefore, we will make use of the panel unit root tests developed by Im et al. (2003, IPS hereafter) and Breitung (2000) in order to determine whether growth of per capita output and physical investment shares contain a unit root. Unlike Li (2002) and McGrattan (1998), we will be looking at stochastic trends in the data rather than deterministic ones, since we believe the distinction between endogenous and exogenous growth models may only be made on the basis of the existence of stochastic trends in the variables under consideration. Arguably, given the length of the time spans of the existing macroeconomic series, the existence of both positive and negative deterministic trends in the data can result from deviations from the long-run path as a response to one-time shocks, and in the long-run such series should revert to their respective long-run means. Non-stationary series, instead, will perpetuate the effect of one-time shocks, and will not revert to their long-run means.

This paper will be structured as follows. Section two reviews the main studies on the link of investment in physical capital and growth. In section three we present the methodology followed in the analysis of stochastic trends in the data as well as the results. In section four, we estimate a distributed lag model in order to determine the long-run impact of productive investment on growth. Section five addresses the issues of endogeneity of investment and the existence of business cycle effects which may lead to a spurious long-run relation between growth and investment. Section six sheds some light on the extent of social returns to productive capital. Section seven summarises the findings and concludes.

2. Brief Review of the Literature

The role of physical investment has received great attention when analysing the existing differences in both productivity levels and growth rates of output across countries and over time. Early international comparisons on the role of physical investment in affecting economic performance (e.g. Hill, 1964) already revealed physical investment as one of the main determinants of growth in the long-run for a sample of OECD countries. Some attention has also been directed to the impact that different types of physical investment can have on growth. In his early study, Hill finds that the investment component with the highest influence on growth appears to be equipment investment, with returns well above those of investment in structures. This has important implications in terms of economic policy, since by subsidising investment in equipment the policy-maker can promote shifts from investment in structures to machines and equipment, which would be favourable for the performance of the economy.

More recent studies such as De Long and Summers (1991, 1992, 1994) have also analysed the effect of physical investment on growth, focusing on the compositional effects of investment. They find that equipment investment appears to be the component of investment which most influences growth, thereby having rates of return well above those predicted by the Solow model particularly in developing countries. This represents some indirect evidence supporting the predictions of endogenous growth models, through the existence of positive externalities and spillovers from equipment investment. Temple (1998) validates the empirical findings of De Long and Summers even after removing key outliers, controlling for the endogeneity of current investment and for the unobserved heterogeneity through the inclusion of continent dummies. Furthermore, Bond et al. (2004) provide evidence that the total investment rate exerts a positive effect on growth for a sample of 98 countries over the period 1960-1998. This takes place not only temporarily, but also in the steady state. These results are robust to different model specifications and estimation methods, which include pooled regressions with both annual and five-year averaged data as well as mean-group estimations.

Jones (1995) provides the first test of the empirical validity of the AK-type growth models using a time series framework. His sample includes 15 OECD countries with data from 1950-1988. Jones shows that while the investment rate in producer durables exhibits an upward deterministic trend and shows nonstationarity when applying augmented Dickey-Fuller (1979, ADF) tests, rates of economic growth remain fairly stable over the period under scrutiny. Thus, if growth rates exhibit no large permanent movements, then there is a strong restriction for testing the validity of endogenous growth models. According to Jones (1995), "if an endogenous growth model predicts that permanent movements in some variable X have permanent effects on growth, then either:

1) X must exhibit no large persistent movements, or
2) Some other variable (or variables) must also have persistent effects on growth that offset the movements of X in a way that is determined by the endogenous growth model", (Jones, 1995, p. 502).

This second possibility is discarded on the grounds that most policy variables that could be complementary to physical investment have improved over the period. These include expenditures on education and R&D, the level of educational attainment and the degree of openness to trade and capital movements. In addition, estimates of distributed lag models do not render clear-cut evidence of a long-run growth effect from physical investment rates. On these grounds, Jones (1995) rejects the empirical validity of AK models. However, McGrattan (1998) challenges Jones' findings on the grounds that his analysis captures short-run patterns in the investment and growth data, which are not generally coincident over the postwar period, rather than long-run trends. She, thus, claims that such short-lived deviations from long-run trends are consistent with AK models slightly more general than the one considered by Jones (1995) by assuming that government policies can not only affect investment/output ratios but also capital/output ratios and labor/leisure decisions.[2]

Along similar lines, Li (2002) extends Jones' analysis, first by widening the sample to 24 OECD countries from 1950 to 1992 and second, by analysing long-run patterns of data on investment rates that go from 1870 to 1987 for five major industrialised countries. Li argues that the relevant investment share for testing the AK models is the total physical investment share. His findings suggest that the case against AK-type models is weakened when analysing the deterministic trends of total investment shares and economic growth. He also estimates distributed lag models and consistently finds a positive long-run effect from total investment to growth for most countries. However, neither McGrattan (1998) nor Li (2002) investigate the stochastic properties of output growth and investment rates series. Rather, they appear to base their conclusions solely on the presence or absence of deterministic trends in economic growth and investment rates. More recently, Romero-Ávila (2006) has revisited Jones' analysis by employing recently developed univariate unit root tests with good size and power for a sample of 26 OECD countries over the period 1950-1992. Overall, the analysis of deterministic and stochastic trends in output growth and investment rates did not render broad support for the empirical validity of AK models.

In this study we extend the work by Jones (1995), McGrattan (1998), Li (2002) and Romero-Ávila (2006) by 1) analysing the empirical validity of AK models for a broader set of countries comprising both the OECD and developing countries for the period 1950-

[2] McGrattan (1998) does not estimate autoregressive distributed lag growth models in order to establish the existence of a positive long-run link between growth and physical investment, as suggested by AK models. Rather, she reports some descriptive evidence through a scatter plot showing a positive relationship between average investment rates and average growth rates for a large cross-section of countries. But this procedure fails to control for the likely endogeneity of investment rates and for the dynamics in the investment-growth nexus.

1992,[3] and 2) by employing panel data techniques which raise statistical power by exploiting the cross-sectional variability of the data.[4] The data are provided by Summers and Heston (1991) with the Penn World Table 5.6.[5]

Arguably, the differing results found by Jones (1995) and Li (2002) may derive from the different definitions of investment used to test the AK model. Since there has been a clear shift from investment in structures to investment in producer durables in some countries, this has made the producer durables investment share look upward-trended while the total investment rate appears flatter over time. We argue that the investment share that should be employed is the one that relates to the productive component of capital. As a result, we will consider investment in machinery and transportation equipment (which both together form producer durables investment) along with non-residential structures. We exclude from the analysis investment in residential construction, since this component of investment is not directly linked to the production process. This exclusion allows us to control to some extent for the possibility that the degree of persistence of investment shares is driven by compositional effects from shifts from investment in residential structures to investment in producer durables.

3. The Stationarity Properties of Output Growth and Investment Shares

3.1 Econometric Approach

The first step is to analyse the time-series properties of the investment shares in productive capital and rates of economic growth in order to determine the degree of persistence of the series. We utilise the panel unit root test proposed by IPS. Compared to time series unit-root tests for individual countries, the pooling of information dramatically increases the number of observations, and hence the power of the test to reject a false null hypothesis. Our panel specification will be of the form:

[3] The list of the countries is provided in the appendix. The full sample consists of 61 countries for which disaggregated data on investment were available. Detailed descriptive statistics of the data used throughout the analysis are provided in the Appendix.

[4]Panel unit root tests constitute a more efficient way to increase statistical power than employing univariate unit root tests with GLS-detrending as previously done in Romero-Ávila (2006).

[5] We have refrained from using the recently released Penn World Table version 6.1, since it does not provide dissagregated data on investment shares.

$$\Delta y_{it} = \alpha_i + \delta_i t + \theta_t + \gamma_i y_{it-1} + \sum_{j=2}^{p_i} \rho_{ij} \Delta y_{i,t-i+1} + \varepsilon_{it} \quad (1)$$

where p_i is the required degree of lag augmentation to make the residuals white noise which is determined by the conventional step-down procedure. α_i and $\delta_i t$ represent the country-specific fixed effects and deterministic trends respectively, and θ_t denotes the time dummies used to account for cross-correlations and interdependencies across different members of the panel which could result from common shocks affecting all panel members in a given period.

The null hypothesis H_0 implies that $\gamma_i = 0$, for all i, i.e. all series have a unit root, which is tested against the alternative H_1 that $\gamma_i < 0$ for $i=1,2, \ldots\ldots N_1$ and $\gamma_i=0$, for $i=N_1+1, N_1+2, \ldots, N$. Assuming that the N cross-section units are independently distributed, the t-statistic can be computed as an average of the individual ADF t-statistics such that:

$$\bar{t}_{NT}(p, \rho) = \frac{\sum_{i=1}^{N} t_{iT}(p_i, \rho_i)}{N} \quad (2)$$

where $t_{iT}(p_i, \rho_i)$ is the t-statistic for testing γ_i=0 in each individual ADF specification. Assuming the existence of the second-order moments of $t_{iT}(p_i, \rho_i)$, the $\bar{t}_{NT}(p, \rho)$ statistic is corrected for small sample size as follows:

$$\bar{Z}_t = \frac{\sqrt{N}\left\{\bar{t}_{NT}(p, \rho) - \frac{1}{N}\sum_{i=1}^{N} E[t_{iT}(p_i, 0) / \gamma_i = 0]\right\}}{\sqrt{\frac{1}{N}\sum_{i=1}^{N} Var[t_{iT}(p_i, 0) / \gamma_i = 0]}} \xrightarrow{d} N(0,1) \quad (3)$$

where $E[t_{iT}(p_i, 0) / \gamma_i = 0]$ and $Var[t_{iT}(p_i, 0) / \gamma_i = 0]$ are the adjustment factors obtained via stochastic simulation.[6] The standardised statistic weakly converges to a one-sided standard normal distribution under the null and diverges under the alternative as T and N tend to infinity and N/T goes to k, where k is a finite constant.[7] Therefore, the panel unit root inference can be conducted by comparing the value of $\bar{Z}_t$ to the critical values from the lower tail of the standard normal distribution.

[6] Such correction factors are provided in IPS for different degrees of lag–length augmentation and sample sizes in the time dimension.

[7] This condition constitutes an important advantage over other tests such as Levin et al. (2002) where N/T must tend to zero as N and T grow large for the validity of the test.

The main strengths of the IPS test compared to others such as the Levin et al. (2002) test, is that γ_i is allowed to differ across countries and only a fraction of panel members is required to be stationary under the alternative hypothesis. However, the IPS test suffers from an enormous decrease in power when country-specific trends are included in the specification as a result of the bias correction applied to the t-statistics (Baltagi and Kao, 2000; Breitung, 2000). To deal with this issue, Breitung (2000) has proposed a panel unit root test which employs unbiased t-statistics. This is achieved by transforming the variables in a way that their t-statistics do not require any small-sample bias correction.

More specifically, from a specification like (1), Breitung (2000) proceeds by transforming the variables $y_{i,t-1}$ and Δy_{it} in a way that their t-statistics can be used to test for the presence of a unit root in the data. He first defines the vectors $y_i =[\Delta y_{i1},\ldots\ldots, \Delta y_{iT}]'$ and $x_i = [y_{i0},\ldots\ldots,y_{i,T-1}]'$ of $T\times 1$ dimension. To construct an unbiased test statistic, he transforms those vectors as follows: $y^*_i=Ay_i=[y^*_{i1},\ldots.y^*_{iT}]'$ and $x^*_i=Bx_i=[x^*_{i1},\ldots.x^*_{iT}]'$ such that $E(y^*_t x^*_i)=0$ for all i and t. This condition will be satisfied by using an upper triangular matrix A, with the elements of each row summing to zero. Therefore, only the present and future observations can be used to transform the terms in first-differences Δy_{it} that are assumed to be white noise. One transformation that fits these requirements is the Helmert one given by:

$$y^*_{it} = s_t[\Delta y_{it} - \frac{1}{T-t}(\Delta y_{i,t+1} + \ldots + \Delta y_{iT})] \quad , t=1,2,\ldots,T-1. \tag{4}$$

where $s^2_t=(T-t)/(T-t+1)$. The matrix B has to satisfy $E(x^*_{it})=0$ and $E(y^*_{it}\ x^*_{it})=0$. A transformation that fits such properties is $x^*_{it} = y_{i,t-1} - y_{i1} - \frac{t-1}{T} y_{iT}$. By further assuming that $\lim_{T\to\infty} E(T^{-1} y_i^{*}{}' y_i^*) > 0$ as well as $\lim_{T\to\infty} E(T^{-1} x_i^{*}{}' A' A x_i^*) > 0$, Breitung presents a statistic that weakly converges to a standard normal distribution under the null according to sequential limit theory with N and then T tending to infinity. The statistic takes the following form:

$$\lambda^*_{UB} = \frac{\sum_{i=1}^{N} \sigma_i^{-2} y_i^{*}{}' x_i^*}{\sqrt{\sum_{i=1}^{N} \sigma_i^{-2} x_i^{*}{}' A' A\ x_i^*}} \xrightarrow{d} N(0,1) \tag{5}$$

for $E(\Delta y_{it} - \beta_i)^2 = \sigma^2{}_i > 0$ and $E(\Delta y_{it} - \beta_i)^4 < \infty$ where $\beta_i = E(\Delta y_{it})$. By allowing for heterogeneous deterministic trends and short-run dynamics across countries without the need of bias adjustment, the Breitung test has more power to reject a false null and is not sensitive to the degree of augmentation in the ADF specifications.

3.2 Results on the Stationarity Properties of Investment Shares and Economic Growth.

In this section we present the results of the IPS as well as the Breitung tests in order to determine whether the series contain stochastic trends. We compute the IPS test using heterogeneous lag-truncation of four and six, since this is in general the longest lag-truncation found for individual ADF statistics.[8] As shown in Table 1, per capita GDP levels expressed in logs appear to be integrated of order one while growth rates of output per capita computed as the log-difference of the levels are I(0), as normally found in the literature. We then test for unit roots in the total investment share and the three components in which it can be decomposed: 1) Investment in machinery and equipment transport, 2) investment in non-residential construction and 3) investment in residential construction, which constitutes the non-productive component of physical investment. We also add up the investment rates in producer durables and non-residential construction into a category called productive investment. As reported in Table 1, the total and productive investment rates as well as the three components analysed separately are found to be stationary with both the IPS and Breitung tests.[9] These results are robust to the inclusion of heterogeneous deterministic trends and to the maximum degree of augmentation of individual ADF specifications.

[Insert Table 1 about here]

[8] The degree of augmentation for the individual ADF specifications were computed following the general-to-specific step-down procedure by which it is necessary to remove insignificant lag-differenced terms until the last term is significant at conventional levels of significance.

[9] As pointed out by Jones (1995), any macroeconomic variable expressed as a share of GDP such as physical investment shares cannot be driven by a pure unit root process, since they are bounded between zero and one, and a stochastic process characterised by a pure unit root would cross such bound sooner or later. However, the investment share can be conceivably driven by a stochastic trend within the interval comprised between zero and one.

This preliminary evidence points to the non-rejection of AK models, since we find that rates of economic growth and investment shares are both stationary, which potentially allows for the existence of a long-run link between productive investment and growth not driven by spurious stochastic trends. These results accord quite well with Li (2002), who showed that total investment shares and rates of economic growth show fairly similar trends in a sample of 24 OECD countries over 1950-1992 supplemented with long-run evidence on five major industrialised countries. However, he does not explicitly test for the existence of stochastic trends and his inferences are based on deterministic trends that may result from transitional dynamics effects rather than from steady state equilibrium. Another difference is that Li focuses on the share of total investment while our focus is on the productive components of physical investment.[10]

These results sharply contrast with Jones' findings, which clearly point to the rejection of AK models. His main argument is that while producer durable investment (and to a less extent the total investment rate) has been rising over the period 1950-1988 in 15 OECD countries, rates of economic growth have remained fairly stable. ADF unit root tests supported the non-stationarity of investment rates as opposed to economic growth rates that were found stationary. However, we show here that once we investigate the existence of stochastic trends in the data using panel unit root tests applied to a much wider sample of countries comprising both the OECD as well as many developing countries, we clearly reject the null of a unit root present in the investment rates. Thus, failure to reject the null of a unit root in the investment data in Jones' paper, in all likelihood derives from the lack of power that time series unit root tests such as the ADF have to reject a false null hypothesis of a unit root.

To verify this, we test for the existence of stochastic trends in the data used by Jones (1995). The results presented in Table 2 show that both the IPS and Breitung tests generally point to the stationarity of the total investment rate and the investment rate in producer durables. Therefore, with the evidence at hand, we cannot reject the empirical

[10] Note that the inferences we could draw on the basis of the panel unit root tests for the total investment share would remain the same: a clear non-rejection of AK models.

validity of the AK model. We can also observe that the claim made by Li (2002) that the differing results between his study and Jones' derive from the investment rate considered does not hold, since both the total investment rate and the investment rate in producer durables appear stationary.

[Insert Table 2 about here]

At this stage, it is important to acknowledge that the test à la Jones may render inconclusive results. This is because despite being unable to reject the AK model on the basis of the stationarity properties of the data, Jones test does not yield evidence directly supporting the AK model either. Therefore, in the next sections we take two avenues to try to shed some light on which growth model most closely represents our data. First, we estimate distributed lag models so as to determine whether the growth impact of productive investment represents a genuine long-run effect or a transitory one. Second, we compute the rates of return to productive investment associated with the estimated growth effects. To the extent these returns are above those predicted by the Solow model, it would yield indirect evidence in favour of AK-type models.

4. Distributed Lag Models of Productive Investment and Growth

4.1 Estimation Procedure

In this section we jointly consider the time series behaviour of output growth and investment rates in productive physical capital by estimating a distributed lag model of the form:[11]

$$\Delta y_{it} = \alpha + \theta_t + \sum_{i=0}^{p} \beta_{ei} e_{t-i} + \sum_{i=0}^{p} \beta_{si} s_{t-i} + \varepsilon_{it} \qquad (6a)$$

where y indicates the natural log of per capita output, e and s stand for the investment share in producer durables and nonresidential structures respectively, t relates to time and i to country. This specification directly derives from the steady-state outcome of an AK model with two types of productive capital: producer durables and nonresidential structures, where long-run economic growth is a function of the investment rates in both types of

[11] These distributed lag models can be safely applied to the estimation of regressions with stationary variables.

productive physical capital.[12] Evans (1997) and Kocherlakota and Yi (1997) show that exogenous growth theory implies

$$\sum_{i=0}^{p} \beta_{ei} = \sum_{i=0}^{p} \beta_{si} = 0 \tag{7a}$$

as the lag order grows sufficiently large. Conversely, support for endogenous AK-type growth models will imply that the impact of the investment shares in producer durables and non-residential investment will be positive

$$\sum_{i=0}^{p} \beta_{ei} > 0 \tag{7b}$$

$$\sum_{i=0}^{p} \beta_{si} > 0 \tag{7c}$$

Therefore, the sum of coefficients must be significantly different from zero for a sufficiently large lag order if endogenous growth predictions are valid. Although it is not clear *ex ante* what constitutes the right lag order in this context, given our sample length, a lag-length equal to six may suffice to capture the long-run impact from productive investment to growth. In the growth literature, it is commonplace to average the data over periods of five or six years in order to get rid of the cyclical component of the data. Rewriting (6a) using the lag operator, we have:

$$\Delta y_{it} = \alpha + \theta_t + A(L)e_{it} + B(L)s_{it} + \varepsilon_{it} \tag{6b}$$

where *A(L)* and *B(L)* represent two lag polynomials of order *p* with roots outside the unit circle. In order to distinguish short-run dynamics from long-run effects, we reparameterise (6b) in line with Jones (1995) and Li (2002) as follows:

$$\Delta y_{it} = \alpha + \theta_t + A(1)e_{it} + C(L)\Delta e_{it} + B(1)s_{it} + D(L)\Delta s_{it} + \varepsilon_{it} \tag{6c}$$

where *C(L)* and *D(L)* are *(p-1)th*-order lag-polynomials such that:

$$c_{is} = -\sum_{j=s+1}^{p} a_{ij}$$
$$d_{is} = -\sum_{j=s+1}^{p} b_{ij}$$

where $s = 1, \dots\dots\dots, p\text{-}1$.

[12] See for instance the AK model of Barro and Sala-i-Martin (1995: chapter 4) which focuses on total physical and human capital accumulation.

In sum, the coefficients *A(1)* and *B(1)* pick up the long-run growth effect of physical investment in producer durables and non-residential construction, while the first-difference terms capture short-run interactions between productive investment and growth. Since we could not reject the empirical validity of AK-type models on the basis of the stationarity properties of investment rates and output growth series, we may find *A(1)* and *B(1)* to be greater than zero.

A source of concern of the kind of models we are dealing with is that current as well as lagged productive investment may be correlated with the error term, as a result of third common factors that may drive output and productive investment over the short/medium term. These short-term deviations from the long-run path should vanish as the lag-length of the polynomials characterising investment grows large. Following Li (2002) we deal with the issue of business cycle effects and possible feedbacks from growth to investment by including leads in the distributed lag models.[13] Let us consider the case when the error structure which may be correlated with the regressors in (6) takes the following form:

$$\varepsilon_{it} = G(L)e_{it+q} + H(L)s_{it+q} + \nu_{it} \quad (8)$$

where *G(L)* and *H(L)* are polynomials of order *2q*. We assume that the new error term ν_{it} is uncorrelated with the leads and lags of the investment rates in durables and nonresidential construction, since otherwise we would still have the problem of business cycle effects. It is also assumed that for large enough values of q, the correlation between ε_{it} and the investment terms are zero beyond q leads and lags. We further assume that cyclical shocks can only affect investment and growth in the short-run, since we do not expect the existence of a long-run relation between ε_{it} and investment shares. Equation (8) can thus be written as $\varepsilon_{it} = G(1)e_{it} + G'(L)\Delta e_{it+q} + H(1)s_{it} + H'(L)\Delta s_{it+q} + \nu_{it}$, where *G(1)* and *H(1)* are zero. By substituting ε_{it} into the growth equation, it renders:

$$\Delta y_{it} = \alpha + \theta_t + A(1)e_{it} + I(L)\Delta e_{it+z} + B(1)s_{it} + K(L)\Delta s_{it+z} + \nu_{it} \quad (9)$$

where *I(L)* and *K(L)* are lag polynomials of order *2z*. *I(L)* and *K(L)* equal *G'(L)* and *H'(L)* respectively when $z > 0$ which accounts for the number of leads in the polynomials.

[13] This practice is similar to the approach by Stock and Watson (1993) who propose the dynamic ordinary least squares estimator (DOLS) which corrects for the endogeneity of regressors and serially correlated errors by using leads of the regressors in first-differences.

Likewise, *I(L)* and *K(L)* equal *C(L)+G'(L)* and *D(L)* + *H'(L)* respectively for $z \leq 0$, as given by the current and lagged terms in the polynomials. For our computational purposes we include 6 lags and 5 leads of the investment shares.[14]

4.2 Estimation Results of the basic model

In Table 3 we present the long-run estimates (*A(1)* and *B(1)*) of the distributed lag models. Model (1) relates to the basic specification which does not include leads while models (2), (3) and (4) control for five leads of first-difference terms of both investment shares. Model (1) shows that the long-run coefficients on investment in producer durables and non-residential structures are significant at the 1% level. The coefficients imply that an increase by one percentage point of GDP for both producer durables and non-residential structures investment brings about a cumulative increase in long-run growth rates of per capita output of 0.157 and 0.186 percentage points, respectively. In model (2) the coefficient on producer durables slightly decreases and the one on non-residential construction increases to 0.266. In models (3) and (4) that control for a constant and a constant and time dummies respectively,[15] the coefficients remain significant at conventional confidence levels and their magnitude almost half with respect to model (2).[16]

[Insert Table 3 about here]

In the next section, we present additional results as robustness checks. We first employ instrumental variables techniques as another way of controlling for the likely endogeneity of investment shares and the possibility of reverse causality going from output growth to investment. Second, we remove likely outliers from the distributed lag models, such as Botswana and Zambia, as suggested by Temple (1998). We will also remove the major oil producers and exporters, since in this case the relationship between investment and growth is purely demand-following driven by market factors such as current external demand for

[14] The results appear fairly similar when different lag and lead lengths are used in the computations. In order to keep a reasonable number of degrees of freedom we set to six and five the number of lags and leads included in the regressions.

[15] The inclusion of time dummies can be an additional way of controlling for common third factors that may drive both investment and output over the cycle.

[16] As noted by Karras (1999) and Evans (1997), if the growth rate of per capita output is stationary around a trend, the distributed lag models we have presented so far may be misspecified by not allowing for a deterministic trend in the set of regressors. As a robustness check, we re-estimated models (1) to (4) by also including a deterministic trend which is assumed to be homogeneous across countries. The coefficients are similar to those of Table 3 and are available from the author upon request.

natural resources or movements in world prices. Instead, our main focus is on the supply-driven character of the investment-growth nexus, which is explained by technological and efficiency factors.

5. Robustness Analysis

Given the likely endogeneity associated with the investment rates in producer durables and non-residential structures even after controlling for the cycle through the inclusion of leads in previous models, we make use of instrumental variable estimators in order to correct for the problem of reverse causality. Since it is quite difficult to find instruments which are closely related to investment while unrelated to growth,[17] we will use lagged values of the investment shares following the intuition of the GMM panel estimators proposed by Arellano and Bond (1991) and Arellano and Bover (1995).[18] These estimators make use of the maximum information available in the data in order to reach asymptotic efficiency. Considering that our regressions already include lagged values of the regressors up to six years, we will use as instruments the investment shares from t-8 to the end of the sample.[19] Lagged values of output growth from t-6 onwards will be used as additional instruments in the models that require four lags of the dependent variable in order to control for the autocorrelation patterns present in the error.

Arellano and Bover (1995) propose the use of an alternative estimator for the case of highly persistent series, where the instruments in levels are weak instruments. As a further robustness check, we make use of this estimator which estimates in a system a specification in first-differences along with one in levels. It, thus, utilises instruments in levels and first differences to improve in efficiency. In order to avoid using redundant

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[17] De Long and Summers make use of saving rates and an orthogonalised equipment price to instrument for equipment investment. Nevertheless, Temple (1998) casts doubts on the validity of such instruments.

[18] It is important to note that data series are not first-differenced since we do not have the problem induced by the correlation of individual country effects and the lagged dependent variable, as our model assumes away cross-country fixed effects. We follow Griliches and Mairesse (1995) and Temple (1998) who point out the pervasive effects of removing the between variability of the data. A further argument for not first-differencing the data is that we could lose valuable information regarding the long-run link between productive investment and growth.

[19] We choose the lag-length of the instruments in a way that we can correct for the possibility of measurement errors in the investment shares in durables and non-residential construction. See more details in Bond et al. (2002)

instruments in first differences that could lead to *overfitting bias*, we only employ Δe_{it-7} and Δs_{it-7} in addition to $\Delta(\Delta y_{it-5})$ for those models that control for four lags of the dependent variable.[20] We will test for the validity of the instruments by using the Sargan test for over-identifying restrictions. For the consistency of the estimates it is also required that the disturbance be not serially correlated. The results of a test for the presence of first and second order correlation in the error are also presented in Table 4.[21]

A further concern in the use of the *difference estimator* (Arellano and Bond, 1991) and to a less extent the *system estimator* (Arellano and Bover, 1995) is the downward bias associated with the standard errors of the estimates when the N-dimension is relatively small, which in turn may lead to spuriously significant regressors.[22] To correct for this possibility we compute heteroskedasticity–consistent standard errors using a two-step estimator à la Arellano and Bond with the small-size correction factors proposed by Windmeijer (2005).[23] Once these adjustments are made, the estimates using instrumental variables should provide a reliable guide of the long-run impact of productive investment on growth.

As shown in Table 4, models (5A) and (6A), which are estimated using the instruments proposed by Arellano and Bond (1991) and Arellano and Bover (1995) respectively, render highly significant long-run coefficients on both types of investment. The Sargan test for over-identifying restrictions point to the validity of the instruments while the tests for first and second order correlation can be easily rejected at 1%, which implies that serial correlation may be a problem that could lead to inconsistent estimates. In order to pick up such correlation patterns in the error structure, we introduce four lagged terms of the dependent variable as regressors, rendering models (5B) and (6B). Now the long-run estimates become slightly smaller and are approximately equal to 0.18. These models

[20] For notation purposes, models 5B and 6B differ from models 5A and 6A respectively in that they control for distributed lags of output growth. In turn, models 5A and 5B are estimated using the instruments proposed by Arellano and Bond (1991); and models 6A and 6B are estimated following Arellano and Bover (1995).

[21] See Arellano and Bond (1991) for details on the construction of the tests.

[22] See Judson and Owen (2000), among others.

[23] The instrumental variable estimations were carried out with the module called DPD available in the software PcGive.10 ©.

appear to be well specified with valid instruments and the absence of serial correlation in the error. Therefore, we can conclude that the long-run effect of productive investment on growth, not only appears to be statistically significant but also of economic relevance. An increase by one percentage point of GDP for both producer durables and non-residential investment brings about a cumulative increase in long-run growth rates of almost 0.2 percentage points.

[Insert Table 4 about here]

Once we have checked that the long-run link between productive investment and growth is not driven by the endogeneity of investment, we now re-estimate the models shown in Table 4 after removing from the sample those countries that are oil producers, those with less than one million inhabitants and those that have been found to be clear outliers when testing the supply-leading hypothesis that explains the technological nexus of productive investment and growth.[24] The results in Table 5 show that the positive growth impact of productive investment remains, even after dropping those countries which are clearly unrepresentative in explaining the supply-driven relationship between investment and growth as predicted by AK models where productive investment is the engine of growth. The only difference is that the coefficients on producer durables investment slightly drop while those on non-residential construction increase. This may result from having purged out the demand-following relation between growth and investment in producer durables which is characteristic of oil-producers and countries with abundant natural resources.

[Insert Table 5 about here]

In the next section, we compute the rates of return to productive investment associated with the estimated growth effects. We anticipate that even though the long-run estimates on producer durables are smaller than those on non-residential investment, the social returns to the former are significantly larger. Overall, our estimates lend support to the

[24] These countries are Iran, Botswana, Swaziland, Zambia, Luxembourg, Iceland and Venezuela. The reason is that oil producer countries invest in productive capital for the extraction of fuel on the basis of external factors such as world growth prospects and world prices movements. Countries like Botswana rich in natural resources have an investment function also driven by external factors such as the expectation about the movement of world prices of diamonds.

claim that producer durables and non-residential investment are complementary and important for growth.

6. Analysis of Social Returns to Productive Investment

As noted above, we depart from existing studies on the effect of physical investment on growth by only considering the productive components of physical investment, i.e. producer durables and non-residential construction. Earlier studies have used a different disaggregation of the data. For instance, De Long and Summers (1991, 1992) disaggregate total investment into equipment investment and a residual category that includes transportation machinery as well as residential and non-residential construction. Temple (1998) splits investment into equipment and total structures. Both studies point to the existence of very high social returns to equipment investment, while very low rate of returns to the other category that embodies productive and non-productive investment in structures. Therefore, by pooling investment in non-residential structures with residential structures, which is unproductive on theoretical grounds, the significantly positive growth effect of investment in non-residential structures may not show up. That may be the reason why other studies find a very high return to machinery and equipment (as we do) but a very low return to the residual investment category.

Two ways have been proposed in the literature for computing the social returns to physical capital. On the one hand, Auerbach et al. (1993) derived an expression that relates the coefficient on investment rates estimated from growth regressions to the private rate of return implied by the neoclassical model. They adopted this framework in order to show that once the regressions by De Long and Summers (1991, 1992) are purged from the effect of main outliers such as Botswana, the rate of return associated with their estimates are consistent with the Solow model.

Assuming that the output shares of each type of investment are constant over the period under analysis, the coefficients they estimate for each type of investment are as follows:

$$\beta_i = \frac{(r+\delta_i)(1-e^{-\lambda_i T})}{(\lambda_i T)} \tag{10}$$

where i represents e for equipment investment and s for structures, and $\lambda_i = (1-\alpha_e-\alpha_s)(g+n+\delta_i)$ stands for the speed of convergence along the transitional path. λ_i is a function of the income shares of each type of capital (α_i as derived from a Cobb-Douglas production function that satisfies Inada conditions) as well as the depreciation rate (δ_i), growth rates of technological change (g) and labour force (n). As Auerbach *et al*. (1993, 1994) note, the immediate effect of a shock to either type of investment will be equal to the gross rate of return to each type of capital, i.e. $r_i+\delta_i$. Also applying L'Hôpital rule, the coefficient on either type of investment will tend to zero for a large enough time period. This latter result is a clear consequence of diminishing returns to investing in either type of capital in the long-run. Given the differences between the depreciation rates of both types of capital, the immediate impact of structures is supposed to be lower than the impact of equipment investment, the opposite happening as T grows large.

On the other hand, Temple (1998) makes use of growth specifications similar in spirit to those of Mankiw et al. (1992) in order to directly estimate the income shares of structures and equipment capital. The rates of return are computed on the basis of the estimates of the income shares of capital by means of the following equation:

$$r_i + \delta_i = \frac{\alpha_i(\delta_i + n + g)}{s_i} \qquad (10)$$

where i stands for e and s as above, and s_i and r_i represent the investment rates and the net private rate of return to each type of capital. Temple (1998) finds larger rates of return than would be consistent with a version of the Solow model augmented with human capital. For instance, for a non-oil sample that comprises both developed and developing countries, the rates of return are around 98% for equipment investment and 12% for structures. For a sample of just developing countries the returns to equipment are even larger. Those results are robust to the exclusion of clear outliers such as Botswana and Zambia. Nevertheless, Temple acknowledges that the error margin in the estimates of these rates of return is quite large.

The approach taken here is the one by Auerbach *et al.* (1993, 1994) since our growth specifications do not render estimates of the income shares and in turn the rates of return to each type of capital. It should be noted that we adopt this framework to have an idea of the extent of social returns associated with our long-run estimates. Despite the fact that for a long enough transitional path from one steady state to another, the differences in predictions of the impact of investment on growth between AK and neoclassical models weaken, we will be able to see whether the rates of return are significantly greater than those predicted by the Solow model.

Following Auerbach et al. (1993, 1994) and De Long and Summers (1991, 1992, 1994) we assume the following values for the parameters of (10): $n+g$ are set at 0.03, δ_e and δ_s are set at 0.15 and 0.02 respectively and $\alpha_e+\alpha_s$ at 0.2, a value that is a bit lower than the one used in the aforementioned studies since they included residential structures. These studies also consider a wide range of values for the net private rate of return to investment and their preferred value is 10%. We first compute the coefficient that would be required in order to obtain a rate of return consistent with the Solow model (i.e. 10%), and then compare it with the coefficient estimated. Using (10) for a value of T equal to 42–which would be compatible with relatively long transitional dynamics– the coefficients on producer durables investment and on non-residential structures consistent with the linearised Solow model would be 0.0412 and 0.0581, respectively. These coefficients are well below those we estimate.

Likewise, if we take the estimates from the regressions that control for endogeneity of investment rates and outliers, in particular model (8B) from Table 5, whose estimates fall in the lower range of those obtained using instrumental variables (0.141 for producer durables and 0.211 for non-residential structures), we use equation (10) to calculate the rates of return that correspond to our estimates. The net rate of return for investment in producer durables equals 0.7 (70%) and 0.415 (41.5%) for non-residential structures, both values well above those predicted by the Solow model (i.e. 10%). This may provide some additional evidence supporting the AK model.

Therefore even though the long-run estimates associated with investment in producer durables are generally lower than those of non-residential construction investment, the net social returns to the former almost double the net social returns to non-residential structures. This stems from the fact that the depreciation rate of producer durables is significantly greater than that of non-residential structures. These results accord quite well with previous findings that assign the main role to equipment investment in the process of economic development. Furthermore, our results lend support to endogenous growth models where productive investment appears to be the engine of growth. These high social returns associated with productive investment and in particular with investment in producer durables may be attributed to the presence of positive externalities to the accumulation of productive capital (Romer, 1986), to the process of technological transfer through trade of capital goods across countries (Eaton and Kortum, 2006) and to embodiment of technological progress in new vintages of capital (Greenwood et al., 1997). It can also be due to the existence of learning by doing processes in the accumulation of physical capital as in Arrow (1962).

In this study we do not pursue further which of these mechanisms are the ones that lead to such high social rates of return to productive capital, hence preventing the economy from entering into the area of diminishing returns as in the neoclassical paradigm. Rather, we aimed at discriminating across two mains strands of the growth literature: Neoclassical growth theory whose maximum advocates are Solow (1956) and Cass (1965) versus the first stream of endogenous growth models, i.e. the AK models that assume constant returns to reproducible capital, thereby making productive investment the engine of sustainable growth in the long-run.

Overall, the analysis of the stationarity properties of investment rates and output growth did not render evidence against the empirical validity of the AK model. These findings together with the consistent estimation of a significant growth impact (purged from business cycle effects) of productive physical investment and the existence of rates of return well above those predicted by the Solow model, appear to run counter to the neoclassical growth paradigm which only allows for the existence of level effects in the long-run.

7. Conclusions

Throughout the analysis, we find some evidence that the forces governing growth may be endogenous, with productive physical investment as a major driving force behind growth. As opposed to earlier cross-section studies on the link between physical investment and growth, the use of the time dimension of the data enables us to study the evolution of output growth and investment rates series over time. This in turn makes it feasible to test the empirical validity of the one-sector AK model against the Solow model.

Our main findings can be summarised as follows. First, by analysing a large sample of 61 countries over the period 1950-1992 under a panel framework, we find that both economic growth rates and investment rates are stationary. So unlike Jones (1995) and Romero-Ávila (2006) we cannot reject endogenous growth predictions on this account. Second, we estimate distributed lag models and consistently find positive long-run growth effects from productive investment, even after controlling for business cycle effects, for the endogeneity of investment rates and for key outliers. By distinguishing between investment in residential construction and productive investment in structures, we find that the latter alongside investment in producer durables are important growth determinants. Third, the social returns associated to the long-run estimates on the producer durables and non-residential investment rates are well above those predicted by the Solow model. In addition, the social returns associated with machinery and transportation equipment almost double those of non-residential investment.

Despite this evidence supporting the empirical validity of AK-type models, we need to be cautious about the interpretation of the findings resulting from empirical exercises similar to those carried out in this study. In this regard, Temple (2003) makes several good remarks. On the one hand, he notes that the term "long-run" is extremely difficult to define and should be conceived as a conceptual device to think about the predictions of growth models along a hypothetical balanced growth path. As he points out, endogenous growth models which essentially differ from neoclassical models in that the growth impact of a policy change may be of a long-term nature rather than a transitional effect, rely on knife-edge conditions that in practice are quite unlikely to hold. On the other hand, considering the time span of the data series available, to know with certainty whether the growth impact we estimated is the result of a continuum of level shifts along the transitional path or represents a genuine growth effect may be unachievable.

Therefore, if we have to choose the results of the analysis which are more relevant in terms of policy-making, we would highlight the fact that we consistently find evidence of a statistical and economically significant impact from productive physical investment on growth. Whether this effect reflects a genuine growth effect as those predicted by AK-type models or a transitory effect as suggested by neoclassical growth models, should not worry us excessively. In welfare terms, both growth theory strands are equally valid since they allow for the existence of level effects.

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References

Arellano, M. and Bond, S. (1991) Some tests of specification for panel data: Monte carlo evidence and an application to employment equations, *Review of Economic Studies,* **58**, 277-297.

Arellano, M. and Bover, O. (1995) Another look at the instrumental variable estimation of error-components models, *Journal of Econometrics,* **68**, 29-51.

Arrow, K.J. (1962). The economic implications of learning by doing, *The Review of Economic Studies,* **29(3)**, 155-173.

Auerbach, A. J., Hassett, K. A. and. Oliner, S. D. (1993) Reassessing the social returns to equipment investment, NBER Working Paper 4405, National Bureau of Economic Research, Cambridge, Mass.

Auerbach, A. J., Hassett, K. A. and. Oliner, S. D. (1994) Reassessing the social returns to equipment investment, *Quarterly Journal of Economics,* **109**, 789-802.

Baltagi, B.H. (1995) *Econometric Analysis on Panel Data*, John Wiley and Sons.

Baltagi, B.H. and Kao, C. (2000) Nonstationary panels, cointegration in panels and dynamic panels: a survey, Economics Department Working Paper, Syracuse University.

Barro, R. (1991) Economic growth in a cross section of countries, *Quarterly Journal of Economics,* **106 (2)**, 407-443.

Barro, R. J. and Sala-i-Martin, X. (1995) *Economic Growth*, McGraw-Hill, Boston, Mass.

Bond, S., Hoeffler, A. and Temple, J. (2001) GMM estimation of empirical growth models, CEPR Working Paper 3048, Centre for Economic Policy Research, London.

Bond, S., Lebeblicioglu, A. and Schiantarelly, F. (2004) Capital accumulation and growth: A new look at the evidence, IZA Discussion Paper No. 1174, Bonn.

Breitung, J. (2000) The local power of some unit root tests for panel data*, in Non-Stationary Panels*, *Panel Cointegration and Dynamic Panels*, Advances in Econometrics, Elsevier Science Inc, **15**, 93-130,

Cass, D. (1965) Optimum growth in an aggregative model of capital accumulation, *Review of Economic Studies*, **32**, 233-240.

De Long , B. J. and Summers, L. H. (1991) Equipment investment and economic growth, *Quarterly Journal of Economics*, **106**, 445-502.

De Long , B. J. and Summers, L. H. (1992) Equipment investment and economic growth: How strong is the nexus?, *Brookings papers on Economic Activity*, **2**, 157-199.

De Long , B. J. and Summers, L. H. (1994) Equipment investment and economic growth: Reply, *Quarterly Journal of Economics*, **109**, 803-807.

Dickey, D. and Fuller, W. A. (1979) Distribution of the estimates for autoregressive time series with a unit root, *Journal of the American Statistical Association*, **74**, 427-431.

Eaton, J. and Kortum, S. S. (2006) Trade in capital goods, *European Economic Review*, forthcoming.

Ericsson, N., Irons, J. and Tryon, R.W. (2001) Output and inflation in the long-run, *Journal of Applied Econometrics*, **16**, 241-253.

Evans, P. (1997) Government consumption and growth, *Economic Inquiry*, **35**, 209-217.

Greenwood, J., Hercowitz, Z. and Krusell, P. (1997) Long-run implications of investment-specific technological change, *American Economic Review*, **87(3)**, 342-62

Griliches, Z. and Miresse, J. (1995) Production functions: The search for identification, NBER Working Paper 5067, National Bureau of Economic Research, Cambridge, Mass.

Hill, T. P. (1964) Growth and investment according to international comparisons, *Economic Journal*, **74,** 287-304.

Hofman, A. (1999) La Inversión en América Latina, Santiago, Chile, Economic Commission for Latin America and the Caribbean (ECLAC), unpublished.

Im, K.S., Pesaran, M.H. and Shin Y. **(**2003) Testing for unit roots in heterogeneous panels, *Journal of Econometrics,* **115(1)**, 53-74.

Jones, C.I. (1995) Time series properties of endogenous growth models, *Quarterly Journal of Economics*, **110**, 495-525.

Judson, R.A. and Owen, A. (1999) Estimating dynamic panel data models: A guide for macroeconomists, *Economic Letters*, **65**, 9-15

Karras, G. (1999) Taxes and growth: Testing the neoclassical and endogenous growth models, *Contemporary Economic Policy*, **17(2)**, 177-188.

Kocherlakota, N.R. and Yi, K. (1997) Is there long-run growth? Evidence from the United States and the United Kingdom, *Journal of Money, Credit and Banking*, **29(2)**, 233-262.

Levin, A., Lin, C-F. and Chu C-S. (2002) Unit root tests in panel data: Asymptotic and finite-sample properties, *Journal of Econometrics*, **108 (1)**, 1-24.

Levine, R. and Renelt, D. (1992) A sensitivity analysis of cross-country growth regressions, *American Economic Review*, **82(4)**, 942-963.

Li, D. (2002) Is the AK model still alive? The long-run relation between growth and investment re-examined, *Canadian Journal of Economics*, **35(1)**, 92-114.

Mankiw, G., Romer, D. and Weil, D. (1992) A contribution to the empirics of economic growth, *Quarterly Journal of Economics*, **107**, 407-437.

McGrattan, E. (1998) A defence of AK growth models, *Federal Reserve Bank of Minneapolis Quarterly Review*, **Fall**, 13-27.

Rebelo, S. (1991) Long-run policy analysis and long-run growth, *Journal of Political Economy*, **99 (3)**, 500-521.

Romer, P. (1986) Increasing returns and long-run growth, *Journal of Political Economy*, **94(5)**, 1002-1037.

Romero-Ávila, D. (2006) Can the AK model be rescued: New evidence from unit root tests with good size and power, *Topics in Macroeconomics*, **6 (1)**, Article 3, 1-42.

Solow, R.M. (1956) A contribution to the theory of economic growth, *Quarterly Journal of Economics*, **70**, 65–94.

Stock, J. H., and Watson, M. W. (1993) A simple estimator of cointegrating vectors in higher order integrated systems, *Econometrica*, **61**, 783-820.

Summers, R. and Heston, A. (1991) The Penn World Table Mark 5: An expanded set of international comparisons, 1950-1988, *Quarterly Journal of Economics*, **106 (2)**, 327–368.

Temple, J. (1998) Equipment investment and the Solow model, *Oxford Economic Papers*, **50**, 39-62.

Temple, J. (1999) The new growth evidence, *Journal of Economic Literature*, **37**, 112-156.

Temple, J. (2003) The long-run implications of growth theories, *Journal of Economic Surveys*, **17 (3)**, 497-510.

Windmeijer, F. (2005) A finite sample correction for the variance of linear two-step GMM estimators, *Journal of Econometrics,* **126 (1)**, 25-51.

TABLES

Table 1: Panel Unit Root Tests

Variable	$\overline{Z}_t$ IPS Test 4 Lags		$\overline{Z}_t$ IPS Test 6 Lags		Breitung Test (λ^*_{UB})
	No Trend	Trend	No Trend	Trend	
Per Capita GDP	5.65	0.40	5.29	-0.96	4.78
Producer Durables Inv. Rate	-2.13**	-3.20***	-2.16***	-3.54***	-4.38***
Non-residential Construction Inv. Rate	-3.85***	-2.69***	-3.63***	-2.23**	-4.75***
Residential Construction Inv. Rate	-4.40***	-5.57***	-3.88***	-4.73***	-4.43***
Productive Inv. Rate	-2.50***	-3.14***	-2.19**	-2.84***	-3.89***
Total Inv. Rate	-3.88***	-3.06***	-3.28***	-2.83***	-3.59***
Per Capita GDP Rate	-30.94***	-31.32***	-26.46***	-25.50***	-18.24***

Note: *,** and *** indicate rejection of the null hypothesis of a unit root at the 10%, 5% and 1% levels, respectively. All panel unit root specifications control for a set of time dummies. The table presents the $\overline{Z}_t$ and λ^*_{UB} statistics that have to be compared with the lower tail of the normal distribution.

Table 2 - Panel Unit Root Tests of Jones Sample

Variable	$\overline{Z}_t$ IPS Test 4 Lags		$\overline{Z}_t$ IPS Test 6 Lags		Breitung Test (λ^*_{UB})
	No Trend	Trend	No Trend	Trend	
Jones-15 OECD countries					
Total Inv. Rate (1950-1988)	-0.16	-3.91***	-0.31	-4.11***	-2.76***
Producer Durables Inv. Rate (1950-1988)	-2.14**	-4.73***	-0.95	-5.05***	-1.88**
Growth of GDP per worker (1950-1988)	-9.70***	-16.79***	-7.77***	-13.64***	-11.37***

Note: See Table 1.

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Table 3: Distributed Lag Growth Models

		Standard Model	Augmented Model with 5 Leads		
		No Deterministics	No Deterministics	Constant	Constant + Time Dummies
		(1)	(2)	(3)	(4)
Producer Durables Inv. Rate	*A(1)*	0.157***	0.144***	0.079*	0.073*
		(3.28)	(2.84)	(1.94)	(1.78)
Non-residential Construction Inv. Rate	*B(1)*	0.186***	0.266***	0.136***	0.111**
		(3.84)	(5.95)	(2.83)	(2.26)
Specification Tests					
Wald (joint)		219.70***	624.90***	179.10***	161.60***
Wald(Dummy)				17.10***	354.70***
AR(1) test		2.969***	1.790*	1.555	1.170
AR(2) test		2.896***	1.410	0.9317	0.6758
Usable observations		2196	1586	1586	1586

Note: The dependent variable is given by the growth rate of GDP per capita. *,** and *** indicate significance at 10%, 5% and 1% respectively. Heteroskedasticity-consistent t-statistics are given in parenthesis. Wald (dummy) tests for the joint-significance of the deterministic components given by the constant and time effects. Wald(joint) tests for the joint-significance of both the long-run and the short-run coefficients. All Wald-type tests are distributed as a χ^2 with the number of degrees of freedom equal to the number of restrictions. The tests labelled by AR(1) and AR(2), test for the presence of first and second-order correlation in the residuals of the model.

Table 4: Distributed Lag Growth Models with Instrumental Variables

	No Lagged Dependent Variable		Lagged Dependent Variable	
	DIFF-EST (5A)	SYS-EST (6A)	DIFF-EST (5B)	SYS-EST (6B)
Producer Durables Inv. Rate	0.228*** (2.61)	0.218** (2.42)	0.187** (2.41)	0.184** (2.21)
Non-residential Construction Inv. Rate	0.264*** (3.59)	0.252*** (3.31)	0.198** (2.48)	0.182** (2.27)
Trend	-0.0004** (-2.39)	-0.0003** (-2.08)	-0.0003** (-2.17)	-0.0003** (-2.00)
Specification Tests				
Wald (joint)	103.5***	94.99***	212.7***	204.6***
Sargan test	54.94	55.10	50.91	51.88
AR(1) test	2.890***	2.903***	-0.073	-0.361
AR(2) test	2.511**	2.552**	-0.273	-0.250
Usable Observatations	2196	2196	2196	2196

Note: The dependent variable is given by the growth rate of GDP per capita. *, ** and *** indicate significance at 10%, 5% and 1% respectively. Heteroskedasticity-consistent t-statistics are given below the estimates. Models 5A and 6A consist of a polynomial in the investment rates of length equal to six. Models 5B and 6B add four distributed lags of the dependent variable to models 5A and 6A. Models 5 (A, B) are estimated with the *difference estimator* of Arellano and Bond (1991). Models 6 (A, B) are estimated with the *system estimator* of Arellano and Bover (1995). Wald(joint) tests for the joint-significance of all coefficients included in the regression and is distributed as a χ^2 with degrees of freedom equal to the number of restrictions. The Sargan test tests the null hypothesis that the instruments are valid and is distributed as a χ^2 with J-K degrees of freedom, where J is the number of instruments and K is the number of regressors. The tests labelled by AR(1) and AR(2), test for the presence of first and second-order correlation in the residuals of the model and are distributed as a standard normal distribution.

Table 5: Distributed Lag Growth Models with Instrumental Variables and No Outliers

	No Lagged Dependent Variable		Lagged Dependent Variable	
	DIFF-EST (7A)	SYS-EST (8A)	DIFF-EST (7B)	SYS-EST (8B)
Producer Durables Inv. Rate	0.194 ** (2.52)	0.189** (2.25)	0. 145** (2.14)	0.141** (1.99)
Non-residential Construction Inv. Rate	0.288*** (4.32)	0.279*** (3.97)	0.230*** (2.98)	0.211*** (2.77)
Trend	-0.0003*** (-1.94)	-0.0003* (-1.76)	-0.0002* (-1.85)	-0.0002 (-1.68)
Specification Tests				
Wald (joint)	138.90***	124.90***	272.40***	258.90***
Sargan test	45.20	46.32	41.28	43.10
AR(1) test	2.601***	2.633***	0.2074	-0.09168
AR(2) test	2.150**	2.127**	-0.4914	-0.4863
Usable Observations	1944	1944	1944	1944

Note: See Table 4.

Appendix 1: List of Countries and Basic Descriptive Statistics

Data and Sources

The main source of the data employed in this study is the Penn World Table version 5.6 developed by Summers and Heston (1991). To compute the growth rate of per capita output, we employ real GDP per capita expressed in 1985 international prices (RGDPL), which is computed as a Laspeyres index. The growth rate of per capita output is calculated as the log-difference of levels of per capita GDP. The investment rate in producer durables is the sum of investment in machinery and transport equipment expressed in 1985 international prices divided by RGDPL. The investment rate in non-residential construction is computed as the sum of business construction and other construction both expressed in 1985 international prices as a share of GDP. Total investment is the sum of investment in producer durables, non-residential construction and residential construction (unproductive component). Data on physical investment rates for Brazil and Costa Rica are obtained from Hofman (1999).

List of Countries

OECD: Australia, Austria, Belgium, Canada, Denmark, Finland, France, West Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, USA.

Asia: Hong Kong, India, Iran, Israel, Korea, Philippines, Sri Lanka, Syria, Taiwan, Thailand.

Africa: Botswana, Ivory Coast, Kenya, Madagascar, Malawi, Mauritius, Morocco, Nigeria, Sierra Leone, Swaziland, Zambia, Zimbabwe.

Latin America: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, Guatemala, Honduras, Jamaica, Mexico, Panama, Peru, Venezuela.

Table A1: Descriptive Statistics

		Per Capita GDP Growth		Producer Durables Inv. Rate		Non-residential Construction Inv. Rate		Total Inv. Rate		Full Sample	Reduced Sample
Country	**Country Code**	**Mean**	**Std. Deviat.**	**Mean**	**Std. Deviat.**	**Mean**	**Std. Deviat.**	**Mean**	**Std. Deviat.**		
Canada	CAN	2.265	2.976	4.125	1.233	7.589	0.548	17.652	1.442	1	1
USA	USA	1.744	2.526	5.590	1.194	4.388	0.556	14.616	0.803	1	1
Austria	AUT	3.510	2.609	6.778	1.279	6.019	1.871	15.811	2.154	1	1
Belgium	BEL	2.673	2.121	7.651	0.906	5.763	0.556	16.963	1.952	1	1
Denmark	DNK	2.368	2.898	6.227	1.276	6.256	1.211	16.772	2.432	1	1
Finland	FIN	2.939	4.080	8.050	1.137	9.500	0.836	23.078	1.927	1	1
France	FRA	2.933	1.889	7.471	1.602	5.456	0.573	16.624	2.270	1	1
West Germany	DEU	3.456	2.839	7.219	1.313	6.887	0.846	18.715	1.388	1	1
Greece	GRC	3.723	3.523	4.271	1.482	8.309	2.113	17.288	3.707	1	1
Iceland	ISL	2.859	4.618	5.183	4.128	4.704	1.958	19.276	4.848	1	0
Ireland	IRL	3.018	2.652	6.380	1.944	4.752	0.980	14.996	3.312	1	1
Italy	ITA	3.642	2.557	7.131	0.971	5.387	1.135	19.434	2.872	1	1
Luxembourg	LUX	2.222	4.401	7.959	2.890	7.243	1.367	18.899	3.301	1	0
Netherlands	NLD	2.558	2.795	7.074	1.215	4.947	0.755	15.462	1.427	1	1
Norway	NOR	3.050	1.788	22.949	14.163	9.391	1.321	35.475	14.994	1	1
Portugal	PRT	4.461	3.810	5.068	1.387	4.560	0.722	16.756	2.636	1	1
Spain	ESP	3.903	3.993	3.064	1.997	6.106	0.889	17.956	2.243	1	1
Sweden	SWE	2.113	1.917	6.938	3.567	5.804	0.863	17.509	3.049	1	1
United Kingdom	GBR	2.044	2.202	6.840	1.062	2.779	0.459	12.134	1.427	1	1
Switzerland	CHE	2.026	3.037	9.507	1.786	10.594	1.147	27.318	3.990	1	1
Turkey	TUR	3.044	5.234	5.050	1.367	5.479	1.082	13.446	2.528	1	1
Australia	AUS	1.860	3.335	8.528	0.819	6.323	0.645	18.839	1.631	1	1
Zew Zealand	NZL	1.273	3.773	6.577	1.735	5.992	0.921	14.853	3.178	1	1
Japan	JPN	5.554	3.320	7.985	2.970	9.367	2.032	20.897	5.097	1	1
Total OECD		2.885	3.378	7.234	4.979	6.400	2.195	18.365	6.255		

Table A1 continued

Country	Country Code	Per Capita GDP Growth		Producer Durables Inv. Rate		Non-residential Construction Inv. Rate		Total Inv. Rate		Full Sample	Reduced Sample
		Mean	Std. Deviat.	Mean	Std. Deviat.	Mean	Std. Deviat.	Mean	Std. Deviat.		
Hong Kong	HKG	5.582	3.586	14.776	9.386	3.992	0.970	22.411	8.820	1	1
India	IND	1.884	4.533	2.390	0.647	3.991	0.726	8.126	1.480	1	1
Iran	IRN	0.865	8.476	1.523	0.775	6.522	7.133	12.901	7.967	1	0
Israel	ISR	3.487	4.159	9.188	1.478	6.155	2.793	25.167	5.948	1	1
Korea	KOR	5.891	5.477	4.253	2.570	10.083	3.071	17.575	5.747	1	1
Philippines	PHL	1.853	3.460	2.872	0.881	5.462	1.894	10.260	2.351	1	1
Sri Lanka	LKA	1.821	4.201	1.945	0.938	12.172	3.877	16.239	4.182	1	1
Syria	SYR	2.923	11.001	4.404	1.294	8.175	5.230	19.029	10.112	1	1
Taiwan	OAN	5.697	2.745	8.362	3.234	10.487	3.077	21.856	7.233	1	1
Thailand	THA	3.631	4.617	3.773	1.309	5.935	1.749	11.825	3.276	1	1
Total Asia		3.363	6.018	5.349	5.213	7.297	4.467	16.539	8.309		
Botswana	BWA	3.921	7.104	4.245	3.108	3.933	2.858	10.214	7.284	1	0
Ivory Coast	CIV	0.460	5.808	1.194	0.547	1.293	0.560	3.692	1.640	1	1
Kenya	KEN	1.119	7.146	3.806	1.585	3.990	1.529	10.716	4.364	1	1
Madagascar	MDG	-1.193	3.949	9.349	8.327	7.555	6.730	18.877	16.819	1	1
Malawi	MWI	1.379	4.877	1.611	1.127	1.926	0.908	4.207	2.332	1	1
Mauritius	MUS	1.526	7.288	3.304	1.289	1.524	0.412	6.503	1.851	1	1
Morocco	MAR	2.341	5.025	1.197	0.434	3.437	1.306	6.780	2.858	1	1
Nigeria	NGA	1.880	9.593	0.766	0.641	2.255	0.710	3.716	1.235	1	1
Sierra Leone	SLE	0.211	8.013	0.339	0.170	0.330	0.149	0.737	0.349	1	1
Swaziland	SWZ	2.407	8.714	7.170	3.812	1.614	0.884	9.925	5.311	1	0
Zambia	ZMB	-0.373	6.804	5.441	3.533	3.577	1.927	9.455	5.674	1	0
Zimbabwe	ZWE	0.843	5.343	2.184	0.639	16.298	9.961	20.721	11.300	1	1
Total Africa		1.210	6.956	3.384	4.064	3.978	5.533	8.795	8.958		

Table A1 continued

Country	Country Code	Per Capita GDP Growth Mean	Per Capita GDP Growth Std. Deviat.	Producer Durables Inv. Rate Mean	Producer Durables Inv. Rate Std. Deviat.	Non-residential Construction Inv. Rate Mean	Non-residential Construction Inv. Rate Std. Deviat.	Total Inv. Rate Mean	Total Inv. Rate Std. Deviat.	Full Sample	Reduced Sample
Dominican Rep.	DOM	2.088	6.149	2.011	0.820	4.675	1.487	12.177	4.364	1	1
Guatemala	GTM	0.920	2.771	3.190	0.658	2.386	0.493	6.717	1.389	1	1
Honduras	HND	0.849	2.883	13.427	4.560	3.535	0.690	18.416	4.978	1	1
Jamaica	JAM	2.393	5.141	7.893	2.539	3.107	0.999	14.102	4.538	1	1
Mexico	MEX	2.509	3.865	5.191	1.716	4.943	0.866	14.431	2.686	1	1
Panama	PAN	2.202	5.231	8.400	3.190	11.079	3.211	21.357	6.153	1	1
Argentina	ARG	0.750	5.384	1.432	0.346	3.871	0.962	6.988	1.771	1	1
Bolivia	BOL	0.738	4.544	1.560	0.677	7.099	3.382	9.648	4.434	1	1
Chile	CHL	1.667	5.904	1.904	0.648	5.150	2.571	10.126	4.044	1	1
Colombia	COL	1.934	2.596	2.584	0.612	10.119	1.932	16.881	2.808	1	1
Ecuador	ECU	2.058	4.156	2.160	0.585	12.550	1.718	17.902	2.548	1	1
Peru*	PER	0.778	6.000	4.474	1.507	6.286	1.290	18.457	4.413	1	1
Venezuela	VEN	0.940	4.683	5.168	1.649	5.238	1.017	13.167	3.503	1	0
Costa Rica	CRI	2.158	4.012	7.332	2.862	8.513	1.264	18.546	2.982	1	1
Brazil	BRA	2.689	4.215	7.316	2.138	6.891	1.408	18.727	3.322	1	1
Total Latin America		1.645	4.692	4.936	3.858	6.363	3.418	14.509	5.849		
Total Sample		2.329	5.101	5.602	4.822	6.061	3.903	15.235	7.958		

*Data on business construction investment was not available for Peru. Therefore, non-residential investment comprises only other non-residential investment.