# The Role of the Elasticity of Substitution in Economic Growth: A Cross-Country Test of the de La Grandville Hypothesis

Debdulal Mallick*
Deakin University

**October 2007**

**The Role of the Elasticity of Substitution in Economic Growth:**

**A Cross-Country Test of the de La Grandville Hypothesis**

**Abstract**

Although the importance of the elasticity of substitution between capital and labor ($\sigma$) has long been recognized in several branches of economics, it has not received enough attention in the growth literature. De La Grandville (1989) showed theoretically that at any stage of an economy's development, the growth rate of income per capita is increasing with $\sigma$. The higher is $\sigma$, the greater the similarity between capital and labor in the production function, and thus diminishing returns sets-in very slowly.

To the best of our knowledge, this is the first paper that tests the de La Grandville hypothesis at the cross-country level. We estimate $\sigma$ for 90 countries from direct estimation of the normalized CES production function and then include these estimators as an explanatory variable in cross-country growth regression. We investigate the sign and significance of the coefficient of $\sigma$ conditioning on country characteristics, initial conditions, institutions and a set of policy variables. After accounting for endogeneity and the fact that $\sigma$ is a "generated" regressor, we find strong support for the de La Grandville hypothesis. The result is robust to the Leamer's (1983) extreme value analysis. We find that $\sigma$ can explain about 30% of the growth rate differential between East Asia and Sub-Saharan Africa.

**Correspondence:**

Debdulal Mallick
School of Accounting, Economics and Finance
Deakin University
221 Burwood Highway, Burwood
Vic 3125, Australia
Email: dmallic@deakin.edu.au
Phone: (61 3) 92517808
Fax: (61 3) 92446285

**Table of Contents**

**The Role of the Elasticity of Substitution in Economic Growth: A Cross-Country**

**Test of the de La Grandville Hypothesis**


## 1 Introduction

The elasticity of substitution between capital and labor ($\sigma$) is a second-order parameter of the production function but has a first-order effect on economic growth. Although the importance of this elasticity has long been recognized in several branches of economics, it has not received much attention in the growth literature. Many important growth issues depend on the precise value of $\sigma$. It affects the possibility of perpetual growth or decline, the growth rate and level of steady state income per capita, the speed of convergence to the steady state, the rate of return on capital, the impact of biased technical change, and the relative role of productive factors and technical efficiency in explaining differences in per capita income. De La Grandville (1989) was the first to systematically explore the relationship between $\sigma$ and economic growth. He showed theoretically that at any stage of an economy's development, the growth rate of income per capita is an increasing function of $\sigma$. To the best of our knowledge, the de La Grandville (1989) hypothesis has not been tested empirically.[1] This paper fills this gap by testing the hypothesis at the cross-country level.

---

[1] Yuhn (1991) conjectured that the higher value of $\sigma$ for South Korea may be a reason for its faster growth than the United States, which has a low $\sigma$.

We begin in Section 2 with a discussion of the relationship between σ and the growth rate of income per capita. Drawing on de La Grandville and Solow (2004), we sketch a proof of the de La Grandville (1989) hypothesis.

In Section 3, we discuss the analytical framework and econometric issues associated with testing the hypothesis. Since economic theory does not provide any guide, we follow the Barro (1991) framework by regressing the growth rate of per capita real GDP on σ and a set of variables related to growth. We investigate the sign and significance of the coefficient of σ, the key variable in our cross-country growth regression, after controlling for other explanatory variables. Since σ is a "generated" regressor, the OLS estimator of the variance of the coefficient of σ in the cross-country regression is inconsistent, and the asymptotic $t$-statistic generally overstates the true value. The 2SLS estimation overcomes this problem (Pagan, 1984). To estimate by the 2SLS, we need some valid instruments for correct inference. Many of the possible determinants of σ such as technological progress, innovations, and the level of institutional development are affected by the growth rate of a country, and therefore cannot be valid instruments as they are not exogenous. Maki and Meredith (1987) argue that if unions raise wages, employers respond by substituting capital for labor. Therefore, a low value of σ is associated with the presence of strong labor union. Easterly and Fischer (1994) argue that σ is low in a socialist economy compared to a capitalist economy because the former accumulates a narrow rather than a broad range of capital goods. Some forms of market-oriented physical or human capital such as entrepreneurial skills, marketing and distribution skills, as well as capital that is sensitive to information are missing in a socialist economy. Musgrave (1969) defined inclination to the socialist

ideas in terms of relative public consumption expenditures because a socialist country interferes more with consumer (private) preferences for goods and services by public financing of "merit" goods. We, therefore, use the percentage of union workers and the share of general government consumption in GDP, which is a proxy for inclination to socialist ideas, as the instruments for $\sigma$.

We obtain data from a variety of sources including the Penn World Table 6.1 (Heston et al., 2002) and the World Bank. Section 4 discusses the data set and estimation method of $\sigma$. We estimate $\sigma$ for 90 countries from direct estimation of the normalized CES production function and then include these estimators as an explanatory variable in the cross-country growth regression.

Results are presented in Section 5. After controlling for country characteristics, initial conditions, institutions, and a set of policy variables, we find a positive and significant coefficient of $\sigma$ that indicates strong support for the de La Grandville hypothesis that growth rate of income per capita is increasing with the value of $\sigma$. Furthermore, $\sigma$ can explains about 30% of the growth rate differential between East Asia and Sub-Saharan Africa. We check the robustness of our results using Leamer's (1983) extreme value analysis (EVA). The coefficient of $\sigma$ remains positive and the *t*-statistics remain large for all combinations of the conditioning variables. Finally, section 6 concludes.


## 2  Per capita output growth and $\sigma$

De La Grandville (1989, p. 479) showed theoretically that "at every instant the growth rate of income per capita is an increasing function of $\sigma$". This hypothesis can be

explained intuitively as follows. The higher is σ, the greater the similarity between capital and labor; thus an increase in capital with labor held fixed does not substantially change the capital-labor ratio, and this in turn resists the pull of diminishing returns to capital (Brown, 1968; p. 50). Therefore, a higher value of σ not only alters the production possibilities, it also expands them.

In the following, we sketch a proof of the de La Grandville hypothesis. The proof is drawn on de La Grandville and Solow (2004; 2006),[2] but relaxes their assumption that the level of capital stock is independent of the value of σ. We follow Klump et al. (2007) in using the normalized CES production function.[3]

$$Y_t/Y_0 = \left[ \alpha \left( K_t/K_0 \right)^{\frac{\sigma-1}{\sigma}} + \left(1-\alpha\right)\left( L_t/L_0 \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \qquad \text{--- (1)}$$

where, $Y_t$, $K_t$, and $L_t$ are real output, real capital stock and labor input. Here $\alpha$ represents the distribution parameter and σ the elasticity of substitution, and $Y_0$, $K_0$, and $L_0$ are benchmark values of $Y_t$, $K_t$, and $L_t$. We assume constant returns to scale and no technological progress. To establish the relationship between σ and the growth rate, countries are distinguished only by their value of σ, so common benchmark points for variables and marginal rate of substitution are required. Without normalization, a change in σ in the CES function not only alters the curvature of the isoquant but also shifts the whole isoquant map so that the comparison of growth paths for different values of σ is impossible. Moreover, the unusual situation that shares of capital and labor in total output

---

[2] De La Grandville and Solow (2004) also prove that the hypothesis holds if the economy exhibits either labor- or capital-augmenting technological progress or both.

[3] Also see Klump and de La Grandville (2000), Klump and Preissler (2000), Rutherford (2003), de La Grandville and Solow (2004).

approach one-half in the special case of the Harrod-Domar model where $\sigma = 0$, is avoided

with normalization to the CES production function (Klump and de La Grandville, 2000,

p. 287; Klump and Preissler, 2000, p. 46). Equation (1) can be written in per capita terms

as

$$\bar{y}_t = f_\sigma(\bar{k}_t) = \left[ \alpha \bar{k}_t^{\frac{\sigma-1}{\sigma}} + (1-\alpha) \right]^{\frac{\sigma}{\sigma-1}} \qquad\qquad \text{--- (2)}$$

where $\bar{y}_t = (Y_t/Y_0)/(L_t/L_0) = y_t/y_0$ is per capita output, and

$\bar{k}_t = (K_t/K_0)/(L_t/L_0) = k_t/k_0$ is the capital-labor ratio.

The growth rate of per capita output is given by $\dfrac{\dot{\bar{y}}_t}{\bar{y}_t} = \left( \dfrac{\partial \bar{y}_t}{\partial \bar{k}_t} \dfrac{\bar{k}_t}{\bar{y}_t} \right) \dfrac{\dot{\bar{k}}_t}{\bar{k}_t}$. The first ratio in

the parenthesis is the marginal product of capital, which under perfect competition equals

price of capital relative to the price of output. So the above expression can be rewritten as

$$\dot{\bar{y}}_t / \bar{y}_t = \left( P_t^K \bar{k}_t / P_t^Y \bar{y}_t \right) \left( \dot{\bar{k}}_t / \bar{k}_t \right). \qquad\qquad \text{--- (3)}$$

The term in the first parenthesis in equation (3) is the capital share of output and is given

by $\mu_t^K = \alpha \left[ \alpha + (1-\alpha)\bar{k}_t^{\frac{1-\sigma}{\sigma}} \right]^{-1}$. It can be shown that $\mu_t^K$ is increasing in $\sigma$:[4]

$$\frac{\partial \mu_t^K}{\partial \sigma} = \frac{1}{\sigma^2} \alpha(1-\alpha)\bar{k}_t^{\frac{1-\sigma}{\sigma}} (\log \bar{k}_t) \left[ \alpha + (1-\alpha)\bar{k}_t^{\frac{1-\sigma}{\sigma}} \right]^{-2} > 0. \qquad \text{---(4)}$$

---

[4] This result requires that $\log \bar{k}_t$ is positive, which in turn implies that $\bar{k}_t > 1$ or $k_t > k_0$. Alternatively, the baseline value of the capital stock, $k_0$ can be set to 1. Therefore, in the range above the normalization value one expects a positive effect of $\sigma$ on economic growth (Klump and de La Grandville, 2000, p. 285). I am thankful to Rainer Klump for mentioning this point to me.

The term in the second parenthesis in equation (3) is the growth rate of the capital-labor

ratio, and from the dynamics of the Solow growth model it is given by

$\dot{\bar{k}}_t / \bar{k}_t = s f_\sigma(\bar{k}) / \bar{k} - (n + \delta)$.[5] The average product of capital, $f_\sigma(\bar{k}_t) / \bar{k}_t$, can be derived

from equation (2) as

$f_\sigma(\bar{k}_t) / \bar{k}_t = 1 / M_t^\sigma$, where $M_t^\sigma = \left[ \alpha + (1 - \alpha) \bar{k}_t^{\frac{1-\sigma}{\sigma}} \right]^{\frac{\sigma}{1-\sigma}}$. We show that $\partial M_t^\sigma / \partial \sigma < 0$. First

express $M_t^\sigma$ as a general means of 1 and $k$, of order $\dfrac{1-\sigma}{\sigma} = \rho$ as

$M_t^\sigma = \left[ \alpha (1)^\rho + (1 - \alpha) \bar{k}_t^\rho \right]^{\frac{1}{\rho}}$. A general mean is increasing in the order of $\rho$ (Hardy et al.,

1952, theorem 16) so that $\partial M_t^\sigma / \partial \rho > 0$. But $\partial \rho / \partial \sigma = -1/\sigma^2 < 0$, so that $\partial M_t^\sigma / \partial \sigma < 0$.

This in turn implies that $\partial \left( f_\sigma(\bar{k}_t) / \bar{k}_t \right) / \partial \sigma = \partial \left( 1 / M_t^\sigma \right) / \partial \sigma > 0$. Combining with the

earlier result $\partial \mu_t^K / \partial \sigma > 0$, we have that $\partial (\dot{\bar{y}}_t / \bar{y}_t) / \partial \sigma > 0$.

De La Grandville (1989) attribute the rapid economic growth rate experienced by

Japan and East Asian countries to the higher value of σ between factors in their industrial

sectors, in addition to the higher savings rate in these countries. His argument is based on

Hicks' (1932) idea that a larger value of σ also entails high transformation rates between

sectors of different factor intensity. When one activity is decreasing to the benefit of the

---

[5] For derivation, see Barro and Sala-i-Martin (1995, chapter-1, p. 18).

other, the increase in production in the second sector can be made larger if the value of σ is high.[6]

## 3  Analytical framework

Recent empirical literature on economic growth is built on Barro (1991) framework that regresses the growth rate of per capita GDP on a number of variables related to growth. Since economic theory does not provide any guide, we follow the tradition,

$$g_i^y = \alpha + \beta\sigma_i + \eta C_i + \gamma X_i + \varepsilon_i \qquad\qquad \text{--- (5)}$$

where $g_i^y$ is the average growth rate of per capita real GDP in country $i$ over the sample period, $\sigma_i$ is the elasticity of substitution in country $i$, $C_i$ is a vector of country characteristics (country-specific fixed effects), $X_i$ is a vector of other variables. Our focus is on the sign and significance of the $\beta$ coefficient.

The choice of variables in $C_i$ and $X_i$ is no easy task. The small size of the sample limits the number of explanatory variables that can be used. The total number of variables in any growth regression has exceeded 65, but there is no consensus on the significance of these variables evincing lack of our understanding of the process of economic growth. Some empirical economists have simply used combinations of variables which they consider potentially important determinants of growth such as market imperfections,

---

[6] This is, in general, not true. The effect of σ on reallocation effect is indeterminate, and depends on the distribution parameter in the CES production function and price of capital relative to price of output. For a discussion, see Chirinko and Mallick (2006).

distortionary taxes, the rule of law, the degree of monopoly, climate, geography, and so on. Most of these variables are not robust to inclusion or exclusion of other variables in the regression. For example, variable $x_1$ is found to have significant effect on economic growth if variables $x_2$ and $x_3$ are included, but becomes insignificant if $x_4$ is included. This led Levine and Renelt (1992) to try to single out some of the most compelling determinants of economic growth by Extreme Bound Analysis (EBA). The only variable that survived the EBA is capital accumulation (investment-output ratio). Interestingly, this variable becomes insignificant when endogeneity is accounted for by using the initial investment rate as the instrument (Barro, 1998; Devrajan et al. 2003).

The EBA has been criticized as too restrictive a test for any variable to pass (Sala-i-Martin, 1997; Sala-i-Martin et al. 2004). Sala-i-Martin et al. (2004), instead of labeling a variable as "robust" or "fragile", performed Bayesian Averaging of Classical Estimates (BACE) to determine its significance with a certain level of confidence. These authors have sorted out 67 variables appearing in any growth regression but many of them overlap. For example, the following five variables—proportion of a country's land area within geographical tropics, prevalence of malaria in 1960s, proportion of a country's population living in geographical tropics, fraction of area within a tropical climate zone, and absolute latitude—are highly correlated. In addition to several country characteristics, Sala-i-Martin et al. (2004) find that primary school enrollment rate in 1960, price of investment goods between 1960 and 1964, initial level of per capita GDP, life expectancy in 1960, and public investment share are significantly related to growth. The variables that are marginally related to growth are overall density in 1960, real

exchange rate distortion and fraction of population speaking a foreign language (a measure of social capital and openness).

Keeping the above in mind, we consider similar initial conditions and policy variables that Sala-i-Martin et al. (2004) find to be significantly or marginally related to growth, while ensuring that the variables do not overlap. These include initial per capita real GDP, initial infant mortality rate, initial primary school enrollment, investment-output ratio, degree of openness measured as the sum of export and import as a percentage of GDP, and black market premium on foreign exchange as a proxy for market imperfection. We also condition on country characteristics such as absolute latitude, dummy for land-locked countries, ethnic fractionalization, and dummies for legal origin. In addition, we include (political) constraints on executives in 1950-94 as a proxy for institutions. Acemoglu et al. (2001) find this variable an important predictor of economic development.

There are three potential sources of endogeneity. Both the current investment-output ratio and current institutions might be affected by the growth rate. A positive coefficient on the investment-output ratio may not necessarily indicate a positive effect of investment on the growth rate; rather it may indicate the positive relation between growth opportunities and investment. Barro (1998, p. 33) argues that this reverse causation is more likely to apply for open economies. The decision to invest domestically rather than abroad reflects the domestic prospects for returns on investment, which is related to domestic opportunities for growth. This is true even if cross-country differences in savings rates are exogenous with respect to growth. We use the initial investment rate as the instrument to account for endogeneity (Barro, 1998; Easterly and Levine, 2001).

Acemoglu et al. (2001) argues that initial institutions affect current institutions, which in turn affect per capita income. We employ constraints on executives in 1900 as the instrument for constraints on executives in 1950-94.

The final source of endogeneity stems from the fact that σ is a "generated" regressor[7] obtained from the first-step estimation of the CES production function. This unobservable regressor has been estimated in calculating the coefficient and standard error in the second-step cross-country growth regression. The imputed unobservable applied in the second-step are therefore measured with sampling error. Murphy and Topel (1985, p. 371) proposed an adjustment for the standard errors of the second-step coefficient. Pagan (1984, p. 226-229) showed that the OLS estimator of the variance of the coefficient of σ is generally inconsistent, and the asymptotic $t$-statistic connected with the second-step OLS estimator generally overstates the true value. The 2SLS or IV will give a consistent estimator.[8] We therefore need to find valid instruments for σ for correct inferences. However, the second-step OLS estimator is perfectly efficient and yields correct inferences for the null hypothesis $\beta = 0$.

---

[7] For a survey on "generated" regressors, see Oxley and McAleer (1993).

[8] Dufour and Jasiak (2001) have suggested two methods for estimation and inference with "generated" regressors. The first is instrument substitution method that uses the instruments directly, instead of "generated" regressors, in order to test hypotheses and build confidence sets about the structural parameter. In our case, this method will not estimate the coefficient of σ, although inference about it can be made. The second method is based on splitting the sample. The "generated" regressors are obtained from a fraction of the sample, while the rest of the sample is used for the main regression (in which "generated" regressor is used). We cannot apply this method because we estimate σ from another data set.

Hicks, when he invented σ in 1932, realized it as a pure technological parameter. He pointed out the three possible ways in which substitution can take place—intra-sectoral substitution between known methods of production, inter-sectoral substitution of production, and substitution arising from new innovations. Capital can be more easily substituted for labor if demand shifts from labor-intensive to capital-intensive goods and services when there is a change in factor and commodity prices. This type of easy substitution is also a mechanism for fending off diminishing returns (Solow, 2005, p. 8). But this technological parameter at the aggregate level is also influenced by institutional settings (Klump and Preissler, 2000, p. 51; de La Grandville and Solow, 2004, p. 37; Solow, 2005, p. 8). In a multi-sector economy, choice among various known production methods by reallocating factors both within and between sectors, as well as application of new production methods are influenced by the institutional framework such as labor unions (Klump and Preissler, 2000, p. 51). If unions raise wages, employers respond by substituting capital for labor (Maki and Meredith, 1987, p. 792). In other words, a low value of σ is associated with the presence of a strong labor union.[9] De La Grandville and

[9] The author is not aware of any empirical work that tests the relationship between σ and unionization at the aggregate level but there are empirical evidences of low σ in the sectors or industries where labor union is relatively strong. Freeman and Medoff (1982) estimated σ both in unionized and non-unionized sectors using two distinct set of data—a 2-digit SIC industry data set based largely on 1972 Census of manufacturing, and Bureau of Labor Statistics' 1968, 1970 and 1972 Expenditures for Employee Compensation surveys. In both cases σs were found to be lower in unionized than non-unionized sectors. Maki and Meredith (1987) also found strong evidence of lower σ in the unionized sector. Their estimates were based on pooled data for twenty 2-digit SIC Canadian manufacturing over the period 1971-81.

Solow (2004, p. 36) conjecture that a country having strong customary and regulatory barriers to large changes in capital-labor ratios will have a lower σ than a country with fewer barriers or none.

Yuhn (1991, p. 344) considered σ a "menu of choice" available to entrepreneurs. He argues that over a long period, the government of South Korea distorted factor prices by artificially cheapening the price of capital goods and this may have been the main reason of the country's very high σ. Saam (2005), in a basic model of trade, shows that a partial liberalization of trade affects the aggregate σ. Klump and Preissler (2000, p. 52) argue that σ should also be related to a country's monetary and financial system. Efficient factor allocations are endangered if money no longer fulfills its function as a reliable unit of account and medium of exchange. Therefore, higher inflation should be expected to be associated with less efficient resource allocation, which in turn implies a lower σ.

Easterly and Fischer (1994, p. 23) argued that σ is low in a socialist economy compared to a capitalist economy because the former accumulates a narrow rather than broad range of capital goods. Some forms of the physical or human capital that were missing in a socialist economy would have been market-oriented entrepreneurial skills, marketing and distribution skills, and information-sensitive physical and human capital.[10]

---

[10] Easterly and Fischer (1994) showed that the rapid growth of the Soviet economy in the 1930s through the 1950s was due to the rising capital-output ratio (they defined it as "extensive" growth). The market-oriented economies such as Japan and South Korea also had similar capital-output ratio, but the marginal product of capital declined very rapidly in the Soviet Union because of its very low σ, which in turn caused its economic retardation. This view is also supported by Bairam (1991) and Blitzer (1970). Bairam (1991, p. 70) demonstrated that the main reason behind the retardation in Soviet growth rates is low and declining σ, not the retardation in the rate of technological progress.

The above discussion demonstrates that the possible determinants of σ are

technological progress, innovations, financial and other institutions, openness to trade,

degree of unionization, and a country's inclination to socialist ideas. However, political

institutions and openness to trade already appear in $X_i$ in equation (5). On the other

hand, technological progress, innovations and development of financial institutions take

place mostly in developed and rapidly growing countries, so that these variables cannot

be valid instruments because these are correlated with the residual in equation (5). This

leaves the remaining two variables—degree of unionization and inclination towards

socialist ideas—as natural candidates for valid instruments. We consider the percentage

of union workers as one of the instruments. This variable is also not among the 67

variables listed by Sala-i-Martin et al. (2004). Our second instrument is the share of

general government consumption in GDP which is a proxy for inclination towards

socialist ideas. Musgrave (1969, p. 4-5) distinguished between socialist and capitalist

economies in terms of relative public consumption expenditures because a socialist

country interferes more with consumer (private) preferences for goods and services

through the public financing of "merit" goods.

The choice of the share of general government consumption in GDP as an

instrument requires explanation because this variable has been included as a regressor in

many growth regressions. There are opposing arguments regarding the role of

government expenditure on economic growth. One argument views government

expenditure detrimental to growth because government operations are conducted

inefficiently, regulatory processes impose excessive burdens and costs on the economic

system, and many of the government's fiscal and monetary policies tend to distort

economic incentives and lower productivity. An opposing point of view suggests that
larger government expenditure stimulates growth by harmonizing the conflicts between
private and social interests, preventing exploitation by foreigners, securing an increase in
productive investment, encouraging human capital formation, and providing a socially
optimal direction for growth and development (Ram, 1986, p. 191). But it may be the
type of government expenditure rather than the level that positively or negatively affects
economic growth. Tanzi and Schuknecht (2000, p. 119) find that government size,
defined in terms of public expenditure, has no significant effect on socioeconomic
indicators. Barro (1990, p. 123), in a cross-country growth regression, obtains a negative
impact of government size on growth. He defines government size as the ratio of
government expenditure to GDP excluding education and defense expenditures.
However, the impact is positive (but not significant) when he uses the ratio of public
investment to GDP as a proxy for government size. We use the share of general
government consumption in GDP that includes all current expenditures for purchases of
goods and services by all levels of government, including capital expenditures on
national defense and security. This variable is therefore not correlated with the residual in
equation (5). It has also not been found significant by Sala-i-Martin et al. (2004).


## 4  Data

Data have been obtained from a variety of sources. The estimation of σ requires
data on real output, labor (workforce) and capital stock. Capital stock is calculated using
the perpetual inventory method from investment data (for details, see Appendix A.1)
obtained from the Penn World Table 6.1 (Heston et al., 2002) for the period 1950-2000,

as are data on per capita real GDP at constant price (RGDPL) and labor. Our institution

variable is the (political) constraints on executives, obtained from the Polity-II dataset

constructed by Ted Gurr and Associates (an update of Gurr, 1997). We take the average

for the period starting from 1950 to the latest available time period (for most countries,

the sample period ends in 1994). Data on union workers are constructed by Martin Rama

and Raquel Artecona (2002), and these are available at five-year intervals for the period

1945-1999. General government consumption share in GDP is collected from the World

Development Indicators (WDI). We use ethnic fractionalization data constructed by

Matthew Krain (1997).[11] We use Global Development Finance (GDF), the World Bank

data for the period 1960-1999 for all other variables. Sources of data are described in

Appendix A.2.

Since $\sigma$ is the most important data series, it is imperative to discuss its estimation

method in detail. The most popular and frequently used equations to estimate $\sigma$ in the

literature are the three first-order conditions of the CES production function for the

capital-output, labor-output and capital-labor ratios. These equations are linear in

parameters and therefore, convenient for estimation. The first of these three equations

relates capital-output ratio with the Jorgensonian user cost of capital which combines

interest, depreciation, and tax rates and the relative price of investment goods. Under

constant returns to scale, the estimated coefficient of the user cost is the aggregate $\sigma$. The

user cost variable cannot be constructed as data on the tax rates are not available at the

cross-country level. The simplest way to overcome this problem would be to treat the tax

---

[11] It is defined as $1 - \sum_{j=1}^{J} \left( \frac{\text{Population in } j\text{th ethnic group}}{\text{Total population}} \right)^2$.

rates as invariant over time so that only the constant term in the equation would be affected. But this would undoubtedly be a flawed assumption as taxes on capital goods have decreased in many countries over the last couple of decades. In addition, Chirinko and Mallick (2007, p. 3) have raised concerns about the estimation of σ from the capital-output equation using aggregate data. They show that if the capital-output ratio and user cost of capital are I(1) and cointegrated, and if factor shares are constant in the long run, then the capital-output equation will always give a value of σ equal to unity independent of the production technology. The second equation equates labor-output ratio with real wage but data for the latter variable are not available at the cross-country level. The third equation that equates capital-labor ratio with the ratio of two input prices can also not be estimated for the same reason.

Another alternative would be the estimation of the second-order Taylor approximation to the CES production function around σ =1, first introduced by Kmenta (1967, p. 180) and estimated by, among others, Zarembka (1970) and Duffy and Papageorgiou (2000). This equation is also linear in parameters, and requires data on output-labor and capital-labor ratios. However, Thursby and Lovell (1978) showed that the σ is estimated from the Kmenta approximation with a large bias and mean square error. The direction of bias can be upward or downward and does not get smaller with large sample size. When σ departs from 1, the bias in all parameter estimates increases. Since the Kmenta approximation is a truncated series of the second order, the remainder term becomes an omitted variable in the regression. Moreover, the Taylor series itself converges to the underlying CES function only on a region of convergence and the Kmenta approximation is a divergent Taylor series outside that region.

Given the limitations mentioned above, we are led to estimate the following normalized CES production function using non-linear least squares (NLS) to obtain σ for each country.

$$Y_t/Y_0 = A_t \left[ \alpha \left( K_t/K_0 \right)^{\frac{\sigma-1}{\sigma}} + (1-\alpha)\left( L_t/L_0 \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \qquad \text{--- (6)}$$

To calculate the normalized value of each variable, we divide each series by its initial value. Equation (6) differs from equation (1) in that a Hicks neutral technology term also appears equation (6) and we assume it grows exponentially according to $A_t = A_0 \exp(\lambda t)$, where $A_0$ is the initial level of technology and $\lambda$ is its constant growth rate. By taking the logarithm on both sides of equation (6), we obtain

$$\log \overline{Y}_t = \log(A_0) + \lambda t + \rho \log \left[ \alpha \overline{K}_t^{\frac{1}{\rho}} + (1-\alpha)\overline{L}_t^{\frac{1}{\rho}} \right] \qquad \text{--- (7)}$$

where, $\rho = \sigma/(1-\sigma)$, $\overline{Y}_t = Y_t/Y_0$, $\overline{K}_t = K_t/K_0$ and $\overline{L}_t = L_t/L_0$. We estimate $\rho$ by NLS and then recover the value of $\sigma$, and calculate its standard error by the "delta method". Antràs (2004) shows that the first-order conditions for the capital-output, labor-output and capital-labor ratios obtain biased estimates of σ if the biased technical change is ignored. He included a calendar time variable to account for the biased technical change. It is not known whether direct estimation of the CES production function excluding the biased technical change will also result in the same bias. However, equation (7) includes a time variable.

We retain in our sample the countries for which data are available for at least 30 years. We also exclude the countries for which the iteration did not converge due to non-concavity with different preset values. We have 90 such countries.

Now we discuss the value of σ estimated for various countries. These are presented in Table 1. The value of σ is less than 0.1 for 18 countries of which nine are from Sub-Saharan Africa. Sierra Leone and Burundi have the lowest value of σ at 0.031. Countries in this region have also experienced very low growth. Sixty-seven out of 90 countries have a value of σ lower than 0.5. The value of σ for the United States is 0.643. The value is the largest for Hong Kong at 2.18, and it is the only country with a value of σ larger than 2. Eight countries have a value of σ greater than 1, among which five are from East Asia. The East Asian countries have also been experiencing rapid growth since the 1960s.

Table 2 reports the mean value of σ by region and growth rate of per capita real GDP. The mean value for all 90 countries is 0.338 with a standard deviation of 0.380. The mean values for the East Asia and Sub-Saharan African countries are 0.737 and 0.275 respectively. For the OECD countries the mean is 0.340. A clear pattern is evident that, on average, the value of σ increases secularly with the growth rate of per capita real GDP. For example, the mean value of σ is 0.203 for the countries with average growth rate less than 1% per year. These values increase to 0.257, 0.336, and 0.491 for the countries with growth rates ranging 1%-2%, 2%-3%, and higher than 3% respectively.

## 5 Results

In this section, we present the results from cross-country growth regressions. We start with a simple OLS regression of per capita real GDP growth on the value of σ for the full sample of 90 countries. The coefficient of σ is 1.771 with a relatively low standard error of 0.370. The R-square is 0.171.

Per capita real GDP growth = 1.596 + 1.771 * (σ)

(0.197) (0.370)

R-square = 0.171, N = 90

(Figures in the parentheses are White (1980) corrected robust standard errors)

This result shows positive and significant impact of σ on economic growth. However, other explanatory variables considered to be related to growth have not been controlled for. Some of these omitted variables, such as institutions and openness, may also be correlated to the value of σ, so the coefficient of σ is estimated with bias.

Table 3 reports some benchmark results for the OLS. We report the sign and significance of the coefficient of σ after conditioning on country characteristics, initial conditions, a set of policy variables, and institutions. In column 1, we condition on the country characteristics that include absolute latitude, dummy for landlocked countries, ethnic fractionalization, and dummies for legal origin. The coefficient of σ slightly decreases to 1.491 with a standard error of 0.262, and R-square increases to 0.414. The coefficient of σ, reported in column 2, remains positive and statistically significant at the 1% level after adding the initial conditions (initial per capita real GDP, initial infant mortality rate, initial primary school enrollment). The sign and significance level do not alter after including investment-output ratio, openness, black market premium, and constraints on the executives in 1950-1994 in the regression. These results are reported in columns 3 and 4. However, the OLS estimators are biased and inconsistent as we have

not accounted for endogeneity of investment-output ratio and institutions, and measurement errors in σ.

To account for endogeneity, we now estimate equation (5) by Fuller's (1977) modified Limited Information Maximum Likelihood (Fuller-$k$) method. Before presenting the results, we discuss the reason for employing the Fuller-$k$ estimation. Recent work with instrumental variables has raised concerns about weak instruments and biased estimates (beginning with Nelson and Startz, 1990). Instrumental relevance is assessed with the test statistic proposed by Stock et al. (2002), which involves an auxiliary regression of the model variable on the instruments and a comparison of the F-statistic for goodness of fit to a critical value. We find that the first-stage F-statistics from the regression of σ on the set of instruments are less than the critical value prescribed by Stock et al. (2002). However, the F-statistics from both regressions of investment-output ratio and constraints on the executives on their instruments are larger than the critical value. We therefore suspect that the 2SLS or GMM would estimate the coefficient of σ with bias. Stock et al. (2002, p. 525) have suggested the Fuller-$k$ estimation for robust inference with weak instruments. Rotemberg (1984) has shown that this estimator is best unbiased to second order. In their Monte Carlo simulations using the Fuller-$k$ estimator, Hahn et al. (2004) have found that bias and mean square error substantially reduce relative to IV and Limited Information Maximum Likelihood (LIML) when instruments are weak.

Results for the Fuller-$k$ estimation are presented in Table 4. Column 1 reports the results after conditioning on the country characteristics. Here the only source of endogeneity is the measurement errors in σ, which we account for using the percentage of

union workers and the share of general government consumption in GDP as the instruments. The sample size now decreases to 70 as data on unionization are available for only this number of countries. The coefficient of σ is 1.871 with a relatively large standard error of 0.821 but the coefficient is significant at the 5% level. The $p$-value of the chi-square statistics of the Anderson-Rubin (1950) over-identification test is 0.253 indicating the validity of the instruments. In column 2, we include the initial conditions to the conditioning variables in column 1. In column 3, we include openness and black market premium. In column 4, we add investment-output ratio, and account for endogeneity using its initial value as the instrument. Constraints on the executives for the period 1950-94 is added in column 5. We use the constraints on the executive in 1900 as the instrument. In all cases, both the sign and significance of the coefficient of σ do not change, and the instruments are found to be valid. It is important to mention that the coefficients of σ are uniformly larger from the Fuller-$k$ than the OLS estimation when the same conditioning variables appear in the equation.

To get an idea about the magnitude of the effect of σ on growth rate, we consider two regions, East Asia and Sub-Saharan Africa. Fourteen East Asian countries in our sample have had the highest average annual growth rate of 3.771%. On the other hand, 28 Sub-Saharan African countries have had the lowest average growth rate of 0.985%. The mean (unweighted) values of σ for these two regions are 0.737 and 0.275, respectively. The value of $\beta$, the coefficient of σ, from the Fuller-$k$ estimation with the full set of variables is 1.831 (column 5 in Table 4). With a difference of 0.462 in σ, there should be on average 0.846 points difference in the growth rates between the two regions. The

actual difference is 2.786 points implying that σ explains about 30% of the growth rate

differential, which is fairly large although much less than the actual difference.

The comparison between the East Asian and OECD (excluding the East Asian

countries) countries is more revealing. The differences in the average value of σ and the

per capita GDP growth rate for these two regions are 0.438 and 0.913, respectively. With

the value of $β$ of 1.831, σ alone explains about 87% of the difference in the growth rates

of the two corresponding regions. Even if we consider the lowest value of $β$ from the

Fuller-$k$ estimation, which is 1.307 (column 2 in Table 4), σ explains about 67% of the

difference in their growth rates.


## 5.1 Robustness tests

*Extreme value analysis:*

Although we have taken considerable care about the choice of the conditioning

variables, the sign and significance of the coefficient of σ may still be subject to

combinations of the variables included in the regression. To check the robustness, we

perform extreme value analysis (EVA) first proposed by Leamer (1983). For a variable of

interest, the extreme values of the distribution of the associated coefficient are their

smallest and largest values when combinations of other regressors enter the regression

model. When the two extreme values are of the same sign, then the variable is considered

to be "robust", otherwise it is "fragile".[12] To determine the robustness of σ we estimate

the following set of regressions,

---

[12] Levine and Renelt's (1992) extreme bound analysis (EBA) is a more restrictive test.
For each model $j$ in equation 8, $β_j$ and its standard deviation are estimated. The lower

$$g_i^y = \alpha_j + \beta_j \sigma_i + \eta_j C_i + \gamma_j x_{i,j} + \varepsilon_{i,j} \qquad\qquad \text{--- (8)}$$

where, the $j$ subscript refers to the $j$-th model, $C_i$ is the vector of the country

characteristics, $x_{i,j} \in X_i$ is a vector of 1 to 7 variables taken from $X_i$. We estimate

equation (8) with all possible combinations of the initial conditions, institutions and

policy variables, while we held $\sigma$ and the country characteristics fixed in all regressions.

The reason for the latter choice is that the country characteristics are given by history and

do not depend in any way on past or present policies of a country. We have a total of

$2^J - 1$ models (with $J = 7$, we have a total of 127 models). If the minimum and maximum

values of $\beta_j$ are of the same sign, then we consider $\sigma$ as a robust predictor of economic

growth.

   The mean and standard deviation, minimum value, and maximum value of the

distribution of estimated coefficient of $\sigma$ are reported in column 1 of Table 5. All models

are estimated by the Fuller-$k$ method. Results show that regardless of the linear

combinations of the initial conditions, institutions and policy variables, we always obtain

a positive coefficient of $\sigma$ with a minimum and maximum of 0.511 and 2.253,

respectively. Similar characteristics for the distribution of its $t$-statistics are reported in

---

extreme bound (LEB) is defined as *Lowest value of [ $\beta_j$ - 2(stand. dev.)$_j$ ]* and the upper

extreme bound (UEB)  as  *Largest value of [ $\beta_j$ + 2(stand. dev.)$_j$ ]*. Their EBA test

suggests that if the LEB for $\sigma$ is negative and the UEB for the same is positive, then $\sigma$ is

not robust.

column 2. The relatively large *t*-values indicate that these coefficients are usually well above zero in a statistical sense.[13]

*Estimation correcting the effect of outliers:*

Although our results are robust to the EVA, in this and next sub-sections we perform more robustness tests. As mentioned in section 4, the value of σ is relatively high for the East Asian countries and low for the Sub-Saharan African countries. Countries in these two regions have also been experiencing very high and low growth, respectively. One can raise the question of whether our results are driven by the larger and smaller values of σ for these two sets of countries. We answer this question by estimating the model including dummies for East Asia and Sub-Saharan Africa to the full set of conditioning variables. Results are reported in column 1 of Table 6. The value of the coefficient of σ is 1.591 with a standard error of 0.749.

We also estimate the model after deleting six most extreme σ data points from our sample, three from each tail of the distribution of σ. This eliminates countries only from Sub-Saharan Africa and East Asia. Results are presented in column 2 of Table 6. The estimated coefficient of σ increases to 2.740 with a standard error of 1.316, so that it is significant at the 5% level.

---

[13] Although our robustness test does not pass the extreme bound analysis (EBA) of Levine and Renelt (1992), in 89.8%, 82% and 44.5% cases, the coefficient of σ is statistically significant at the 10%, 5% and 1% levels, respectively. The BACE employed by Sala-i-Martin et at. (2004) uses the weighted average of the coefficients estimated by the OLS where the weights are given by posterior probabilities. The EVA can be though of a weighted average with equal weights.

*Analysis with refined sample:*

The standard errors of the σ estimators are large for a number of countries, and thus these estimators are not statistically different from zero. Next robustness test retains the countries for which the σ estimator is statistically significant at least at the 5% level. Results for 44 such countries are presented in columns 3 and 4 of Table 6. In column 4, the additional variables are dummies for East Asia and Sub-Saharan Africa. Results for the Fuller-*k* estimation show that in both regressions the coefficients of σ are positive and statistically significant at the 1% and 5% level, respectively.

The PWT recognizes poor quality of its data for many countries, especially the developing ones. It has categorized the countries in terms of quality of data with types A and B having better quality data, while types C and D having relatively poor quality data. To further test the robustness of our results we retain only those countries with A and B types data, which are mostly OECD countries. This eliminates from our sample all Sub-Saharan African countries and some East Asian countries. Now we rerun some of the previous regressions for the reduced sample of only 26 countries. The results are reported in columns 1-3 of Table 7. In column 1, we report the results after conditioning only the country characteristics. In column 2, we condition on the full set of variables other than institution. The reason for excluding institution is that the countries in this reduced sample do not vary much in terms of institutional development. In column 3, we add dummy for East Asia. All models are estimated by the Fuller-*k* method. The positive coefficients of σ and low standard errors in all columns further confirm the robustness of our earlier results for the full sample.

## 5.2  *Alternative specification*

Our previous analysis is based on the assumption of a linear relationship between σ and growth rate. In the following equation, we extend the analysis to allow for a flexible functional form by specifying a quadratic equation in σ.

$$g_i^y = \alpha + \beta\sigma_i + \delta\sigma_i^2 + \eta C_i + \gamma X_i + \varepsilon_i \qquad\qquad \text{--- (9)}$$

Now $\beta$, the coefficient of σ, does not refer to the marginal effect of σ on the growth rate because of the quadratic specification. It is now given by $\beta + 2\delta\bar{\sigma}$, where, $\bar{\sigma}$ is the mean value of σ. Results are reported in Table 8. Column 1 reports the results for the full sample of 70 countries. The coefficients of σ and σ-squared are both positive but not statistically significant. With the mean value of σ of 0.357, the marginal effect is 3.01 with a standard error of 1.90, which is larger than the maximum value of $\beta$ obtained from the EVA. In columns 2 and 3, results for 44 countries for which the σ estimators are significant at least at the 5% level are reported. Column 3 adds dummies for East Asia and Sub-Saharan Africa as additional regressors. In both regressions, the coefficient of σ is positive and that of σ-squared is negative, but not statistically significant. The marginal effect is 1.412 when dummies for East Asia and Sub-Saharan Africa are excluded, and it is 1.651 when these dummies are included. We also replicate the above exercise for 26 countries with better quality data types A and B. Results are reported in columns 4 and 5. In Column 5, we include dummy for East Asia. In both regressions, the coefficients of σ are positive and significant, but the coefficients of σ-squared are now negative and significant thus rejecting a linear relationship between σ and the growth rate in favor of a concave one.  The marginal effects are 1.109 and 1.283, respectively.

It is important to mention that measurement errors in σ are compounded in its square. The value of the F-statistics from the first-stage regression of σ-squared on its instruments is lower than that from the regression of σ. Unable to find additional instruments for σ (and its square), we have used the second and third powers of both the percentage of union workers and the share of general government consumption as additional instruments. The F-statistics, although increase with new additional instruments, still remain below the critical value proposed by Stock et al. (2002). Therefore, we have employed Fuller-$k$ estimation to correct the bias for the estimated coefficients.

## 6  Conclusion

Although there are some recent theoretical advances on the importance of σ in economic growth, we are unaware of any previous empirical research. This paper finds that growth rate of income per capita is increasing with σ thus strongly supporting the de La Grandville (1989) hypothesis. Results are robust in a variety of ways including the Leamer's (1983) extreme value analysis. We find that σ can explain about 30% of the growth rate differential between East Asia and Sub-Saharan Africa. We suggest that both theoretical and empirical research on economic growth should pay more attention to the role of this neglected parameter.

# References

Acemoglu, D. et al., 2001. The Colonial Origins of Comparative Development: An Empirical Investigation. *American Economic Review* 91 (December), 1369-1401.

Antràs, P., 2004. Is the US Aggregate Production Function Cobb-Douglas? New Estimates of the Elasticity of Substitution. *Contributions to Macroeconomics* 4 (1, April), 1-34.

Bairam, E., 1991. Elasticity of Substitution, Technical Progress and Returns to Scale in Branches of Soviet Industry: A New Production Function Approach. *Journal of Applied Econometrics* 6 (1), 91-96.

Barro, R.J., 1990. Government Spending in a Simple Model of Endogenous Growth. *Journal of Political Economy* 98 (2), 103-125.

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

Barro, R.J., 1998. Determinants of Economic Growth: A Cross-Country Empirical Study. Cambridge, Massachusetts: MIT Press.

Barro, R.J., Sala-i-Martin, X., 1995. Economic Growth. Cambridge, Massachusetts: MIT Press.

Blitzer, C., 1970. Elasticity of Substitution and the Retardation of Soviet Growth Rates. *Review of Economics and Statistics* 52 (1, February), 104-108.

Brown, M., 1968. On the Theory and Measurement of Technological Change. Cambridge, UK: Cambridge University Press.

Chirinko, R.S., Mallick, D., 2006. The Elasticity of Derived Demand, Factor Substitution, and Product Demand: Corrections to Hicks' Formula and Marshall's Four Rules. CESifo Working Paper No. 1742.

Chirinko, R.S., Mallick, D., 2007. The Fisher/Cobb-Douglas Paradox, Factor Shares and Cointegration. CESifo Working Paper No. 1998.

De La Grandville, O., Solow, R.M., 2004. Determinants of Economic Growth: Is Something Missing? mimeo, MIT.

De La Grandville, O., Solow, R.M., 2006. A Conjecture on General Means. *Journal of Inequalities in Pure and Mathematics* 7 (1), 1-3.

Devrajan, S. et al., 2003. Low Investment is not the Constraint on African Growth. *Economic Development and Cultural Change* 51 (3), 547-571.

Duffy, J., Papageorgiou, C.E., 2000. A Cross Country Empirical Investigation of the Aggregate Production Function Specification. *Journal of Economic Growth* 5 (March), 87-120.

Dufour, J., Jasiak, J., 2001. Finite Sample Inference Methods for Simultaneous Equations and Models with Unobserved and Generated Regressors. *International Economic Review* 42 (3, August), 815-843.

Easterly, W., Levine, R., 2001. It's Not Factor Accumulation: Stylized Facts and Growth Models. *World Bank Development Review* 15 (2), 177-219.

Easterly, W., Fischer, S., 1994. The Soviet Economic Decline: Historical and Republican Data. NBER Working Paper No. 4735.

Freeman, R.B., Medoff, J., 1982. Substitution Between Labor and Other Production Inputs in Unionized and Nonunionized Manufacturing. *Review of Economics and Statistics* 64 (2, May), 220-233.

Fuller, W.A., 1977. Some Properties of a Modification of the Limited Information Estimator. *Econometrica* 45 (4, May), 939-953.

Gurr, T.R., 1997. Polity II: Political Structures and Regime Change: 1800-1986. Unpublished Paper (Limited Revised Edition), University of Colorado, Boulder.

Hahn, J. et al., 2004. Estimation with weak instruments: Accuracy of higher-order bias and MSE approximations. *Econometrics Journal* 7 (1, Jun), 272-306.

Hardy, G., et al., 1952. Inequalities. Second Edition, Cambridge: Cambridge Mathematical Library.

Heston, A. et al., 2002. Penn World Tables Version 6.1. Download Database. Center for International Comparisons, University of Pennsylvania.

Hicks, J.R., 1963. The Theory of Wages. Second Edition, London: MacMillan & Co., First edition published in 1932.

Klump, R., Preissler, H., 2000. CES Production Functions and Economic Growth. *Scandinavian Journal of Economics* 102 (1), 41–56.

Klump, R., de La Grandville, O., 2000. Economic Growth and the Elasticity of Substitution: Two Theorems and Some Suggestions. *American Economic Review* 90 (March), 282-291.

Klump, R. et al., 2007. The long-term sucCESs of the neoclassical growth model. *Oxford Review of Economic Policy* 23 (1), 94-114.

Kmenta, J., 1967. On Estimation of the CES Production Function. *International Economic Review* 8 (June), 180-189.

Krain, M., 1997. State-Sponsored Mass Murder: The Onset and Severity of Genocides and Politicides. *Journal of Conflict Resolution* 41 (3), 331-360.

Leamer, E.E., 1983. Let's Take the Con Out of Econometrics. *American Economic Review* 73 (1, March), 31-43.

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

Maki, D.R., Meredith, L.N., 1987. A Note on Unionization and the Elasticity of Substitution. *Canadian Journal of Economics* 20 (4, November), 792-801.

Murphy, K.M., Topel, R.H., 1985. Estimation and Inference in Two-Step Econometric Models. *Journal of Business and Economic Statistics* 3 (4), 370-379.

Musgrave, R.A., 1969. Fiscal Systems. New Haven: Yale University Press.

Nehru, V., Dhareshwar, A., 1993. A New Database on Physical Capital Stock: Sources, Methodology and Results. *Revista De Analisis Economico* 8 (1), 37-59.

Nelson, C.R., Startz, R., 1990. Some Further Results on the Exact Small Sample Properties of the Instrumental Variables Estimator. *Econometrica* 58 (July), 967-976.

Oxley, L., McAleer, M., 1993. Econometric Issues in Macroeconomic Models with Generated Regressors. *Journal of Economic Surveys* 7 (1), 1-40.

Pagan, A., 1984. Econometric Issues in the Analysis of Regressions with Generated Regressors. *International Economic Review* 23 (1, February), 221-247.

Ram, R., 1986. Government Size and Economic Growth: A New Framework and Some Evidence from Cross-Section and Time-Series Data. *American Economic Review* 76 (1, March), 191-203.

Rama, M., Artecona, R. 2002. A Database of Labor Market Indicators across Countries. unpublished manuscript, Washington, DC: The World Bank.

Rotemberg, T.J., 1984. Approximating the Distribution of Econometric Estimators and Test Statistics. In: Griliches, Z., Intriligator, M.D. (Eds.). *Handbook of Econometrics*, Vo. 2. Amsterdam, North-Holland.

Rutherford, T.F., 2003. Lecture Notes on Constant Elasticity Functions. University of Colorado, Boulder.

Saam, M., 2005. Trade Liberalization as a Determinant of the Elasticity of Substitution between Capital and Labor. University of Frankfurt, Germany.

Sala-i-Martin, X., 1997. I Just Ran Two Million Regressions. *American Economic Review* 87 (2, May), 178-83.

Sala-i-Martin, X. et al., 2004. Determinants of Long-Term Growth: A Bayesian Averaging of Classical Estimates (BACE) Approach. *American Economic Review* 94 (4, September), 813-35.

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

Solow, R.M., 2005. Reflections on Growth Theory. In: Aghion, P., Durlauf S.N. (Eds.).

*Handbook of Economic Growth*, Vol. 1A. Amsterdam, North-Holland.

Stock, J. et al., 2002. A Survey of Weak Instruments and Weak Identification in Generalized Method of Moments. *Journal of Business & Economic Statistics* 20 (October), 518-529.

Tanzi, V., Schuknecht, L., 2000. Public Spending in the 20[Th] Century. Cambridge, UK: Cambridge University Press.

Thursby, J.G, Lovell, C.A.K., 1978. An Investigation of the Kmenta Approximation to the CES Function. *International Economic Review* 19 (2, June), 363-377.

White, H., 1980.  A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity. *Econometrica* 48 (May), 817-838.

Yuhn, K., 1991. Economic Growth, Technical Change Biases, and the Elasticity of Substitution: A Test of the de La Grandville Hypothesis. *Review of Economics and Statistics* 73 (May), 340-346.

Zarembka, P., 1970. On the Empirical Relevance of the CES Production Function. *Review of Economics and Statistics* 52 (February), 47-53.

# Table 1: Value of σ (and standard error) by country

| Country | σ | Standard error | Country | σ | Standard error |
|---|---|---|---|---|---|
| Argentina | 0.112125 | 0.119246 | Japan | 0.330502 | 0.018359 |
| Australia | 0.230056 | 0.064782 | Kenya | 0.094002 | 0.085541 |
| Austria | 0.231658 | 0.018088 | Korea,  South | 1.440629 | 0.133021 |
| Burundi | 0.031128 | 0.118136 | Sri Lanka | 0.428039 | 0.045442 |
| Belgium | 0.238228 | 0.016259 | Lesotho | 0.833528 | 0.076187 |
| Benin | 0.332678 | 0.106454 | Luxembourg | 0.332951 | 0.281706 |
| Bangladesh | 0.152298 | 1.98311 | Morocco | 0.10223 | 0.102193 |
| Brazil | 0.126055 | 0.027758 | Madagascar | 0.564631 | 0.238793 |
| Barbados | 0.133728 | 0.151819 | Mexico | 0.087222 | 0.021677 |
| Central African Republic | 0.093348 | 0.036106 | Mozambique | 0.082835 | 4.879769 |
| Canada | 0.236155 | 0.026096 | Mauritania | 0.098026 | 0.069101 |
| Switzerland | 0.154932 | 0.042077 | Mauritius | 0.687388 | 0.169961 |
| Chile | 0.099882 | 0.08532 | Malawi | 0.714232 | 1.645645 |
| China | 0.548428 | 0.223212 | Malaysia | 1.52205 | 0.204276 |
| Cote d'Ivoire | 0.144398 | 0.090111 | Namibia | 0.200169 | 0.121008 |
| Cameroon | 0.088743 | 0.089997 | Niger | 0.171831 | 0.095679 |
| Congo, Republic of | 0.164589 | 0.195408 | Nigeria | 0.177224 | 0.051825 |
| Colombia | 0.146666 | 0.027822 | Nicaragua | 0.084334 | 0.248448 |
| Comoros | 0.144026 | 0.45805 | Netherlands | 0.164692 | 0.034891 |
| Cape Verde | 0.31098 | 0.521797 | Norway | 0.76199 | 0.119417 |
| Costa Rica | 0.114007 | 0.033344 | Nepal | 0.563015 | 0.080016 |
| Denmark | 1.321511 | 0.348453 | New Zealand | 0.175233 | 0.392015 |
| Dominican Republic | 0.503423 | 0.179549 | Panama | 0.264794 | 0.051536 |
| Ecuador | 0.126152 | 0.074637 | Philippines | 0.07539 | 0.037409 |
| Spain | 0.126667 | 0.026001 | Papua New Guinea | 0.518458 | 3.492253 |
| Ethiopia | 0.082016 | 0.047478 | Portugal | 0.488343 | 0.072907 |
| Finland | 0.196602 | 0.029357 | Paraguay | 1.279504 | 0.318853 |
| Fiji | 0.137551 | 0.629335 | Romania | 0.085242 | 0.203029 |
| France | 0.216632 | 0.012479 | Singapore | 0.538795 | 0.135964 |
| Gabon | 0.119191 | 0.254436 | Sierra Leone | 0.030915 | 0.087541 |
| United Kingdom | 0.195042 | 0.128566 | El Salvador | 0.191256 | 0.120343 |
| Ghana | 0.140967 | 0.156114 | Sweden | 1.197656 | 0.051194 |
| Gambia | 0.278348 | 0.038403 | Seychelles | 0.872653 | 0.219188 |
| Guatemala | 0.088517 | 0.029357 | Syria | 0.170084 | 0.125793 |
| Guyana | 0.083337 | 0.678061 | Chad | 0.783858 | 0.059549 |
| Hong Kong | 2.184898 | 0.976902 | Togo | 0.06811 | 0.102317 |
| Honduras | 0.112279 | 0.035493 | Thailand | 0.196835 | 0.025899 |
| Indonesia | 1.138845 | 0.106714 | Trinidad &Tobago | 0.053797 | 0.076715 |
| India | 0.515283 | 0.353573 | Tunisia | 0.133854 | 0.129543 |
| Ireland | 0.684165 | 0.221576 | Turkey | 0.685593 | 0.104076 |
| Iran | 0.070374 | 0.079274 | Taiwan | 1.282201 | 0.059961 |
| Iceland | 0.23863 | 0.053815 | USA | 0.643052 | 0.086263 |
| Israel | 0.135631 | 0.051943 | Venezuela | 0.261887 | 0.145368 |
| Italy | 0.115633 | 0.014464 | Zambia | 0.133313 | 0.044274 |
| Jordan | 0.331228 | 0.158966 | Zimbabwe | 0.258562 | 0.165507 |

**Table 2: Value of σ by region and real GDP growth rate**

| Region/ real GDP growth rate | σ | | Number of countries |
|---|---|---|---|
| | **Mean** | **Standard Deviation** | |
| All | 0.338 | 0.380 | 90 |
| East Asia | 0.737 | 0.657 | 14 |
| Sub-Saharan Africa | 0.275 | 0.264 | 28 |
| OECD | 0.340 | 0.312 | 24 |
| OECD (excluding East Asian countries) | 0.299 | 0.223 | 20 |
| GDP growth rate <1% | 0.203 | 0.192 | 22 |
| GDP growth rate >=1% but <2% | 0.257 | 0.315 | 17 |
| GDP growth rate >=2% but <3% | 0.336 | 0.241 | 22 |
| GDP growth rate >=3% | 0.491 | 0.537 | 29 |

**Table 3: OLS estimation of equation (5): Per capita real GDP growth rate is the dependent variable**

$$g_i^y = \alpha + \beta\sigma_i + \eta C_i + \gamma X_i + \varepsilon_i \qquad\qquad \text{--- (5)}$$

| Explanatory variables | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | | | | |
| σ | **1.491 (0.262)*** | **0.983 (0.230)*** | **0.831 (0.219)*** | **0.825 (0.221)*** |
| **Fixed factors (C)** | | | | |
| Latitude | 0.014 (0.005) | 0.017 (0.004) | 0.011 (0.003) | 0.011 (0.003) |
| Landlocked | -0.740 (0.441) | -0.485 (0.259) | -0.870 (0.211) | -0.862 (0.211) |
| Ethnic fractionalization | -1.246 (0.508) | -0.715 (0.409) | -0.675 (0.358) | -0.689 (0.362) |
| British Legal origin | -0.160 (0.441) | 0.344 (0.316) | -0.186 (0.271) | -0.190 (0.273) |
| French Legal origin | -0.702 (0.396) | -0.040 (0.281) | -0.222 (0.256) | -0.230 (0.254) |
| **Initial conditions ($X_1$)** | | | | |
| Initial per capita real GDP (log) | | -1.185 (0.193) | -1.012 (0.156) | -1.032 (0.163) |
| Initial infant mortality rate | | -0.008 (0.004) | -0.002 (0.004) | -0.001 (0.004) |
| Initial primary school enrollment | | 0.028 (0.005) | 0.017 (0.005) | 0.017 (0.005) |
| **Institutions ($X_2$)** | | | | |
| Constraints on the executives in 1950-1994 | | | | 0.022 (0.051) |
| **Other controls ($X_3$)** | | | | |
| Investment-output ratio (log) | | | 1.209 (0.255) | 1.201 (0.256) |
| Openness (X+M as % of GDP) | | | 0.007 (0.003) | 0.007 (0.003) |
| Black market premium | | | -0.0003 (0.0003) | -0.0003 (0.0003) |
| Constant | 2.526 (0.442) | 9.606 (1.789) | 5.299 (1.834) | 5.338 (1.870) |
| R-square | 0.414 | 0.717 | 0.818 | 0.818 |
| N | 88 | 88 | 88 | 88 |

Column 1: Only the country-characteristics are the conditioning variables.
Column 2: Initial per capita real GDP, initial infant mortality rate, and initial primary school enrollment rate are included in column 1.
Column 3: Investment-output ratio, openness and black market premium are added to the conditioning variables in column 2.
Column 4: Constraints on the executives in 1950-1994 is added to the conditioning variables in column 3.

Figures in the parentheses are the White (1980) heteroskedasticity corrected robust standard errors.

*** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level (The significance of only the coefficient of σ is mentioned)

**Table 4: Fuller-*k* estimation of equation (5): Per capita real GDP growth rate is the dependent variable**

$$g_i^y = \alpha + \beta\sigma_i + \eta C_i + \gamma X_i + \varepsilon_i \qquad\qquad \text{--- (5)}$$

| Explanatory variables | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| | | | | | |
| σ | 1.871 (0.821)** | 1.307 (0.520)** | 1.360 (0.513)*** | 1.587 (0.509)*** | 1.831 (0.587)*** |
| **Fixed factors (C)** | | | | | |
| Latitude | 0.012 (0.005) | 0.016 (0.004) | 0.014 (0.004) | 0.013 (0.003) | 0.011 (0.004) |
| Landlocked | -0.937 (0.443) | -0.708 (0.299) | -0.879 (0.293) | -1.094 (0.292) | -1.146 (0.305) |
| Ethnic fractionalization | -1.055 (0.442) | -0.609 (0.421) | -0.571 (0.417) | -0.437 (0.373) | -0.556 (0.416) |
| British Legal origin | -0.241 (0.439) | 0.244 (0.329) | -0.123 (0.333) | -0.110 (0.294) | -0.069 (0.311) |
| French Legal origin | -0.626 (0.443) | -0.151 (0.290) | -0.423 (0.326) | -0.205 (0.289) | -0.191 (0.295) |
| **Initial conditions (X₁)** | | | | | |
| Initial per capita real GDP (log) | | -0.941 (0.190) | -0.829 (0.190) | -0.768 (0.168) | -0.844 (0.176) |
| Initial infant mortality rate | | -0.007 (0.004) | -0.002 (0.004) | -0.000 (0.004) | 0.001 (0.004) |
| Initial primary school enrollment | | 0.024 (0.005) | 0.025 (0.005) | 0.015 (0.006) | 0.008 (0.009) |
| **Institutions (X₂)** | | | | | |
| Constraints on the executives in 1950-1994 | | | | | 0.140 (0.156) |
| **Other controls (X₃)** | | | | | |
| Investment-output ratio (log) | | | | 1.190 (0.387) | 1.385 (0.450) |
| Openness (X+M as % of GDP) | | | 0.007 (0.004) | 0.005 (0.003) | 0.006 (0.004) |
| Black market premium | | | -0.000 (0.000) | -0.000 (0.000) | -0.000 (0.000) |
| Constant | 2.434 (0.642) | 7.921 (1.925) | 6.393 (1.924) | 3.242 (2.287) | 2.893 (2.391) |
| Chi-sq (1) *p*-value[#] | 0.253 | 0.801 | 0.686 | 0.315 | 0.203 |
| N | 70 | 70 | 70 | 70 | 70 |

# Chi-sq(1) *p*-value of Anderson-Rubin statistic (over-identification test of all instruments)

Column 1: Only the country-characteristics are the conditioning variables. Percentage of union workers, and share of general government consumption in GDP are the instruments for σ.

Column 2: Initial per capita real GDP, initial infant mortality rate, and initial primary school enrollment rate are included in column 1.

Column 3: Openness and black market premium are added to the conditioning variables in column 2.

Column 4: Investment-output ratio is added to the conditioning variables in column 3. Initial investment-output ratio is the instrument for average investment-output ratio.

Column 5: Constraints on the executives in 1950-1994 is added to the conditioning variables in column 4. Constraints on the executives in 1900 is the instrument for constraint on executives in 1950-1994.
Figures in the parentheses are the White (1980) heteroskedasticity corrected robust standard errors.
*** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level (The significance of only the coefficient of σ is mentioned)

**Table 5: Extreme value analysis for the coefficient of σ using the Fuller-*k* estimation**

|  | Coefficient | *t*-statistics |
|---|---|---|
|  | (1) | (2) |
| Mean  [S.D.] | 1.533 [0.424] | 2.494 [0.618] |
| Minimum | 0.511 | 0.844 |
| Maximum | 2.253 | 3.683 |

Extreme-value analysis using all possible combinations of the 7 conditioning variables in equation (8) (in all cases σ and country-characteristics are held fixed). There are $2^7$ -1 = 127 possible combinations.

Column 1: Contains the mean and standard deviation, minimum and maximum values of the distribution of the coefficient of σ.

Column 2: Contains the same statistics for the distribution of the associated t-statistics. The t-statistics are calculated using White (1982) heteroskedasticity corrected standard errors.

**Table 6: Fuller-*k* estimation of equation (5): Per capita real GDP growth rate is the dependent variable**

$$g_i^y = \alpha + \beta\sigma_i + \eta C_i + \gamma X_i + \varepsilon_i \qquad\qquad \text{--- (5)}$$

| Explanatory variables | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | | | | |
| σ | 1.591 (0.749)** | 2.740 (01.316)** | 2.230 (0.576)*** | 1.960 (0.971)** |
| **Fixed factors (C)** | | | | |
| Latitude | 0.010 (0.004) | 0.010 (0.004) | 0.008 (0.005) | 0.007 (0.006) |
| Landlocked | -1.065 (0.402) | -1.376 (0.377) | -0.985 (0.403) | -0.953 (0.559) |
| Ethnic fractionalization | -0.531 (0.400) | -0.556 (0.426) | -0.021 (0.588) | -0.073 (0.520) |
| British Legal origin | -0.141 (0.288) | -0.140 (0.378) | -0.313 (0.380) | -0.334 (0.416) |
| French Legal origin | -0.287 (0.285) | -0.041 (0.453) | -0.103 (0.372) | -0.170 (0.377) |
| East Asia dummy | -0.026 (0.453) | | | 0.003 (0.758) |
| Sub-Saharan Africa dummy | -0.279 (0.350) | | | -0.364 (0.507) |
| **Initial conditions (X$_1$)** | | | | |
| Initial per capita real GDP (log) | -0.871 (0.168) | -0.894 (0.200) | -0.987 (0.241) | -0.882 (0.277) |
| Initial infant mortality rate | 0.001 (0.004) | -0.000 (0.004) | -0.004 (0.004) | -0.003 (0.004) |
| Initial primary school enrollment | 0.009 (0.007) | 0.000 (0.012) | 0.008 (0.008) | 0.010 (0.007) |
| **Institutions (X$_2$)** | | | | |
| Constraints on the executives in 1950-1994 | 0.110 (0.127) | 0.159 (0.150) | 0.188 (0.156) | 0.084 (0.156) |
| **Other controls (X$_3$)** | | | | |
| Investment-output ratio (log) | 1.264 (0.461) | 1.979 (0.802) | 1.540 (0.521) | 1.473 (0.849) |
| Openness (X+M as % of GDP) | 0.007 (0.003) | 0.007 (0.003) | 0.005 (0.006) | 0.005 (0.005) |
| Black market premium | -0.000 (0.000) | -0.000 (0.000) | -0.000 (0.001) | -0.000 (0.001) |
| Constant | 3.768 (2.413) | 2.036 (3.485) | 3.371 (2.631) | 3.300 (2.394) |
| Chi-sq (1) *p*-value[#] | 0.689 | 0.349 | 0.179 | 0.19561 |
| N | 70 | 64 | 44 | 44 |

# Chi-sq(1) *p*-value of Anderson-Rubin statistic (over-identification test of all instruments)

Column 1: East Asia and Sub-Saharan Africa dummies are added to column 5 in Table 2.3.
Column 2: Six extreme σ data points, three from each tail of the distribution of σ, have been deleted from the sample. Estimation is based on a sample of 64 countries.

Column 3-4: Values of σ with at least 5% level of significance have been retained. Sample size is 44.

Figures in the parentheses are the White (1980) heteroskedasticity corrected robust standard errors.

*** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level (The significance of only the coefficient of σ is mentioned)

**Table 7: Fuller-*k* estimation of equation (5): Per capita real GDP growth rate is the dependent variable**

$$g_i^y = \alpha + \beta\sigma_i + \eta C_i + \gamma X_i + \varepsilon_i \qquad\qquad \text{--- (5)}$$

| Explanatory variables | (1) | (2) | (3) |
|---|---|---|---|
| | | | |
| σ | 2.581 (0.928)*** | 0.441 (0.158)*** | 0.451 (0.185)** |
| **Fixed factors (C)** | | | |
| Latitude | 0.006 (0.006) | -0.006 (0.003) | -0.008 (0.005) |
| Landlocked | 0.012 (0.494) | -0.003 (0.149) | -0.000 (0.156) |
| Ethnic fractionalization | -0.087 (1.23) | 0.556 (0.482) | 0.606 (0.500) |
| British Legal origin | 0.195 (0.561) | -0.548 (0.186) | -0.591 (0.204) |
| French Legal origin | 0.425 (0.440) | -0.373 (0.147) | -0.411 (0.165) |
| East Asia dummy | | | -0.144 (0.329) |
| **Initial conditions ($X_1$)** | | | |
| Initial per capita real GDP (log) | | -2.237 (0.232) | -2.327 (0.306) |
| Initial infant mortality rate | | -0.015 (0.007) | -0.017 (0.008) |
| Initial primary school enrollment | | 0.009 (0.005) | 0.009 (0.005) |
| **Other controls ($X_3$)** | | | |
| Investment-output ratio (log) | | -0.848 (0.380) | -0.890 (0.406) |
| Openness (X+M as % of GDP) | | 0.009 (0.001) | 0.009 (0.001) |
| Black market premium | | -0.027 (0.008) | -0.030 (0.008) |
| Constant | 1.800 (0.528) | 24.206 (3.393) | 25.323 (4.187) |
| Chi-sq (1) *p*-value[#] | 0.800 | 0.767 | 0.654 |
| N | 26 | 26 | 26 |

\# Chi-sq(1) *p*-value of Anderson-Rubin statistic (over-identification test of all instruments)

Columns 1-3: Countries with better quality (A and B) data categorized by PWT are included. Sample size is 26.

Column 1: Only the country-characteristics are the conditioning variables. Percentage of union workers, and share of general government consumption in GDP are the instruments for σ.

Column 2: Initial per capita real GDP, initial infant mortality rate, initial primary school enrollment rate, investment-output ratio, openness and black market premium are included to the conditioning variables in column 1. Initial investment-output ratio is the instrument for average investment-output ratio.

Column 3: East Asia dummy is added to the conditioning variables in column 2.

Figures in the parentheses are the White (1980) heteroskedasticity corrected robust standard errors.

*** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level (The significance of only the coefficient of σ is mentioned)

**Table 8: Fuller-*k* estimation of equation (9): Per capita real GDP growth rate is the dependent variable**

$$g_i^y = \alpha + \beta\sigma_i + \delta\sigma_i^2 + \eta C_i + \gamma X_i + \varepsilon_i \qquad\qquad \text{--- (9)}$$

| Explanatory variables | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| | | | | | |
| σ | 3.528 (2.849) | 0.701 (2.696) | 1.108 (2.248) | 1.485 (0.591)** | 1.694 (0.690)** |
| σ-squared | -0.725 (1.393) | 0.759 (1.421) | 0.579 (1.218) | -0.486 (0.223)** | -0.531 (0.242)** |
| Mean value of σ | 0.357 | 0.469 | 0.469 | 0.387 | 0.387 |
| Marginal effect | 3.010 (1.900) | 1.412 (1.451) | 1.651 (1.352) | 1.109 (0.423)*** | 1.283 (0.511)** |
| **Fixed factors (C)** | | | | | |
| Latitude | 0.009 (0.004) | 0.007 (0.005) | 0.006 (0.006) | -0.006 (0.004) | -0.010 (0.005) |
| Landlocked | -1.352 (0.498) | -0.874 (0.442) | -0.961 (0.536) | 0.067 (0.165) | 0.090 (0.190) |
| Ethnic fractionalization | -0.633 (0.536) | -0.319 (0.899) | -0.173 (0.809) | 0.576 (0.564) | 0.705 (0.571) |
| British Legal origin | 0.045 (0.468) | -0.375 (0.410) | -0.397 (0.448) | -0.438 (0.215) | -0.502 (0.206) |
| French Legal origin | -0.047 (0.448) | -0.335 (0.408) | -0.322 (0.410) | -0.191 (0.176) | -0.208 (0.192) |
| East Asia dummy | | | -0.149 (0.790) | | -0.265 (0.393) |
| Sub-Sahara Africa dummy | | | -0.158 (0.476) | | |
| **Initial conditions (X$_1$)** | | | | | |
| Initial per capita real GDP (log) | -0.898 (0.214) | -1.061 (0.243) | -1.033 (0.285) | -2.160 (0.319) | -2.305 (0.357) |
| Initial infant mortality rate | 0.002 (0.005) | -0.002 (0.006) | -0.002 (0.005) | -0.017 (0 .009) | -0.021 (0.010) |
| Initial primary school enrollment | -0.006 (0.016) | 0.014 (0.010) | 0.013 (0.009) | 0.005 (0.005) | 0.004 (0.006) |
| **Institutions (X$_2$)** | | | | | |
| Constraints on the executives in 1950-1994 | 0.328 (0.154) | 0.245 (0.123) | 0.191 (0.135) | | |
| **Other controls (X$_3$)** | | | | | |
| Investment-output ratio (log) | 1.920 (0.785) | 1.054 (0.839) | 1.294 (0.970) | -0.533 (0.606) | -0.550 (0.616) |
| Openness (X+M as % of GDP) | 0.007 (0.004) | 0.007 (0.007) | 0.006 (0.007) | 0.008 (0.001) | 0.008 (0.001) |
| Black market premium | 0.000 (0.000) | 0.001 (0.001) | 0.000 (0.002) | -0.023 (0.009) | -0.027 (0.008) |
| Constant | 1.484 (3.357) | 4.874 (3.261) | 4.367 (3.014) | 22.782 (4.937) | 24.469 (5.150) |
| Chi-sq (1) *p*-value[#] | 0.857 | 0.394 | 0.441 | 0.180 | 0.260 |
| N | 70 | 44 | 44 | 26 | 26 |

# Chi-sq(1) *p*-value of Anderson-Rubin statistic (over-identification test of all instruments)
Column 1: Estimation based on a sample of 70 countries.
Column 2: Values of σ with at least 5% level of significance have been retained. Sample size is 44.
Column 3: East Asia and Sub-Saharan Africa dummies have been added in column 2.
Column 4: For countries with A and B quality data. Sample size is 26.
Column 5: East Asia dummy has been added in column 4.

Percentage of union workers, general share of government consumption in GDP, and their second and third powers are the instruments for σ and its square.
Figures in the parentheses are the White (1980) heteroskedasticity corrected robust standard errors.

Marginal effect is calculated by $\beta + 2\delta\overline{\sigma}$, where, $\overline{\sigma}$ = mean value of σ.

*** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level (The significance of only the coefficient of σ, σ-squared and the marginal effect are mentioned)

## Appendix

### A.1: Calculation of capital stock

We use the perpetual inventory method to construct capital stock series. Suppose, $I_t$ is the gross investment at time period $t$, and $\delta$ is the constant rate of depreciation, then the capital stock at $t$, $K_t$ is given by

$$K_t = I_t + (1 - \delta)K_{t-1} \qquad\qquad \text{--- (A.1)}$$

Initial capital stock, $K_0$, is constructed using the following method. We first rearrange equation-A.1 to get an expression for investment.

$$I_t = \left[ \frac{K_t}{K_{t-1}} - (1-\delta) \right] K_{t-1} = (g + \delta)K_{t-1} \qquad\qquad \text{--- (A.2)}$$

where, g is the constant growth rate of capital stock.

Substituting equation-A.2 into equation-A.1, we obtain $K_t = (1+g)K_{t-1}$. Working backward recursively we can express capital stock in period $t$-$1$ in terms of initial capital stock as $K_0$, $K_{t-1} = (1+g)^{t-1}K_0$. Next, we substitute this equation into the investment equation A.2 to express investment in period $t$ in terms of initial capital stock, $K_0$ as

$I_t = \dfrac{g+\delta}{1+g}(1+g)^t K_0$. Finally, take logarithms to both sides to obtain

$$\ln I_t = \ln\left( \frac{g+\delta}{1+g} K_0 \right) + t\ln(1+g) = \alpha_1 + t\beta \qquad\qquad \text{--- (A.3)}$$

where, $\alpha_1 = \ln\left( \dfrac{g+\delta}{1+g} K_0 \right)$, and $\beta = \ln(1+g) \approx g$. We estimate equation-A.3 to obtain $\hat{\alpha}_1$

and $\hat{\beta}$, and given the depreciation rate we can recover $K_0$ as

$$K_0 = \exp(\hat{\alpha}_1)\frac{1+\hat{\beta}}{\hat{\beta}+\delta}.$$

Advantage of this method is that it uses all available information to estimate the initial capital stock.

Data on depreciation rate is not available for most of the countries. This has led the cross-country growth accounting studies to use a common depreciation rate for all countries. Following

the growth accounting literature (Mankiw, Romer and Weil, 1992; Nehru and Dhareswar, 1993; Easterly and Levine, 2001) we use a common 4% depreciation rate for all countries.

**A.2: List of variables and data sources**

| Variable | Source |
|---|---|
| Real GDP | Penn World Table 6.1 |
| Investment-output ratio | Penn World Table 6.1 |
| Labor | Penn World Table 6.1 |
| Latitude | Global Development Finance (GDF) Growth Database, World Bank |
| Landlocked | GDF |
| Ethnic fractionalization | Matthew Krain |
| British Legal origin | GDF |
| French Legal origin | GDF |
| Infant mortality rate | GDF |
| Primary school enrollment | GDF |
| Openness (Export and import as % of GDP) | GDF |
| Black market premium | GDF |
| Constraints on the executives | Polity-II (Ted Gurr and Associates) |
| General government consumption (% of GDP) | World Development Indicator, World Bank |
| Fraction of union workers | Martin Rama (The World Bank in Vietnam) and Raquel Artecona |