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Working paper

The Importance of Cognitive Skills in Macroeconomic Models of Growth and Development.

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Abstract

In a highly influential and thought provoking study, Hanushek, E.A., and Woessmann, L., (NBER Working Paper No.14633, 2009) provide evidence in favor of a strong causal effect of cognitive skills on growth. To quote: "… the simple premise that improving the schools can produce benefits in national growth rates is strongly supported". Whilst we concur with this premise, we are rather sceptical whether the Mincerian approach followed by Hanushek and Woessmann (op.cit.) can sufficiently account for the contribution of cognitive skills on national growth rates. To further explore the importance of cognitive skills on growth and development we revisit macroeconomic models where cognitive skills are the key determinant of the path of human capital and its rate of accumulation. Our empirical results strongly support the workings of a "learning-by-doing" hypothesis where cognitive skills together with physical capital determine the paths of human capital, of output per worker, and growth.

JEL Codes: O15, O41, O47

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1. Introduction

Motivated by the thought provoking and influential paper of Hanushek and Woessmann (2009), we endeavour to further explore the contribution of cognitive skills on the paths of labor productivity and its growth rate. To this effect, in section 2 we revisit the augmented Solow model with exogenous growth to introduce cognitive skills and physical capital as determinants of human capital and proceed to remodel, accordingly, labor productivity and its conditional convergence. In section 3 we develop an endogenous growth model where cognitive skills, together with physical capital, contribute directly to the accumulation of effective human capital. We then proceed to remodel growth. The findings from investigating these models empirically are reported in Tables I-IV in the Appendix. A discussion on the empirical findings is presented in section 4 which concludes the main body of this paper. A list of the countries participating in this study together with a description of the data and its sources are reported in Tables V –VI in the Appendix. .

2. An Augmented Solow Model with Cognitive Skills

In what follows we shall let Y denote the level of output, K the stock of physical capital, L the number of workers engaged in the production of Y, h an index of skills embodied in the representative worker, $H \equiv hL$ the stock of human capital and A an index of labor-augmenting technical progress. The production of output in the *ith* country at time *t* , Y_{it}, is assumed to exhibit constant returns to scale in K_{it} and in $(A_{it}H_{it})$. As a result:

$$(1)\ \ Y_{it} = (A_{it}H_{it})^{1-\alpha} K_{it}{}^{\alpha} = (A_{it}h_{it}L_{it})^{1-\alpha} K_{it}{}^{\alpha}, \qquad 1 > \alpha > 0$$

Where α measures the elasticity of output with respect to physical capital. Accordingly, output per worker is determined by:

(2) $(Y_{it} / L_{it}) = (A_{it} h_{it})^{1-\alpha} (K_{it} / L_{it})^{\alpha}$

Where Ah measures the level of effective human capital per worker.

2.1 Modeling Effective Human Capital per Worker

Letting $COGN$ and SCH denote the level of cognitive skills and the average number of school years attended by the representative worker, respectively, and g the growth rate of labor-augmenting technical progress at the technology frontier, the path of effective human capital per worker can be defined by:

(3) $(Ah)_{it} = (K_i / L_i)_t^{\delta_1} \exp[(\delta_2 COGN_i)(\delta_3 SCH_{it})(gt)]^{1-\delta_1}$

Log-linearizing the expression in (3) above, applying time derivatives, taking $COGN$ and SCH to be time invariant and observing that on the balanced growth path $(Ah)_{it}$ and $(K / L)_{it}$ grow at a rate equal to g, one can verify that (3) can describe the equilibrium path of effective human capital per worker in a model with exogenous growth.

2.2 An Autoregressive Distributed Lag Model of Output per Worker

On the assumption that the logarithm of output per worker follows a stochastic, autoregressive, distributed lag process, the relations defined by (2)-(3) suggest that such a process can be described by:

$$(4) \quad \ln(Y/L)_{it} = \beta_0 + \rho \ln(Y/L)_{it-1} + \beta_1 \ln(K/L)_{it} + \beta_2 COGN_i + \beta_3 SCH_{i\,t-1} + \beta_4 g(t-1) + \varepsilon_{it}$$

Where ε_{it} is assumed to be white noise. Re-parameterizing (4) we arrive at:

(5)

$$\Delta \ln(Y/L)_{it} = -(1-\rho)[-\gamma_0 + \ln(Y/L)_{it-1} - \gamma_1 \ln(K/L)_{it} - \gamma_2 COGN_i - \gamma_3 SCH_{it-1} - \gamma_4 g(t-1)] + \varepsilon_{it}$$

Where: $\gamma_0 = (\beta_0/1-\rho)$, $\gamma_1 \equiv (\beta_1/1-\rho)$, $\gamma_2 = (\beta_2/1-\rho)$, $\gamma_3 = (\beta_3/1-\rho)$, $\gamma_4 = (\beta_4/1-\rho)$

Assuming the period of observation to be sufficiently long so that $\Delta \ln(Y/L) \cong \Delta \ln(K/L)$, noting that $\ln(K/L)_{it} \equiv \Delta \ln(K/L)_{it} + \ln(K/L)_{it-1}$, and using (5) to solve for $\ln(Y/L)_{it}$ we arrive at:

$$(6) \quad \ln(Y/L)_{it} = \gamma_0 + \gamma_1 \ln(K/L)_{it} + \gamma_2 COGN_i + \gamma_3 SCH_{it} + \gamma_4 gt - [\frac{\Delta \ln(K/L)_{it+1}(1-\beta_1)}{(1-\rho)}] + \tilde{\eta}_{it+1}$$

Where $\tilde{\eta}_{it+1} \equiv \{(\varepsilon_{it+1})/(1-\rho)\}$ plus deviations between $\Delta \ln(Y/L)_{it+1}$ and $\Delta \ln(K/L)_{it+1}$.

On the assumption that the saving rate, to be denoted by s, is a good proxy for $\Delta \ln(K/L)$, we can use s_{it+1} to substitute $\Delta \ln(K/L)_{it+1}$ out to arrive at:

$$(7) \quad \ln(Y/L)_{it} = \tilde{\gamma}_0 + \gamma_1 \ln(K/L)_{it} + \gamma_2 COGN_i + \gamma_3 SCH_{it} - [\frac{s_{it+1}(1-\beta_1)}{(1-\rho)}] + \tilde{\eta}_{it+1}$$

Where $\tilde{\gamma}_0 \equiv \gamma_0 + \gamma_4 gt$

Letting $\ln(Y/L)_i, \ln(K/L)_i, SCH_i,$ record time averages over the 1985-2006 period, and s_i record time averages over the 1996-2006 period, the cross-section model we tested empirically can be described by:

$$(8) \quad \ln(Y/L)_i = \delta_0 + \delta_1 \ln(K/L)_i + \delta_2 COGN_i + \delta_3 SCH_i + \delta_4 s_i + \upsilon_{it+1}$$

Where $\delta_0 = \tilde{\gamma}_0$, $\delta_1 = \gamma_1$, $\delta_2 = \gamma_2$, $\delta_3 = \gamma_3$, $\delta_4 = -\{(1-\beta_1)/(1-\rho)\}$

2.3 Modeling the Conditional Convergence of Output per Worker

Since $\Delta \ln(K/L) = g$ along the balanced growth, the evolution of $\ln(Y/L)_i$ along this path can be described by:

$$(9)\ \ \ln(Y/L)_i = \tilde{\delta}_0 + \delta_1 \ln(K/L)_i + \delta_2 COGN_i + \delta_3 SCH_i + \upsilon_{it+1}$$

Where: $\tilde{\delta}_0 = \delta_0 - [(1-\beta_1)/(1-\rho)]g$,

Letting $GR_i \equiv [(Y/L)_{i(2006)} - (Y/L)_{i(1963)}]/43$ define the exponential average growth rate of output per worker in the *ith* economy between 1963 and 2006, the conditional convergence model to be estimated empirically can be described by:

$$(10)\ \ GR_i = -[(1-e^{-\lambda(43)})/43][\ln(Y/L)_{(1963)} - \{\tilde{\delta}_0 + \delta_1 (K/L)_i + \delta_2 COGN_i + \delta_3 SCH_i\}] + v_{t+1}$$

3. Endogenous Growth with Cognitive Skills

A convenient way to introduce endogenous growth would be to revisit (3) with the view to replacing the exogenous g. To fix ideas, consider an economy-say the *ith* economy- which, by assumption, is not on the technology frontier. In such an economy human capital accumulates partly through the process of learning by doing associated with domestic investment and partly through the process of technology transfers associated mainly with imitation. Let this latter part of human capital accumulation be denoted by, say, $\tilde{g}_{it}$, and assume that $\tilde{g}_{it}$ increases with $COGN_i$, and with the distance of $(Ah)_{i_t}$ from the world frontier of effective human capital, the latter to be denoted by $(Ah)_t*$, to write:

$$(11)\ \ \tilde{g}_{it} = \alpha_1 COGN_i + \alpha_2 \ln[\frac{(Ah)_t*}{(Ah)_{it}}], \qquad \alpha_1 > 0, \quad \alpha_2 > 0,$$

If $COGN$ can serve as a proxy for human capital and human capital can serve as a proxy for the fraction of time the representative agent spends in education rather than in the production of the final product, then one cannot fail to notice that (11) resembles a synthesis of ideas in Lucas(1988), Benhabib and Spiegel (1994), and Hanushek and Woessmann (2009).

Using the expression in $\tilde{g}_{it}$ described above to replace the exogenous g in the path of $(Ah)_{it}$ described by (3), above, we arrive at:

$$(12)\quad (Ah)_{it} = B(K/L)_{it}^{\psi}[\exp(\tilde{g}_{it})t]^{1-\psi}$$

Log-linearizing (12), taking time derivatives, and plugging in the right-hand side of (11) we arrive at:

$$(13)\quad (A\dot{h}/Ah)_{it} = \psi\{(\dot{K}/K)_{it} - (\dot{L}/L)_{i}\} + (1-\psi)[\alpha_1 COGN_i + \alpha_2 \ln[\{(Ah^*)_t /(Ah)_{it}\}],$$

If the time horizon over which the variables in (13) are observed is sufficiently long to assume that $(A\dot{h}/Ah)_{it}$ = $(\dot{K}/K)_{it} - (\dot{L}/L)$ = GR_{it}, then an expression for GR_{it} simplifies to:

$$(14)\quad GR_{it} = \alpha_1 COGN + \alpha_2 \ln[\frac{(Ah)^*_t}{(Ah)_{it}}]$$

To implement (14) empirically we have used $\ln(Y/L)_{USA\,t}$ in place of the unobservable $\ln(Ah)*_t$, and $\ln(Y/L)_{it}$ in place of $\ln(Ah)_{it}$. Our decision not to introduce direct measures of $(Ah)*_t$ and $(Ah)_{it}$ in implementing (14) was influenced partly by the desire to minimize the effect of measurement errors and partly by the fact that Benhabib and Spiegel (op.cit.) have used income levels to proxy for technology levels successfully.

To further explore how the distance from the technology frontier affects growth we controlled for two dates: 1963, the initial date, and 1985 which was thought to be the date when a large number of countries would be approaching their balanced growth paths. Accordingly, we have tested two cross section regressions, each representing a reparameterized version of the other :

$$(15a)\quad GR_i = \beta_0 + \beta_1 COGN + \beta_2\{(\dot{K}/K)_i - (\dot{L}/L)_i\} + \beta_3 \ln[\frac{(Y/L)_{USA(1963)}}{(Y/L)_{i(1963)}}] + \beta_4 \ln[\frac{(Y/L)_{USA(1985)}}{(Y/L)_{i(1985)}}]$$

$$(15b)\quad GR_i = \beta_0 + \beta_1 COGN + \beta_2\{(\dot{K}/K)_i - (\dot{L}/L)_i\} + \beta_4[\ln\{\frac{(Y/L)_{USA(1985)}}{(Y/L)_{i(1985)}}\} - \ln\{\frac{(Y/L)_{USA(1963)}}{\ln(Y/L)_{i(1963)}}]$$

$$+ (\beta_3 + \beta_4)[\ln\{\frac{(Y/L)_{USA(1963)}}{\ln(Y/L)_{i(1963)}}\}]$$

To distinguish between the role of cognitive skills in facilitating technology transfers and their role in contributing to growth along the steady-state path we have tested the following relation:

$$(16)\, GR_i = \xi_0 + \xi_1 COGN + \xi_2[\ln\{\frac{(Y/L)_{USA(1963)}}{(Y/L)_{i(1963)}}] + \xi_3[\ln\{\frac{(Y/L)_{USA(1985)}}{(Y/L)_{i,(1985)}}\} - \ln\{\frac{(Y/L)_{USA(1963)}}{(Y/L)_{i(1963)}}]$$

$$+ \xi_4 (COGN)_i[\ln\{\frac{(Y/L)_{USA(1985)}}{(Y/L)_{i(1985)}}\} - \ln\{\frac{(Y/L)_{USA(1963)}}{(Y/L)_{i(1963)}}\}]$$

Finally, to facilitate a comparison between the size of growth explained by cognitive skills and the size of growth explained by "catching-up" we have estimated a relation where variables appear in standardized form. Specifically, attaching the prefix Z to a variable to indicate that the said variable appears in standardized form, and having established that the growth rate of the capital –labor ratio is not statistically significant in (15a) -(15b) we have estimated the relation given by:

$$(17)\ Z\,GR_i = \beta_0 + \beta_1 ZCOGN + \beta_2 Z\ln[\frac{(Y/L)_{USA(1963)}}{(Y/L)_{i(1963)}}] + \beta_3 Z\ln[\frac{(Y/L)_{USA(1985)}}{(Y/L)_{i(1985)}}]$$

4. Discussing the Empirical Findings and Concluding the Paper

The major finding in this paper, which confirms the findings in Hanushek and Woessmann (op.cit.), is that the quality of education measured by cognitive skills is the key determinant of human capital. Specifically, once the effect of cognitive skills has been controlled for, the number of schooling years attended is found to be statistically insignificant in determining labor productivity and is growth rate.

Another important finding in our study is that estimates of the elasticity of output per worker with respect to capital per worker are substantially higher than the share of income accruing to capital. For instance, the coefficient estimate on $\ln(K/L)$ in Table I is above 0.8. In Table II a speed of adjustment to the steady-state path of 0.01834 and a coefficient estimate of 0.01346 attached to the stock of physical capital per worker implies a capital elasticity of about 0.73. What these estimates indicate is that there is a very substantial externality associated with capital accumulation thus providing support to the hypothesis of "learning-by-doing". It is interesting to note that estimates of capital elasticity in Table 3 of Benhabib and Spiegel (op.cit.) range between a high of 0.871 and a low of 0.643- results which validate our findings

Estimates of the relation described by (16) presented in Table III confirm that a country which is behind the technology frontier initially has the potential of experiencing a higher growth rate than the rate to be enjoyed at the balanced growth path. Take for instance a country that enjoys the sample average level of cognitive skills measured at 4.52675, that $\ln[\frac{Y_{USA}}{Y_i}]_{1963} = 1.20400$, and that the speed it is closing the gap to the technology frontier is measured by the sample average defined by $\ln[\frac{Y_{USA}}{Y_i}]_{1985} - \ln[\frac{Y_{USA}}{Y_i}]_{1963} = -0.28803$. Then simple arithmetic confirms that this country must be growing at the sample exponential average rate of 2.2621% per annum.

One interesting implication of the model is that it can “predict” the growth rate along the balanced growth path. To see this suppose, for instance, that the cognitive skills index at the technology frontier is about 5.0 (slightly above the USA index). Then, according to the model’s parameter values this country will be growing at an exponential average rate of, approximately, to 1.175% which is taken to be the growth on the balanced growth path predicted by the model defined by 100(5)(0.00235)

According to the mechanics of the model (see, for instance, (14)) countries below the technology frontier whose index of cognitive skills is below the level enjoyed by the countries at this frontier have two choices: (a) maintain their current level of cognitive skills but keep a standard of living permanently below the standard of living at the frontier or (b) or raise the cognitive skill index through investment in education quality and close the gap in the standard of living. In either case all countries will be growing at the same rate at the balanced growth path: Being below the frontier makes it easier (cheaper) to imitate than to innovate thus permitting a country with a lower cognitive skills index to grow at the same rate as the innovator country.

Is it the strength of the “catching up” process that dominates during in the convergence period or is it the strength of cognitive skills which is mainly responsible in defining the growth rate at the balanced growth path? Turning to (17) and reparameterizing the estimates appearing in Table IV, suggests that “catching up” overwhelms cognitive skills in strength during convergence.

In order to control for the impact of climate/geography on growth and development, we have run cross-section growth regressions to include “Tropicar”, a variable that measures the percentage of a country’s area that lies in the tropics (see, Gallup, Sachs and Mellinger (1999)). Suffice to say that “Tropicar” turned out to be statistically insignificant.

In summary, human capital measured by an index of cognitive skills, is shown to directly affect the growth rate of human capital and thereby the growth rate of output per worker, to facilitate the technology diffusion process, and to affect directly the path of development as well

Appendix

Table I: Coefficient Estimates of the Determinants of $\ln(Y/L)$ in (8)

Constant	1.32237*** (0.31188)
$\ln(K/L)$	0.81307*** (0.044187)
$COGN$	0.23291*** (0.05129)
SCH	0.00689 (0.00997)
s	-4.37799*** (0.60769)

$R^2 = 0.9801$, Number of Observations: 48, $F(4,43) = 777.9$, Prob>F =0.000, RMSE = 0.13477

Robust standard errors in parentheses. *** ** Denote significance at the 1% and 5% respectively

Table II: Coefficient Estimates of the Determinants of GR in (10)

Constant	0.02028 (0.01295)
$\ln(Y/L)_{1963}$	-0.01834^{***} (0.00149)
$\ln(K/L)$	0.01346^{***} (0.00218)
COGN	0.00575^{***} (0.00186)
SCH	0.00059 (0.00048)

$R^2 = 0.8568$, Number of Observations: 48, $F(4,43) = 124.13$, Prob>F =0.000, RMSE = 0.00482

Robust standard errors in parentheses. *** ** Denote significance at the 1% and 5% respectively

Table III: Coefficient Estimates of the Determinants of in GR in (15a)-(15b), and (16)

Constant	-0.00003 (0.00570)	-0.00003 (0.00570)	0.00260 (0.00523)
$(\dot{K}/K)-n$	-0.00130 (0.04178)	-0.00130 (0.04178)	
COGN	0.00296** (0.00115)	0.00296** (0.00115)	0.00235** (0.00104)
$\ln[\frac{Y_{USA}}{Y_i}]_{1963}$	0.02488*** (0.00131)	0.002323*** (0.0008648)	0.00215** (0.00084)
$\ln[\frac{Y_{USA}}{Y_i}]_{1985}$	-0.02256*** (0.00158)		
$\ln[\frac{Y_{USA}}{Y_i}]_{1985}$ - $\ln[\frac{Y_{USA}}{Y_i}]_{1963}$		-0.022559*** (0.00158)	-0.01580*** (0.00331)

(COGN) $\ln[\frac{Y_{USA}}{Y_i}]_{1985}$ - $\ln[\frac{Y_{USA}}{Y_i}]_{1963}$

-0.00162**
(0.00078)

$R^2 = 0.9690$, Number of Observations: 48, $F(4,43) = 307.23$, Prob>F =0.000, RMSE = 0.00224. Robust standard errors in parentheses. *** ** Denote significance at the 1% and 5% respectively

Table IV: Coefficient Estimates of the Determinants of ZGR in (17)

Constant	0.00000 (0.02625)
ZCOGN	0.14960** (0.05615)
$Z\ln[\frac{Y_{USA}}{Y_i}]_{1963}$	2.037321*** (0.05875)
$Z\ln[\frac{Y_{USA}}{Y_i}]_{1985}$	-1.69261*** (0.0888638)

$R^2 = 0.9690$, Number of Observations: 48, $F(3,44) = 418.93$, Prob>F =0.000, RMSE = 0.18188.

Robust standard errors in parentheses. *** ** Denote significance at the 1% and 5% respectively

Table V: A List of the Countries Participating in this Study

(1) Argentina, (2) Australia, (3) Austria, (4) Belgium, (5) Botswana, (6) Brazil

(7) Canada, (8) Chile, (9) China, (10) Colombia (11) Cyprus, (12) Denmark,

(13) Egypt, (14) Finland, (15) France, (16) Ghana, (17) Greece, (18) Hong Kong ,

(19) Iceland, (20) India, (21) Indonesia, (22) Iran, (23) Ireland, (24) Israel, (25) Italy,

(26) Japan, (27) Jordan, (28) Korea, (29) Luxembourg, (30) Malaysia, (31) Mexico,

(32) Morocco, (33) Netherlands, (34) New Zealand, (35) Norway, (36) Peru,

(37) Philippines, (38) Portugal (39) Romania, (40) Singapore, (41) South Africa,

(42) Spain, (43) Sweden, (44) Switzerland, (45) Tunisia, (46) UK, (47) Uruguay,

(48) USA,

Table VI: The Data Utilized in Tables I-III

(Y/L): PPP Converted GDP Chain per Worker at 2005 prices, PWT 7.0

(K/L): Capital-Labor Ratio, EPWT Version 4.0

$(COGN)$: Cognitive Skills Data, in Hanushek and Woessmann (2009)

SCH: Average Years of Total Schooling, Barro and Lee (2010), BL(2010) MF2599, v 1.2

(I/Y): Investment Share of PPP Converted GDP Per Capita at 2005 Constant Prices, PWT 7.0

$q \equiv (PI/P)$: Price Level of Investment/Price Level of GDP, PWT 7.0

$s \equiv q(I/Y)$: The Measure of the Saving Rate Utilized in this Paper

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