Cognitive Skills, Openness and Growth*

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Abstract

A significant positive relationship exists between the ratios of trade and educational spending to GDP implying that countries which are more open on the trade front also spend more on education. An open economy endogenous growth model with human capital is developed to understand this stylized fact. The model predicts that countries with greater cognitive skills spend more on education, and grow faster. These countries open up on the trade front to finance import of raw materials for investment goods production which becomes scarce due to the diversion of resources to education. The model highlights the importance of the productivity of human capital or cognitive skill as an important economic fundamental determining the cross country correlation between growth, trade share and education share.

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1 Introduction

While the relationships between trade openness and growth as well as growth and education have been well explored, little effort has been made to understand these variables in an integrated growth model. Do open countries invest more in human capital? The issue is relevant for both empirical and theoretical reasons. It is well known that human capital is a vehicle of growth and growing economies are more open. A plethora of literature exists showing the connection between growth and education in a closed economy context (Barro (1991), Mankiw, Romer and Weil (1992), Jorgenson and Fraumeni (1992), Parente and Prescott, (2002)).[1] There is also a significant volume of literature addressing the issue of openness and growth (Grossman and Helpman (1990), Manning (1982), Cartiglia (1997)).[2] However, it is not clear from the extant literature what common fundamentals link education, openness and growth. This paper is a quest for such fundamentals.

We propose that the cognitive skills of a country's population are powerfully connected to growth, openness and education. The cognitive skills of pupils reflect the quality of schooling. Hanushek and Woessmann (2008) measure these cognitive skills by the Programme for International Student Assessment (PISA) test scores in mathematics and science, primary through the end of secondary school for all years (PISA scale divided by 100). They argue that differences in quality of schooling make cognitive skills differ even though the years of schooling are the same across countries. This results in cross-country differences in returns to schooling and growth rates.

[1]Bils and Klenow (2000), however, point out that the growth effects of schooling may be overestimated due to reverse causality from growth to schooling. Basu and Bhattarai (2011) show that the growth effect of schooling could depend on the government bias in education.

[2] Basu and Guariglia (2007) point out that FDI can complement human capital and could be beneficial for growth at the expense of greater inequality. Galor and Mountford (2008) further show that gains from trade are more directed towards investment in education and growth in OECD countries while these gains are more channelled towards higher fertility and population growth in case of developing countries.

The development facts that we present in the next section show that there is a significant cross country positive correlation between trade share, education share and cognitive skills. This motivates us to develop an open economy growth model to understand this linkage. In our model, the principal driver of this skill-based technical change is cognitive skill. Higher cognitive skills of pupils could enhance the returns from schooling which provides the nation an incentive to divert raw labour from the goods to education sector. This gives rise to a relative scarcity of physical capital with respect to human capital. If the bulk of physical capital is made from imported raw materials from abroad, such a shortage makes it necessary for the economy to open up more on the trade front. Thus countries with higher cognitive skills invest more in education and also become more open on the trade front. We demonstrate this hypothesis in terms of an open economy endogenous growth model with human capital in the tradition of Becker (1975) and Lucas (1988). The paper derives closed form solutions for balanced growth rate, educational investment rate and openness showing how cognitive skills jointly determine all these three macroeconomic variables. To the best of our knowledge, our paper is the first in the literature which explores the role of cognitive skills in determining openness, education and growth within an endogenous growth model.

The rest of the paper is organized as follows. The following section documents some development facts. Section 3 lays out the endogenous growth model. Section 4 describes the long run properties of the model. Section 5 performs short run analysis in terms of impulse responses. Section 6 concludes.

2 Some Development Facts

To gain empirical motivation, in this section we present some cross-country development facts about education, openness, growth and cognitive skills.

Table 1 reports the summary statistics for these variables. Data show enormous variations across countries. Among 186 countries, openness measured by the ratios of exports $\left(\frac{x}{y}\right)$, imports $\left(\frac{m}{y}\right)$ and sum of exports and imports $(\frac{x+m}{y})$ to GDP vary remarkably. Small and highly developed countries like Singapore export around 221 percent of GDP followed by Aruba, Hong Kong, Luxemburg and Macao which have openness of more than 100 percent. On the other extreme, there are countries such as Argentina, Brazil, USA and India with exports less than 10 percent of their GDP. Only 45 countries in the world export more than 50 percent of their GDP. The median export ratio is 29 percent. Similar variation is seen in the education spending ratio ($Educ$) among 175 countries. Countries like Guam, American Samoa and New Caledonia spend more than 10 percent of gross national income (GNI) in education while countries like Laos, Congo, Chad, Haiti, Myanmar, Bangladesh, Somalia and Indonesia have less than 1.5 percent of their GNI in it. The range of cognitive skills in the sample of 77 countries is from 3.089 (South Africa) to 5.338 (South Korea). Average growth rate of GDP was 3.88 percent per year. Ukraine (-1.6 percent) and Bosnia and Herzegovina (16.9 percent) are outliers mainly because of missing data series.

To motivate our theoretical model where the home country produces investment goods with the aid of imported raw materials, we take merchandise imports (defined in the IMF's DOTS from the World Bank's WDI database) to be a good indicator of imported raw materials (rm). Such imports include spare parts, food, agricultural raw materials, fuels, ores & metals and manufactured products. These imported raw materials are the US dollar c.i.f value of goods purchased from the rest of the world as shown in Table 1.

The trends of cross country averages of ratio of education spending to GNI, growth rates of GDP and ratios of imports and exports to GDP are shown in Figure 1 for the last thirty five years.[3] The secular rising trends in

[3]See the note of Table 1 for definitions of variables and the Appendix B for the list of countries for each variable.

Table 1: Summary Statistics: 1971-2007

Variable	N	Mean	StDev	Min	Q1	Median	Q3	Max
$Educ$	175	4.08	1.667	0.823	2.776	4.045	5.09	11.583
$\frac{x}{y}$	186	36.96	25.26	3.38	20.2	29.48	48.01	221.15
g	186	3.88	2.322	-1.624	2.613	3.668	4.742	16.882
$\frac{m}{y}$	186	43.97	24.4	8.3	26.91	37.02	58.69	196.3
$\frac{x+m}{y}$	186	80.93	47.21	15.85	50.31	71.27	105.81	417.45
Q	75	4.5298	0.5629	3.089	4.107	4.641	4.995	5.338
$\frac{rm}{y}$	181	64.62	38.02	14.69	39.9	57.66	79.9	286.14

Definitions of variables:

- $Educ$: Education expenditure (% of GNI) for 1960-2006.
- $\frac{x}{y}$: Exports of goods and services (% of GDP) for 1960-2006.
- g : Growth rate of GDP (annual %) for 1960-2006.
- $\frac{m}{y}$: Imports of goods and services (% of GDP) for 1960-2006.
- $\frac{x+m}{y}$: Total trade (% of GDP), for 1960-2006.
- $\frac{rm}{y}$: Merchandise trade (% of GDP), as in the IMF's DOTS, for 1960-2006.
- Q : Cognitive skills of pupils (based on average PISA scores in math and science).

import and export ratios indicate the rapid pace of globalization in the last four decades. This rise is associated with an increase in the ratio of education spending to GDP during this period.

2.1 Cross-country relationship between education, openness and growth

Table 2 reports the cross-country correlations between time averages of openness, growth and education spending ratios. Four measures of openness are used, namely $x/y, m/y,(x+m)/y$ and rm/y which are defined in Table 1. For all these four measures, statistically significant (at the 5% level) positive correlations are found between openness and education as well as openness and growth. These positive correlations are reasonably robust with respect to finer partitions of countries.

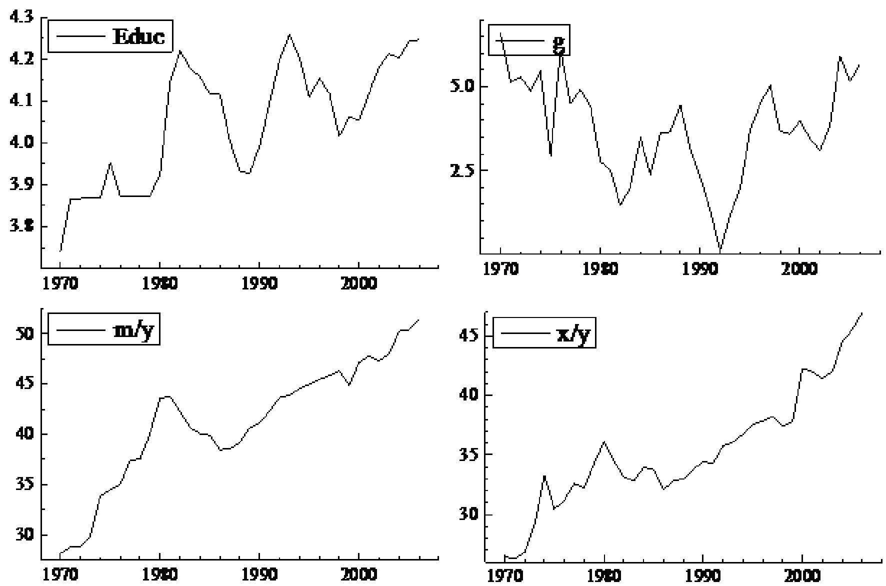

Figure 1: Averages of education spending ratios, growth rates, import and export ratios

Table 2: Pearson Correlation Coefficients among Ratios of Education Spending, Imports and Exports and Growth Rates

	$Educ$	$\frac{x}{y}$	g	$\frac{m}{y}$	$\frac{x+m}{y}$	rm/y
$Educ$	1					
$\frac{x}{y}$	0.23(0.01)	1				
g	-0.16(0.029)	0.17(0.023)	1			
$\frac{m}{y}$	0.23(0.002)	0.81(0.000)	0.14(0.051)	1		
$\frac{x+m}{y}$	0.24(0.001)	0.95(0.000)	0.16(0.026)	0.94(0.000)	1	
rm/y	0.18(0.011)	0.82(0.000)	0.13(0.082)	0.80(0.000)	0.85(0.000)	1
Note: p-values are in the parenthesis. See notes in Table 1 for definitions of variables.						

Table 2 also shows a negative correlation between growth rates and education spending. This reflects the fact that low income countries tend to grow faster than higher income countries which makes the education share to correlate negatively with growth. To verify this conjecture, we sort the data between low income and high income countries. For low income countries, the correlation is -0.17 while for high income countries it is .002. The relationship between education and growth is nonlinear and it cannot be captured by a linear regression analysis. Basu and Bhattarai (2011) identify government bias in education as a crucial determinant of the strength of relationship between growth and public spending on education and find a U shaped relation between education and growth.

2.2 Panel Regressions

To check further for robustness of the relationship, we run panel regressions covering a sample period of 1971-2006 for 14 categories of countries in the world after controlling for fixed and random effects. These 14 groups based on the World Development Indicators (2007) include countries with low income, middle income, lower middle income, upper middle income, Asia and Pacific, Latin American, Middle Eastern, South Asia, South Africa, high income, high income OECD and highly indebted ones. Each country has 36 years of observation from 1971 to 2006. One degree of freedom is lost for each country in the dynamic panel regression. List of countries included in each of these 14 categories is given in Appendix B2.

Tables 3 and 4 report static panel regressions of export share $\left(\frac{x}{y}\right)$, import share $(\frac{m}{y})$ on education share ($Educ$) and growth rate (g).[4] While both models are significant on the basis of F and χ^2 tests, the random effect model is recommended by the Breusch-Pagan LM test.[5]

Table 3: Static Panel Regression of Export Ratio on Education Spending Ratio and Growth Rate

Dep Variable: $\frac{x}{y}$	Fixed Effect	Random Effect
$Educ$	2.707***	2.550***
g	81.056***	80.558***
Constant	8.335***	8.927***
Tests	$F(2, 488) = 36.44(0.000)$	Wald: χ^2 (2) = 71.7 (0.000)
Sample	N =14; T=36; NT= 504	N =14; T =36; NT= 504
Within	0.1299	0.1299
Between	0.006	0.006
Overall	0.0556	0.0556
Breusch-Pagan LM Test for random effect model χ^2 (2) = 1545.0 (0.000)		
See notes in Table 1 for definitions of variables.		

We find clear evidence of positive impacts of education spending ratio ($Educ$) and growth rates (g) on ratios of exports $\left(\frac{x}{y}\right)$ and imports $\left(\frac{m}{y}\right)$. Fixed and random effect estimates presented in Tables 3 and 4 provide strong empirical evidence for the central hypothesis of this paper that countries that

[4]These regression results are robust on the grounds of stationarity and cointegration criteria. We have performed common panel unit root tests and Pedroni's (1999) panel cointegration tests involving $\frac{m}{y}$, $\frac{x}{y}$, $Educ$ and g and found a long run relationship. These results are not reported here for brevity but available from the authors upon request.

[5]It is important to note that the panel regression results reported here only show a long run relationship between openness, education and growth. Many factors could contribute to an endogenous long run relationship between these three variables. In this paper, we focus on cognitive skills.

spend more on education and grow faster are more open. The Breusch-Pagan LM test suggests that random effect model is more appropriate although there is little difference in the estimates between these two models.

Table 4: Static Panel Regression of Import Ratio on Education Spending Ratio and Growth Rate

Dep Variable: $\frac{m}{y}$	Fixed Effect	Random Effect
$Educ$	2.462***	2.329***
g	72.089***	70.907***
$Constant$	10.590***	11.110***
Tests	$F(2, 488) = 35.3(0.000)$	Wald: χ^2 (2) = 67.8 (0.000)
Sample	N =14; T=36; NT= 504	N =14; T=36; NT= 504
Within	0.126	0.126
Between	0.012	0.012
Overall	0.0163	0.0163
Breusch-Pagan LM Test for random effect model χ^2 (2) = 2218.2 (0.000)		
See notes in Table 1 for definitions of variables.		

In these panel regressions, there is a potential problem of endogeneity of regressors due to correlation of the unobserved panel level effects with the lagged dependent variables. This could lead to inconsistency of estimates. Arellano and Bover (1995) and Blundell and Bond (1998) employ a GMM method to remove such inconsistency which is appropriate for a large panel and fewer periods. Estimations based on Blundell-Bond (1998) system method are reported in Tables 5 and 6. Both Arellano-Bover and Blundell-Bond estimation methods perform better than the Arellano-Bond (1991) estimator for our sample. A robust and significant dynamic panel relationship holds between the overall trade share and growth. Although education spending ratio has a positive sign as expected, it is not statistically significant. This issue could be investigated further as richer and better data sets become available.

Table 5: Dynamic Panel Regression of Trade Ratio on Education Spending Ratio and Growth Rate: Arellano-Bover/Blundell-Bond Estimation

Dep Variable: $\frac{x+m}{y}$	Coefficient	Z-value	p>|z|
$\frac{x+m}{y}(-1)$	1.119***	33.47	0.00
$\frac{x+m}{y}(-2)$	-0.177	-3.11	0.00
$\frac{x+m}{y}(-3)$	0.035***	0.83	0.41
$Educ$	0.167	0.70	0.49
g	31.003***	5.40	0.00
$Constant$	0.554	0.57	0.571
Wald χ^2 (5) = 11013.6 (0.000).			
Sample size N=14; T=33; NT =462			

Table 6: Dynamic Panel Regression of Import Ratio on Education Spending Ratio and Growth Rate: Arellano-Bover/Blundell-Bond Estimation

Dep Variable: $\frac{m}{y}$	Coefficient	Z-value	p>|z|
$\frac{m}{y}(-1)$	1.151***	34.33	0.00
$\frac{m}{y}(-2)$	-0.338***	-5.89	0.00
$\frac{m}{y}(-3)$	-0.124***	2.94	0.00
$Educ$	0.093	0.71	0.48
g	15.226***	5.00	0.00
Constant	1.135**	2.11	0.04
Wald χ^2 (5)= 7933.6 (0.000)			
Sample size N=14; T=33; NT =462			

2.3 Is cognitive skill a driver of the cross-country relationship between openness, education and growth?

The central hypothesis of this paper is that the cross-country relationship between openness, education and growth is attributed to cross-country variation of a common fundamental which is cognitive skill. To see the empirical plausibility of such a hypothesis we compute the cross-country correlation and regression of export, import and education shares on cognitive skill which are reported in Tables 7 and 8. The high cognitive skill of pupils, measured by international test scores in mathematics and science could result from numerous factors including better quality of schooling, as well as education subsidy.[6] Using cross section data set from Hanushek and Woessmann (2008) for cognitive skills for 2006 we compute the cross-country correlations of cognitive skills with export, import and education shares for all 75 countries and selectively for low and high cognitive skill countries as reported in Table 7. High-cognitive skill countries with a score more than 4.803 tend to spend less time on education and have a higher trade share.

Table 7: Pearson correlation coefficients among cognitive skill, imports, exports and education shares

	Low cognitive skill countries			High cognitive skill countries		
	$\frac{x}{y}$	$\frac{m}{y}$	$Educ$	$\frac{x}{y}$	$\frac{m}{y}$	$Educ$
Cog Skill (Q)	0.268	0.341	0.053	0.444	0.426	-0.315
p-values	0.086	0.027	0.740	0.01	0.014	0.075
See Appendix B2 for countries in this sample and also notes in Table 1						

The data for cognitive skill are limited and only available for a single year, 2006, from Hanushek and Woessmann (2008). Thus standard Granger causality tests are not possible. We thus explore the causal relation between cognitive skills and the above variables using a cross section regression of averages of growth rate (g), education ratios ($Educ$) imports $\left(\frac{m}{y}\right)$ and exports shares $\left(\frac{x}{y}\right)$ on cognitive skill as a right hand side variable. The effects of cognitive skills on openness and growth are found to be positive and significant at the 5% level as shown in Table 8. The coefficient of cognitive skill on education spending ratio regression is negative but not found statistically significant at the 5% level. However, when splitting the sample between low cognitive skill and high cognitive skills (using the median as the cut-off point), a positive relationship, although not statistically significant, emerges

[6] Hanushek and Woessmann (2008) dataset contains 75 countries. They compute the cognitive skills average of each country based on PISA test scores in mathematics and science. We thank them for providing us this data.

between these two variables for low cognitive-skill countries.

Reverse regressions of cognitive skill on growth or openness measures (not reported here for brevity) are not found to be statistically significant which tends to suggest that cognitive skill is the driving force in determining the three important macroeconomic variables. Although such static regressions do not necessarily lead us to conclude anything about the causal ordering, it provides enough motivation for our endogenous growth model where cognitive skill is a driver of the cross-country relationship between openness and growth.

Table 8: Regression of growth rate, export and import shares on congnitive skills

	g	$Educ$	$Educ\_low$	$Educ\_high$	$\frac{x}{y}$	$\frac{m}{y}$
Constant	-18.95	18.62**	3.35	16.88**	-558.0*	-470.8*
Cognitive-skill (Q)	4.50***	-2.76	0.11	-2.41	120.0**	102.0**
R^2	0.18	0.10	0.02	0.08	0.20	0.18
F	4.2**	3.4*	0.05	2.86	7.7***	6.9**
DW	2.6	1.75	2.04	1.71	2.70	2.60
N	33	33	41	34	33	33

See notes on Table 1. $Educ\_low$ and $Educ\_high$ stand for education ratios of low and high cognitive skill countries respectively.

The development facts emerging from these panel correlation and regression analyses can be summarized as follows. First, there is a significant cross-country positive correlation between trade openness and educational investment. Second, countries with a higher cognitive skill index tend to grow faster and are more open on the trade front. These correlation and regression results are used to motivate the formulation of an endogenous growth model in the next section. The central object of this growth modelling is to understand the linkage between cognitive skill, openness and education by cross country variation of cognitive skills alone.

3 The Model

The model is a small open economy adaptation of the Lucas-Uzawa (Lucas, 1988) model. There are two sectors, goods and education. We view the problem from the perspective of a representative small open economy in a global environment. The home country produces the output in the goods sector (y_t) with physical capital (k_t) and home grown intangible or human capital (h_t). The human capital evolves following the linear technology:

$$h_{t+1} = (1 - \delta_h)h_t + Q_t h_t \tag{1}$$

where $\delta_h \in (0, 1)$ is the rate of depreciation[7] and Q_t is a crucial human capital fundamental called cognitive skills of the home country's population. Given the current level of human capital (h_t), the human capital achieved in the following period will be greater if the cognitive skills, Q_t are higher. The introduction of this cognitive skills variable is motivated by the recent work of Hanushek and Woessmann (2008).[8] By cognitive skill, we mean the learning ability of pupils. This learning ability could depend partly on parent's and pupil's schooling efforts. We posit the following technology for the cognitive skill.

$$Q_t = A_{Ht}.l_{Ht}^{\theta} \tag{2}$$

where $\theta > 0$ and l_{Ht} is the fraction of raw labour time (inelastically supplied at unity) allocated to schooling. We do not impose any restriction such as diminishing returns to schooling efforts in augmenting cognitive skill as the nature of returns to scale in human capital is a debatable question. In fact, increasing returns to cognitive skill are quite plausible (θ exceeding unity)

[7] Alternatively $(1 - \delta_h)$ could be thought of as the degree of intergenerational transmission of knowledge as in Bandyopadhyay and Basu (2005).

[8] Basu and Guariglia (2008) also use the same human capital investment technology to understand the effect of education on the pace of industrialization.

if there is family based externality.[9] For example, in addition to parent's own effort, the child can additionally benefit if other family members such as grandparents could spend time on the child's education. This is akin to what Friedman (1962) calls "neighbourhood effect" of education in a free society. In our calibration exercise, we allow a range of variation of θ around the baseline value of unity.[10] The variable A_{Ht} is an exogenous educational total factor productivity (TFP) variable that depends on a host of institutional and public policy factors including positive externality and social returns of public spending on education.[11]

Final goods (y_t) are produced with the help of human and physical capital via the Cobb-Douglas production technology:

$$y_t = A_{Gt} {k_t}^{\alpha} (l_{Gt} h_t)^{1-\alpha} \tag{3}$$

with $0 < \alpha < 1$. The variable A_{Gt} is the date t exogenous total factor productivity (TFP) in the goods sector, and l_{Gt} $(= 1 - l_{Ht})$ is the fraction of raw labour directed to the goods sector production.

We assume the following stationary stochastic processes for these two TFP shocks around the steady state:

$$A_{Gt} - \bar{A}_G = \rho_G (A_{Gt-1} - \bar{A}_G) + \xi_t^G \tag{4}$$

$$A_{Ht} - \bar{A}_H = \rho_H (A_{Ht-1} - \bar{A}_H) + \xi_t^H \tag{5}$$

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[9] For example, Romer (1986) specifies a production technology with increasing returns to knowledge capital.

[10] When θ equals unity, the human capital technology reduces to Lucas (1988) technology which we treat as our baseline for calibration. In our sensitivity analysis, we allow θ to range from 0.98 to 1.02.

[11] We abstract from public policy and institutional factors that could influence public policy. Basu and Bhattarai (2010) explore a model where the cognitive skill could depend on the public spending on education. Basu (2009) argues that malnutrition could impair pupil's learning ability.

where $\bar{A}_G$ and $\bar{A}_H$ are the steady state TFP of the goods and education sectors. Autocorrelation coefficients ρ_G and ρ_H are positive fractions and ξ_t^G and ξ_t^H are white noises.

Final goods are used for consumption (c_t), domestic investment (i_t^d) and export (x_t). The resource constraint facing the home country is:

$$c_t + i_t^d + x_t = y_t \tag{6}$$

The home country imports raw materials (rm_t) at a fixed price p^k. Examples of these imported raw materials are machine tools, technology blueprints, patents etc.

Investment goods (i_t^k) are produced combining domestic nontraded investment goods (i_t^d) and imported raw materials (rm_t) in fixed proportions using the following Leontief production function:

$$i_t^k = \min\left[i_t^d, rm_t\right] \tag{7}$$

which means that $i_t^k = i_t^d = rm_t$ along an efficient production frontier.[12]

The domestic physical capital stock evolves following the standard linear depreciation rule:

$$k_{t+1} = (1-\delta_k)k_t + i_t^k \tag{8}$$

The home country finances these imported raw materials by a combination of export and foreign borrowing (b_t) at a fixed world interest rate, r^*. The current account equation is given by:

[12] An example could help to motivate such a technological environment. Suppose the home country produces an extra computer (i_t^k). It requires a home produced mother board (i_t^d) and an imported co-processor (rm_t). Thus an increase in investment in physical capital necessitates an equi-proportionate increase in imported raw materials/intermediate input.

$$x_t + b_{t+1} = (1 + r^*)b_t + p^k rm_t \tag{9}$$

The home country faces a borrowing constraint. The amount that it can borrow in the international market is constrained by the current capital stock of home country, which means[13]:

$$b_t \leq k_t \tag{10}$$

The time-line is as follows. At date t, the state of the economy is characterized by k_t, h_t and b_t. The home country after realizing the TFP shocks, ξ_t^G and ξ_t^H, makes decisions about goods production (y_t), schooling time (l_{Ht}), exports (x_t), external borrowing (b_{t+1}) and consumption (c_t) which maximizes the following expected utility functional:

$$E_0 \sum_{t=0}^{\infty} \beta^t U(c_t)$$

subject to (1) through (10).

Assuming that the borrowing constraint binds, plugging (7), (8) , (9) and (10) into (6) one gets the combined resource constraint:

$$c_t + p^k k_{t+1} - \{(1 + p^k)(1 - \delta_k) - 1 - r^*\}k_t = y_t. \tag{11}$$

[13]Such a borrowing constraint can be motivated as follows. While setting a credit limit, the external lending agency (say the World Bank) takes into consideration the long run growth prospect of the home country. Thus in principle, the borrowing limit is determined by the present value of the future stream of output of the home country. Since along a balanced growth path, home country's output/capital ratio is a constant, the borrowing limit is thus proportional to the capital stock, k_t. We assume here an exogenous borrowing constraint. Such a borrowing constraint can be rationalized by following the lines of reasoning of Eaton and Gersovitz (1981) who show that the borrowing limit is the minimum of the amount that a country wishes to borrow and the credit ceiling determined by the lender based on their perception of default risk of the sovereign country.

4 Balanced Growth Properties

Hereafter we specialize to a logarithmic utility function, $U(c_t) = \ln c_t$, to analyze the long run and short run properties of the model. In order to focus on the long run properties of the model, we assume also that the two productivity variables, A_{Gt} and A_{Ht} are fixed at the stationary levels $\bar{A}_G$ and $\bar{A}_H$.

The balanced growth equations for the key macroeconomic variables are as follows. The Appendix A.2 shows the details of the derivation.

Growth Rate:

$$1 + g = \frac{h_{t+1}}{h_t} = \frac{k_{t+1}}{k_t} = \frac{c_{t+1}}{c_t} = \beta[1 - \delta_h + \bar{A}_H l_H^{\theta-1}(l_H + \theta l_G)] \tag{12}$$

Export Share in GDP:

$$\frac{x_t}{GDP_t} = \frac{\alpha\beta(1 - \delta_h + \bar{A}_H)(p^k - 1) + \alpha(1 + r^*) - \alpha(1 - \delta_k)p^k}{MPK} . \frac{\theta l_G}{\theta l_G + (1 - \alpha)l_H} \tag{13}$$

Import Share in GDP:

Denote the import bill of raw materials as m_t. By definition, $m_t = p^k.rm_t$. Thus, import share in GDP is given by:

$$\frac{m_t}{GDP_t} = \frac{\alpha p^k\{\beta(1 + \bar{A}_H - \delta_h) - (1 - \delta_k)\}}{MPK} . \frac{\theta l_G}{\theta l_G + (1 - \alpha)l_H} \tag{14}$$

where MPK denotes the marginal product of physical capital.

Education Share in GDP:

$$Educ = \frac{(1 - \alpha)l_H}{\theta l_G + (1 - \alpha)l_H} \tag{15}$$

where GDPat date t is defined as:

$$GDP_t = \lambda_t y_t + \mu_t Q_t h_t \tag{16}$$

Few clarifications about these equations are in order. Equation (12) is the balanced growth rate which depends in a quite standard way on the relative time allocations, the productivity parameters entering the human capital technology (1) and the subjective discount factor β. Export and import shares in (13) and (14) depend on the balanced growth properties of the model and thus they depend on the same set of parameters as well as the goods sector technology coming through the marginal product of capital term. The share of education in GDP in (15) is carefully computed by taking into account that the GDP consists of final goods and education services which are produced in two different sectors. These two items have different shadow prices which are proportional to the marginal costs of diverting resources from one sector to the another. While computing the GDP one needs to multiply each item by its respective shadow prices which are the relevant Lagrange multipliers. This explains the GDP equation (16).

4.1 Comparative Statics and Simulation

The primary purpose of this section is to understand how the steady state balanced growth rate (g), openness (measured by $((x+m)/GDP)$ and education share ($Educ$) respond to changes in the long run cognitive skills (Q). It may be noted from (2) that cognitive skill is endogenous because it depends on the time allocated to the education sector, l_H. How this time spent on schooling influences cognitive skill Q depends on the two schooling technology parameters, namely $\bar{A}_H$ and θ, which are our main focus of attention in this section. Countries may differ in these two cognitive skill parameters which could give rise to cross country dispersion in growth, education share and openness.[14] Such a comparative statics analysis could give useful insights why high-cognitive-skill countries invest more in schooling, grow faster and are more open, which is the central question in this paper.

An inspection of the growth equation, (12), the export and import share equations (13) and (14), the education share (15) equation reveals that these two cognitive skill parameters appear either explicitly or implicitly in all these equations. We start from a baseline case $\theta = 1$ for which we have tractable analytical results. We have the following proposition.

Proposition 1 *If $\theta = 1$, along the balanced growth path, the following results hold:*

$$l_H = \beta - \frac{(1-\beta)(1-\delta_h)}{\bar{A}_H} \tag{17}$$

$$Educ = \frac{(1-\alpha)l_H}{1-\alpha l_H} \tag{18}$$

$$\frac{k}{h} = \left[\frac{\alpha \bar{A}_G}{p^k(1-\delta_h+\bar{A}_H)+(1+r^*)-(1-\delta_k)(1+p^k)}\right]^{\frac{1}{1-\alpha}}(1-l_H) \tag{19}$$

$$MPK = p^k(1-\delta_h+\bar{A}_H)+(1+r^*)-(1-\delta_k)(1+p^k) \tag{20}$$

Proof: Appendix A.3.

A sharp implication of Proposition 1 is that a long run increase in cognitive skill ($\bar{A}_H$) raises the time allocation (l_H) to the education sector and a higher education share ($Educ$). This results in a higher stock of human capital which depresses the ratio of physical to human capital ratio (k/h). Thus it raises the marginal product of capital (MPK). Because of nonlinearity,

[14] It is needless to mention here that many factors besides cognitive skills could give rise to cross country variation in these three key variables. Our focus in this paper is on cognitive skill.

it is not analytically obvious how export and import shares in equations (13) and (14) respond to a change in $\bar{A}_H$. We, therefore, resort to a numerical simulation based on a calibrated version of this model. This baseline model will also be used in the next section for performing short run analysis.

There are nine parameters, $\bar{A}_G$, $\bar{A}_H$, p^k, r^*, α, β, δ_h, δ_k, and θ which describe the preferences, technology and accumulation processes in the economy. Parameters α and β are fixed at the conventional levels as in many studies including Prescott (1986). The second moment parameters for the two forcing processes A_{Gt} and A_{Ht} are also fixed at levels as in Maffezzoli (2000). The world interest rate r^* is fixed at 4% in line with the Bank of England estimate.[15] The depreciation rates δ_k and δ_h are fixed at the values calibrated by Maffezzoli (2000) who also has a two sector growth model similar to ours. The goods sector TFP scale parameter $\bar{A}_G$ is fixed at 1.2 as in Basu et al. (2011). The human capital productivity scale parameter $\bar{A}_H$ is fixed to target a 3.67% median growth rate for our sample of 182 countries. The relative price of capital p^k is fixed at 6 to target the median trade share of 71.27% for our sample of 186 countries. The cognitive skill parameter θ is fixed at 1 on par with Proposition 1. Such a value of θ gives rise to a 2:1 time allocation between goods and education sectors which is consistent with other studies including Benk et al. (2009) and Basu et al. (2009). Table 9 reports the baseline values of these parameters.

Table 9: Baseline Parameters

α	p^k	$\bar{A}_H$	$\bar{A}_G$	r^*	β	δ_h	δ_k	θ	ρ_G	ρ_H	σ_G	σ_H
0.65	6.00	0.172	1.2	0.04	0.9	0.020	0.011	1.00	0.962	0.962	0.032	0.032

Table 10 reports the comparative statics of the steady state variables with respect to a small change in $\bar{A}_H$. In line with proposition 1, a higher $\bar{A}_H$ induces agents to invest more time to schooling and less time in goods

[15] See http://www.bankofengland.co.uk/statistics/rates/baserate.pdf.

Table 10: Comparative Statics with respect to $\bar{A}_H$

$\bar{A}_H$	l_H	Q	$(x_t + m_t)/y_t$	g	$Educ$	k_t/h_t
0.172	0.330	0.057	0.676	3.68%	0.147	0.303
0.18	0.356	0.064	0.705	4.40%	0.162	0.256
0.19	0.384	0.073	0.733	5.30%	0.179	0.210
0.20	0.410	0.082	0.754	6.20%	0.196	0.176
0.21	0.433	0.091	0.768	7.10%	0.211	0.145

production because education has a higher marginal return vis-a-vis goods production. As agents transfer resources away from goods to education, the physical to human capital ratio falls (last column of the Table 10), and growth rate rises. Such a scarcity of physical capital raises the marginal product of physical capital (due to diminishing returns to factor proportion). Recall from (7) that physical capital is produced with the aid of home grown investment goods, i_t^d and the imported raw materials rm_t in fixed proportion. Since the home country has the option to finance the purchase of raw materials through the current account, it will take advantage of it by raising its export and import shares. Thus the country becomes more open on the trade front. The bottom-line is that as a consequence of higher $\bar{A}_H$, the home country invests more in education, its growth rises and its trade share also increases.

Our baseline model reproduces an education share of GDP (14%) which is a bit higher compared to the median 4.04 % of education spending ratio ($Educ$) for our sample of countries as reported in Table 1. It is important to understand that a 4.04% median public spending ratio is an underestimate of investment spending on schooling in the context of our model where an aggregative household spends time and resources in schooling. There are at least two reasons why the official data on public spending on education may not reflect the steady state education spending ratio based on our aggregative model. First, the education expenditure data only refer to public spending on education and do not include private spending on education. Whatever limited cross-country evidence is available for private spending on education, it suggests that it is substantial. Armellini and Basu (2009) estimate the ratio of household to total spending on education for a limited sample of 34 countries and find that the mean ratio is about 20%. In addition, Johnes (1993) compiles the same estimate for 10 major countries and finds that it ranges from 3.5% to 50.3%. Second, the education expenditure in our model is directly proportional to time to schooling l_{Ht} which basically reflects the opportunity cost of schooling due to the lost wages at work. For example, parents might spend a significant amount of time in tutoring their children which means a lot of schooling efforts. Goryan, Hurst, Kearney (2008) use the time use surveys for several countries to report that parents use about 25 percent of active time on average (8 hours a week) to take care and educate their children. In a similar vein, Blankenau and Camera (2009) argue that schooling attendance may be the same across countries but efforts may differ.

Table 11 reports the marginal effects of an increase in the value of θ below or above unity. Since θ is the elasticity of cognitive skill with respect to time spent on schooling, a higher θ means that the agent can increase the cognitive skills of his child by adding less time to schooling. The time freed up can be dedicated to goods production to produce more consumables. This lowers the share of education spending in GDP. A larger θ lowers the cognitive skills Q as parents devote less time to schooling of kids and this sharply lowers the growth rate. Since output decreases, a slight fall in openness results as the economy produces less output and can export less. Overall, growth, education share and openness decrease as θ increases.

To sum up: If countries differ in terms of the long run skills Q due to either differences $\bar{A}_H$ or θ a positive cross country correlation between long run growth, openness and education share arises.

Table 11: Comparative Statics with respect to θ

θ	l_H	Q	$(x_t + m_t)/y_t$	g	$Educ$	k_t/h_t
0.98	0.331	0.058	0.682	3.81%	0.150	0.295
0.99	0.330	0.057	0.679	3.74%	0.149	0.299
1.0	0.330	0.057	0.676	3.68%	0.147	0.303
1.01	0.329	0.056	0.673	3.61%	0.145	0.307
1.02	0.328	0.055	0.669	3.54%	0.144	0.312

4.2 Role of TFP in the Goods Sector

What is the role of the goods sector productivity, $\bar{A}_G$, in determining the same correlation? It is straightforward to verify from Proposition 1 and (13) and (14) that this steady state TFP has no effects on balanced growth, education share and trade shares because MPK is independent of $\bar{A}_G$ (see equation (20)). This basically means that a rise in $\bar{A}_G$ is offset by a rise in (k/h) to keep the MPK constant. This intuition is confirmed in Table 12. Thus in our model, the long run cross country correlation between openness and education is driven by cognitive skill alone.

Table 12: Comparative Statics with respect to $\bar{A}_G$

$\bar{A}_G$	l_H	Q	$(x_t + m_t)/y_t$	g	$Educ$	k_t/h_t
1.2	0.330	0.057	0.676	3.68%	0.147	0.303
1.3	0.330	0.057	0.676	3.68%	0.147	0.381
1.4	0.330	0.057	0.676	3.68%	0.147	0.471
1.5	0.330	0.057	0.676	3.68%	0.147	0.574
1.6	0.330	0.057	0.676	3.68%	0.147	0.690

5 Short Run Dynamics

Until now we only analyzed the long run properties of the model. Such a long run analysis can be motivated by cross-country comparisons of various long run averages such as average growth, trade share and education share. The underlying assumption here is that each country is in different long run steady states and the research question is to understand what drives the cross-country dispersion in steady states? There are two productivity fundamentals, A_G and A_H in goods and education sectors among which we identify the latter as the crucial determinant of the cross country dispersion of growth, education share and trade share. However, such a long run analysis cannot reflect how a country can respond to shocks to its productivity fundamentals, A_G and A_H. Shocks to these fundamentals can arise due to changes in tax policy. For example, a one-time education subsidy in the form of hiring high quality teachers can have an impact upon the cognitive skill, A_H. On the other hand, institution of a temporary capital income tax could hurt the goods sector productivity, A_G. Analysis of this kind of *within-country* response to shocks necessitates a short run analysis to which we turn now.

5.1 Impulse Responses

Appendix A.4 summarizes the relevant short run equations. There are eight relevant endogenous variables, namely, l_{Ht}, x_t/y_t, m_t/y_t, $Educ_t$, ca_t/y_t, k_t/h_t, Q_t, and y_{t+1}/y_t and two exogenous variables, A_{Ht} and A_{Gt}. Among these endogenous variables, only k_t/h_t is predetermined. The impulse response analysis is based on log-linearized deviations of these variables from the steady state. Since this is a model of endogenous growth, the log-linearization is done around the balanced growth path described earlier. Figures 2 and 3 represent the impulse responses of various endogenous variables with respect to shocks to TFP in each sector, namely ξ_t^G and ξ_t^H based on (4) and (5) given the baseline parameters in Table 9.[16] In response to a positive shock to ξ_t^G, more time is devoted to goods production and less to schooling. This

[16] A variant of the algorithm of Blanchard and Kahn (1980) is used to plot the impulse responses. All calculations are done using DYNARE developed by Julliard (1996).

makes educational investment fall. Lower schooling effort also lowers the cognitive skills. Since output growth rate depends on schooling effort directly (see (A.25)), the growth rate also falls. This loss of output depresses the home country's export share. On the other hand, as the human capital base decreases due to less time to schooling, the physical to human capital ratio (k/h) rises. This necessitates more import of raw materials due to the fixed coefficient technology (7). The current account turns into a deficit while the total trade share $\frac{x+m}{GDP}$ increases slightly as imports increase more than the loss of exports.

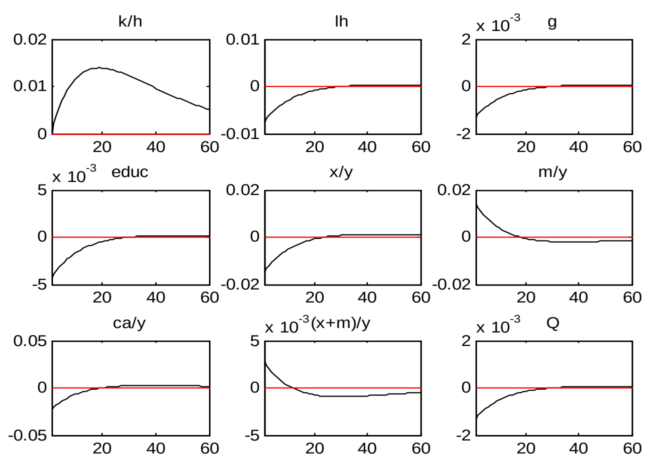

Figure 2: Impulse responses with respect to Ag

In response to a cognitive skill shock, ξ_t^H, the impulse responses behave differently. Agents devote more time to schooling and less time to production of final goods. This raises output growth rate, educational share and cognitive skills. As GDP grows,the home country exports more. Imports initially drop as the country invests more resources in the education sector. However, the consequent rise in the marginal product of capital induces more domestic investment. The home country then requires to import more raw materials

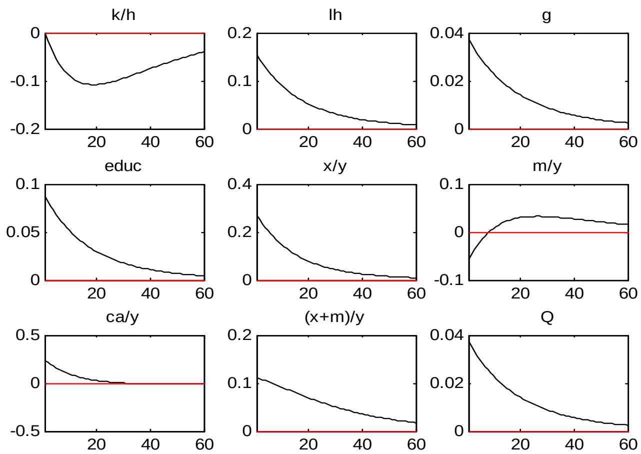

Figure 3: Impulse responses with respect to Ah

to produce more investment goods using the fixed coefficient technology (7). Overall, the current account turns into surplus. The openness measured by overall trade share increases.

The analysis of the transitional dynamics vividly illustrates that the short run effects of these two types of productivity shocks have very different implications for the short run correlations between growth, openness and education. The short run correlation between growth, openness and education depends on which shock is predominant. If the predominant shock is TFP in goods sector, growth correlates positively with cognitive skill and education, while it correlates negatively with openness. Moreover, openness and education correlate negatively. On the other hand, if the predominant shock arises from the education technology (which we call cognitive skill), growth, openness and education share tend to correlate positively .[17]

[17]The variance decomposition of these two orthogonalized shocks, ξ_t^G, ξ_t^H suggests that the latter accounts about 99% of the variation of relevant endogenous variables. Thus short run analysis also points to the direction that the shocks to education technology could be an important driver for growth, openness and education.

6 Conclusion

A plethora of literature exists about the relationship between openness and growth. There is also a voluminous literature on education and growth. However, less is known about the fundamentals driving openness, education and growth. The motivation for this study comes from the cross-country evidence that cognitive skill powerfully connects trade openness and educational spending across countries. We construct an open economy endogenous growth model in the tradition of Lucas (1988) to understand this relationship. The time allocation between goods production and schooling in the spirit of Becker (1975) is an essential ingredient of human capital growth. Our model identifies cognitive skill measured by international test scores in and science that enhances the productivity of human capital. This cognitive skill is a crucial driver of the cross- country relationship between education and trade openness. In terms of our endogenous growth model, we demonstrate that the cross-country differences in cognitive skill play a central role in determining the cross-country correlation between trade share and education share. This corroborates the development facts outlined in the paper that countries with higher cognitive skill grow faster, are more open and spend more on education.

Our model is the first in the literature showing explicitly the connection between cognitive skill, growth and trade openness. It is of course true that several factors besides cognitive skill are important determinants of growth, openness and education. For example, degree of democracy, trade and non-trade barriers, exchange rate volatilities could matter for openness. An evaluation of these factors on openness and growth in itself can be an agenda for future research. A useful extension of our work will also be to bring skill differences in technology suggested by Epifani and Gancia (2008) and explore the implications for skill premium in the context of endogenous growth.

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A Appendix

A.1 First Order Conditions

Let λ_t, μ_t be the Lagrange multipliers associated with the flow budget constraint (6), human capital technology, (1).

First order conditions are:

$$c_t : \beta^t U'(c_t) = \lambda_t \tag{A.1}$$

$$k_{t+1} : \lambda_t p^k = E_t \lambda_{t+1} \left[A_{Gt+1} \alpha k_{t+1}^{\alpha-1} (l_{Gt+1} h_{t+1})^{1-\alpha} + (1-\delta_k)(1+p^k) - (1+r^*) \right] \tag{A.2}$$

$$\begin{aligned} h_{t+1} \quad : \quad & \mu_t = E_t \mu_{t+1} \{1 - \delta_h + A_{Ht+1} l_{Ht+1}^{\theta})\} \\ & + E_t \lambda_{t+1} \left\{ A_{Gt+1} (1-\alpha) k_{t+1}^{\alpha} h_{t+1}^{-\alpha} l_{Gt+1}^{1-\alpha} \right\} \end{aligned} \tag{A.3}$$

$$l_{Gt} : \lambda_t (1-\alpha) A_{Gt} l_{Gt}^{-\alpha} k_t^{\alpha} h_t{}^{1-\alpha} - \mu_t A_{Ht} h_t \theta l_{Ht}^{\theta-1} = 0 \tag{A.4}$$

A.2 Derivation of the Balanced Growth Equations

Along the balanced growth path, we assume that $A_{Gt} = \bar{A}_G, A_{Ht} = \bar{A}_{H.}$ We also exploit the fact that the raw labour allocation variables l_{Gt} and l_{Ht} are stationary along the balanced growth path.

Rewrite (A.3) as:

$$\frac{\mu_t}{\lambda_t} = \frac{\mu_{t+1}}{\lambda_{t+1}}.\frac{\lambda_{t+1}}{\lambda_t}.\left[1 - \delta_h + \bar{A}_{H.}l_H^{\theta}\right] + \frac{\lambda_{t+1}}{\lambda_t}.\left[\bar{A}_G(1-\alpha)l_G^{1-\alpha}.\left(\frac{k}{h}\right)^{\alpha}\right]$$

Use (A.4) to substitute out $\frac{\mu_t}{\lambda_t}$ and noting that in the steady state $\frac{\mu_t}{\lambda_t}$ is a constant, one gets:

$$1 = \frac{\lambda_{t+1}}{\lambda_t}.\left[1 - \delta_h + \bar{A}_{H.}l_H^{\theta}\right] + \frac{\lambda_{t+1}}{\lambda_t}.\frac{\lambda_t}{\mu_t}.\left[\bar{A}_G(1-\alpha)l_G^{1-\alpha}.\left(\frac{k}{h}\right)^{\alpha}\right]$$

Next use (A.1) to rewrite the above as:

$$1 + g = \beta\left[1 - \delta_h + \bar{A}_{H.}l_H^{\theta}\right] + \beta\frac{\lambda_t}{\mu_t}.\left[\bar{A}_G(1-\alpha)l_G^{1-\alpha}.\left(\frac{k}{h}\right)^{\alpha}\right] \qquad \text{(A.5)}$$

Finally note from (A.4) that

$$\frac{\mu_t}{\lambda_t} = \frac{\bar{A}_G(1-\alpha)l_G^{-\alpha}.\left(\frac{k}{h}\right)^{\alpha}}{\theta\bar{A}_{H.}l_H^{\theta-1}}$$

which upon substitution in (A.5) gives

$$1 + g = \beta[1 - \delta_h + \bar{A}_H l_H^{\theta-1}(l_H + \theta l_G)]$$

Using (A.1), we get the following balanced growth rate (g) as follows:

$$=> 1 + g = \frac{h_{t+1}}{h_t} = \frac{k_{t+1}}{k_t} = \frac{c_{t+1}}{c_t} \tag{A.6}$$

Using (A.1), (A.3) and A.4) we get the balanced growth rate (12)

To get the export share equation (13) use (9), (8) and (10) which gives:

$$x_t + k_{t+1} = (1 + r^*)k_t + p^k(k_{t+1} - (1 - \delta_k)k_t)$$

Divide through by y_t and use the fact that along a balanced growth path k_t/y_t is a constant and for the Cobb-Douglas production function (3), $MPK = \alpha y_t/k_t$, to get:

$$\frac{x_t}{y_t} = \frac{\alpha\beta(1 - \delta_h + \bar{A}_H)(p^k - 1) + \alpha(1 + r^*) - \alpha(1 - \delta_k)p^k}{MPK} \tag{A.7}$$

By definition, the export share in GDP is given by:

$$\frac{x_t}{GDP_t} = \frac{x_t}{y_t} . \frac{y_t}{GDP_t} \tag{A.8}$$

Next use (16) and (A.4) to rewrite:

$$\frac{y_t}{GDP_t} = \frac{\theta l_G}{\theta l_G + (1 - \alpha)l_H} \tag{A.9}$$

Plug (A.7) and (A.9) into (A.8) to get (13).

To get the import share equation (14), notice first that the share of import in GDP is given by:

$$\frac{m_t}{GDP_t} = \frac{p^k rm_t}{y_t} . \frac{y_t}{GDP_t}$$

which after using the fact that $rm_t = i_t^k$ due to the fixed coefficient production function (7) is given by:

$$\frac{m_t}{GDP_t} = \frac{p^k(k_{t+1} - (1-\delta_k)k_t)}{y_t} \cdot \frac{y_t}{GDP_t} \tag{A.10}$$
$$= p^k \left\{ \frac{k_{t+1}}{y_{t+1}}(1+g) - (1-\delta_k)\frac{k_t}{y_t} \right\} \cdot \frac{y_t}{GDP_t}$$
$$= \frac{\alpha p^k \left\{(1+g) - (1-\delta_k)\right\}}{MPK} \cdot \frac{y_t}{GDP_t}$$

which proves (14).

To derive the education share in GDP, note first that by definition:

$$Educ = \frac{\mu_t A_{Ht} l_{Ht}^{\theta} h_t}{\lambda_t y_t + \mu_t A_{Ht} l_{Ht}^{\theta} h_t} \tag{A.11}$$

Plug (A.4) into (A.11) to substitute out λ_t/μ_t to obtain (15).

A.3 Proof of Proposition 1

When $\theta = 1$, (12) reduces to

$$1 + g = \beta(1 + \bar{A}_H - \delta_h) \tag{A.12}$$

Based on (1) one gets another balanced growth equation:

$$1 + g = 1 + l_H \bar{A}_H - \delta_h \tag{A.13}$$

Equating (A.12) and (A.13) one obtains (17). Equation (18) follows from (15) by setting $\theta = 1$.

Next note that the following third balanced growth equation can be obtained from the Euler equation for physical capital (A.2).

$$1+g=p_k^{-1}\beta\left[\bar{A}_G\alpha l_G^{1-\alpha}\left(\frac{k}{h}\right)^{\alpha-1}+(1-\delta_k)(1+p^k)-(1+r^*)\right] \quad \text{(A.14)}$$

Equating (A.12) to (A.14) one can solve $l_G^{1-\alpha}\left(\frac{k}{h}\right)^{\alpha-1}$ which yields (19).

To get (20) simply observe that $MPK=\alpha y/k$ which is simply $\bar{A}_G\alpha l_G^{1-\alpha}\left(\frac{k}{h}\right)^{\alpha-1}$. Plugging the expression for (19) the result is immediate.//

A.4 Summary of Short-run Equations

Define

$$\Omega_t=\frac{\theta l_{Gt}}{\theta l_{Gt}+(1-\alpha)l_{Ht}} \quad \text{(A.15)}$$

The short run system is given by equations (A.16) to (A.25) are:

$$\frac{k_{t+1}}{h_{t+1}}=\Omega_t.\frac{p^k\left(1-\delta_k\right)\frac{k_t}{h_t}+A_{Gt}(\frac{k_t}{h_t})^\alpha l_{Gt}^{1-\alpha}-\frac{c_t}{h_t}-\left(1+r^*\right)\frac{k_t}{h_t}}{\{1-\delta_h+A_{Ht}(1-l_{Gt})^\theta\}} \quad \text{(A.16)}$$

$$1=df_{t+1}.\frac{\alpha A_{Gt+1}\left(\frac{k_{t+1}}{h_{t+1}}\right)^{\alpha-1}l_{Gt+1}^{1-\alpha}+(1-\delta_k)(1+p^k)-1-r^*}{p^k} \quad \text{(A.17)}$$

$$\theta^{-1}.l_{Ht}^{1-\theta}\frac{A_{Gt}}{A_{ht}}.l_{Gt}^{-\alpha}.(\frac{k_t}{h_t})^\alpha=$$

$$df_{t+1}\left[\frac{A_{Gt+1}}{A_{ht+1}}.\theta^{-1}.l_{Ht+1}^{1-\theta}l_{Gt+1}^{-\alpha}.(\frac{k_{t+1}}{h_{t+1}})^\alpha\left\{1-\delta_h+A_{Ht+1}(1-l_{Gt+1})\right\}+A_{Gt+1}\left\{\frac{k_{t+1}}{h_{t+1}}\right\}^\alpha l_{Gt+1}^{1-\alpha}\right] \quad \text{(A.18)}$$

where df_{t+1} is the discount factor given by

$$df_{t+1} = \frac{\beta(c_t/h_t)}{(c_{t+1}/h_{t+1})} \frac{1}{(A_{Ht+1}(1-l_{Gt+1})^{\theta} + 1 - \delta_h)} \tag{A.19}$$

Export and import share equations are given by:

$$\begin{aligned} \frac{x_t}{GDP_t} &= \Omega_t.[1 + r^* - p^k(1-\delta_k)](k_t/y_t) \\ &+ (p^k - 1)(k_{t+1}/y_{t+1})(A_{Gt+1}/A_{Gt}) \left(\frac{k_{t+1}/h_{t+1}}{k_t/h_t}\right)^{\alpha} \{1 - \delta_h + A_{Ht} l_{ht}^{\theta}\}. \left\{\frac{l_{Gt+1}}{l_{Gt}}\right\}^{1-\alpha} \end{aligned} \tag{A.20}$$

$$\frac{m_t}{GDP_t} = \Omega_t.p^k \left[\frac{k_{t+1}}{y_{t+1}}.\frac{A_{Gt+1}}{A_{Gt}}.\left(\frac{k_{t+1}/h_{t+1}}{k_t/h_t}\right)^{\alpha} \left\{\frac{l_{Gt+1}}{l_{Gt}}\right\}^{1-\alpha} \{1 - \delta_h + A_{Ht} l_{ht}^{\theta}\} - (1-\delta_k).\frac{k_t}{y_t}\right] \tag{A.21}$$

The ratio of current account to GDP is defined as:

$$\frac{ca_t}{GDP_t} = \left[\frac{x_t}{y_t} - \frac{m_t}{y_t}\right].\Omega_t \tag{A.22}$$

The openness is defined as:

$$open_t = \frac{x_t + m_t}{y_t}.\Omega_t \tag{A.23}$$

The education share equation is given by:

$$Educ_t = \frac{(1-\alpha) l_{Ht}}{\theta l_{Gt} + (1-\alpha) l_{Ht}} \tag{A.24}$$

Finally the growth rate of output is given by:

$$\frac{y_{t+1}}{y_t} = \frac{A_{Gt+1}}{A_{Gt}}.\left[\frac{A_{Gt+1}}{A_{Gt}}\right]\left[\frac{k_{t+1}/h_{t+1}}{k_t/h_t}\right]^{\alpha} \{A_{Ht} l_{Ht}^{\theta} + 1 - \delta_h\}.\left[\frac{l_{Gt+1}}{l_{Gt}}\right]^{1-\alpha} \tag{A.25}$$

A.5 Outline of the Derivation of the Short-run Equations

Rewrite (6) as:

$$k_{t+1} = \frac{(1-\delta_k)(1+p^k)k_t + A_{Gt}k_t^{\alpha}(l_{Gt}h_t)^{1-\alpha} - c_t - (1+r^*)k_t}{p^k} \tag{A.26}$$

Dividing (A.26) by (1), one gets (A.16). (A.17) can be obtained by combining (A.1),(A.2) and (10).

Use (A.3) and (A.4) to obtain (A.18).

The discount factor (A.19) is basically $\beta c_t/c_{t+1}$. This can be rewritten as

$\beta\{(c_t/h_t)/(c_{t+1}/h_{t+1})\}(h_{t+1}/h_t)^{-1}$. After using (1), one gets the expression for (A.19).

To obtain the export share equation (A.20) , use (10) and (9) to obtain:

$$x_t = (1+r^*)k_t + (p^k-1)k_{t+1} - p^k(1-\delta_k)k_t \tag{A.27}$$

Divide through by y_t and multiply by Ω_t as in (A.15) to obtain (A.20).

To get (A.21), use

$$\frac{m_t}{y_t} = \frac{p^k(k_{t+1} - (1-\delta_k)k_t)}{y_t} \tag{A.28}$$

which can be rewritten as:

$$\frac{m_t}{y_t} = p^k(\frac{k_{t+1}}{y_{t+1}}.\frac{y_{t+1}}{y_t} - (1-\delta_k)\frac{k_t}{y_t}) \tag{A.29}$$

which after using the production function (3) and the human capital equation (1) together with (A.15) yields the expression (A.21).

The expression for the current account (A.22) follows by definition. The expression for (A.24) is the same as the steady state expression (1). The expression for the growth rate in (A.25) follows from the use of the production function (3) and the human capital equation (1).

B Data for the Empirical Analysis

B.1 Notes on data access and manipulations

Data Sources:

- g : Growth rate of GDP (annual %) for 1960-2006, World Development Indicators, 2008.
- $Educ$: Education expenditure (% of GNI) for 1960-2006, World Development Indicators, 2008.
- $\frac{x}{y}$: Exports of goods and services (% of GDP) for 1960-2006, World Development Indicators, 2008.
- $\frac{m}{y}$: Imports of goods and services (% of GDP) for 1960-2006, World Development Indicators, 2008.
- $\frac{x+m}{y}$: Total trade (% of GDP), for 1960-2006, World Development Indicators, 2008.
- $\frac{rm}{y}$: Merchandise trade (% of GDP),as defined in the IMF's DOTS , for 1960-2006, World Development Indicators, 2010.
- Q : Cognitive skills of pupils reflects the quality of schooling measured by the PISA test scores in mathematics and science and taken from Hanushek and Woessmann (2008) for 2006.

Notes on data access and manipulations

1. The World Development Indicators-database was accessed from at:

   http://www.esds.ac.uk/international/.

2. For each of these variables, the time average is first computed for each country over the period 1960-2006. Countries with missing data have a shorter

sample period. Then a cross country mean, median, skewness (indicating the difference between mean and median) and the inter-quartile ranges are computed.

3. For many of these emerging countries, export ratios ($\frac{x}{y}$) show up more than their GDP in the balance of payments account. For example, Singapore buys textiles in China and sells them in Europe; it buys high tech equipment from the US and sells to China. In both cases goods are not produced in Singapore but these are counted as exports of Singapore. This explains why export share in GDP can exceed unity in extremely open countries.

4. Data for education ratio ($Educ$) is not available for 11 countries: Aruba, Bosnia and Herzegovina, Macao, China, Micronesia, Fed. Sts., Montenegro, Palau, Serbia, Turkmenistan, United Arab Emirates, West Bank and Gaza, Yemen Rep. Countries such as Cayman Islands, Guam, Isle of Man, Marshall Islands, Mayotte, Monaco, Netherlands Antilles, San Marino, and Timor-Leste are dropped from computations because of missing data in more than two variables.

B.2 Countries in the Empirical Analysis

1. For Correlations: Algeria, Angola, Antigua and Barbuda, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahamas, Bahrain, Bangladesh, Barbados, Belarus, Belgium, Belize, Benin, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Brunei Darussalam, Bulgaria, Burkina Faso, Burundi, Cambodia, Cameroon, Canada, Cape Verde, Central African Republic, Chad, Chile, China, Colombia, Comoros, Congo Dem. Rep., Congo Rep., Costa Rica, Cote d'Ivoire, Croatia, Cuba, Cyprus, Czech Republic, Denmark, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, Arab Rep., El Salvador, Equatorial Guinea, Eritrea, Estonia, Ethiopia, Fiji, Finland, France, Gabon, Gambia, Georgia, Germany, Ghana, Greece, Grenada, Guatemala, Guinea-Bissau, Guinea, Guyana, Haiti, Honduras, Hong Kong-China, Hungary, Iceland, India, Indonesia, Iran, Islamic Rep., Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Korea, Rep., Kuwait, Kyrgyz Republic, Lao PDR, Latvia, Lebanon, Lesotho, Liberia, Libya, Lithuania, Luxembourg, Macao-China, Macedonia-FYR, Madagascar, Malawi, Malaysia, Maldives, Mali, Malta, Mauritania, Mauritius, Mexico, Micronesia-Fed. Sts., Moldova, Mongolia, Montenegro, Morocco, Mozambique, Myanmar, Namibia, Nepal, Netherlands, New Zealand, Nicaragua, Nigeria, Niger, Norway, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Portugal, Qatar, Romania, Russian Federation, Rwanda, Samoa, Saudi Arabia, Senegal, Serbia, Seychelles, Sierra Leone, Singapore, Slovak Republic, Slovenia, Solomon Islands, Somalia, South Africa, Spain, Sri Lanka, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines ,Sudan, Suriname, Swaziland, Sweden, Switzerland, Syrian Arab Republic, Tajikistan, Tanzania, Thailand, Togo, Tonga, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Uganda, Ukraine, United Arab Emirates, United Kingdom, United States, Uruguay, Uzbekistan, Vanuatu, Venezuela, Vietnam, West Bank and Gaza, Yemen Rep., Zambia, Zimbabwe.

2. For Cognitive Skill: Albania, Argentina, Armenia, Australia, Austria, Bahrain , Belgium, Botswana, Brazil, Bulgaria, Canada, Chile, China, Colombia, Cyprus, Czech Republic, Denmark, Egypt, Arab Rep., Estonia, Finland, France, Germany, Ghana, Greece, Hong Kong, China, Hungary, Iceland, India, Indonesia, Iran, Islamic Rep., Ireland, Israel, Italy, Japan, Jordan, Korea, Rep., Kuwait, Latvia, Lebanon, Lithuania, Luxembourg, Macao, China, Macedonia, FYR, Malaysia, Mexico, Moldova, Morocco, Netherlands, New Zealand, Nigeria, Norway, Peru, Philippines, Poland, Portugal, Romania, Russian Federation, Saudi Arabia, Serbia, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Swaziland, Sweden, Switzerland, Thailand, Tunisia, Turkey, United Kingdom, United States, Uruguay, Palestine, Zimbabwe.

3. For Panel Regression Models: Fourteen groups of countries used in panel regression are based on the World Development Indicators (2007). The official data (available using Athens login from the www.esds.ac.uk/international/WDI) define these categories (with our own notation for each category in parentheses) as follows:

1. World aggregate is average of all countries of the world (Wrld).
2. Low-income economies (Linc) are those in which 2007 GNI per capita was $935 or less including Afghanistan, Bangladesh, Benin, Burkina Faso, Burundi, Cambodia, Central African Republic, Chad, Comoros, Congo, Dem. Rep., Côte d'Ivoire, Eritrea, Ethiopia, Gambia, The, Ghana, Guinea, Guinea-Bissau, Haiti, Kenya, Korea, Dem. Rep., Kyrgyz Republic, Lao PDR, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Myanmar, Nepal, Niger, Nigeria, Pakistan, Papua New Guinea, Rwanda, São Tomé and Principe, Senegal, Sierra Leone, Solomon Islands, Somalia, Tajikistan, Tanzania, Togo, Uganda, Uzbekistan, Vietnam, Yemen, Rep., Zambia, Zimbabwe.
3. Middle-income economies (Minc) are those in which 2007 GNI per capita was between $936 and $11,455 including countries in: Lower middle income and Upper middle income groups.
4. Lower-middle-income (Lminc) economies are those in which 2007 GNI per capita was between $936 and $3,705 and include: Albania, Algeria, Angola, Armenia, Azerbaijan, Bhutan, Bolivia, Bosnia and Herzegovina, Cameroon, Cape Verde, China, Colombia, Congo, Rep., Djibouti, Dominican Republic, Ecuador, Egypt, Arab Rep., El Salvador, Georgia, Guatemala, Guyana, Honduras, India, Indonesia, Iran, Islamic Rep., Iraq, Jordan, Kiribati, Lesotho, Macedonia, FYR, Maldives, Marshall Islands, Micronesia, Fed. Sts., Moldova, Mongolia, Morocco, Namibia, Nicaragua, Paraguay, Peru, Philippines, Samoa, Sri Lanka, Sudan, Swaziland, Syrian Arab Republic, Thailand, Timor-Leste, Tonga, Tunisia, Turkmenistan, Ukraine, Vanuatu, West Bank and Gaza.
5. Upper-middle-income economies (Upminc) are those in which 2007 GNI per capita was between $3,706 and $11,455 including: American Samoa, Argentina, Belarus, Belize, Botswana, Brazil, Bulgaria, Chile, Costa Rica, Croatia, Cuba, Dominica, Fiji, Gabon, Grenada, Jamaica, Kazakhstan, Latvia, Lebanon, Libya, Lithuania, Malaysia, Mauritius, Mayotte, Mexico, Montenegro, Palau, Panama, Poland, Romania, Russian Federation, Serbia, Seychelles, South Africa, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Suriname, Turkey, Uruguay, Venezuela, RB.
6. Low- and middle-income economies (lmdinc) are those in which 2007 GNI per capita was $11,455 or less and include the following country groups: East Asia & Pacific, Europe & Central Asia, Latin America & Caribbean, Middle East & North Africa, South Asia and Sub-Saharan Africa.
7. East Asia and Pacific regional aggregate (ASPC) includes: American Samoa, Cambodia, China, Fiji, Indonesia, Kiribati, Korea, Dem. Rep., Lao PDR, Malaysia, Marshall Islands, Micronesia, Fed. Sts., Mongolia, Myanmar, Palau, Papua New Guinea, Philippines, Samoa, Solomon Islands, Thailand, Timor-Leste, Tonga, Vanuatu, Vietnam.
8. Latin America and Caribbean regional aggregate (LTACA) includes Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Re-

public, Ecuador, El Salvador, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Suriname, Uruguay, Venezuela, RB.

9. Middle East and North Africa regional aggregate (MDEAST) includes: Algeria, Djibouti, Egypt, Arab Rep., Iran, Islamic Rep., Iraq, Jordan, Lebanon, Libya, Morocco, Syrian Arab Republic, Tunisia, West Bank and Gaza, Yemen, Rep.

10. South Asia (SAsia) economies include: Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka.

11. Sub-Saharan Africa (SSAFR) includes: Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Dem. Rep., Congo, Rep., Côte d'Ivoire, Eritrea, Ethiopia, Gabon, Gambia, The, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mayotte, Mozambique, Namibia, Niger, Nigeria, Rwanda, São Tomé and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe.

12. High-income economies (Hiinc) are those in which 2007 GNI per capita was $11,456 or more and include: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Rep., Luxembourg, Netherlands, New Zealand, Norway, Portugal, Slovak Republic, Spain, Sweden, Switzerland, United Kingdom, United States.

13. High income non-OECD economies (HinOECD) are those in which 2007 GNI per capita was $11,456 or more and include: Andorra, Antigua and Barbuda, Aruba, Bahamas, The, Bahrain, Barbados, Bermuda, Brunei Darussalam, Cayman Islands, Channel Islands, Cyprus, Equatorial Guinea, Estonia, Faeroe Islands, French Polynesia, Greenland, Guam, Hong Kong, China, Isle of Man, Israel, Kuwait, Liechtenstein, Macao, China, Malta, Monaco, Netherlands Antilles, New Caledonia, Northern Mariana Islands, Oman, Puerto Rico, Qatar, San Marino, Saudi Arabia, Singapore, Slovenia, Trinidad and Tobago, United Arab Emirates, Virgin Islands (U.S.).

14. Heavily indebted poor countries (HIPC) include: Afghanistan, Benin, Bolivia, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Comoros, Congo, Dem. Rep., Congo, Rep., Côte d'Ivoire, Eritrea, Ethiopia, Gambia, The, Ghana, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Kyrgyz Republic, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Nepal, Nicaragua, Niger, Rwanda, São Tomé and Principe, Senegal, Sierra Leone, Somalia, Sudan, Tanzania, Togo, Uganda, Zambia.