cef.up Centro de Economia e Finanças da UPorto

cef.up working paper
2014-05

# Explaining Differences in the Productivity of Capital Across Countries in the Context of 'New' Growth Theory

**Kevin S. Nell**
**A.P. Thirlwall**

Centro de Economia e Finanças da UP
www.fep.up.pt

**Explaining Differences in the Productivity of Capital Across Countries in the Context of 'New' Growth Theory**[1]

Kevin S. Nell[a] and A.P. Thirlwall[b]

November 2014

**Abstract**

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

**Keywords:** new growth theory; investment; productivity of capital

**JEL codes:** O11, O33, O43, O47

**Institutional Affiliations:** [a]Center for Economics and Finance, University of Porto (CEF.UP), Portugal; [b] School of Economics, University of Kent, United Kingdom

**Address for correspondence:** Kevin S. Nell, Center for Economics and Finance, Faculty of Economics, University of Porto, Rua Dr Roberto Frias S/N, 4200-464 Porto, Portugal, e-mail: knell@fep.up.pt.

[1] We would like to thank Alan Carruth, Carlos Santos, Hans-Martin Krolzig, Margarida De Mello, Natércia Fortuna and seminar participants at the School of Economics, University of Kent and CEF.UP for valuable comments on an earlier draft of the paper. Kevin Nell is grateful for financial support from the Thirlwall Visiting Research Fellowship offered by the School of Economics, University of Kent, and Portuguese Public Funds obtained through FCT (Fundação para a Ciência e a Tecnologia) under the project PEst-OE/EGE/UI4105/2014.

## 1. Introduction

The main purpose of this paper is to use the framework of ‘new’ growth theory to explain differences in the productivity of capital across countries by converting a typical ‘new’ growth theory estimating equation into a productivity of capital equation and estimating the determinants of productivity differences explicitly. This is not done in the ‘new’ growth theory literature, but as Levine and Renelt (1992) remark: “If we include INV [the share of investment in 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 capital. Apart from explaining differences in the productivity of capital explicitly, the advantage of using the productivity of capital 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 (Barro, 1991, 1998) 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-to-specific model selection procedure incorporated in the software programme Autometrics

(Doornik and Hendry, 2013)[2]. The paper therefore has three novel features. It provides a simple way of measuring the marginal productivity of capital; it provides an unambiguous test of the returns to capital, and uses for the first time a computer-automated general-to-specific methodology for identifying the causal determinants of differences in the productivity of capital across countries.

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). 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 marginal product of capital 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 marginal product of capital 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 (i.e. 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

[2] 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).

Lucas that there was no evidence that the marginal product of capital was lower in rich countries than poor countries (or that the capital-output ratio was higher in rich countries than poor countries)[3].

A constant capital-output ratio is the simplest version of 'new' growth theory – the AK model – and if investment ratios are the same across countries, differences in growth must be due to differences in the productivity of capital, as in the Harrod growth formula. If we write:

$$Y = AK \tag{1}$$

where *Y* is national output; *K* is the quantity of capital (broadly defined) and *A* is a constant, it is immediately obvious (see Hussain and Thirlwall, 2000) that this model is none other than the Harrod (1939) growth equation of $g = s/c$, where *g* is the growth of output, *s* is the ratio of savings to GDP and *c* is the actual incremental capital-output ratio, $dK/dY$. To see this, totally differentiate equation (1) and divide through by *Y* which gives:

$$\frac{dY}{Y} = \frac{dAK}{Y} + \frac{dKA}{Y} = \frac{AI}{Y} \tag{2}$$

or

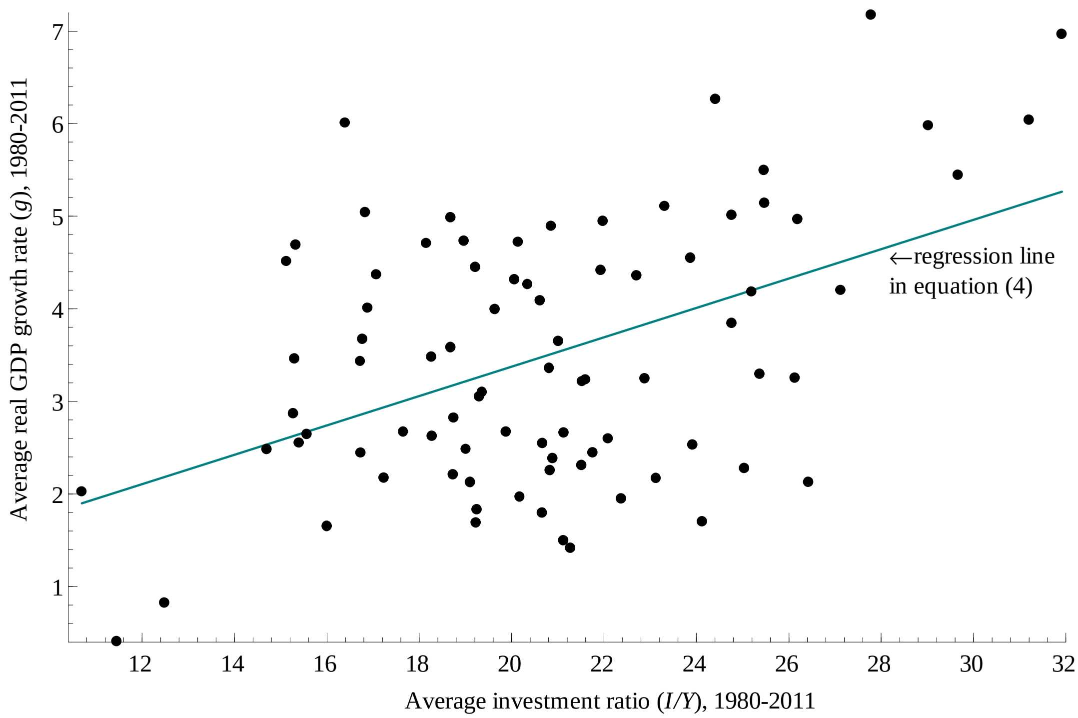
$$g = s / c \tag{3}$$

where $s = I/Y$ in the national accounts and *c* is the reciprocal of the marginal product of capital, $A = dY/dK$. What this means is that if the capital-output ratio is the same across countries, there would be a perfect correlation between real GDP growth and the ratio of investment to GDP. To the extent that there is not a perfect correlation, this must be due to differences in the productivity of capital. In Figure 1 below we show a scatter diagram of the relationship between GDP growth and the investment ratio for the 84 countries that we take over the period 1980-2011.

[3] 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.

**Figure 1:**

The Relationship Between Investment and Growth




Notes:

1) Data source: World Bank Development Indicators (see Table 3 and Appendix 1).
2) Figure 1 is scaled according to the lowest investment ratio in the sample, which is 10.7%.

The simple regression and correlation between investment and growth (t-values in parentheses) is:

$$g_i = \underset{(0.28)}{0.20} + \underset{(4.79)}{0.16}(I/Y)_i \qquad i = 1...84 \qquad (4)$$

The $R^2$ is 0.22 which leaves a lot of the variance in the growth of output to be explained by differences in the productivity of capital – or differences in the incremental capital-output ratio.[4]

[4] Taking account of population growth ($p$) and regressing the growth of per capita income on the investment ratio gives (absolute t-values in parentheses): $(g-p)_i = -\underset{(4.73)}{2.64} + \underset{(7.94)}{0.21}(I/Y)_i$ : $R^2$ = 0.43, leaving just over half the variance of per capita income growth to be explained by differences in the productivity of capital.

In ‘new’ growth theory regressions, therefore, which include investment, all that ‘new’ growth theory is trying to do is to explain differences in the productivity of capital – as noted by Levine and Renelt (1992) referred to earlier. But ‘new’ growth theory never does this explicitly and has no unambiguous test of whether or not there are diminishing returns to capital. In the next section we convert a standard ‘new’ growth theory estimating equation into a capital productivity equation and show how the transformed model provides a direct test of the returns to capital. Section 3 examines to what extent our new marginal product of capital measure differs across rich and poor countries. Section 4 introduces the econometric specifications, the twenty potential explanatory variables, and discusses the computer-automated general-to-specific model selection procedure. Section 5 estimates the capital productivity model and section 6 discusses the results. Section 7 concludes.

## 2. Measuring the Productivity of Capital

There are a few studies which attempt to measure the marginal product of capital, or its reciprocal, the capital-output ratio, across countries using a variety of techniques and data sets (e.g. King and Levine, 1994; Benhabib and Spiegel, 1994, and Caselli and Feyrer, 2007). The results differ according to the data and procedures used. King and Levine (1994) use estimates of the capital stock from Summers and Heston (1991) for 112 countries over the period 1950-88 and conclude that capital-output ratios are strongly positively associated with the level of economic development; that is, diminishing returns to capital. In our view the estimates of the capital-output ratios are far too low; 2.59 for OECD countries and only 1.6 for non-OECD and non-oil producing countries. There is no adjustment for the contribution of labour force growth to output. Benhabib and Spiegel (1994) don’t say how many countries they take but conclude from their regressions: “Income to capital ratios in the current data set are negatively related to income levels at a 5% confidence level...[so] poorer countries should have higher returns to physical capital inputs" (p. 163). This would also suggest diminishing returns to capital, but, as in King and Levine, all output growth is attributed to capital and none to labour. Caselli and Feyrer (2007), in their study of 53 countries, measure the productivity of capital by its rate of return. They argue that the productivity of capital in poor countries is exaggerated because the relative price of investment goods is higher and no deduction is made for income accruing to land and natural resources. When these two factors are allowed for they find that the marginal product of capital is remarkably similar across countries. In fact, on average, rich countries have a slightly higher marginal product of capital than poor countries.[5] In an early growth accounting study, Denison (1967) remarks that although levels of output per head and capital per head differ across countries, the capital-output ratio appears remarkably constant across countries – one of Kaldor's (1961) stylised facts referred to earlier.

So, studies differ in their conclusions, but they are hardly comparable because of differences in procedures used which are often quite complex. None of the studies takes the obvious approach of dividing the long-run growth 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[6].

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

$$\frac{dY/Y}{I/Y} = \frac{dY}{I} = \frac{dY}{dK} \tag{5}$$

Now take a typical 'new' growth theory estimating equation of the form:

$$\left(\frac{dY}{Y} - \frac{dP}{P}\right)_i = \alpha_0 + \alpha_1 \left(\frac{I}{Y}\right)_i + \alpha_2 \mathrm{PCY}_i + \alpha_3 \mathrm{X}_i \tag{6}$$

[5] Without adjustment, the average marginal product for 29 low income countries is 29%, and for 24 low income countries, 11%.

[6] But output growth still includes income accruing to land and natural resources which is excluded from the Caselli and Feyrer (2007) study.

where $\left(dY/Y - dP/P\right)_i$ is the growth of per capita income in country $i$ ; $\left(I/Y\right)_i$ is the ratio of investment to GDP; $\mathrm{PCY}_i$ is the initial level of per capita income (to test for convergence), and $\mathrm{X}_{\mathrm{i}}$ is a vector of other growth determinants. Dividing equation (6) by $\left(I/Y\right)_i$ gives:

$$\left(\frac{dY/Y - dP/P}{I/Y}\right)_i = \alpha_0\left(I/Y\right)_i^{-1} + \alpha_1 + \alpha_2\left(\frac{\mathrm{PCY}}{I/Y}\right)_i + \alpha_3\left(\frac{\mathrm{X}}{I/Y}\right)_i \qquad (7)$$

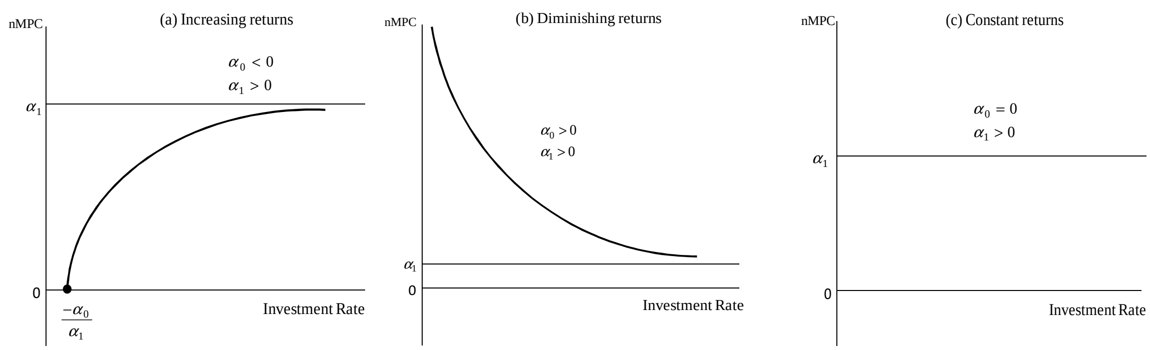
$\frac{dY/Y}{I/Y} = dY/I = dY/dK$ is the unadjusted marginal product of capital. The full expression on the left hand side of equation (7) is what we call the adjusted or net marginal product of capital (adjusting for the contribution that population growth, $dP/P \equiv p$, makes to output growth through the growth of the workforce).[7] The relationship between the net marginal product of capital (nMPC) and the inverse of the investment ratio provides a direct measure of the returns to capital, as shown in Figures 2(a)-(c).The coefficient $\alpha_1$ is the constant or asymptote. The sign of $\alpha_0$ measures *directly* whether or not there are diminishing returns to capital. A negative sign in Figure 2(a) implies increasing returns; a positive sign in Figure 2(b) indicates diminishing returns, and if $\alpha_0$ is not significantly different from zero in Figure 2(c) this would indicate constant returns to capital i.e. no relation between the quantity of investment relative to GDP and its productivity. The sign on the initial per capita income variable in equation (7) measures whether or not there is conditional convergence, but a negative sign can no longer be interpreted, as Barro (1991) does for example, as a rehabilitation of the neoclassical model with diminishing returns to capital because this has already been controlled for.[8]

[7] This distinction is equivalent to that between the gross incremental capital-output ratio (ICOR) and the net ICOR (see Leibenstein, 1966; Vanek and Studenmund, 1968).

[8] 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).

**Figure 2:**

The Returns to Capital




## 3. Descriptive Analysis

To test for diminishing returns to capital, and the determinants of capital productivity, we shall be basically running regressions of type equation (6) and equation (7), 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 Table 3 below (see section 4.2) and Appendix 1. 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 gross capital productivity and net (adjusted for population growth) capital productivity across the World Bank's income classification of countries in 2013: low income (LI); lower middle income (LMI); upper middle income (UMI), and high income (HI), and also across the quartiles of countries from poorest to richest based on their initial per capita income level in 1980. The results are given in Tables 1 and 2, together with the standard deviation of all the variables in parentheses.

**Table 1:**

World Bank Income Classification (2013) and Capital Productivity

| Income Classification (number of countries) | Gross MPC (%) | (*g* – *p*) (%) | Net MPC (%) | *I/Y* (%) |
|---|---|---|---|---|
| LI (13 countries) | 21.35 (7.92) | 0.86 (1.44) | 4.10 (9.58) | 16.93 (3.46) |
| LMI (23 countries) | 18.52 (6.32) | 1.35 (1.49) | 6.47 (7.50) | 19.94 (4.23) |
| UMI (17 countries) | 18.32 (4.14) | 2.17 (1.26) | 9.45 (4.45) | 22.13 (3.93) |
| HI (31 countries) | 13.10 (4.90) | 2.07 (0.97) | 8.91 (3.40) | 22.16 (3.58) |

Note: Standard deviations in parentheses.

**Table 2:**

Income Quartiles: Initial Per Capita Income Levels 1980

| Income Classification (number of countries) | Gross MPC (%) | (*g* – *p*) (%) | Net MPC (%) | *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 both tables gives the average unadjusted or gross marginal product of capital (MPC); column 2 gives the average growth of per capita income (*g* – *p*); column 3 gives the average population adjusted or net MPC, and column 4 gives the average investment ratio (*I/Y*). Table 1 shows that the poorest countries have a higher gross productivity of capital than richer countries, but this conclusion is reversed when population growth is allowed for. In the low income countries, the adjusted productivity of capital is as low as 4 percent, whereas it is nearly 9 percent in the high income countries. But note that the standard deviations in the low- and middle- income countries are much larger than in the upper middle-income and high income countries. Table 2 tells a similar story, except now the net productivity of capital is more equal across low and high income countries. The richest quartile of countries has a productivity of 7.7 percent, and the poorest quartile has a productivity of 6.5 percent, but again 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.

If we further divide our sample of 84 countries into equal halves according to 1980 per capita income levels, and compare the productivity of capital in the poorest and richest countries, we get a net productivity of capital of 8.9 percent for rich countries and 6.5 percent for poor countries, with standard deviations of 3.5 percent and 8.2 percent in each half, respectively. These net marginal product of capital estimates are very close to those of Caselli and Feyrer (2007) using a smaller sample of countries and different estimating techniques. They calculate (Table 3, p. 555) marginal capital productivity estimates of 8.4 percent for rich countries and 6.9 percent for poor countries, which are close to our estimates, but with much smaller standard deviations of 1.9 percent in the rich half and 3.7 percent in the poor half. Banerjee and Duflo (2005), in their survey of rates of return in developing countries, conclude: "It seems that the average returns are actually not much higher than 9% or so, which is the usual estimate for the average stock market return in the U.S. (p. 483)."

Overall, therefore, what the raw evidence in this paper shows is that while, on average, the net marginal productivity of capital seems 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. The econometric results reject the neoclassical hypothesis of a simple linear inverse relation between the investment ratio and the productivity of capital, but there are a number of factors which explain this wide variation in the net marginal product of capital across rich and poor countries.

## 4. Econometric Model, Data and Estimation Procedure

### *4.1 Econometric Model*

The Barro-type (1991, 1998) per capita income growth rate model in equation (6) can formally be converted into an econometric specification by introducing an error term:

$$(g-p)_i = \alpha_0 + \alpha_1 \left(\frac{I}{Y}\right)_i + \alpha_2 \text{lnRGDP80}_i + \alpha_3 \text{X}_i + \varepsilon_i \,, \qquad i = 1...84 \tag{8}$$

where $(g-p)_i$ is the average per capita income growth rate in country *i* over the period 1980-2011; $\alpha_0$ is an intercept term; $(I/Y)_i$ is the average investment ratio over the period 1980-2011; $\text{lnRGDP80}_i$ is the natural logarithm of the initial level of real GDP per capita income in 1980; $\text{X}_i$ is a vector of other growth determinants; and $\varepsilon_i$ is an unobserved error term.

Dividing (8) by $(I/Y)_i$ gives the econometric specification of the net marginal product of capital (nMPC) model in equation (7):

$$\text{nMPC}_i = \alpha_0 (I/Y)_i^{-1} + \alpha_1 + \alpha_2 \left(\frac{\text{lnRGDP80}}{I/Y}\right)_i + \alpha_3 \left(\frac{\text{X}}{I/Y}\right)_i + \left(\frac{\varepsilon}{I/Y}\right)_i \qquad i = 1...84 \tag{9}$$

Since our main interests are to test the diminishing returns to capital hypothesis and to identify the determinants of capital productivity, one approach would be to estimate equation (9) directly. Note, however, that equations (8) and (9) are mathematically equivalent – the same parameters appear in both equations. It is therefore possible to *derive* the parameter estimates of capital productivity in equation (9) by estimating the per capita income growth rate model in equation (8). 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 (8) is well behaved then dividing it by the investment ratio to derive equation (9) 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 (8) and derive the capital productivity estimates in equation (9). Contra-wise, if the per capita income growth rate, equation (8), 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 capital productivity equation (9) directly.

In the empirical section, as our basic starting point, we will first estimate the net marginal product of capital model in equation (9) and observe the results. If necessary we can then estimate, as a robustness test, the per capita income growth rate model in equation (8) to obtain the derived capital productivity measures.

### *4.2 Computer-Automated Model Selection Procedure and Data*

Table 3 lists 20 potential regressors of the models in equations (8)-(9) for our cross-section sample of 84 developed and developing countries reported in Appendix 1[9]. The expected sign on each of the variables is given in parentheses based on theory and results already found in the literature. The selection of variables includes monetary, fiscal, trade, financial development, geography and institutional/political indicators, as well as the average growth of population 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

[9] Table 3 reports the original data sources of variables 4, 14, 15, 16, 17, and 18. 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. It would have been ideal to include research and development (R & D) as an additional potential explanatory variable. However, R & D as a proportion of GDP is not available for several developing countries over our full sample period 1980-2011. Appendix 1 discusses the chosen sample of 84 countries in more detail.

empirical literature (see, for example, Barro, 1991, 1998; Durlauf et al., 2005; Hendry and Krolzig, 2004; Hoover and Perez, 2004; Levine and Renelt, 1992; Sala-i-Martin, 1997; Temple, 1999; and other references cited in Table 3).

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)[10]. 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).

Owen (2003) succinctly describes the Gets methodology as "...the formulation of a 'general' unrestricted model that is congruent with the data and the application of a 'testing' down process, eliminating variables with coefficients that are not statistically significant, leading to a simpler 'specific' congruent model that encompasses rival models" (p. 609). In this context, the Autometrics algorithm "...utilizes 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" (Ericsson, 2012, p. 2). For a detailed discussion of the simplification process that underlies Autometrics, see Doornik (2009), Doornik and Hendry (2013) and Ericsson (2012).

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

**Table 3**: List of Variables

| Variable (Expected Sign) | Description | Comments | Source |
|---|---|---|---|
| **Dependent Variables:** | | | |
| 1) *g* | Growth rate of real GDP at domestic prices. | Average: 1980-2011. | WBDI. |
| 2) $(g - p)$ | Growth rate of real GDP per capita. | Average: 1980-2011. | WBDI. |
| 3) nMPC | Net marginal product of capital: $(g - p)/(I/Y)$ | Average: 1980-2011. | WBDI. |
| **Independent Variables (regressors):** | | | |
| 4) ABLAT (+) | Absolute latitude from the equator. | Measures the impact of geography on economic development. See Gallup et al. (1999). | See Sala-i-Martin (1997) for source. |
| 5) 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). |
| 6) GCON (-) | Ratio of general government consumption expenditure to GDP. | Average: 1980-2011. | WBDI. |
| 7) GEX (+) | Growth rate of real exports of goods and services. | Average: 1980-2011. | WBDI. |
| 8) GPO ($p$), (-) or (+) | Growth rate of population. | Average: 1980-2011. Scale effects (+) or resource depletion (-). | WBDI. |
| 9) INFL (-) or (+) | Inflation rate derived from the GDP deflator. | Average: 1980-2011. | WBDI. |
| 10) INFLSDEV (-) | Standard deviation of the inflation rate derived from the GDP deflator. | 1980-2011. | WBDI. |
| 11) INV ($I/Y$), (+) | 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. |
| 12) 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).

**Table 3:** List of Variables (Continued)

| Independent Variables: | | | |
|---|---|---|---|
| Variable (Expected Sign) | Description | Comments | Source |
| 13) 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. |
| 14) MINING (+) | The share of mining and quarrying in GDP. | Data are for the year 1988 or the closest possible year. | Hall and Jones (1999). |
| 15) 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). |
| 16) REVCOUP (-) | Revolutions and Coups. | Number of military coups and revolutions | Barro (1991). |
| 17) 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). |
| 18) 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) |
| 19) SECTER80 (+) | Average years of secondary and tertiary education of total population. | Initial value in 1980. | Barro and Lee (2013). |
| 20) [SECTER80×lnRGDP80] (-) | Interactive (product) term, with variables defined above. | Initial values in 1980. | Barro and Lee (2013); WBDI. |
| 21) TOTED80 (+) | Total education: average years of primary, secondary and tertiary education of total population. | Initial value in 1980. | Barro and Lee (2013). |
| 22) [TOTED80×lnRGDP80] (-) | Interactive (product) term, with variables defined above. | Initial values in 1980. | Barro and Lee (2013); WBDI. |
| 23) 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).

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 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 3 are measured as close as possible to the beginning of the period (which is 1980). In this way, it is possible to estimate the impact on the net marginal product of capital 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, we rely on the Autometrics modelling procedure to select a well-specified, statistically robust and theory-consistent empirical model.

## 5. Empirical Results

### *5.1 Direct Capital Productivity Estimates*

Consistent with the Gets modelling approach described in the previous section, the capital productivity equation (9) is specified to include all the potential regressors listed in Table 3, except the investment ratio and rule of law index. The impact of the investment ratio on per capita income growth is measured by the asymptote or constant ($\alpha_1$) in equation (9). As discussed in Appendix 1, 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 2 we provide detailed information about the settings that we use to obtain the specific models in Tables 4 and 5 below.

Column (i) of Table 4 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 the 1% and 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.

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 4 across different sub-samples[11]. Two F-tests for structural stability, denoted as Chow (*n*), are reported in Table 4. 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.

[11] 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.

**Table 4:**

Regression Results of the Capital Productivity Equation (9)[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: $\chi^2$ [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).

An important feature of the specific model in Table 4 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 2(c). 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 4, we include the rule of law index (RULELAW) as an additional variable in the GUM. 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; Easterly and Levine, 2003). Despite its perceived importance in the literature, RULELAW is eliminated in the Gets modelling process for the reduced sample of 79 countries and does not enter the specific model[12].

### *5.2 Per Capita Income Growth Rate Estimates*

Although the direct capital productivity estimates in Table 4 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 (8) as well. Recall from the discussion in section 4 that equations (8) and (9) contain the same economic information, which makes it possible to derive the estimates of capital productivity equation (9).

[12] The RULELAW regression results are available on request.

By following the same modelling procedure as before, the GUM for the per capita income growth rate equation (8) includes all the independent variables listed in Table 3, except the rule of law index. Table 5 reports the specific model chosen by Autometrics for our consistent sample of 84 countries (see Appendix 2 for a discussion of the settings used in the model reduction process).

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 90$^{th}$ 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[13], is not evident in our study.

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

**Table 5:**

Regression Results of the Per Capita Income Growth Rate Equation (8)[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 $\times$ 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: $\chi^2$ [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.

It is important to note that, in effect, the specific model in Table 5 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 ($\alpha_0$) in the per capita income growth rate equation (8) measures the returns to capital in the converted net capital productivity equation (9) through the $(I/Y)^{-1}$ term. Recall that the significance and sign of $\alpha_0$ in equation (9) determine whether there are diminishing, increasing or constant returns to capital, as depicted in Figures 2(a)-(c). 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.

From the regression results in Table 5, we obtain the fitted values of the per capita income growth rate model in equation (8) (absolute t-statistics in parentheses):

$$\begin{aligned}(g-p)_i = 0 &+ \underset{(5.99)}{0.1451}(I/Y)_i - \underset{(2.54)}{0.2045}\ln\text{RGDP80}_i + \underset{(3.10)}{0.9412}\text{TOTED80}_i \\ &- \underset{(3.12)}{0.0976}(\text{TOTED80}\times\ln\text{RGDP80})_i - \underset{(2.60)}{0.0549}\text{GCON}_i + \underset{(4.04)}{0.1310}\text{GEX}_i \\ &- \underset{(2.82)}{0.0004}\text{INFLSDEV}_i + \underset{(3.42)}{0.0278}\text{ABLAT}_i - \underset{(3.54)}{0.2299}\text{PRIGHTS}_i \\ &+ \underset{(3.07)}{0.0053}\text{TOPEN}_i + \hat{u}_{1i}\end{aligned} \qquad (10)$$

Equation (10) explicitly imposes a zero intercept term (or zero autonomous growth) to show that it is statistically insignificant in the model reduction process.

## 6. Derived Capital Productivity Estimates and Interpretation of Results

The fitted values of the net marginal product of capital $(\text{nMPC}_i)$ model in equation (9) can be derived by dividing (10) by $(I/Y)_i$ (absolute t-values in parentheses):

$$
\begin{aligned}
\text{nMPC}_i = {} & 0\times\left(I/Y\right)_i^{-1} + \underset{(5.99)}{0.1451} - \underset{(2.54)}{0.2045}\left(\frac{\text{lnRGDP80}}{I/Y}\right)_i + \underset{(3.10)}{0.9412}\left(\frac{\text{TOTED80}}{I/Y}\right)_i \\
& - \underset{(3.12)}{0.0976}\left(\frac{\text{TOTED80}\times\text{lnRGDP80}}{I/Y}\right)_i - \underset{(2.60)}{0.0549}\left(\frac{\text{GCON}}{I/Y}\right)_i + \underset{(4.04)}{0.1310}\left(\frac{\text{GEX}}{I/Y}\right)_i \\
& - \underset{(2.82)}{0.0004}\left(\frac{\text{INFLSDEV}}{I/Y}\right)_i + \underset{(3.42)}{0.0278}\left(\frac{\text{ABLAT}}{I/Y}\right)_i - \underset{(3.54)}{0.2299}\left(\frac{\text{PRIGHTS}}{I/Y}\right)_i \\
& + \underset{(3.07)}{0.0053}\left(\frac{\text{TOPEN}}{I/Y}\right)_i + \hat{u}_{2i}
\end{aligned}
\qquad (11)
$$

A comparison between the derived capital productivity estimates in equation (11) and the direct estimates in Table 4 shows that the regression models closely match each other. This is not surprising, given that the per capita income growth rate equation (8) and the capital productivity equation (9) are mathematically equivalent. The only difference can be found in their statistical properties. Going back to the discussion of the econometric specifications in section 4, it was argued that if the error term of per capita income growth rate equation (8) is well behaved, then dividing it by the investment ratio in the capital productivity equation (9) may cause econometric problems. Indeed, when we estimate capital productivity equation (9) directly in Table 4, there is evidence of heteroscedasticity and outliers.  For the sake of rigour, we will focus our discussion on the derived capital productivity estimates in equation (11), even though the direct estimates in Table 4 (column (ii)) are similar in magnitude, significance levels and statistically robust once heteroscedasticity effects and the two outlying observations are accounted for. It is apparent that none of our main discussion points would change if we instead use the direct estimates in Table 4 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 (10). Table 6 lists the partial $R^2$ coefficients of the variables in descending order. Based on this criterion, the investment ratio is ranked first followed by nine significant determinants of capital productivity. Note that, for a given investment effect on per capita income growth in equation (10), all the other variables determine cross-country per capita income growth rate differences through their effect on the productivity of capital. This is made explicit in capital productivity equation (11), where the impact 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 net marginal product of capital.

**Table 6:**

Partial $R^2$ Coefficient of Explanatory Variables in Equation (10)

| Variable | Partial $R^2$ Coefficient |
|---|---|
| *I/Y* | 0.3270 |
| **Determinants of Net Marginal Product of Capital (nMPC)** | |
| GEX | 0.1803 |
| PRIGHTS | 0.1452 |
| ABLAT | 0.1364 |
| TOTED80 $\times$ lnRGDP80 | 0.1167 |
| TOTED80 | 0.1149 |
| TOPEN | 0.1129 |
| INFLSDEV | 0.0965 |
| GCON | 0.0841 |
| lnRGDP80 | 0.0805 |

The analysis now turns to a detailed discussion of the empirical results in equations (10) and (11), 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 (10) provide a measure of the returns to capital in the converted productivity equation (11) through the $(I/Y)^{-1}$ term. (See the discussion of the corresponding theoretical specifications in equations (6) and (7), and the different returns to capital scenarios depicted in Figures 2(a)-(c)). 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 equation, 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 assumption that knowledge or technology is a public good freely available to all countries. The main implication of this assumption 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 only way in which the neoclassical model can explain per capita income growth rate differences in a given period is through transitional dynamics i.e. 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 (10) is positive and significant $(\alpha_0 > 0)$; 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 (11) through the $(I/Y)^{-1}$ term. The graphical representation of the diminishing returns to capital hypothesis is illustrated in Figure 2(b).

The empirical evidence in this paper, however, does not support the diminishing returns to capital assumption of the neoclassical model. The results in the capital productivity equation (11) show that the inverse of the investment ratio, $(I/Y)^{-1}$, is an insignificant determinant of the net marginal product of capital: $\hat{\alpha}_0 = 0$. Returning to Figure 2(c), 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 equation (10). Thus, once all the cross-country determinants of growth are accounted for in (10), there is no evidence of a fixed or common rate of growth among the sample of 84 countries.

### *6.2 Investment Ratio*

The investment ratio (*I/Y*) is a highly significant determinant of per capita income growth in equation (10), with its impact giving the average net marginal product of capital of 14.5% in the capital productivity equation (11). 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). 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 Mankiw et al. (1992) and Barro (1991) 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 capital productivity specification in (11) 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 6, 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 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). At first, these causality tests would seem to contradict the results, and interpretation of the investment-growth nexus, in this paper. It is highly 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 31-year averages over the period 1980-2011 is to ensure that we measure the long-run impact of investment on growth. Moreover, since the empirical model in Table 5 passes all the diagnostic tests, including the misspecification test, the evidence suggests that the long-run impact of investment on growth is not driven by omitted variables.

More recent panel data evidence in Bond et al. (2010) supports the cross-country evidence presented in this paper. They take a sample of 75 countries over the period 1960 to

2000 using annual pooled data with country-specific effects and address 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 a productivity of capital of 33 percent, which is high. For individual countries, the mean estimate of the country coefficients shows a lower effect on growth with a productivity of capital of 16 percent. This is very close to our estimate in equation (10) of approximately 14%.

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 capital. We now examine the empirical determinants of the net marginal product of capital in equation (11).

### *6.3 Initial Level of Per Capita Income*

The initial level of per capita income, lnRGDP80, enters the capital productivity equation (11) 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; 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 ($\lambda$) implied by the estimate on the initial per capita income variable is slow at 0.74 percent (t-value = 2.74) per annum[14].

Great care needs to be taken, however, 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 (11) 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

[14] Following Mankiw et al. (1992), the conditional convergence rate ($\lambda$) 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 (11), 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 possibility is to include a structural change variable in the capital productivity 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.[15]

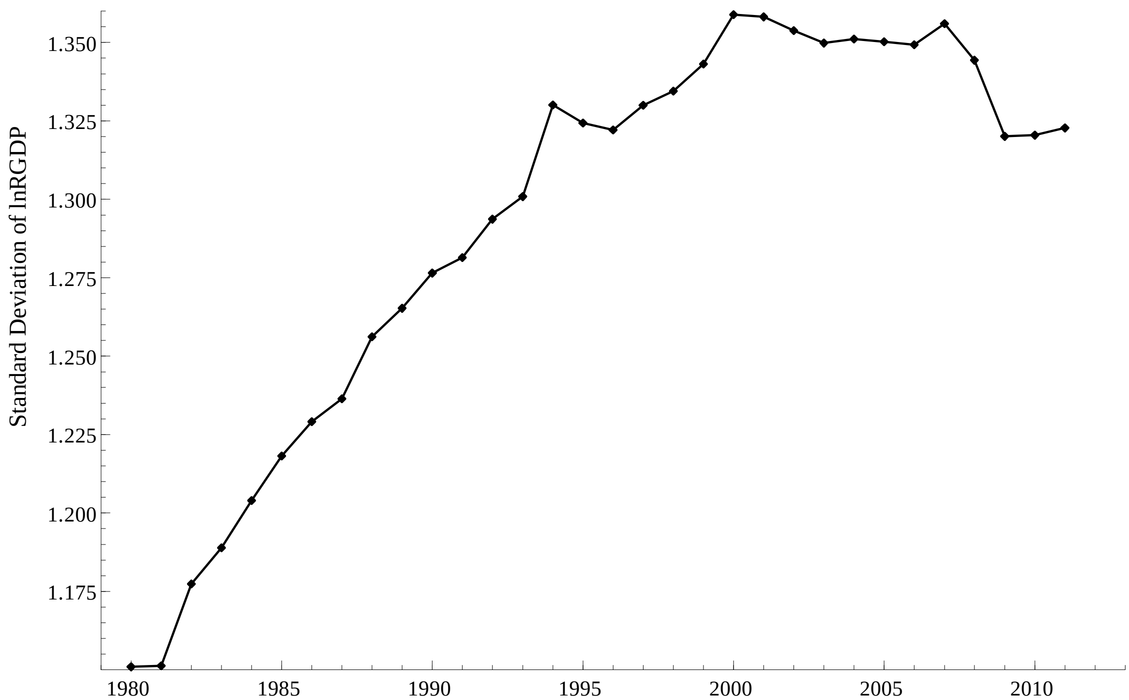
Another way to analyse whether there has been absolute convergence/divergence is to plot the standard deviation of real per capita income (lnRGDP) across our sample of 84 countries for each year over the period 1980-2011. Figure 3 shows that the standard deviation increases up to the year 2000, then 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.

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 capital. 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.

[15] 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 3**

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).

### *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 capital. Estimates in equation (11) show that an increase of one year in education increases the productivity of capital by nearly one percentage point. This is consistent with the work of Barro (1998) showing a positive relation between the 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 (i.e. to 'catch-up') is related to education (see Barro, 1998). The result in equation (11) shows that it does. The significant negative coefficient on the TOTED80 $\times$ 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 impact of education is taken into account. This, in turn, implies that an extra year of schooling raises the conditional convergence rate from 0.73 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 slightly faster rate.

### *6.5 Trade variables*

The results in equation (11) show the two trade variables of the degree of openness (TOPEN) and growth of exports (GEX) as statistically significant, but the impact 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 capital, while a 10 percentage point difference in export growth is associated with a 1.3 percentage point difference in capital productivity. The difference in result should not surprise because the openness variable is essentially picking up static trade gains to the efficiency with which capital is being used, while export growth is picking up dynamic gains from trade. The impact of export growth on capital productivity 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 capital. The impact, however, is not large. Equation (11) shows that a one percentage point increase in the government consumption/GDP ratio (GCON) reduces the productivity of capital by 0.05 percentage points. The channels through which a higher level of government current expenditure may reduce the productivity of capital 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[16].

Equation (11) shows that a 10 percentage point increase in the standard deviation of inflation (INFLSDEV) reduces the productivity of capital by only 0.004 percentage points. The main channel through which macro-instability reduces the productivity of capital 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.

[16] 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 impact of his adjusted ratio on per capita income growth is almost three times larger than our 0.05 estimate. These differential findings imply that some part of government consumption spending may be growth promoting.

### *6.7 Geography and Institutions*

The results in equation (11) show that both geography and institutions matter for the productivity of capital. 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 net productivity of capital is 0.2 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 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 (11) shows that a difference between one and seven in the index (PRIGHTS) is associated with a reduction in the productivity of capital of 1.38 percentage points. Democracy would appear to be good for growth.

There is a debate in the economic development literature on the importance of geography versus institutions in explaining the fortune of nations (see Acemoglu et al. 2001; Acemoglu et.al., 2002; Easterly and Levine, 2003; Rodrik et. al., 2004; Sachs and collaborators, 2004; Sachs, 2008; and Thirlwall, 2011 for a survey of the debate). Acemoglu et al. (2001) and Rodrik et al. (2004) argue that institutions trump geography in the sense that geography is not a direct determinant of economic development, as advocated by Sachs and collaborators (2004) and Sachs (2008). They show that geography affects economic development indirectly via its impact on the quality of institutions. Note, however, that these studies are concerned with the impact of institutions on the *level* of development. As Rodrik et al. (2004: p.156) emphasise, although their results show that institutions dominate in a model that explains levels of per capita income across countries, the same result may not necessarily hold for a per capita income *growth rate* equation. Indeed, as our results show, both institutions and geography are independent determinants of long-run growth.

## 7. Conclusion

In this paper we have shown a simple way of defining the marginal productivity of capital, 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 which is risky 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 general-to-specific 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 productivity of capital *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 6); and the growth of exports is the most important determinant of differences in the net marginal productivity of capital 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.

There is evidence of conditional (beta) convergence, but we attribute this to ‘catch-up’ or structural change because the orthodox explanation of diminishing returns to capital is rejected by the data. Tests for absolute (sigma) convergence shown in Figure 3 show *divergence* from 1980 up to the year 2000 and then some evidence of convergence due to the fast growth of many poor African economies since 2000. 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.

**References**


Abramovitz, M. (1986). Catching Up, Forging Ahead, and Falling Behind, *Journal of Economic History*, 46(2), 385-406.

Acemoglu, D., S. Johnson and J.A. Robinson (2001). The Colonial Origins of Comparative Development: An Empirical Investigation, *American Economic Review*, 91(5), 1369-1401.

Acemoglu, D., S. Johnson and J.A. Robinson (2002). Reversal of Fortune: Geography and Institutions in the Making of the Modern World Income Distribution, *Quarterly Journal of Economics*, 117(4), 1231-1294.

Aghion, P. and P. Howitt (2007). Capital, Innovation, and Growth Accounting, *Oxford Review of Economic Policy*, 23(1), 79-93.

Alesina, A., E. Spolaore and R. Wacziarg, R. (2000). Economic Integration and Political Disintegration, *American Economic Review*, 90 (5), 1276-1296.

Amable, B. (1993). Catch-Up and Convergence: A Model of Cumulative Growth, *International Review of Applied Economics*, 7(1), 1-25.

Attanasio, O.P., L. Picci and A. E. Scorcu (2000). Saving, Growth, and Investment: A Macroeconomic Analysis Using a Panel of Countries. *Review of Economics and Statistics*, 82(2), 182-211.

Baltagi, B.H. (1995). *Econometric Analysis of Panel Data*, (New York: John Wiley and Sons).

Banerjee, A.V. and E. Duflo (2005). Growth Theory Through the Lens of Development Economics, in: Philippe Aghion and Steven Durlauf (ed.), *Handbook of Economic Growth*, edition 1, volume 1, 473-552, (The Netherlands: Elsevier).

Barro, R.J. (1991). Economic Growth in a Cross Section of Countries, *Quarterly Journal of Economics*, 106(2), 407-443.

Barro, R.J. (1998). *Determinants of Economic Growth: A Cross-Country Empirical Study*, (London: MIT Press).

Barro, R.J. and J.W. Lee (2013). A New Data Set of Educational Attainment, 1950-2010, *Journal of Development Economics*, 104, 184-198.

Baumol, W.J. (1986). Productivity Growth, Convergence and Welfare: What the Long-Run Data Show, *American Economic Review*, 76(5), 1072-1085.

Beck, T., A. Demirgüç-Kunt and R. Levine (2000). A New Database on the Structure and Development of the Financial Sector, *World Bank Economic Review*, 14(3), 597-605.

Benhabib, J. and M.M. Spiegel (1994). The Role of Human Capital in Economic Development: Evidence from Average Cross-Section Data, *Journal of Monetary Economics*, 34(2), 143-173.

Blomström, M., R. Lipsey and M. Zejan (1996). Is Fixed Investment the Key to Economic Growth?, *Quarterly Journal of Economics*, 111(1), 269-276.

Bond, S., A. Leblebicioglu and F. Schiantarelli (2010). Capital Accumulation and Growth: A New Look at the Empirical Evidence, *Journal of Applied Econometrics*, 25(7), 1073-1099.

Carroll, C.D, and D.N. Weil (1994). "Saving and Growth: A Reinterpretation." *Carnegie-Rochester Conference Series on Public Policy*, 40(1), 133-192.

Caselli, F. and J. Feyrer (2007). The Marginal Product of Capital, *Quarterly Journal of Economics*, 122(2), 535-568.

DeLong, J.B. and L.H. Summers (1992). Equipment Investment and Growth: How Strong is the Nexus?, *Brookings Papers of Economic Activity*, (2), 157-199.

DeLong, J.B. and L.H. Summers (1993). How Strongly Do Developing Countries Benefit From Equipment Investment?, *Journal of Monetary Economics*, 93(3), 395-415.

Denison, E.F. (1967). *Why Growth Rates Differ*, (Washington DC: The Brookings Institute).

Doornik, J.A. (2009). Autometrics, in: J.L. Castle and N. Shephard (ed.), *The Methodology and Practice of Econometrics: A Festschrift in Honour of David F. Hendry*, Chapter 4, 88-121, (Oxford: Oxford University Press).

Doornik, J.A. and D.F. Hendry (2013). *Empirical Econometric Modelling, PcGive 14*, vol. 1, (London: Timberlake Consultants).

Dowrick, S. and D.T. Nguyen (1989). OECD Comparative Economic Growth 1950-85: Catch-Up and Convergence, *American Economic Review*, 79(5), 1010-1030.

Dowrick, S. and N. Gemmell (1991). Industrialisation, Catching Up and Economic Growth: A Comparative Study Across the World's Capitalist Economies, *Economic Journal*, 101(405), 263-275.

Durlauf, S.N., P.A Johnson and J.R.W. Temple (2005). Growth Econometrics, in: Philippe Aghion and Steven Durlauf (ed.), *Handbook of Economic Growth*, edition 1, volume 1A, Chapter 8, 555-677, (The Netherlands: Elsevier).

Easterly, W. and R. Levine (2003). Tropics, Germs, and Crops: How Endowments Influence Economic Development, *Journal of Monetary Economics*, 50(1), 3-39.

Ericsson, N.R. (2012). Detecting Crises, Jumps, and Changes in Regime, draft, *Board of Governors of the Federal Reserve System*, Washington D.C., November.

Fagerberg, J. (1994). Technology and International Differences in Growth Rates, *Journal of Economic Literature*, 32(3), 1147-1175.

Gallup, J. L., J.D. Sachs and A.D. Mellinger (1999). Geography and Economic Development, *International Regional Science Review*, 22(2), pp. 179-232.

Gastil, R. D., and subsequent editors. (1983, 1986 and other years), *Freedom in the World*, (Westport CT: Greenwood).

Ghose, A. (2004). Global Inequality and International Trade, *Cambridge Journal of Economics*, 28(2), 229-252.

Gomulka, S. (1971). *Inventive Activity, Diffusion and the Stages of Economic Growth*, (London: Routledge).

Gomulka, S. (1990). *The Theory of Technological Change and Economic Growth*, (London: Routledge).

Gujarati, D.N. (2003). *Basic Econometrics*, (McGraw-Hill: New York).

Hall, R. E., and C. I. Jones. (1999). Why Do Some Countries Produce So Much More Output Per Worker than Others?, *Quarterly Journal of Economics*, 114(1), 83-116.

Harrod, R. F. **(**1939). An Essay in Dynamic Theory, *Economic Journal*, 49(193), 14-33.

Hendry, D.F. (1995), *Dynamic Econometrics*, (Oxford: Oxford University Press)

Hendry, D.F. and H-M Krolzig (1999). Improving on 'Data Mining Reconsidered' by K.D. Hoover and S.J. Perez, *Econometrics Journal*, 2(2), 202-219.

Hendry, D.F. and H-M. Krolzig (2001). *Automatic Econometric Model Selection Using PcGets*, (London: Timberlake Consultant Ltd.)

Hendry, D.F. and H-M. Krolzig (2004). We Ran One Regression, *Oxford Bulletin of Economics and Statistics*, 66(5), 799-810.

Hendry, D.F. and H-M. Krolzig (2005). The Properties of Automatic Gets Modelling, *Economic Journal*, 115 (502), C32-C61.

Hoover, K.D. and S.J. Perez (1999). Data Mining Reconsidered: Encompassing and the General-to-Specific Approach to Specification Search, *Econometrics Journal*, 2(2), 167-191.

Hoover, K.D. and S.J. Perez (2004). Truth and Robustness in Cross-Country Growth Regressions, *Oxford Bulletin of Economics and Statistics*, 66(5), 765-798.

Hussein, K. and A. P. Thirlwall (2000). The AK Model of New Growth Theory is the Harrod Growth Equation: Investment and Growth Revisited, *Journal of Post Keynesian Economics*, 22(3), 427-435.

Kaldor, N. (1961). Capital Accumulation and Economic Growth, in: F. Lutz (ed.), *The Theory of Capital*, (London: Macmillan).

King, R.G. and R. Levine (1993). Finance and Growth: Schumpeter Might be Right, *Quarterly Journal of Economics*, 108(3), 717-737.

King, R.G. and R. Levine (1994). Capital Fundamentalism, Economic Development, and Economic Growth, *Carnegie-Rochester Conference Series on Public Policy*, 40(1), 259-292.

Krolzig, H-M. and D. Hendry (2001). Computer Automation of General to Specific Model Selection Procedures, *Journal of Economic Dynamics and Control*, 25(6-7), 831-866.

Leibenstein, H. (1966). Incremental Capital-Output Ratios and Growth Rates in the Short Run, *Review of Economics and Statistics*, 48(1); 20-27.

Levine, R. (1997). Financial Development and Economic Growth: Views and Agenda, *Journal of Economic Literature*, 35(2), 688-726.

Levine, R. and D. Renelt (1992). A Sensitivity Analysis of Cross-Country Growth Regressions, *American Economic Review*, 82(4), 942-963.

Lucas, R. Jr. (1988) On the Mechanics of Economic Development, *Journal of Monetary Economics,* 22 (1), 3-42.

Mankiw, N. G., D. Romer, and D. N. Weil (1992). A Contribution to the Empirics of Economic Growth, *Quarterly Journal of Economics*, 107(1), 407-38.

McCombie, J.S.L. and A. P. Thirlwall (1994). *Economic Growth and the Balance of Payments Constraint*, (London: Macmillan).

McCombie, J.S.L. and A. P. Thirlwall (2004). *Essays on Balance of Payments Constrained Growth: Theory and Evidence,* (London: Routledge).

Owen, P.D (2003). General-to-Specific Modelling Using PcGets, *Journal of Economic Surveys* , 17(4), 609-628.

Rodrik, D., A. Subramanian and F. Trebbi (2004). Institutions Rule: The Primacy of Institutions over Geography and Integration in Economic Development", *Journal of Economic Growth*, 9(2), 131-165.

Romer, P. (1986). Increasing Returns and Long-Run Growth, *Journal of Political Economy*, 94(5), 1002-1037.

Sachs, J. (2008), Institutions Matter but not for Everything: the Role of Geography and Resource Endowments in Development Shouldn't be Underestimated, in: G. Secondi (ed), *The Development Economics Reader*, (London: Routledge).

Sachs, J.D. and A. Warner (1995). Economic Reform and the Process of Global Integration, *Brookings Papers on Economic Activity*, (1), 1-118.

Sachs, J.D. and Collaborators of the UN Millennium Project (2004). Ending Africa's Poverty Trap, *Brookings Papers on Economic Activity*, (1), 117-240.

Sala-i-Martin, X.X (1997). I just Ran Two Million Regressions, *American Economic Review*, 87(2), 178-183.

Schwarz, G.  (1978). Estimating the Dimensions of a Model, *Annals of Statistics*, 6(2), 461-464.

Solow, R.M. (1956). A Contribution to the Theory of Economic Growth, *Quarterly Journal of Economics*, 70(1), 65-94.

Summers, R. and A. Heston (1991). The Penn World Table (Mark 5): An Expanded Set of International Comparisons 1950-88, *Quarterly Journal of Economics*, 106(2), 327-368.

Temple, J. (1999). The New Growth Evidence, *Journal of Economic Literature*, 37(1), 112-156.

Thirlwall, A. P. (2011). *Economics of Development: Theory and Evidence, Ninth Edition*, (London: Palgrave-Macmillan).

Thirlwall, A. P. (2013). *Economic Growth in an Open Developing Economy: the Role of Structure and Demand*, (Cheltenham: Edward Elgar).

Vanek, J. and A.H. Studenmund (1968). Towards a Better Understanding of the Incremental Capital-Output Ratio, *Quarterly Journal of Economics*, 82(3), 452-454.

**APPENDIX 1:** List of Countries

Our cross-country dataset consists of 84 countries for all the variables listed in Table 3, 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 the rule of law index is not available are marked with an asterisk (*) in the table below. 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; Hendry and Doornik, 2013), China and Lesotho are also excluded from the sample.

| Number | Country | Income Classification (World Bank, 2013) |
|---|---|---|
| 1 | Argentina | Upper middle income |
| 2 | Australia | High income |
| 3 | Austria | High income |
| 4 | Bangladesh | Low income |
| 5 | Belgium | High income |
| 6 | Benin* | Low income |
| 7 | Bolivia | Lower middle income |
| 8 | Botswana | Upper middle income |
| 9 | Brazil | Upper middle income |
| 10 | Cameroon | Lower middle income |
| 11 | Canada | High income |
| 12 | Chile | High income |
| 13 | Colombia | Upper middle income |
| 14 | Congo, Democratic Republic | Low income |
| 15 | Congo, Republic | Lower middle income |
| 16 | Costa Rica | Upper middle income |
| 17 | Cote d'Ivoire | Lower middle income |
| 18 | Cyprus | High income |
| 19 | Denmark | High income |
| 20 | Dominican Republic | Upper middle income |
| 21 | Ecuador | Upper middle income |
| 22 | Egypt | Lower middle income |
| 23 | El Salvador | Lower middle income |

| | | |
|---|---|---|
| 24 | Finland | High income |
| 25 | France | High income |
| 26 | Gambia | Low income |
| 27 | Germany | High income |
| 28 | Ghana | Lower middle income |
| 29 | Greece | High income |
| 30 | Guatemala | Lower middle income |
| 31 | Honduras | Lower middle income |
| 32 | Hong Kong | High income |
| 33 | Iceland | High income |
| 34 | India | Lower middle income |
| 35 | Indonesia | Lower middle income |
| 36 | Israel | High income |
| 37 | Italy | High income |
| 38 | Japan | High income |
| 39 | Jordan | Upper middle income |
| 40 | Kenya | Low income |
| 41 | Korea | High income |
| 42 | Luxembourg | High income |
| 43 | Malawi | Low income |
| 44 | Malaysia | Upper middle income |
| 45 | Mali | Low income |
| 46 | Malta | High income |
| 47 | Mauritania* | Lower middle income |
| 48 | Mauritius* | Upper middle income |
| 49 | Mexico | Upper middle income |
| 50 | Morocco | Lower middle income |
| 51 | Mozambique | Low income |
| 52 | Netherlands | High income |
| 53 | New Zealand | High income |
| 54 | Nicaragua | Lower middle income |
| 55 | Norway | High income |
| 56 | Pakistan | Lower middle income |
| 57 | Panama | Upper middle income |
| 58 | Paraguay | Lower middle income |
| 59 | Peru | Upper middle income |
| 60 | Philippines | Lower middle income |
| 61 | Portugal | High income |
| 62 | Rwanda* | Low income |
| 63 | Senegal | Lower middle income |
| 64 | Sierra Leone | Low income |
| 65 | Singapore | High income |
| 66 | South Africa | Upper middle income |
| 67 | Spain | High income |

| | | |
|---|---|---|
| 68 | Sri Lanka | Lower middle income |
| 69 | Sudan | Lower middle income |
| 70 | Swaziland* | Lower middle income |
| 71 | Sweden | High income |
| 72 | Switzerland | High income |
| 73 | Syria | Lower middle income |
| 74 | Tanzania | Low income |
| 75 | Thailand | Upper middle income |
| 76 | Togo | Low income |
| 77 | Trinidad & Tobago | High income |
| 78 | Tunisia | Upper middle income |
| 79 | Turkey | Upper middle income |
| 80 | Uganda | Low income |
| 81 | United Kingdom | High income |
| 82 | United States | High income |
| 83 | Uruguay | High income |
| 84 | Zambia | Lower middle income |

**APPENDIX 2:** 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 capital productivity estimates in Table 4 are obtained with a target size of $p_1$=5% ( $p_{11}$ = 2.5%), and the per capita income growth rate estimates in Table 5 with a target size of $p_2$=2.5% ( $p_{22}$ = 1.25%). In the case of the estimates in Table 4, 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 5 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.