Explaining Differences in the Productivity of Investment across Countries in the Context of 'New' Growth Theory[1]

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Abstract

The purpose of this paper is to explain differences in the productivity of investment across 84 rich and poor countries over the period 1980-2011, and to test the orthodox neoclassical assumption of diminishing returns to capital. The productivity of investment is measured as the ratio of the long-run growth of GDP to a country's gross investment ratio. Twenty potential determinants are considered using a general-to-specific model selection algorithm. Education, government consumption, geography, export growth, openness, political rights and macroeconomic instability are the most important variables. The data also suggest constant returns to capital, so investment and the determinants of productivity of investment differences matter for long-run growth.

Keywords: new growth theory; investment; productivity of investment; cross-country growth regression

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1. Introduction

The origins of 'new growth theory' go back to the mid-1980s when Baumol (1986) was one of the first to reveal that the countries of the world were not converging in terms of productivity and per capita GDP, contrary to one of the basic predictions of orthodox neoclassical growth theory (Solow, 1956) based on the assumptions of identical tastes and preferences across countries; a common technology, and diminishing returns to capital (or falling marginal product of capital (MPK)). Since the first two assumptions of the basic neoclassical model are manifestly false, there could never have been the presumption of unconditional convergence; only conditional convergence controlling for differences in the levels of savings and investment across countries, and other factors that affect the productivity of capital such as education, technology differences and the structure of economies. The absence of convergence is also consistent with the MPK not falling as countries get richer and accumulate more capital. It was this that inspired the early work of Romer (1986) and Lucas (1988) who argued that externalities to education and research and development expenditure would keep the MPK from falling and, because of this, investment would matter for long run growth, with growth endogenous in this sense and not simply determined by the exogenous growth of the labour force and technical progress (that is, by the growth of the labour force in efficiency units – the term originally coined by Harrod, 1939). Interestingly, Kaldor (1961) had already argued over twenty years prior to Romer and Lucas that there was no evidence that the capital-output ratio was lower in rich countries than poor countries.[2]

Against this background, the main purpose of the paper is to use the framework of new growth theory to explain differences in the productivity of investment across countries

[2] Kaldor replaces the neoclassical production function with a technical progress function where there is an interdependence between capital accumulation and technical progress which preserves the capital-output ratio.

by converting a standard new growth theory estimating equation into a productivity of investment equation and estimating the determinants of productivity of investment differences explicitly. This is not done in the new growth theory literature where researchers typically specify a Barro-type (1991, 1998, 2015) regression model with per capita income growth as the dependent variable rather than the productivity of investment.[3] Apart from explaining differences in the productivity of investment explicitly, the advantage of using the productivity of investment as the dependent variable is that we can test directly whether or not there are diminishing returns to capital, rather than relying indirectly on the sign of the initial per capita income (PCY) variable in the traditional new growth theory regressions where the negative sign could be the result of 'catch-up' or faster structural change in poorer countries and not the result of diminishing returns to capital. As Benhabib and Spiegel (1994) remark in their paper on the role of human capital in development: *"A negative coefficient estimate on initial income levels may not be a sign of convergence due to diminishing returns, but of catch-up from adoption of technology from abroad. These two forces may be observationally equivalent in simple cross-country growth accounting exercises"* (p. 160). This is also one of the reasons why conditional convergence in Barro-type growth regressions does not imply rejection of the AK (constant returns to capital) model (Temple, 1999: p.123). Our data set will be 84 countries over the period 1980-2011, using twenty potential explanatory variables, the significance of which will be tested using the automated general-

[3] Barro-type regressions typically include a wide range of potential explanatory variables that may determine cross-country per capita income growth rate differences on the premise that existing theory does not provide an exact guideline as to which variables to consider. Examples of Barro-type studies include those conducted by Levine and Renelt (1992); Sala-i-Martin (1997); Fernándex et al. (2001); Hendry and Krolzig (2004); Hoover and Perez (2004); Ciccone and Jarociński (2010); Ding and Knight (2011); and Moral-Benito (2012). The Mankiw et al. (1992) study, in contrast, provides an example of a theory-specific approach, where the authors develop and test an augmented version of Solow's (1956) model.

to-specific (Gets) model selection procedure incorporated in the software programme Autometrics (Doornik and Hendry, 2013).[4]

This paper, therefore, has several novel features. First, it provides a simple way of measuring the productivity of investment. Second, it provides an unambiguous and unbiased test of the diminishing returns to capital hypothesis compared with some of the conventional methods that have been used in the literature. Third, and in a more general context, we show that a standard new growth theory regression model contains 'hidden' information about the determinants of productivity of investment differences across countries, and that an explicit conversion into a productivity of investment equation provides valuable policy-related information. Fourth, as we shall show later on, to test the diminishing returns to capital hypothesis in a theory-consistent way, it is necessary to take long-run cross-country data rather than panel data in a Barro-type regression model. By using the Gets modelling procedure referred to above, we are able to select an empirical model that is well specified and statistically robust when subjected to a battery of diagnostic tests, including a series of structural stability tests across rich and poor countries. This is rare for cross-country studies, which generally encounter econometric problems due to cross-country heterogeneity and omitted variable bias.[5]

In the next section we convert a standard new growth theory estimating equation into a productivity of investment equation and show how the transformed model provides a direct test of the diminishing returns to capital hypothesis. The section also outlines why the methodology advanced in this paper provides a novel extension to the existing literature. Section 3 examines to what extent our productivity of investment measure differs across rich

[4] See also Doornik (2009). As we shall discuss in more detail later on, Autometrics can be viewed as a third-generation model selection algorithm that retains many features of Hoover and Perez's (1999) pioneering work, and the novel extensions developed by Hendry and Krolzig (1999) that appear in their computer-automated model selection algorithm, PcGets (see Hendry and Krolzig, 2001).

[5] For an excellent treatment of the econometric issues in growth economics, see Temple (1999) and Durlauf et al. (2005).

and poor countries. Section 4 introduces the econometric specifications, the twenty potential explanatory variables, and discusses the computer-automated Gets model selection procedure. Section 5 estimates the productivity of investment model and section 6 discusses the results. Section 7 summarises the main findings and outlines some policy implications.

2. Empirical and Theoretical Models

To measure the productivity of investment, we divide the long-run output growth rate of countries (dY/Y) by their average ratio of gross fixed capital formation to GDP (I/Y). This does not require any new estimation of the capital stock across countries. The data are readily available from the World Bank.

Therefore, we define the gross productivity of investment, unadjusted for population growth, as:

$$\frac{dY/Y}{I/Y} = \frac{dY}{I} = \frac{dY}{dK} \tag{1}$$

where I = dK is gross fixed capital formation. Equation (1) is simply the inverse of the actual incremental capital-output ratio (ICOR), as defined in Harrod (1939). It is important to stress that the gross productivity of investment defined in this way is true by definition, since output growth is identically equal to the investment ratio multiplied by the actual (gross) productivity of investment: dY/Y = (I/Y)(dY/I). It follows that in new growth regressions which include the investment ratio as an independent variable, all that new growth theory is trying to do is to explain differences in the gross productivity of investment. As Levine and Renelt (1992) remark: "If we include INV [the investment share of GDP in the equation], the only channel through which other explanatory variables can explain growth differentials is [through] *the efficiency of resource allocation" (p.946);* in other words, by the productivity of investment. But new growth theory never takes the productivity of investment explicitly as the dependent variable and has no unambiguous test of whether or not there are diminishing returns to capital. To see this, take a typical new growth theory estimating equation of the form:

$$\left(\frac{dY}{Y} - n\right)_i = \alpha_0 + \alpha_1\left(\frac{I}{Y}\right)_i + \alpha_2 \ln PCY_i + \alpha_3 X_i \tag{2}$$

where per capita income growth in country i, $[(dY/Y) - n]_i$, is defined as the growth rate of output (dY/Y) minus population growth (n); α_0 is a constant; $(I/Y)_i$ is the ratio of investment to GDP; $\ln PCY_i$ is the log of the initial level of per capita income (to test for convergence), and X_i is a vector of other growth determinants. Dividing equation (2) by $(I/Y)_i$ gives:

$$\left(\frac{dY/Y - n}{I/Y}\right)_i = \alpha_0 (I/Y)_i^{-1} + \alpha_1 + \alpha_2\left(\frac{\ln PCY}{I/Y}\right)_i + \alpha_3\left(\frac{X}{I/Y}\right)_i \tag{3}$$

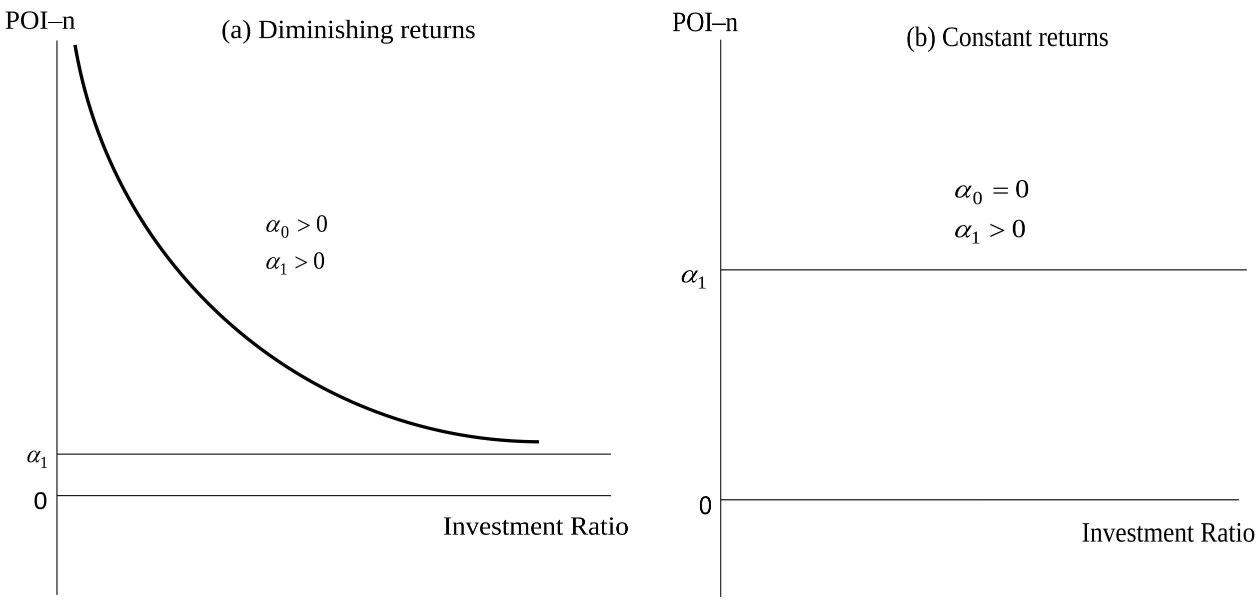
$\frac{dY/Y}{I/Y} = \frac{dY}{I} = \frac{dY}{dK}$ is the gross productivity of investment unadjusted for the contribution that population growth makes to output growth, while the full expression on the left-hand side of equation (3) is what we call the adjusted gross productivity of investment (adjusting for the contribution that population growth, n, makes to output growth through the growth of the workforce).[6] The relationship between the population-adjusted gross productivity of investment (POI–n) and the inverse of the investment ratio provides two different hypotheses of the returns to capital, as shown in Figures 1(a)-(b). The coefficient α_1 is the constant or asymptote. The sign of α_0 measures directly whether or not there are diminishing returns to capital. A positive sign in Figure 1(a) indicates diminishing returns, and if α_0 is not significantly different from zero in Figure 1(b) this would indicate constant returns to capital, that is, no relation between the quantity of investment relative to GDP and its productivity. The sign on the initial per capita income variable in equation (3) measures whether or not there is conditional convergence, but a negative sign can no longer be interpreted, as Barro

[6] This distinction is similar to Leibenstein's (1966) unadjusted and population-adjusted ICOR.

(1991) does for example, as a rehabilitation of the neoclassical model with diminishing returns to capital because this has already been controlled for.[7]

Figure 1:

Different Returns to Capital Hypotheses



Barro-type (1991, 1998, 2015) regressions such as equations (2) and, by implication, the transformed productivity of investment model in equation (3), are often viewed as informal or ad hoc because they are not derived from an underlying theoretical model (see Temple, 1999). In what follows, however, we will show that the empirical specifications in equations (2)-(3) can be interpreted in terms of two competing theoretical models: Solow's (1956) neoclassical model with diminishing returns to capital, and AK-style endogenous growth models with constant returns.

[7] Controlling for differences in the level of education across countries, Barro (1991) argues: *"Thus, in this modified sense, the data support the convergence hypothesis of neoclassical growth models [based on diminishing returns to capital]. A poor country tends to grow faster than a rich country, but only for a given quantity of human capital." (p. 409).*

2.1 *Solow's Neoclassical Model*

In the Solow model, the production function is given by (see Mankiw et al., 1992):

$$Y(t) = B(t)K(t)^{\alpha} L(t)^{1-\alpha} \qquad 0 < \alpha < 1 \tag{4}$$

where Y is output, K is capital, L is labour, and B is the level of technology.[8] Each variable is expressed as a function of time, t.

The capital accumulation equation is given by:

$$dK^{N}(t) = iY(t) - \delta K(t) \tag{5}$$

where $dK^{N}(t) \equiv dK^{N}/dt$ is the time derivative of net investment, i = I(t)/Y(t) is the gross investment ratio, and δ is the depreciation rate.[9] Gross investment is defined as net investment plus depreciation. To see this, equation (5) can be rewritten as:

$$\underbrace{dK^{N}(t)}_{\text{net investment}} + \underbrace{\delta K(t)}_{\text{depreciation}} = \underbrace{dK(t)}_{\text{gross investment}} = iY(t) = I(t) \tag{6}$$

where the time derivative of gross investment, $dK(t) \equiv dK/dt$, can be expressed as iY(t) = I(t). Note that dK(t) = I(t) is consistent with the definitional gross productivity of investment measure in equation (1) and the empirical specification in equation (3). In growth rates equation (6) becomes:

$$\left(\frac{dK^{N}(t)}{K(t)} + \delta\right) = \frac{dK(t)}{K(t)} = i\frac{Y(t)}{K(t)} \tag{7}$$

Taking growth rates of equation (4) and substituting for the growth rate of capital in equation (7) gives:

$$\frac{dY(t)}{Y(t)} = g_B + i\frac{\alpha Y(t)}{K(t)} + (1-\alpha)\frac{dL(t)}{L(t)} \tag{8}$$

[8] For ease of exposition, technology is assumed to be 'Hicks-neutral' instead of 'Harrod-neutral', as in Mankiw et. al (1992). Nevertheless, Kennedy (1962) formally shows that Hicks and Harrod neutrality are equivalent in the Cobb-Douglas production function.

[9] Similar to Mankiw et al. (1992), the Solow model is set in continuous time. The counterpart of the continuous time expression in equation (5) is the discrete time expression, $K_{t+1} - K_t = iY_t - \delta K_t$.

where g_B (> 0) is the exogenous growth rate of technological progress, αY/K is the MPK, $dY(t) \equiv dY/dt$ is the time derivative of output, and $dL(t) \equiv dL/dt$ is the time derivative of labour. Following the Solow model assumption that population growth is equal to labour force growth (dL(t)/L(t) = n), equation (8), at a given point in time in country i, can be written in per capita terms as:

$$\left(\frac{dY}{Y} - n\right)_i = g_B + \left(\frac{I}{Y}\right)_i \left(\frac{\alpha Y}{K}\right)_i - \alpha(n)_i \tag{9}$$

Comparing equation (9) with the empirical specification in equation (2), it can be seen that the constant, α_0, proxies the exogenous rate of technological progress, g_B, which is assumed to be the same across countries in the Solow model, while the initial level of per capita income and the vector of X_i variables represent the MPK and population growth rate. To explicitly interpret the Solow model in terms of the regression specification in equation (2), equation (9) can be transformed in the following way:

$$\left(\frac{dY}{Y} - n\right)_i = g_B + \beta_0 \left(\frac{I}{Y}\right)_i + \beta_1 Z_i \tag{10}$$

where $\beta_0 = \alpha Y/K$ and $Z_i = f[(\alpha Y/K)_i, n_i]$. When cross-country differences in the vector of Z_i variables are controlled for, which includes differences in the MPK, then the parameter on the investment ratio, β_0, gives the average $MPK \equiv \alpha Y/K$ of the sample.

Dividing equation (10) by the investment ratio (I/Y) gives the population-adjusted productivity of investment equation:

$$\left(\frac{dY}{dK} - \frac{n}{I/Y}\right)_i = g_B (I/Y)^{-1} + \beta_0 + \beta_1 \left(\frac{Z}{I/Y}\right)_i \tag{11}$$

where β_0 is the asymptote. The empirical specifications in equations (2)-(3) can now be compared with the theoretical predictions of the Solow model in equation (11). A positive sign on α_0, which is the constant in equation (2), shows that countries share a common exogenous rate of growth. This implies diminishing returns to capital in equation (3) and Figure 1(a): the productivity of investment falls as investment rises. To explain why a common exogenous rate of growth implies diminishing returns in a theory-consistent way, note that a positive α_0 in the empirical equation (3) proxies the common exogenous rate of technological progress, g_B, in the Solow equation (11). The Solow model assumption of a common long-run growth rate across countries ($\alpha_0 \approx g_B$) can only hold if there are diminishing returns to capital; otherwise long-run growth rates would diverge (Mankiw et al., 1992; Hall and Jones, 1999). Empirical evidence showing, $\alpha_0 \approx g_B > 0$, would therefore support the diminishing returns to capital hypothesis.

2.2 AK-style Endogenous Growth Models

Consider the production function of the AK model:

$$Y(t) = A(t)K(t)L(t)^{1-\alpha} \tag{12}$$

In the simplest version of the AK model (Y = AK), L is constant and contained in A. In this version, however, we assume that all the variables, including technology (A), are a function of t. The essence of the AK model is that the share of capital in income (α), alone, understates its contribution to production due to learning-by-doing effects associated with embodied technical progress and/or human capital when K is broadly defined (Romer, 1986; Lucas, 1988; Jones, 1995; Li, 2002; Bond et al. 2010). When these externalities are taken into account, the exponent on K becomes unity.

Taking growth rates of equation (12) and substituting for the growth rate of capital in equation (7) gives:

$$\frac{dY(t)}{Y(t)} = g_A + i\frac{Y(t)}{K(t)} + (1-\alpha)\frac{dL(t)}{L(t)} \tag{13}$$

Rewriting equation (13) in per capita terms at a specific point in time in country i:

$$\left(\frac{dY}{Y}-n\right)_i=(g_A)_i+\left(\frac{I}{Y}\right)_i\left(\frac{Y}{K}\right)_i-\alpha(n)_i \tag{14}$$

The initial level of per capita income and the vector of X_i variables in equation (2) approximate g_A, Y/K and n in equation (14). To explicitly interpret the model in terms of the regression specification in equation (2), we follow the same procedure as before and rewrite equation (14) as

$$\left(\frac{dY}{Y}-n\right)_i=0+\phi_0\left(\frac{I}{Y}\right)_i+\phi_1 W_i \tag{15}$$

where $\phi_0=Y/K$; $W_i = f[(g_A)_{i,}(Y/K)_i, n_i]$, and '0' explicitly shows that the common exogenous rate of technological progress across countries (g_B) in the Solow specification of equation (10) becomes zero in the AK model. When cross-country differences in the vector of W_i variables are controlled for, the parameter on the investment ratio, ϕ_0, gives the average $MPK \equiv Y/K$.

The population-adjusted productivity of investment is obtained by dividing equation (15) by the investment ratio:

$$\left(\frac{dY}{dK}-\frac{n}{I/Y}\right)_i=0(I/Y)_i^{-1}+\phi_0+\phi_1\left(\frac{W}{I/Y}\right)_i \tag{16}$$

One of the key differences compared with the Solow model specification in equation (11) is that the common exogenous rate of growth of technological progress across countries is zero ($g_B=0$). The constant returns to capital assumption of the AK model implies that countries grow at different rates in the long run; there is no common exogenous rate of growth, g_B, as assumed in the Solow model. In this version of the AK model, technology grows at different rates across countries, which is denoted by $(g_A)_i$ in the vector of W_i variables.

The AK model in equation (16) is nested in the empirical specification of equation (3). Evidence of a zero estimate on $\alpha_0 \approx g_B = 0$ implies constant returns to capital in Figure 1(b).

The main policy implication of the AK model is that differences in the investment ratio and the determinants of the productivity of investment generate permanent growth effects across countries, as opposed to the transitory growth effects predicted by the Solow model.

2.3 A Comparison with Alternative Approaches

How does the methodology developed in the previous section compare with alternative approaches that have been followed in the literature? As a starting point, consider an influential body of literature that supports the diminishing returns to capital hypothesis of the Solow model. As Temple (1999) remarks in his authoritative review of the literature: "The strongest result in the investment-growth literature is that the returns to physical capital are almost certainly diminishing, in agreement with the Solow-Swan growth model and most theoretical work since. This is the finding of both convergence regressions and cross-*country growth accounting (Benhabib and Spiegel, 1994; King and Levine, 1994)" (p.* 138).

Our response to the 'diminishing returns to capital view' in the literature is twofold. First, we have already noted that the sign on the initial level of per capita income in equation (3) does not provide an unambiguous test of the returns to capital. A negative sign, which is the finding of almost all cross-country growth studies that test for conditional convergence, may pick up technology catch-up rather than diminishing returns to capital. The novel feature of the specification in equation (3) is that we don't have to rely on the sign of the initial per capita income variable, but can test the diminishing returns to capital hypothesis directly through the sign and significance of α_0 in Figure 1(a)-(b).

Second, although empirical tests of the Solow model and cross-country growth accounting generally report an elasticity of output with respect to capital of less than one, which implies diminishing returns to capital, there are several limitations. Consider the Solow model in Mankiw et al. (1992) and many other studies that have adopted a similar approach (see, for example, Temple's (1999) literature review; Temple, 1998; Hoeffler, 2002; Cohen and Soto, 2007; Ding and Knight, 2009). Although Mankiw et al. (1992) report capital elasticities of less than one, their theory-specific production function approach is set up to give such a result. In the original version of the Solow model, the investment rate elasticity is equal to $\alpha/(1 - \alpha)$, which only holds if the diminishing returns to capital assumption, $0 < \alpha < 1$, is imposed a priori. Thus, irrespective of the magnitude of the estimated investment rate elasticity, the derived capital elasticity (α) will always be less than one. The same argument applies to augmented versions of the Solow model. Contrast this with the methodology advanced in this paper. The empirical specifications in equations (2)-(3) provide close proxies of the Solow model in equations (10)-(11) and the AK-type models in equations (15)-(16). Within this framework, it is possible to conduct an unbiased test of the diminishing returns to capital hypothesis without a priori imposing a specific form on the production function.

As an alternative, some studies have directly estimated the elasticity of output with respect to capital in a growth accounting framework. Here too the capital elasticity is generally found to be less than one, thus supporting the diminishing returns to capital assumption of the Solow model (Benhabib and Spiegel, 1994; King and Levine, 1994; Senhadji, 2000; Cohen and Soto, 2007). This approach, however, relies on the construction of a capital stock series by the perpetual inventory method, which requires assumptions about the initial value of the capital stock and data on depreciation rates across countries (Easterly and Levine, 2001; Caselli and Feyrer, 2007; Cohen and Soto, 2007). As far as depreciation rates are concerned, the lack of data inevitably leads researchers to arbitrarily assume the same depreciation rate across rich and poor countries (Mankiw et al., 1992; Easterly and Levine, 2001; Caselli and Feyrer, 2007; Cohen and Soto, 2007).

To examine how the depreciation rate affects the modelling framework in this study, consider equation (7). If the depreciation rate, δ, is the same across countries, cross-country differences in the growth rate of the gross capital stock, dK/K, are in effect picking up differences in the growth rate of the net capital stock, dK^N/K. Holding everything else constant, and assuming the same depreciation rate across countries, an increase in the investment ratio would raise the growth rate of the net capital stock in equation (7). This, in turn, would lead to a faster rate of growth in per capita income in equation (10). For a given growth effect of the investment ratio, the other explanatory variables in the vector Z_i are capturing cross-country differences in the efficiency of net investment if, and only if, the rate of depreciation is the same in all the countries. This is made explicit in equation (11) where the dependent variable is the population-adjusted productivity of investment and the growth effect of the investment ratio is the asymptote, β_0. If the depreciation rate assumption is relaxed, so that δ becomes δ_i, the model would measure differences in the efficiency of gross investment. Thus, our assumption of similar depreciation rates, which may be a reasonable one given the lack of reliable data, is no different from what has been the norm in the growth literature. The key difference is that the construction of a capital stock series requires the researcher to arbitrarily assume a specific value for the depreciation rate. For example, Caselli and Feyrer (2007) assume a value of 6% for their sample of countries and Easterly and Levine (2001) a value of 7%. In contrast, because the modelling strategy in this paper does not rely on the build-up of a capital stock series, it is not necessary to make assumptions about a specific value for the depreciation rate or the initial value of the capital stock.

To avoid measurement errors associated with the construction of a capital stock variable, researchers have used the gross investment ratio as a proxy for physical capital accumulation. Studies by Li (2002), Romero-Ávila (2009) and Bond et al. (2010) all find evidence of a long-run causal link from the investment ratio to per capita income growth in their sample of countries. These findings support the theoretical underpinnings of AK-style endogenous growth models, as opposed to the influential ‘diminishing returns to capital view’ in the literature.

To summarise, although the Barro-type regressions models that underlie our methodology have been criticised for their *ad hoc* nature, we have shown that it is possible to interpret these models in a theory-consistent and unbiased way; either from the perspective of Solow’s diminishing returns to capital model or AK-style endogenous models with constant returns. Within this framework, we provide an independent and unambiguous test of the returns to capital. We also motivate the relevance of our approach in terms of what has been done in the literature. In short, studies that *a priori* adopt the Solow model as their theoretical framework do not really test the diminishing returns to capital hypothesis in an unbiased way – the capital elasticity, by construction, is less than one. Moreover, a negative and significant sign on the initial per capita income variable in growth regressions may pick up technology catch-up rather than diminishing returns to capital. Measurement errors associated with the construction of a latent capital stock variable further suggest that the less than unit capital elasticity estimates that are generally found in the literature should be treated with some caution. In contrast, the diminishing returns to capital test proposed in this study does not rely on the build-up of a capital stock series or the sign on the initial level of per capita income variable.

3. Descriptive Analysis

To test for diminishing returns to capital, and the determinants of productivity of investment differences, we shall be basically running regressions of type equation (2) and equation (3), using the software Autometrics (Doornik and Hendry, 2013). We have assembled a consistent data set for 84 developed and developing countries of the world which includes twenty explanatory variables over the period 1980-2011. The definition of the variables, and the countries taken, are given in Appendix A. In the next section we provide a more detailed discussion of the econometric models, data and estimation procedure used.

Before econometric estimation, however, it is informative to look at the raw data on the unadjusted gross productivity of investment and adjusted gross productivity of investment (adjusted for population growth) across the quartiles of countries from poorest to richest based on their initial per capita income level in 1980. The results are given in Table 1, together with the standard deviation of all the variables in parentheses.

Table 1:

Income Quartiles: Initial Per Capita Income Levels in 1980

Income Classification (number of countries)	**Unadjusted POI (%)**	**[(dY/Y) – n] (%)**	**POI–n (%)**	**I/Y (%)**
Poorest quartile (21 countries)	22.05 (7.00)	1.38 (1.64)	6.54 (9.05)	18.03 (3.99)
Second poorest quartile (21 countries)	17.33 (5.32)	1.55 (1.60)	6.40 (7.44)	21.52 (4.72)
Second richest quartile (21 countries)	17.52 (4.17)	2.26 (1.23)	10.00 (4.14)	21.82 (4.36)
Richest quartile (21 countries)	10.75 (2.94)	1.64 (0.43)	7.76 (2.20)	21.34 (2.36)

Note: Standard deviations in parentheses.

The first data column in Table 1 gives the average unadjusted gross productivity of investment (POI) over the period 1980-2011; column 2 gives the average growth rate of per capita income [(dY/Y) – n]; column 3 gives the average population-adjusted gross POI (POI–n), and column 4 gives the average investment ratio (I/Y). The table shows that the poorest quartile has a higher unadjusted gross productivity of investment than the richest quartile, but this conclusion is reversed when population growth is allowed for. The adjusted estimates show that the poorest quartile has a gross productivity of investment of 6.54 percent and the richest quartile has a gross productivity of investment of 7.76 percent. Although the gross adjusted productivity of investment estimates do not differ much across the different quartiles, the standard deviations in the poorest two quartiles are large relative to the richest two quartiles. Overall, this means that there is large cross-section variation within the poorest countries and also across countries.

To conclude, what the raw evidence in this paper shows is that while, on average, the gross adjusted productivity of investment estimates seem to be roughly equal across groups of countries, there is wide variation within groups of countries, and this is what we will try and explain with our econometric modelling.

4. Econometric Model, Data and Estimation Procedure

4.1 Econometric Model

The Barro-type (1991, 1998, 2015) per capita income growth rate model in equation (2) can formally be converted into an econometric specification by introducing an error term:

$$\left(\frac{dY}{Y} - n\right)_i = \alpha_0 + \alpha_1\left(\frac{I}{Y}\right)_i + \alpha_2 \ln RGDP80_i + \alpha_3 X_i + \varepsilon_i\ , \qquad i = 1...84 \qquad (17)$$

where $[(dY/Y) - n]_i$ is the average per capita income growth rate in country i over the period 1980-2011; α_0 is an intercept term; $(I/Y)_i$ is the average investment ratio over the period 1980-2011; $\ln RGDP80_i$ is the natural logarithm of the initial level of real GDP per capita income in 1980; X_i is a vector of other growth determinants; and ε_i is an unobserved error term.

Dividing (17) by $(I/Y)_i$ gives the econometric specification of the population-adjusted gross productivity of investment (POI –n) model in equation (3):

$$\left(\mathrm{POI}-\mathrm{n}\right)_{\mathrm{i}} = \alpha_0\left(\mathrm{I}/\mathrm{Y}\right)_{\mathrm{i}}^{-1} + \alpha_1 + \alpha_2\left(\frac{\ln\mathrm{RGDP80}}{\mathrm{I}/\mathrm{Y}}\right)_{\mathrm{i}} + \alpha_3\left(\frac{\mathrm{X}}{\mathrm{I}/\mathrm{Y}}\right)_{\mathrm{i}} + \left(\frac{\varepsilon}{\mathrm{I}/\mathrm{Y}}\right)_{\mathrm{i}} \qquad \mathrm{i} = 1...84 \qquad (18)$$

Since our main interests are to test the diminishing returns to capital hypothesis and to identify the determinants of productivity of investment differences, one approach would be to estimate equation (18) directly where the sign and significance of α_0 measures whether or not there are diminishing returns to capital. Note, however, that equations (17) and (18) are mathematically equivalent – the same parameters appear in both equations. It is therefore possible to derive the parameter estimates of the productivity of investment model in equation (18) by estimating the per capita income growth rate model in equation (17). This could be an option, because although the two models are mathematically equivalent, they may differ in terms of their statistical properties. If the error term in equation (17) is well behaved then dividing it by the investment ratio to derive equation (18) may introduce heteroscedasticity and other undesirable side-effects, such as outliers and misspecification problems. In this scenario, it is preferable to estimate the per capita income growth rate in equation (17) and derive the productivity of investment estimates in equation (18). Contra-wise, if the per capita income growth rate, equation (17), suffers from heteroscedasticity, then dividing it by the investment ratio may solve the problem. This is one of the remedial techniques suggested in the econometrics literature if, and only if, the variance of the error term is proportional to the square of the investment ratio (see Gujarati, 2003). In this case, it is advisable to estimate the productivity of investment equation (18) directly.

In the empirical section, as our basic starting point, we will first estimate the productivity of investment model in equation (18) and observe the results. If necessary we can then estimate, as a robustness test, the per capita income growth rate model in equation (17) to obtain the derived productivity of investment estimates.

4.2 Computer-Automated Model Selection Procedure and Data

We have taken 20 potential explanatory variables of the models in equations (17)-(18) for our cross-section sample of 84 developed and developing countries reported in Appendix A (see Table 1A for the list of countries and Table 2A for a detailed description of all the variables).[10] In Table 2A, the expected sign on each of the variables is given in parentheses based on theory and results already found in the literature. A summary description of the explanatory variables are: 1) absolute latitude from the equator (ABLAT); 2) FDEV90 (ratio of liquid liabilities to GDP); 3) GCON (general government consumption expenditure to GDP ratio); 4) GEX (growth rate of real exports of goods and services); 5) GPO [n] (growth rate of population); 6) INFL (inflation rate derived from GDP deflator); 7) INFLSDEV (standard deviation of the inflation rate); 8) INV [I/Y] (gross fixed investment ratio); 9) lnPOP80 (log of the population size in 1980); 10) lnRGDP80 (log of the initial real GDP per capita income level in 1980); 11) MINING (share of mining and quarrying in GDP); 12) OPEN (proportion of years in the interval 1965-1990 in which an economy is open to trade); 13) REVCOUP (number of coups and revolutions); 14) PRIGHTS (political rights index that ranges from 1 to 7, with 1 indicating countries with the highest level of political rights and 7 the lowest); 15) RULELAW (rule of law index recorded once for each country in the early 1980s); 16) SECTER80 (average years of secondary and tertiary education in 1980); 17) SECTER80×lnRGDP80 (interactive term with variables defined above); 18) TOTED80 (average years of primary, secondary and tertiary education); 19) TOTED80×lnRGDP80 (interactive term with variables defined above); 20) TOPEN (ratio of total trade to GDP).

The selection of variables includes monetary, fiscal, trade, financial development, geography and institutional/political indicators, as well as the average growth of population

[10] Table 2A in Appendix A reports the original data sources of variables 1, 11, 12, 13, 14, and 15. These variables have also been used in Sala-i-Martin's (1997) empirical study and can be downloaded from Hoover and Perez's (2004) website at http://www.csus.edu/indiv/p/perezs/Data/data.htm.

and its initial size to capture potential market size effects. The list also includes measures of physical and human capital accumulation proxied by the gross fixed investment ratio and average years of schooling, respectively. The chosen variables are representative of some of the key growth determinants that have been identified in the literature (see, for example, Barro, 1991, 1998, 2015; Durlauf et al., 2005; Hendry and Krolzig, 2004; Hoover and Perez, 2004; Levine and Renelt, 1992; Mankiw et al., 1992; Sala-i-Martin, 1997; Temple, 1999).

Given the long list of potential regressors, a major empirical issue is to decide on an appropriate methodology to select the final model. In this paper, we employ Hendry's (1995) general-to-specific (Gets) model selection procedure, as embodied in the computer-automated Autometrics programme of Doornik and Hendry (2013). Autometrics is the direct outcome of several novel and innovative developments in automated Gets modelling. Hoover and Perez (1999) first proposed an automated Gets algorithm that captured many features of the Hendry/LSE methodology. Hendry and Krolzig (1999) extended the Hoover-Perez algorithm in several distinct ways and created a second-generation model selection programme called PcGets (see Hendry and Krolzig, 2001; Hendry and Krolzig, 2005; Krolzig and Hendry, 2001).[11] Autometrics can be seen as a third-generation algorithm that shares many features of previous algorithms, albeit with some notable differences (Doornik, 2009; Doornik and Hendry, 2013). By starting with a general unrestricted model that is congruent with the data, Ericsson (2012) succinctly describes the Autometrics algorithm as *"...[utilising] one*-step and multi-step simplifications along multiple paths following a tree search method. Diagnostic tests serve as additional checks on the simplified models, and encompassing tests resolve *terminal models"* (p. 2).

To iron out any business cycle fluctuations in the per capita growth rate and investment ratio series, we use long-run cross-country data over the period 1980-2011. The

[11] Owen (2003) provides an excellent overview of the PcGets software programme.

use of long-run averages minimizes potential endogeneity problems that may arise from short-run business cycle correlations between these two series. The same argument applies to other flow variables in our dataset. In addition, following Sala-i-Martin (1997), all the stock variables in Table 2A of Appendix A are measured as close as possible to the beginning of the period (which is 1980). In this way, it is possible to estimate the effect on the productivity of investment and per capita income growth (1980-2011) after the initial shock to an independent variable, which should take care of simultaneity problems.

In a more general context, as will become apparent from our discussion in section 6.1, to test the diminishing returns to capital hypothesis in a theory-consistent way, it is necessary to use cross-country data averaged over the longest possible period, rather than panel data averaged over 5 or 10 year intervals. As a result, we do not rely on panel data methods, which are now customary in empirical studies on growth economics, to resolve econometric problems associated with cross-country heterogeneity and omitted variables bias. The Autometrics modelling procedure that we employ, however, provides the empirical researcher with a wide range of diagnostic and structural stability tests to examine whether the econometric problems most common in cross-country studies appear in the final selected model. In short, our empirical modelling strategy is based on specifying an initial unrestricted model that is general enough to avoid a potential omitted variable bias. We then rely on the Gets algorithm of Autometrics to select a well-specified, statistically robust and theory-consistent empirical model.

5. Empirical Results

5.1 Direct estimates of the Productivity of Investment Equation

Consistent with the Gets modelling approach described earlier, the productivity of investment equation (18) is specified to include all 20 potential regressors summarised in the previous section (and listed in detail in Table 2A of Appendix A), except the rule of law index. The effect of the investment ratio on per capita income growth is measured by the asymptote or constant (α_1) in equation (18), while the inverse of the investment ratio measures the returns to capital. As discussed in Table 1A of Appendix A, the rule of law index (RULELAW) is available for 79 countries, but for now we will consider our largest consistent sample of 84 countries. Before the general unrestricted model (GUM) is tested down to a specific model, the empirical researcher has to make several decisions about the settings that will be used in the Autometrics programme (see Doornik, 2009; Doornik and Hendry, 2013). In Appendix B we provide detailed information about the settings that we use to obtain the specific models in Tables 2 and 3 below.

Column (i) of Table 2 reports the specific model chosen by Autometrics for the sample of 84 countries. The outlier detection test of Autometrics, which is based on the significance levels of the largest residuals, identifies two country dummy variables. The regression model is well determined, with all the variables significant at either the 1% or 5% confidence levels. Although heteroscedasticity is detected at the 1% significance level in column (i), the model remains well determined when heteroscedasticity-consistent standard errors (HCSE) are used in column (ii). The diagnostic tests further show that the model is well specified and that the residuals are normally distributed.

Table 2:

Regression Results of the POI–n Equation (18)[a]

Independent variable	(i) Specific Model	(ii) Specific Model (HCSE)[a]
$(I/Y)^{-1}$	0	0
Asymptote ($\hat{\alpha}_1$)	0.1306*** (5.26)	0.1306*** (4.87)
lnRGDP80/(I/Y)	–0.1539** (2.07)	–0.1539** (2.45)
TOTED80/(I/Y)	0.8155*** (2.70)	0.8155** (2.32)
(TOTED80 × lnRGDP80)/(I/Y)	–0.0834*** (2.68)	–0.0834** (2.39)
ABLAT/(I/Y)	0.0287*** (3.60)	0.0287*** (3.94)
GCON/(I/Y)	–0.0682*** (3.35)	–0.0682*** (2.80)
GEX/(I/Y)	0.1191*** (4.06)	0.1191** (2.40)
INFLSDEV/(I/Y)	–0.0004*** (4.75)	–0.0004*** (7.11)
PRIGHTS/(I/Y)	–0.1927*** (3.07)	–0.1927*** (2.72)
TOPEN/(I/Y)	0.0051*** (2.67)	0.0051*** (3.76)
Country dummy (Côte d'Ivoire)[b]	0.1108*** (2.91)	0.1108*** (7.94)
Country dummy (Rwanda)[b]	–0.1370*** (3.38)	–0.1370*** (7.96)
Diagnostic Tests[c]		
R^2	0.72	
Standard error ($\hat{\sigma}$)	0.035	
Reset (misspecification): F-test	{0.35}	
Normality test: χ^2 [2]	{0.85}	
Heteroscedasticity(S): F-test	{0.01}***	
Heteroscedasticity(X): F-test	{0.00}***	
Chow (43): F-test	{0.93}	
Chow (77): F-test	{0.70}	
Number of observations (N)	84 countries	

Notes:

a. The figures in parentheses (·) are absolute t-statistics and the figures in curly brackets {·} p-values. *** denotes significance at the 1% level and ** at the 5% level. The t-statistics in column (ii) are derived from heteroscedasticity-consistent standard errors (HCSE).

b. The significance levels of Côte d'Ivoire and Rwanda's scaled residuals are 0.97% and 1.63%, respectively, which fall below the one-tail 2.5% critical value of the outlier detection test. Thus, because the null of outliers (against the alternative of no outliers) cannot be rejected at the 2.5% significance level, two country dummies are automatically added to the regression model.

c. Two heteroscedasticity tests are reported: one that uses squares (S) and the other squares and cross-products (X). The null hypotheses of the diagnostic tests are the following: i) no functional form misspecification (using squares and cubes), ii) homoscedasticity, iii) the residuals are normally distributed, and iv) structural stability based on Chow tests. For more details, see Doornik and Hendry (2013).

As an additional test, we order the initial (1980) levels of per capita income of the 84 countries in ascending order, and use the parameter constancy test of Autometrics to examine the structural stability of the specific model in Table 2 across different sub-samples.[12] Two F-tests for structural stability, denoted as Chow (n), are reported in Table 2. The first one tests for a break at the sample mid-point (n = 0.5N, where N is the number of countries), and the other for a break at the 90th percentile of the sample (n = 0.9N). Both tests are statistically insignificant, showing that the regression model is structurally stable across the different sub-samples of rich and poor countries. Overall, the constancy and diagnostic tests show that the heteroscedasticity effects reported in column (i) of Table 2 are not due to non-constancies or omitted variables. This, in turn, implies that the corrected standard errors in column (ii) are indeed correcting for true heteroscedasticity.

An important feature of the specific model in Table 2 is that the inverse of the investment ratio, $(I/Y)^{-1}$, becomes redundant in the model reduction process. In effect, the specific model imposes a zero coefficient on $(I/Y)^{-1}$, which implies constant returns to capital in Figure 1(b). To verify, in a more direct way, that the zero coefficient restriction is a plausible assumption, we test the significance of $(I/Y)^{-1}$ in the specific model. The coefficient estimate of $(I/Y)^{-1}$ enters with a positive sign (0.66), but remains statistically insignificant, irrespective of whether we use the unadjusted standard errors in column (i) (t-value: 0.41) or the adjusted standard errors in column (ii) (t-value: 0.40).

To test the robustness of the specific model in Table 2, we include the rule of law index (RULELAW) as an additional variable in the GUM for our reduced sample of 79 countries. Maintenance of the rule of law is often identified as a key determinant of economic development in the literature (see Acemoglu et al., 2001; Barro, 1998; Rodrik et al., 2004;

[12] See Owen's (2003: pp. 613-614) overview and empirical application of the parameter constancy test in PcGets. We use the same settings in Autometrics.

Easterly and Levine, 2003). Despite its perceived importance in the literature, RULELAW is eliminated in the Gets modelling process and does not enter the specific model.[13]

5.2 Per Capita Income Growth Rate Estimates

Although the direct productivity of investment estimates in Table 2 are well determined and statistically sound based on most of the diagnostic tests, there is evidence of heteroscedasticity. It is therefore informative, as a robustness check, to estimate the per capita income growth rate equation (17) as well. Recall from the discussion in section 4 that equations (17) and (18) contain the same economic information, which makes it possible to derive the estimates of the productivity of investment in equation (18).

By following the same modelling procedure as before, the GUM for the per capita income growth rate equation (17) includes all the independent variables summarised in section 4.2 and listed in Table 2A of Appendix A, except the rule of law index. Table 3 reports the specific model chosen by Autometrics for our consistent sample of 84 countries (see Appendix B for a discussion of the settings used in the model reduction process).

[13] The RULELAW regression results are available on request. Rodrik et al. (2004: p. 156) argue that RULELAW may be a more relevant determinant of differences in *levels* of per capita income across countries, rather than growth rates.

Table 3:

Regression Results of the Per Capita Income Growth Rate Equation (17)[a]

Independent variable	Specific Model
Intercept ($\hat{\alpha}_0$)	0
I/Y	0.1451*** (5.99)
lnRGDP80	–0.2045** (2.54)
TOTED80	0.9412*** (3.10)
TOTED80 × lnRGDP80	–0.0976*** (3.12)
ABLAT	0.0278*** (3.42)
GCON	–0.0549** (2.60)
GEX	0.1310*** (4.04)
INFLSDEV	–0.0004*** (2.82)
PRIGHTS	–0.2299*** (3.54)
TOPEN	0.0053*** (3.07)
Diagnostic Tests[b]	
R^2	–
Standard error ($\hat{\sigma}$)	0.75
Reset (misspecification): F-test	{0.53}
Normality test: χ^2 [2]	{0.53}
Heteroscedasticity(S): F-test	{0.65}
Heteroscedasticity(X): F-test	{0.23}
Chow (43) F-test	{0.96}
Chow (77) F-test	{0.68}
Autometrics outlier test: value of the largest scaled residual[c]	2.36
Number of observations (N)	84 countries

Notes:

a. The figures in parentheses (·) are absolute t-statistics and the figures in curly brackets {·} p-values. *** denotes significance at the 1% level and ** at the 2.5 % level.

b. Two heteroscedasticity tests are reported: one that uses squares (S) and the other squares and cross-products (X). The null hypotheses of the diagnostic tests are the following: i) no functional form misspecification (using squares and cubes), ii) homoscedasticity, iii) the residuals are normally distributed, and iv) structural stability based on Chow tests. For more details, see Doornik and Hendry (2013).

c. The significance level of the largest scaled residual is 1.81%, which exceeds the one-tail 1.25% critical value of the outlier detection test. Thus, the null of outliers (against the alternative of no outliers) can be rejected at the 1.25% significance level.

The specific model is well determined and statistically robust based on the battery of diagnostic tests. None of the tests reject the null of a well specified model, normality, homoscedasticity and no outlying observations. To examine the structural stability of the model, we again order the 1980 per capita income levels of the 84 countries in ascending order. The Chow tests for structural breaks at the sample mid-point and 90th percentile of the sample are statistically insignificant, which show that the model is structurally stable across rich and poor countries. The main results do not change when RULELAW is included as an additional explanatory variable in the GUM for our reduced sample of 79 countries. Taken together, the diagnostic tests of the model suggest that one of the main concerns that have been raised against the use of cross-country data, namely cross-country heterogeneity in the parameters of interest[14], is not evident in our study.

It is important to note that, in effect, the specific model in Table 3 imposes a zero intercept term because it becomes redundant in the Gets model reduction process. The insignificance of the intercept term or absence of autonomous growth in per capita income is of particular interest in this paper. The intercept (α_0) in the per capita income growth rate equation (17) measures the returns to capital in the converted productivity of investment equation (18) through the $(I/Y)^{-1}$ term. Recall that the significance and sign of α_0 in equation (18) determine whether there are diminishing or constant returns to capital, as depicted in Figures 1(a)-(b). To confirm that the zero restriction on the intercept term is indeed valid, we directly test its significance in the specific model. The intercept enters with a positive coefficient estimate of 1.34, but the t-value of 0.80 shows that it is not significantly different from zero.[15]

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[14] See, for example, Baltagi (1995) and the empirical study of Attanasio et al. (2000: p. 185).

[15] Following the suggestion of an anonymous referee, we also examine what happens when the intercept is fixed. This option of Autometrics ensures that the intercept appears in the final selected model, irrespective of its significance level. With this restriction imposed, we re-estimate the GUM in equation (17). In the final selected model, the intercept contains a negative sign and is not significant at the 5% level. Given that its

From the regression results in Table 3, we obtain the fitted values of the per capita income growth rate model in equation (17) (absolute t-statistics in parentheses):

$$\begin{aligned}\left(\frac{dY}{Y}-n\right)_i &= 0 + \underset{(5.99)}{0.1451}(I/Y)_i - \underset{(2.54)}{0.2045}\ln RGDP80_i + \underset{(3.10)}{0.9412}TOTED80_i \\ &- \underset{(3.12)}{0.0976}(TOTED80\times \ln RGDP80)_i - \underset{(2.60)}{0.0549}GCON_i + \underset{(4.04)}{0.1310}GEX_i \\ &- \underset{(2.82)}{0.0004}INFLSDEV_i + \underset{(3.42)}{0.0278}ABLAT_i - \underset{(3.54)}{0.2299}PRIGHTS_i \\ &+ \underset{(3.07)}{0.0053}TOPEN_i + \hat{u}_{1i}\end{aligned} \tag{19}$$

Equation (19) explicitly includes a zero intercept term (or zero autonomous growth) to show that it is statistically insignificant in the model reduction process.

6. Derived Estimates and Interpretation of Results

The fitted values of the population-adjusted productivity of investment model in equation (18) can be derived by dividing (19) by $(I/Y)_i$ (absolute t-values in parentheses):

$$\begin{aligned}(POI-n)_i &= 0\times(I/Y)_i^{-1} + \underset{(5.99)}{0.1451} - \underset{(2.54)}{0.2045}\left(\frac{\ln RGDP80}{I/Y}\right)_i + \underset{(3.10)}{0.9412}\left(\frac{TOTED80}{I/Y}\right)_i \\ &- \underset{(3.12)}{0.0976}\left(\frac{TOTED80\times \ln RGDP80}{I/Y}\right)_i - \underset{(2.60)}{0.0549}\left(\frac{GCON}{I/Y}\right)_i + \underset{(4.04)}{0.1310}\left(\frac{GEX}{I/Y}\right)_i \\ &- \underset{(2.82)}{0.0004}\left(\frac{INFLSDEV}{I/Y}\right)_i + \underset{(3.42)}{0.0278}\left(\frac{ABLAT}{I/Y}\right)_i - \underset{(3.54)}{0.2299}\left(\frac{PRIGHTS}{I/Y}\right)_i \\ &+ \underset{(3.07)}{0.0053}\left(\frac{TOPEN}{I/Y}\right)_i + \hat{u}_{2i}\end{aligned} \tag{20}$$

A comparison between the derived estimates in equation (20) and the direct estimates in Table 2 shows that the regression models closely match each other. This is not surprising,

significance level falls well above our threshold level of 2.5% (see Appendix B), together with an incorrect theoretical sign, it is plausible to eliminate the intercept from the final model. Although this result is consistent with the final selected model in Table 3, the main drawback is that the initial level of per capita income is now dropped in the model reduction process. This variable is often found to be a statistically robust determinant of per capita income growth in the empirical literature (see, for example, Sala-i-Martin, 1997; Barro, 2015). To cross check whether the final selected model in Table 3 is robust, we compare it with the direct estimates in Table 2. The comparison shows that the same variables are selected, including the initial level of per capita income, while the growth effect of the investment ratio is captured by the significant asymptote or 'intercept' in Table 2. We also check whether the results in Table 2 are robust when the intercept is fixed in the model reduction process. When this is done, we obtain an identical final model to the one in Table 2, in which the intercept is highly significant. Overall, the results across the two specifications reinforce each other, suggesting that the final selected model in Table 3 is statistically robust. All these results are available on request.

given that the per capita income growth rate equation (17) and the productivity of investment equation (18) are mathematically equivalent. We have also argued that the two sets of results reinforce each other, especially if it is acknowledged that the robust standard errors in Table 2 correct for true heteroscedasticity effects rather than misspecification problems. We will focus our discussion on the derived estimates in equation (20), even though the direct estimates in Table 2 (column (ii)) are virtually identical. It is apparent that none of our main discussion points would change if we instead use the direct estimates in Table 2 as our empirical model.

As a starting point, it is informative to look at the partial coefficient of determination (partial R^2) of each explanatory variable in the per capita income growth rate equation (19). Table 4 lists the partial R^2 coefficients of the variables in descending order of importance.

Table 4:

Partial R^2 Coefficient of Explanatory Variables in Equation (19)

Variable	Partial R^2 Coefficient
I/Y	0.3270
Determinants of the POI–n	
GEX	0.1803
PRIGHTS	0.1452
ABLAT	0.1364
TOTED80 × lnRGDP80	0.1167
TOTED80	0.1149
TOPEN	0.1129
INFLSDEV	0.0965
GCON	0.0841
lnRGDP80	0.0805

Based on this criterion, the investment ratio is ranked first followed by nine significant determinants of the population-adjusted productivity of investment (POI–n). Note that, for a given investment effect on per capita income growth in equation (19), all the other variables determine cross-country per capita income growth rate differences through their effect on the productivity of investment. This is made explicit in equation (20), where the effect of investment on per capita income growth is the constant or asymptote, $\hat{\alpha}_1 = 0.1451$, and all the remaining variables are determinants of the productivity of investment. The analysis now turns to a detailed discussion of the empirical results in equations (19) and (20), and how the main findings relate to the existing growth literature.

6.1 Returns to Capital

It is important to reiterate that the sign and significance of the intercept term in the per capita income growth rate equation (19) provide a measure of the returns to capital in the converted productivity of investment equation (20) through the $(I/Y)^{-1}$ term. This is apparent from the corresponding empirical specifications in equations (2) and (3), the different returns to capital scenarios depicted in Figures 1(a)-(b) and the theoretical models in sections 2.1-2.2. To explain, in a theory-consistent way, why the intercept term in the per capita income growth rate equation serves as a measure of the returns to capital in the productivity of investment model, it is necessary to look at one of the key assumptions of Solow's (1956) canonical neoclassical growth model. Empirical applications and extensions of the neoclassical model, such as those in Mankiw et al. (1992) and Hall and Jones (1999), impose a common rate of technological progress across countries on the assumptions that the MPK is subject to diminishing returns and that technology is a public good freely available to all countries. The main implication of these assumptions is that, in the long run, per capita income in all countries will grow at the same, exogenously determined rate of technological progress (Fagerberg, 1994). The common rate of technological progress is denoted by g_B in the theoretical specifications of the Solow model in equations (10)-(11).

The only way in which the neoclassical model can explain per capita income growth rate differences in a given period is through transitional dynamics, that is, permanent shocks to investment, and other growth determinants, which generate temporary deviations from the fixed or exogenous rate of technological progress. Empirical support for the neoclassical model would have to show that the intercept term in the per capita income growth rate equation (19) is positive and significant $(\alpha_0 \approx g_B > 0)$; in other words, that there is evidence of positive autonomous growth once all the explanatory variables are set to zero. This would indicate that some proportion of growth across countries is fixed or exogenous, which, in turn, implies diminishing returns to capital in equation (20) through the $(I/Y)^{-1}$ term. The graphical representation of the diminishing returns to capital hypothesis is illustrated in Figure 1(a). It should now also be apparent, as already noted in section 4.2, why a rigorous test of the diminishing returns to capital hypothesis in a typical Barro-type regression model requires the use of long-run cross-country data, rather than panel data. Evidence of diminishing returns to capital implies a fixed or common long-run growth rate across countries, which may not be captured in an adequate way if the researcher uses panel data averaged over the customary 5 or 10 year intervals.

The empirical evidence in this paper, however, does not support the diminishing returns to capital assumption of the neoclassical model. The results in equation (20) show that the inverse of the investment ratio, $(I/Y)^{-1}$, is an insignificant determinant of the productivity of investment: $\hat{\alpha}_0 = 0$. Returning to Figure 1(b), this result implies that there are constant returns to capital at the asymptote, $\hat{\alpha}_1 = 0.1451$, with no relation between the ratio of investment to GDP across countries and its productivity. Evidence of constant returns is consistent with zero autonomous growth in the per capita income growth rate in equation (19). Thus, once all the cross-country determinants of growth are accounted for in (19), there is no evidence of a fixed or common rate of growth among the sample of 84 countries. The results support the constant returns to capital assumption of the AK model in equations (15) and (16), in which $\hat{\alpha}_0 \approx g_B = 0$ implies long-run differences in cross-country growth rates.

6.2 Investment Ratio

The investment ratio (I/Y) is a highly significant determinant of per capita income growth in equation (19), with its effect giving the average population-adjusted productivity of investment of 14.5% in equation (20). Similar to our study, cross-country studies that use 25- to 30-year averages generally find a statistically significant relationship between per capita income growth and the investment ratio, even after controlling for other determinants of growth (Barro, 1991; DeLong and Summers, 1992, 1993; Levine and Renelt, 1992; Mankiw et al. 1992; Sala-i-Martin, 1997; Temple, 1998).

There is an important difference, however, between the way in which we interpret our investment result compared with the conventional interpretation in the cross-country growth literature. Evidence of constant returns in this paper implies that changes in the investment ratio across countries generate permanent growth effects in per capita income. This contrasts with the neoclassical interpretation in Barro (1991, 1998) where a negative sign on the initial level of real per capita income is interpreted as diminishing returns to capital, so that permanent shocks to the investment ratio only generate temporary growth effects. As we shall emphasise below, because the productivity of investment specification in (20) provides a direct and unambiguous test of the returns to capital, the negative sign on the initial level of per capita income can no longer be interpreted as evidence of diminishing returns, as also pointed out by Benhabib and Spiegel (1994) quoted earlier.

The evidence presented thus far suggests that the investment ratio is a key determinant of long-run growth in our cross-country sample. This is further underlined by the partial R^2 coefficients of the different explanatory variables in Table 4, which show that the investment ratio is the single most important determinant of cross-country per capita income growth rate differences.

How does the cross-country evidence presented in this paper compare with panel data studies in the growth literature? Empirical studies that explore the cross-section and time-series variation in the data generally find that output growth ‘Granger-causes’ investment, but not the other way around (see, for example, Attanasio et al., 2000; Blomström et al., 1996; Carroll and Weil, 1994; King and Levine, 1994).[16] At first, these causality tests would seem to contradict the results, and interpretation of the investment-growth nexus, in this paper. It is probable, however, that panel studies are capturing short-run business cycle correlations between investment and growth rather than long-run effects. Several panel studies use investment and growth rates averaged over 5-year periods (Blomström et al., 1996; Carroll and Weil, 1994) or, in the case of Attanasio et al. (2000), non-averaged data. We have previously emphasised the importance of adjusting the investment ratio and per capita income growth rate data for cyclical fluctuations. Indeed, the main motivation for using a 31-year average over the period 1980-2011 is to ensure that we measure the long-run effect of investment on growth. Moreover, since the empirical model in Table 3 passes all the diagnostic tests, including the misspecification test, the evidence suggests that the long-run effect of investment on growth is not driven by omitted variables.[17]

More recent panel data evidence in Bond et al. (2010) supports the cross-country evidence presented in this paper. They specify an AK-style endogenous growth model, rather than a Barro-type regression model, and test it for a sample of 75 countries over the period 1960 to 2000 using annual pooled data with country-specific effects. Their analysis also

[16] Although the studies interpret their results in a causal sense, a note of caution. Granger-causality tests, as performed in the cited studies, examine whether past values of a variable predict the current value of another. Thus, although changes in output growth predict investment, it does not necessarily mean that output growth causes investment.
[17] Temple (1998) uses long-run average growth rates and shows that the returns to equipment investment in developing countries remain high, irrespective of whether instrumental variables are used or not.

addresses some econometric issues that have been neglected in previous panel studies, which include dynamic model specifications to filter out business cycle fluctuations. They report that *"...a permanent increase* in investment as a share of GDP from 9.1% (the first quartile of our sample distribution) to 15.1% (the sample median) is predicted to increase the annual *growth rate of GDP per worker by about 2 percentage points" (p. 1087).* This implies an average population-adjusted productivity of investment of 33 percent, which is high. For individual countries, the mean estimate of the country coefficients shows a lower effect on growth with an average population-adjusted productivity of investment of 16 percent. This is very close to our estimate in equation (20) of 14.5 percent.

The long-run growth effect of investment is consistent with the prediction of several theoretical models. These include Romer's (1986) AK-style endogenous growth model and Aghion and Howitt's (2007) augmented Schumpeterian growth model, in which capital accumulation determines research and development activities through its demand-creating and cost-reducing effects. Although the fixed investment ratio is an important individual determinant of long-run growth, still a lot of the variance in cross-country growth can be explained by differences in the productivity of investment. We now examine the empirical determinants of the productivity of investment in equation (20).

6.3 Initial Level of Per Capita Income

The initial level of per capita income, lnRGDP80, enters equation (20) with a negative sign and is statistically significant at the 2.5% level. Within the framework of the neoclassical model (Solow, 1956), this result is taken as evidence of conditional (beta) convergence due to diminishing returns to capital (see, for example, Barro, 1991, 1998, 2015; Mankiw et al. 1992; Temple, 1999). In other words, holding all the other explanatory variables constant, the negative sign shows that poor countries with low capital-labour ratios grow faster relative to rich countries with higher capital-labour ratios because the productivity of capital falls as investment rises. The speed of conditional convergence (λ) implied by the estimate on the initial per capita income variable is slow at 0.74 percent (t-value = 2.74) per annum.[18]

As we have said before, however, great care needs to be taken in interpreting the negative sign on the initial per capita income variable as necessarily rehabilitating the neoclassical model because there are other conceptually distinct reasons for expecting a negative sign. First, there is the notion of 'catch-up'. Poor countries might be expected to grow faster than rich countries because they have a backlog of technology to absorb which they have not had to pay for themselves (see Gomulka, 1971, 1990; Abramovitz, 1986; Dowrick and Nguyen, 1989; Dowrick and Gemmell, 1991; Amable, 1993; Benhabib and Spiegel, 1994). But 'catch-up' involves an upward shift in the whole production function and is conceptually distinct from diminishing returns to capital which involves a movement along a production function. Is conditional convergence picking up diminishing returns to capital in the neoclassical sense or 'catch-up'? As Fagerberg (1994) notes in his survey of technology and international growth rate differences, tests of the two hypotheses are indistinguishable using initial per capita income as a regressor (or initial per capita income of a country relative to the technological leader).

One of the novel and important features of our study, however, is that we have been able to test the hypothesis of diminishing returns to capital directly (as opposed to indirectly through the sign on the initial per capita income variable) and find that the econometric evidence rejects it. Thus the negative sign on the initial level of per capita income in equation (20) is more likely to be picking up the effect of 'catch-up', although it could also be picking up the effect of structural change, with poor countries growing faster than rich countries

[18] Following Mankiw et al. (1992), the conditional convergence rate (λ) can be derived from the following formula: $-(1-e^{-\lambda t}) = \alpha_2$. We obtain the estimate on the initial level of per capita income ($\hat{\alpha}_2 = -0.2045$) from equation(20), while our sample period (1980-2011) implies that $t = 31$. Plugging these values into the Mankiw et al. formula, we get a conditional convergence rate of 0.74 percent per annum.

(holding other variables constant) because of a faster shift of resources from low productivity sectors to higher-productivity sectors; for example, from agriculture to industry. The only way to identify this latter possibility is to include a structural change variable in the productivity of investment estimating equation.

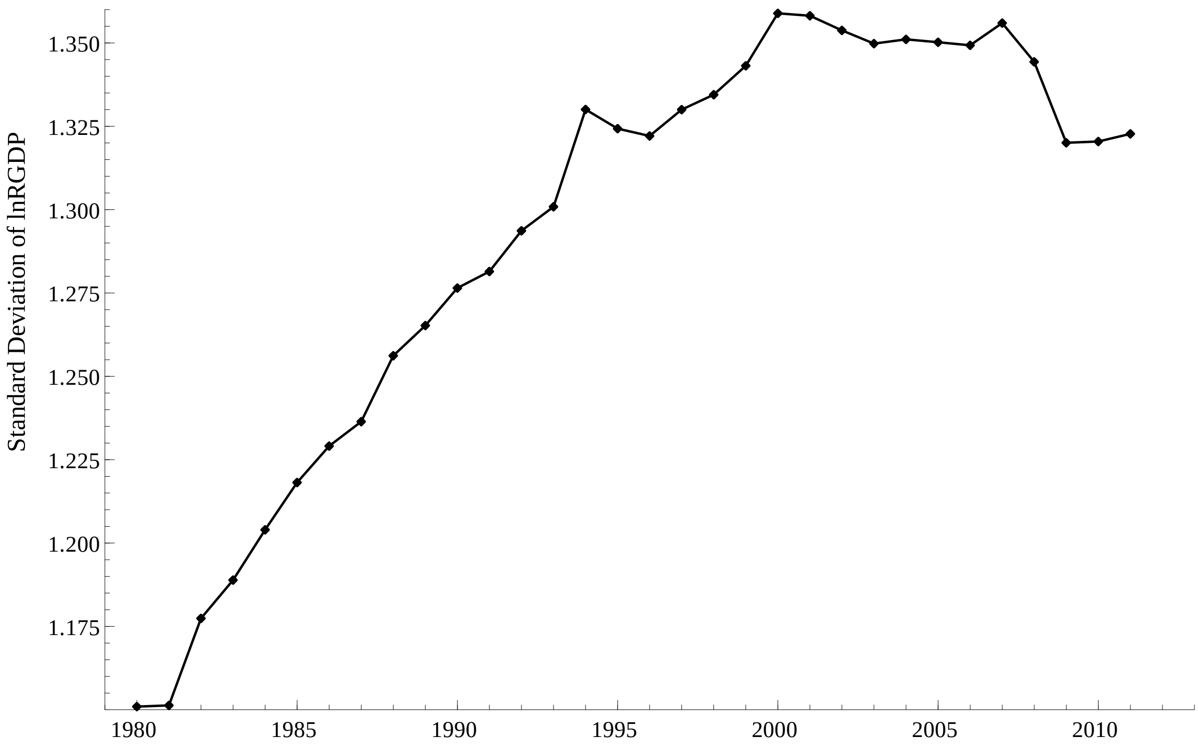
Conditional (or beta) convergence, of course, does not mean absolute (or sigma) convergence. This depends on the relative rates of growth of rich and poor countries taking all growth factors into account. Some evidence of possible actual divergence is already given in Table 2. The richest two quartiles of countries in 1980 grew faster on average than the poorest two quartiles. The difference is especially pronounced between the second richest quartile and the two poorest ones. Note, however, that the standard deviations of the poorest two quartiles are much larger than the richest quartile which means that while, on average, there will be absolute divergence, some poor countries will catch up. In fact, in our sample of 84 countries, 32 out of 63 countries in the poorest three quartiles grew faster than the average of 1.64 percent per annum of the richest quartile.[19]

Another way to analyse whether there has been absolute convergence/divergence is to plot the standard deviation of real per capita income (lnRGDP) across our sample of 84 countries for each year over the period 1980-2011. Figure 2 shows that the standard deviation increases up to the year 2000, then levels off and starts to decline. The decline is largely due to the fast growth of many poor African countries in the first decade of the new millennium.

[19] Ghose (2004) in a study of 96 countries over the period 1981-97 finds that only 17 out of 76 developing countries taken converged on the per capita income of the 20 developed countries.

Figure 2

The Standard Deviation of Real Per Capita Income (lnRGDP), 1980-2011



Note:

lnRGDP is the natural logarithm (ln) of the purchasing-power-parity adjusted real GDP per capita income level (constant 2005 dollars). Source: World Bank Development Indicators (2012).

Given our finding of constant returns to capital across countries, growth rate differences between rich and poor countries, as shown in Table 2, will persist for given differences in the investment ratio and determinants of the productivity of investment. This contrasts with the orthodox neoclassical prediction of a common long-run growth rate, once all transitional dynamics of changes in investment and other factors have dissipated.

6.4 Education

With regard to education, our results show that the initial stock of education, TOTED80, as measured by the average years of primary, secondary and tertiary education in

1980, impacts positively on the productivity of investment. Estimates in equation (20) show that an increase of one year in education increases the productivity of investment by nearly one percentage point. This is consistent with the work of Barro (1998) showing a positive relation between the initial stock of education and the growth of per capita income across countries.

The interaction term of the initial level of education with the initial level of per capita income tests whether the ability of countries to absorb new technology (that is to 'catch-up') is related to education (see Barro, 1998). The result in equation (20) shows that it does. The significant negative coefficient on the TOTED80 × lnRGDP80 variable (–0.0976) means that the negative coefficient on the initial level of per capita income increases from 0.2045 to 0.3021 (t-value = 3.62) when the effect of education is taken into account. This, in turn, implies that an extra year of schooling raises the conditional convergence rate from 0.74 percent to 1.2 percent (t-value = 4.44) per annum. Or put in another way, an extra year of schooling enables a country with a backlog of technology to catch-up at a faster rate.

6.5 Trade variables

The results in equation (20) show the two trade variables of the degree of openness (TOPEN) and growth of exports (GEX) as statistically significant, but the effect of the former is much weaker than the latter. A 10 percentage point difference in the openness variable is associated with only a 0.05 percentage point difference in the productivity of investment, while a 10 percentage point difference in export growth is associated with a 1.3 percentage point difference in the productivity of investment. The difference in result should not surprise because the openness variable is essentially picking up the effect of static trade gains on the efficiency with which capital is being used, while export growth is picking up dynamic gains from trade. The effect of export growth on the productivity of investment works from the supply-side and the demand-side. Export growth allows a faster growth of imports which can aid the productivity of domestic capital. Export growth has a direct effect on demand growth in an economy which helps to keep capital fully employed, and export growth can lift a balance of payments constraint on domestic growth allowing all other components of demand to expand faster without causing shortages of foreign exchange. There is a rich literature of the role of exports and foreign exchange in countries achieving high rates of economic growth (see McCombie and Thirlwall, 1994, 2004; Thirlwall, 2013).

6.6 Macroeconomic Variables

Our model using Autometrics finds that government consumption as a proportion of GDP, and the standard deviation of the inflation rate, as a measure of macroeconomic instability, both impact negatively on the productivity of investment. The effect, however, is not large. Equation (20) shows that a one percentage point increase in the government consumption/GDP ratio (GCON) reduces the productivity of investment by 0.05 percentage points. The channels through which a higher level of government current expenditure may reduce the productivity of investment are numerous but the main effect is likely to be a diversion of resources away from the higher productivity of the private sector, and the debt implications of government borrowing to finance consumption. Many new growth theory studies also find government current expenditure affects negatively the growth of output (see, for example, Barro, 1998). This does not necessarily mean, of course, that government expenditure is undesirable, particularly if it is used for welfare enhancement in areas of education, health provision, and support for the poor. There may be a trade-off between growth and welfare provision or equally a complementary relationship.[20]

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[20] Due to the lack of data over our sample period, we are not able to adjust the government consumption ratio for welfare effects. Barro's (1998) government consumption ratio, on the other hand, excludes spending on education and defense. The negative effect of his adjusted ratio on per capita income growth is almost three

Equation (20) shows that a 10 percentage point increase in the standard deviation of inflation (INFLSDEV) reduces the productivity of investment by only 0.004 percentage points. The main channel through which macro-instability reduces the productivity of investment is through the difficulty that an unstable economy has in maintaining a full employment level of output. Stop and start policies of governments confronted with inflation, and other sources of instability, are not conducive to the full utilisation of capital capacity. If instability is associated with foreign exchange shortages, this also makes it hard to operate capital efficiently if there is difficulty in paying for spare parts from abroad.

6.7 Geography and Institutions

The results in equation (20) show that both geography and institutions matter for the productivity of investment. Geography in our study is measured by absolute latitude (ABLAT), or distance from the equator. The coefficient estimate of 0.0278 indicates that for a country 10 degrees north or south of the equator, the productivity of investment is 0.28 percentage points higher. This may have something to do with sectorial differences in productivity between agriculture and industry; with differences in the productivity of agriculture itself between temperate and tropical zones, and with work effort. Tropical zones specialise more in agriculture than industry; agricultural productivity is lower in the tropics than in temperate zones, and cooler climates are less debilitating for workers than the heat of the tropics. The growth performance of countries in the tropics may also be slower relative to countries situated in temperate zones due to high transport costs to core markets and high disease burdens (Gallup et al., 1999).

Since the rule of law index is a redundant variable in the model reduction process (see section 5), institutions in our study are measured by a political rights index, as a measure of

times larger than our 0.05 estimate. These differential findings imply that some part of government consumption spending may be growth promoting.

democracy, as originally compiled by Gastil (1983, 1986). The index ranges from one to seven, with one indicating the highest level of political rights and seven the lowest. Equation (20) shows that a difference between one and seven in the index (PRIGHTS) is associated with a reduction in the productivity of investment of 1.38 percentage points. Democracy would appear to be good for growth.

7. Conclusion

In this paper we have shown a simple way of defining and measuring the productivity of investment, and estimating its determinants, by dividing a new growth theory equation by a country's investment ratio. This also makes it possible to estimate directly whether or not there are diminishing returns to capital, without interpreting the negative sign on the initial per capita income variable as 'proof' of diminishing returns to capital which is problematic because the negative sign could be the result of 'catch-up' or faster structural change in poor countries which are both conceptually distinct from movements along a production function. The econometric evidence from our sample of 84 countries over the period 1980-2011, using the Gets model selection algorithm of Autometrics, rejects the hypothesis of diminishing returns to capital and supports the assumption of constant returns, as represented by the AK model of new growth theory. On the other hand, we also find that the standard deviation of the population-adjusted productivity of investment within groups of poor countries is higher than within rich countries. We find that the investment ratio is the single most important determinant of growth rate differences between countries (see Table 4); and the growth of exports is the most important determinant of differences in the productivity of investment between countries, followed by political rights as a proxy for institutions; latitude; education and its interaction with initial per capita income; trade openness; macroeconomic instability; government consumption as a proportion of GDP, and the initial level of per capita income.

The Gets modelling procedure rejects the role of financial variables, mining as a proportion of GDP, population growth and size, and the number of revolutions and coups. A key policy implication of the constant returns to capital finding of our study is that the investment ratio and other significant determinants of the productivity of investment outlined above matter for long-run growth.

There is evidence of conditional (beta) convergence, but we attribute this to 'catch-up' or structural change because the orthodox neoclassical explanation of diminishing returns to capital is rejected by the data. Tests for absolute (sigma) convergence, as shown in Figure 2, provide evidence of divergence from 1980 up to the year 2000 and then some evidence of convergence due to the fast growth of many poor African economies in the decade prior to 2011. In general it seems clear that new growth theory, and particularly the constant returns to capital assumption of the AK model, can go a long way in explaining persistent divisions in the world economy between rich and poor countries.

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APPENDIX A, Table 1A – List of Countries

Number	Country	Number	Country
1	Argentina	43	Malawi
2	Australia	44	Malaysia
3	Austria	45	Mali
4	Bangladesh	46	Malta
5	Belgium	47	Mauritania*
6	Benin*	48	Mauritius*
7	Bolivia	49	Mexico
8	Botswana	50	Morocco
9	Brazil	51	Mozambique
10	Cameroon	52	Netherlands
11	Canada	53	New Zealand
12	Chile	54	Nicaragua
13	Colombia	55	Norway
14	Congo, Democratic Republic	56	Pakistan
15	Congo, Republic	57	Panama
16	Costa Rica	58	Paraguay
17	Cote d'Ivoire	59	Peru
18	Cyprus	60	Philippines
19	Denmark	61	Portugal
20	Dominican Republic	62	Rwanda*
21	Ecuador	63	Senegal
22	Egypt	64	Sierra Leone
23	El Salvador	65	Singapore
24	Finland	66	South Africa
25	France	67	Spain
26	Gambia	68	Sri Lanka
27	Germany	69	Sudan
28	Ghana	70	Swaziland*
29	Greece	71	Sweden
30	Guatemala	72	Switzerland
31	Honduras	73	Syria
32	Hong Kong	74	Tanzania
33	Iceland	75	Thailand
34	India	76	Togo
35	Indonesia	77	Trinidad & Tobago
36	Israel	78	Tunisia
37	Italy	79	Turkey
38	Japan	80	Uganda
39	Jordan	81	United Kingdom
40	Kenya	82	United States
41	Korea	83	Uruguay
42	Luxembourg	84	Zambia

Note: Our cross-country dataset consists of 84 countries for all the variables listed in Table 2A below, except the rule of law index (RULELAW). The sample size is reduced to 79 countries if we include the rule of law index as an additional explanatory variable. The five countries for which RULELAW is not available are marked with an asterisk (*). The sample excludes the following oil-producing countries: Algeria, Gabon Iran, Iraq, Kuwait, Nigeria, Oman, Saudi Arabia, and Venezuela. Several countries listed in World Bank Development Indicators (2012) were omitted from the sample due to missing variables. Lastly, based on the outlier detection test of Autometrics (Doornik, 2009; Doornik and Hendry, 2013), China and Lesotho are also excluded from the sample.

APPENDIX A, Table 2A – List of Variables

Variable (Expected Sign)	Description	Comments	Source
Dependent Variables:			
dY/Y	Growth rate of real GDP at domestic prices.	Average: 1980-2011.	WBDI.
[(dY/Y) – n]	Growth rate of real GDP per capita.	Average: 1980-2011.	WBDI.
POI–n	Population-adjusted gross productivity of investment: [(dY/Y) – n]/(I/Y)	Average: 1980-2011.	WBDI.
Independent Variables (regressors):			
1) ABLAT (+)	Absolute latitude from the equator.	Measures the effect of geography on economic development. See Gallup et al. (1999).	See Sala-i-Martin (1997) for source.
2) FDEV90 (+)	Ratio of liquid liabilities to GDP. The ratio is a measure of financial development, as discussed in Levine (1997).	Following King and Levine (1993), we use an initial value. For most countries a value in 1990 is available. For those countries without a 1990 value, we chose the closest possible year in the interval 1991-1994.	The latest version of the dataset (November 2013) described in Beck et al. (2000).
3) GCON (–)	Ratio of general government consumption expenditure to GDP.	Average: 1980-2011.	WBDI.
4) GEX (+)	Growth rate of real exports of goods and services.	Average: 1980-2011.	WBDI.
5) GPO (n), (–) or (+)	Growth rate of population.	Average: 1980-2011. Scale effects (+) or resource depletion (-).	WBDI.
6) INFL (–) or (+)	Inflation rate derived from the GDP deflator.	Average: 1980-2011.	WBDI.
7) INFLSDEV (–)	Standard deviation of the inflation rate derived from the GDP deflator.	1980-2011.	WBDI.
8) INV (I/Y), (+)	Fixed investment ratio = the ratio of gross fixed capital formation (I) to GDP (Y). Both I and Y are nominal domestic price values.	Average: 1980-2011.	WBDI.
9) lnPOP80 (+)	Natural logarithm (ln) of the population size in 1980.	Measures scale effects associated with market size. See Alesina et al. (2000).	WBDI.

Note: World Bank Development Indicators, 2012 (WBDI, 2012).

APPENDIX A, Table 2A – List of Variables (Continued)

Variable (Expected Sign)	Description	Comments	Source
10) lnRGDP80 (–)	Natural logarithm (ln) of the initial level of purchasing-power-parity adjusted real GDP per capita income in 1980 (constant 2005 dollars).	The initial level for most of the countries is 1980. For the small number of countries without a 1980 value, the closest possible year.	WBDI.
11) MINING (+)	The share of mining and quarrying in GDP.	Data are for the year 1988 or the closest possible year.	Hall and Jones (1999).
12) OPEN (+)	Measures the proportion of years in the interval 1965-1990 in which an economy is open to international trade.	The binary index takes a value of 1 or 0, where 1 indicates open and 0 closed.	Sachs and Warner (1995).
13) REVCOUP (–)	Revolutions and Coups.	Number of military coups and revolutions	Barro (1991).
14) PRIGHTS (–)	A political rights index that measures democracy compiled by Gastil and his associates (1982-1983 and subsequent issues) from 1972 to 1994.	The index ranges from 1 to 7, with 1 indicating the group of countries with the highest level of political rights and 7 the lowest.	Barro (1998).
15) RULELAW (+)	Rule of law index recorded once for each country in the early 1980s.	The index ranges from 0 to 1, with 0 indicating the worst maintenance of the rule of law and 1 the best.	Barro (1998)
16) SECTER80 (+)	Average years of secondary and tertiary education of total population.	Initial value in 1980.	Barro and Lee (2013).
17) [SECTER80×lnRGDP80] (–)	Interactive (product) term, with variables defined above.	Initial values in 1980.	Barro and Lee (2013); WBDI.
18) TOTED80 (+)	Total education: average years of primary, secondary and tertiary education of total population.	Initial value in 1980.	Barro and Lee (2013).
19) [TOTED80×lnRGDP80] (–)	Interactive (product) term, with variables defined above.	Initial values in 1980.	Barro and Lee (2013); WBDI.
20) TOPEN (+)	The ratio of total trade (imports + exports) to GDP. Measures trade openness.	Average: 1980-2011	WBDI.

Note: World Bank Development Indicators, 2012 (WBDI, 2012).

APPENDIX B – Settings of Autometrics

The Gets model selection algorithm of Autometrics provides the empirical modeller with several 'target sizes' to choose from, which then sets the critical value at which regressors will be eliminated in the model reduction process (Doornik, 2009; Doornik and Hendry, 2013). In this application we consider three (two-tailed) target sizes: p_1=1%, p_1=2.5%, and p_1=5%. Each target size, in turn, corresponds to a one-tailed critical value for the automated outlier detection test: p_{11}= 0.05%, p_{11}= 1.25% and p_{11} = 2.5%, where the null hypothesis is outliers against the alternative of no outliers. The outlier test is designed to detect countries with large residuals. Say, for example, the researcher chooses a target size of p_1=1%, then, by default, the critical value for the outlier detection test is p_{11}= 0.05%. This option will ensure that the final selected model retains variables that are clearly statistically significant, but at the cost of excluding some variables that may actually matter (Hendry and Krolzig, 2001; Ericsson, 2012). A target size of p_1=5% (p_{11} = 2.5%), on the other hand, may err on the side of keeping some variables, even though they don't actually matter.

Thus, a key empirical issue it to select an appropriate target size. Our empirical strategy is the following. As a basic guide line, we estimate Gets models for each target size and then choose the regression model that passes all the diagnostic tests at the 10% significance level. If this strategy yields inconclusive results, for example, when all the models fail the same diagnostic test, then we use the Schwarz (1978) criterion (SC) to select the final model. Based on these criteria, the productivity of investment estimates in Table 2 are obtained with a target size of p_1=5% (p_{11} = 2.5%), and the per capita income growth rate estimates in Table 3 with a target size of p_2=2.5% (p_{22} = 1.25%). In the case of the estimates in Table 2, all the models with different target sizes showed signs of heteroscedasticity, so the SC was used to select the appropriate model. The regression model in Table 3 with p_2 =2.5% (p_{22} = 1.25%), on the other hand, was the only one that passed all the diagnostic tests.

Finally, Autometrics provides an option to conduct a pre-search test, with the objective of removing variables at an early stage that are clearly insignificant in the initial GUM. This option can significantly reduce the number of search paths during the next stage of the algorithm (see Ericsson, 2012; Owen, 2003). In our application, the pre-search option is switched on.