ESSAYS IN THE ECONOMICS OF EDUCATION

by

CASEY ABINGTON

B.S., University of Central Missouri, 2003
M.B.A., University of Central Missouri, 2004

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AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the
requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Economics
College of Arts and Sciences

KANSAS STATE UNIVERSITY
Manhattan, Kansas

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Abstract

The first essay examines the allocation of education spending. Human capital investment in early childhood can lead to large and persistent gains. Beyond this window of opportunity, human capital accumulation is more costly. Despite this, government education spending is allocated disproportionately toward late childhood and young adulthood. The consequences of a reallocation are examined using an overlapping generations model with private and public spending on early and late childhood education. Taking as given the higher returns to early investment, the model shows the current allocation may nonetheless be appropriate. With a homogeneous population, this can hold for moderate levels of government spending. With heterogeneity, this can hold for middle income workers. Lower income workers, by contrast, may benefit from a reallocation.

The second essay provides a detailed review of the human capital proxies used in growth regressions. Economic theory and intuition tells us that human capital is important for economic growth, and now most empirical growth studies include a human capital component. Human capital is a complex concept that is difficult to quantify in a single measure. A number of proxies have been proposed, with most focusing on an aspect of education. The consensus is that human capital is poorly proxied. For each of the most commonly used measures, I give a description, discuss trends, summarize the literature and results, compare advantages and disadvantages, and list data sets. This review will serve as a useful reference for any researcher including human capital in a growth regression.

The final essay explores the importance of a variety of human capital measures for growth using the Bayesian Averaging of Classical Estimates (BACE) approach proposed by Sala-i-Martin, Doppelhofer, and Miller (2004). BACE combines standard Bayesian methods with the classical approach to address the problem of model uncertainty. A new data set is constructed that includes 35 human capital variables. The analysis shows that multiple human capital measures are robustly significant for growth. Some of these variables are IQ scores, the duration of primary and secondary education, average years of primary education, average years of female higher education, and higher education enrollment.

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William Blankenau

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Part I

Chapter 1: Government Education Expenditures in Early and Late Childhood

1   Introduction

Research by education specialists, psychologists, and economists is bringing into sharp focus a fundamental feature of human capital accumulation. Human capital investment in early childhood can lead to large and persistent gains while investment beyond this window of opportunity yields diminished returns. Recent work by Cunha, Heckman, Lochner, and Masterov (CHLM 2007) provides a comprehensive overview of work in the field.[1]

One conclusion of their overview is that the process of human capital accumulation is best modeled as a hierarchical process wherein early childhood education sets the stage for productive education in late childhood. Skills attained early in life leave a learner better prepared to take advantage of later opportunities to develop more refined skills. Similarly, late childhood investment reinforces investment in early childhood. Without follow-up investment, early investment is unproductive over the longer term.

This complementarity is often neglected when economists model human capital accumulation. While it is becoming more common to think about a hierarchical education process, this is typically to distinguish between K-12 and college education.[2] CHLM argue that the more meaningful distinction is between human capital investment during and after "critical" periods for the acquisition of particular skills. Perhaps the most straight-forward example is the critical period for developing IQ. By age 10, the IQ of a child is essentially set. Before that time it is more malleable.[3] Low investment in the first 10 years leaves IQ lower and later investment less productive. At the same time, low investment later in life fails to exploit the potential to turn IQ into specific life skills.

Since government is a ubiquitous presence in funding human capital production, the nature of the process might suggest that government should allocate resources disproportionately toward early childhood education. Presently, it does not. In 2004, about .3% of GDP was spent by government on pre-primary education in educational institutions for students aged 3-6 while 4% of

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[1]See also Carneiro and Heckman (2003), Knudsen, Heckman, Cameron, and Shonkoff (2006), and Currie (2001(b)).

[2]See, for example, Driskill and Horowitz (2002), Su (2004), Kaganovich (2005), Blankenau (2005), and Restuccia and Urrutia (2004).

[3]See Jensen (1980) and the discussions in CHLM and Cunha and Heckman (2007).

1

GDP was spent by government on K-12 education.[4] With the duration of K-12 around six times that of pre-primary education, this suggests that on a per capita basis government spending on K-12 education is more than 2.2 times that on pre-primary education. On a per student basis, the difference is less pronounced as pre-primary enrollment is lower. Still, pre-primary per student expenditures are only 63% as large as upper secondary expenditures. Within K-12 education, spending is again weighted toward the later years. Per student spending on primary education is about 84% of upper secondary spending.[5]

Human capital spending is more than just education spending. In addition, government affects spending beyond its direct payments. A fuller analysis of relative spending levels would consider health care expenditures, tax breaks for day-care, after school programs, and a variety of related issues. While a complete accounting is a useful endeavor for later work, the conclusion that government does not spend disproportionately on human capital in early childhood is likely robust to any fuller analysis.

With spending concentrated in later years and development opportunities arising early, the allocation of government spending may have important implications. This paper considers the general equilibrium effects of allocating government expenditures across early and late childhood. We build a heterogeneous agent overlapping generations model where general human capital is generated in a two-stage hierarchical education system. The first period generates early human capital. An agent's endowment of early human capital depends on an exogenous family effect, first stage family spending, and first stage government spending. The second stage generates general human capital as a function of early human capital and second stage spending by the family and government.

Families value consumption and the lifetime income of their offspring. They allocate income across consumption spending and education spending at the two stages. Government interacts with households through taxation and provision of education inputs at each stage of childhood. The provision of education inputs has two consequences. There is a direct effect as inputs increase but also general equilibrium effects as private education spending adjusts in response. Two questions

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[4]These numbers are not reported directly. However, table B2.2 of OECD Education at a Glance (2007) states that .4% of GPD is spent in total pre-primary education and 4.4% is spent on K-12 education. Table B3.2a of this same publication indicates that about 75% of pre-primary and 90% of K-12 funding is provided by government.

[5]Table B1.1a of Education at a Glance (2007) provides expenditures per student for pre-primary education, primary education, lower secondary education, and upper secondary education. The figures are arrived at by taking the ratio and, in the case of pre-primary, weighting it by the relative shares funded by government found in table B3.2a.

dominate the analysis. Is it best for government to concentrate its spending on one stage of education or to balance expenditures across the two stages? Secondly, if more concentrated expenditures are best, which level should be the focus of government expenditures?

The intuition is most clear when family and government inputs are perfectly substitutable so we focus on this case. Roughly speaking, a family prefers balanced spending only if government spending is high relative to personal income. When overall spending as a share of income is in a high intermediate range, an agent's income is maximized with government spending concentrated on early childhood education. When overall spending is in a low intermediate range, an agent's income is maximized with government spending concentrated on late childhood. Below some threshold level, the allocation of spending is irrelevant.

Results stem from the nature of human capital development and the crowding out of private spending by public spending. At high levels of spending relative to income, private spending is fully crowded out so the level of expenditure is dictated by government choices. In this case, productivity of public expenditures is key to output. Productivity is highest with a more balanced allocation. Since public spending is high in relation to the lowest incomes in the economy, this suggests that low income families are better off with more balanced government expenditures. At low levels of government spending relative to income, public spending simply displaces private spending, leaving total spending at each stage unchanged. This suggests that high income families may be unaffected by the allocation.

Between the relative extremes is the case where one type of spending is fully (or largely) crowded out and the other is not. When the allocation favors late childhood education, family spending at this stage is fully crowded out by government spending and family spending remains positive at the early childhood stage. This matches the situation in the U.S. where more than 90% of K-12 education spending is provided by government. With a disproportionate level of private K-12 spending by higher income families, this implies that some share of the population spends little or nothing privately on K-12 education. For these agents, an allocation toward early childhood education crowds out some early childhood spending. Since later spending is zero, there is no offsetting 'crowding in' of later spending. While the mix of spending may be more productive, total education spending decreases. This effect can dominate, leading to lower output. Hence, concentrated spending can maximize the income of middle income families.

After establishing that middle income families might prefer concentrated expenditure, we show

that the preferred stage of concentration depends on family income. While the lower income workers in this group would prefer government spending concentrated on early childhood education, the rest prefer a focus on late childhood education. In essence, the larger of the expenditures (public or private) should be allocated to the most productive stage. For some middle income workers public spending exceeds private. It is best to allocate this to early childhood. For the more wealthy, the opposite holds. All told, the current concentration of government spending on late childhood education can be optimal for some income levels. At other income levels it may not be optimal but still preferred to more balanced spending. With the most wealthy indifferent, this leaves only the most poor to benefit from a reallocation.

We present the model in Section 2 and consider a special case in Section 3. Here agents are homogeneous and private and public spending are perfect substitutes. Much of the intuition is captured by this special case. Section 4 demonstrates this point by showing that the results are little changed in a more general case preserving homogeneity. Section 5 considers heterogeneity. Section 6 summarizes, provides some more speculative insights on policy implications, and concludes the paper.

2 The Model

2.1 The Technology of Education

We consider an overlapping generations economy where agents live four periods. In each period, a mass of new agents, normalized to one, enters the economy and passes through early childhood. In the subsequent period, these agents are in late childhood. Throughout childhood, agents are passive economic agents. They receive endowments of human capital in each period but make no decisions of their own. Agents enter early adulthood in their third period. This is an active period where agents allocate income as specified below.[6] In addition, young adults each have one child. Thus the young adults in period t are parents to the new agents in that period. The fourth period of life is late adulthood where agents face a separate allocation decision and are parents to the late childhood generation.

The agents born in each period may be heterogeneous and are indexed by $j \in \mathcal{J} \equiv [0, 1]$. A productivity parameter is related to the index through the function $a_j = a(j)$ where a_j is the

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[6]In an earlier version of this paper, young adults also made a choice to attend college or not. This proves unimportant for our main points.

productivity of agent j and $0 < a_j \le a_{j'} < \infty$ for all $j < j'$. If the middle inequality is strict for at least one j, j' pair, there is heterogeneity in productivity. Though not modeled, we assume that through nature and nurture a child inherits the productivity of her parents. While this overstates the heritability of productivity, recent evidence suggests considerable dynastic persistence in relative earnings. For example, Mazumder (2005) estimates the intergenerational elasticity in earnings to be about .6.[7] In our model, inheritance of a is the channel through which such persistence arises.

Agent j in early childhood is endowed with $h_{1j(t)}$ units of early childhood human capital, which indicates that the endowment is time and agent specific. We hereafter compromise on precision in favor of aesthetics by suppressing the j and t notation when no confusion arises. The endowment is a function of ability and resources invested on behalf of the agent in her first period, i_1. In late childhood, the agent is endowed with general human capital. The size of this endowment depends on ability, early childhood human capital, and resources invested on behalf of the agent in her second period, i_2. Specifically,

$$
\begin{aligned}
h_1 &= a i_1^{\gamma_1} \\
h_2 &= \begin{cases} A a \left[\gamma_2 i_2^\rho + (1 - \gamma_2) h_1^\rho \right]^{\frac{1}{\rho}} & \text{if} \quad \rho \ne 0 \\ A a i_2^{\gamma_2} h_1^{1-\gamma_2} & \text{if} \quad \rho = 0 \end{cases}
\end{aligned}
\tag{1}
$$

where $\gamma_1, \gamma_2 \in [0,1]$ with $\min[\gamma_1, \gamma_2] < 1$, $\rho \le 1$, and $A > 0$ are common across agents and fixed through time while other items are agent and time specific. The parameter A serves as a scalar in the production of human capital while γ_1 and γ_2 govern the curvature of the functions. The parameter ρ governs the substitutability of early childhood investment and late childhood investment in creating human capital. This specification is similar to Cunha and Heckman (2007).

Education investments, i_1 and i_2, depend on spending by parents and government. We expect that spending by government and families are largely substitutable as inputs into the production of human capital. For example, the productivity of otherwise identical books and teachers does not differ according to the means of finance, and students may learn as much from school field trips as from family outings. On the other hand, parents may provide some inputs that do not substitute well for government inputs. For example, a family may live in a more costly neighborhood in order to gain educational or peer-effect advantages for the child. To accommodate possible imperfect

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[7]In the U.S., recent estimates are .4 or greater. See, for example, Solon (1999). Solon (2002) provides a review of elasticity estimates across nations.

substitutability, we specify

$$i_k = \begin{cases} B \left[\alpha f_k^\eta + (1 - \alpha) g_k^\eta \right]^{\frac{1}{\eta}} & \text{if} \quad \eta \neq 0 \\ B f_k^\alpha g_k^{1-\alpha} & \text{if} \quad \eta = 0 \end{cases} \tag{2}$$

for $k \in \{1, 2\}$ where f_1 and g_1 are family and government resources devoted to early childhood education while f_2 and g_2 are resources devoted to late childhood education. The specification requires $\eta \leq 1$. With $\eta = 0$, this is the specification used (for example) by Blankenau (2005), and with $\eta = 1$, this is the specification used by Glomm and Kaganovich (2003).

2.2 The Agents' Problem

Each agent is endowed with one unit of time in each period. Agents receive an income of wh_2 in each period of adulthood.[8] Here w is the wage per unit of human capital. With an interest rate exogenously given by r, the present value of lifetime income is

$$I = wh_2 \left(1 + r^{-1} \right). \tag{3}$$

In modeling education choices, it is common to consider the possibility of borrowing constraints. Such constraints play a key role in a wide variety of recent research. Some examples are Rangazas (2002) and Restuccia and Urratia (2004). We exclude such considerations for two reasons. First, we show below that for low income agents most or all education expenditures are made by government. Thus low income agents, for whom constraints are most likely to bind, are not interested in borrowing. Secondly, recent work by Carneiro and Heckman (2002) indicates that few families are credit constrained in making education decisions later in life. It would be reasonable, still, to impose credit constraints for those who spend significantly on children in early childhood. This is likely to be of modest importance.

We will use $\hat{\ }$ notation to indicate items that relate to the children of the generation being considered. For example, while I is the income of the generation being considered, $\hat{I}$ is the income of the offspring.

Each agent has preferences given by

$$U_j = \ln c_3 + \beta \ln c_4 + \xi \ln \hat{I}. \tag{4}$$

Here c_3 and c_4 denote consumption in the third and fourth periods of life, and $\beta < 1$ discounts the future. Aside from own consumption, the agent cares about the lifetime income of her children

---

[8]It is simple to allow for human capital to be gained also through experience so that income rises through the life cycle. As this serves only to scale our results, it is omitted.

where the term ξ scales the importance of progeny income. Parents can effect progeny income through spending on human capital in the first and second periods of childhood. Combining period budget constraints and defining τ to be the tax rate on income, the agent's allocation problem is to choose c_3, c_4, f_1, and f_2 to maximize equation (4) subject to the relationships in equation (1) and

$$
\begin{aligned}
I\left(1-\tau\right) \geq c_3 + \tfrac{c_4}{r} + f_1 + \tfrac{f_2}{r}, \\
c_3, c_4 \geq 0, \\
f_1, f_2 \geq 0, \\
\hat{I} = \hat{I}\left(\hat{h}_2\right), \ \hat{h}_2 = \hat{h}_2\left(\hat{\imath}_1, \hat{\imath}_2\right), \\
\hat{\imath}_1 = \hat{\imath}_1\left(f_1, g_1\right) \ \text{and} \ \hat{\imath}_2 = \hat{\imath}_2\left(f_2, g_2\right).
\end{aligned}
\tag{5}
$$

2.3   Other Entities

A large number of identical firms employ labor to produce identical consumption goods according to

$$
Y = ZH \tag{6}
$$

where $Z > 0$ is a scalar, Y is output, and H is the human capital adjusted labor input of a representative firm. Since all markets are competitive $w = Z$ will hold in equilibrium.

We assume that government taxes all labor income at the common rate τ and uses the revenue to fund early and late childhood education. Furthermore, government spends equally on all children over their lifetime. Given this and the normalization of the generation size to one, a balanced budget requires that

$$
G = g_1 + g_2 = ZH\tau \tag{7}
$$

where G is total government spending in period t.

It is convenient to scale spending to the size of the economy. We do this by making total spending in any period proportional to output. Furthermore, we define ψ to be the share of G that is devoted to early childhood education. Thus we set

$$
G = \varsigma Y, \quad \varsigma \psi Y = g_1, \quad \varsigma\left(1 - \psi\right)Y = g_2 \tag{8}
$$

where $\varsigma \in [0, 1]$ is the share of output devoted to government education spending.

To complete the model, we assume that agents can borrow and lend in an international market. Here a unit of the consumption good today purchases a claim to r units in the subsequent period. This makes the interest rate exogenous as required for analytical tractability.

2.4 Equilibrium

The dynamics of the model are simple to trace. However, our concern is with comparative statics and as such we focus on a steady-state equilibrium. In this case, the total amount of labor available in each period, H_2 is

$$H_2 = 2 \int\limits_{j=0}^{1} h_{2j} dj \tag{9}$$

where the 2 reflects that two generations are at work in each period.

Definition 1. A steady-state competitive equilibrium in this economy is a wage w, income, allocations and educational outcomes $\left\{ I_j, c_{3,j}, c_{4,j}, f_{1,j}, f_{2,j}, h_{1,j}, h_{2,j}, \hat{I}_j, \hat{h}_{1,j}, \hat{h}_{2,j} \right\} \ \forall j \in \mathcal{J}$, labor supply and demand $\{H_2, H\}$, and fiscal instruments instruments $\{\tau, \varsigma, \psi, g_1, g_2\}$ such that

1. Human capital allocations satisfy equation (1).

2. Each agent takes $h_{1,j}, h_{2,j}$, fiscal instruments, and the choices of others as given and chooses $c_{3,j}, c_{4,j}, f_{1,j}, f_{2,j}$ to satisfy equation (4) subject to the constraints in equation (5).

3. The firms choose labor inputs to maximize profits, $w = Z$.

4. Government spending satisfies equation (7).

5. The labor market clears, $H_2 = H$.

6. Surpluses and shortages in the goods market are accommodated by the international bond market.[9]

7. $h_{2,j} = \hat{h}_{2,j}$ and similarly other generation specific variables are constant.

3 A Special Case

The model generally requires numerical solutions but insights can be gained by first looking at a special case. For this purpose we maintain the following assumption throughout this section:

Assumption 1: $\eta = r = 1$, $\rho = 0$, $\alpha = .5$.

Setting $\eta = 1$, $\alpha = .5$ makes government spending perfectly substitutable with private spending and

$$i_k = f_k + g_k. \tag{10}$$

---

[9]Implications of the model are qualitatively robust to the closed economy case where the goods market clears.

Setting $\rho = 0$ simplifies the human capital expression to

$$h_2 = \bar{A} i_1^{\gamma} i_2^{\gamma_2} \tag{11}$$

where $\gamma = (1 - \gamma_2) \gamma_1$ and $\bar{A} = A a^{2 - \gamma_2}$. Setting $r = 1$ is an algebraic convenience with little consequence for any of our results. Using a different r serves only to scale some of our later findings.

For this section and the next, we also assume that all agents are of equal ability. This requires Assumption 2:

Assumption 2: $a_j = a_{j'} \; \forall j$ and $j' \in \mathcal{J}$.

3.1 Equilibria

We show below that for any choice of parameters in the steady state, a unique equilibrium exists. This equilibrium can be one of four types, depending on family education expenditures. In both early childhood and late childhood, family spending can be zero or positive. To distinguish the types, we use the notation $f = (f_1^*, f_2^*)$ to indicate that family spending is positive at both stages and $f = (0, 0)$ to indicate zero spending at both stages. Similarly $f = (f_1^*, 0)$ means that there is positive family spending only on early childhood while $f = (0, f_2^*)$ means positive spending only on late childhood. With this, we are ready to state Proposition 1:

Proposition 1. If Assumptions 1 and 2 hold, then

$$f = \begin{cases} (f_1^*, 0) & \text{if} & \psi \leq \min\left[1 - \xi\gamma_2 \left(\beta_1\varsigma\right)^{-1}, \; \xi\gamma \left(1 - \varsigma\right) \left((1 + \beta)\varsigma\right)^{-1}\right] \\ (f_1^*, f_2^*) & \text{if} & 1 - \xi\gamma_2 \left(\beta_1\varsigma\right)^{-1} \leq \psi \leq \xi\gamma \left(\beta_1\varsigma\right)^{-1} \\ (0, 0) & \text{if} & \xi\gamma \left(1 - \varsigma\right) \left((1 + \beta)\varsigma\right)^{-1} \leq \psi \leq 1 - \xi\gamma_2 \left(1 - \varsigma\right) \left((1 + \beta)\varsigma\right)^{-1} \\ (0, f_2^*) & \text{if} & \psi \geq \max\left[\xi\gamma \left(\beta_1\varsigma\right)^{-1}, \; 1 - \xi\gamma_2 \left(1 - \varsigma\right) \left((1 + \beta)\varsigma\right)^{-1}\right] \end{cases} \tag{12}$$

where $\beta_1 \equiv 1 + \beta + (\gamma_2 + \gamma)\xi$.

Proposition 1 divides the $\varsigma \in [0, 1] \times \psi \in [0, 1]$ space into four regions, each permitting exactly one of the four types of equilibria. At the border between any two regions, both types of equilibria are supported but little gained in discussing this knife-edge case and we hereafter omit it. The first line of equation (12) shows that for ψ sufficiently small, families spend on early childhood but not on late childhood education. The last line shows that for ψ sufficiently large, families spend on late childhood education but not on early childhood. The second and third lines show that for intermediate values of ψ, families spend at either both or neither level of education. In each case, the cutoff points between equilibria types depend on the level of spending.

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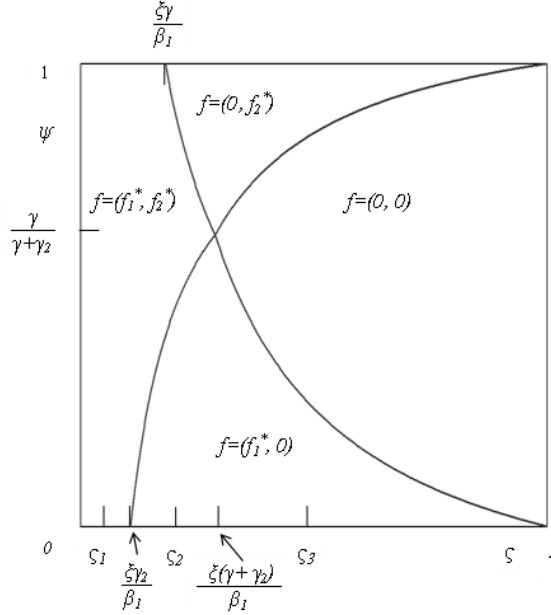
Figure 1: Equilibria. The curves divide the $\varsigma \times \psi$ space into four regions. Where $f = (f_1^*, f_2^*)$, families spend on both levels of education and where $f = (0,0)$ they spend on neither. Otherwise they spend on one level of education. Where $f = (0, f_2^*)$ they spend on late childhood and where $f = (f_1^*, 0)$ they spend on early childhood.

Figure 1 serves as an example. Here we show the partition of the $\varsigma \times \psi$ space for a particular parameterization. We set $\gamma_2 = .15$, which is in the range used by Blankenau and Simpson (2004). To reflect a higher productivity for expenditures in early childhood we set $\gamma_1 = .3$. This gives $\gamma = .225$. We set $\beta = .63$ to reflect an annual discount rate of .97 over 15 years and set $\xi = 1 + \beta$.

To see how ψ and ς jointly determine the type of equilibrium, it is useful to consider three values of ς. First, consider $\varsigma = \varsigma_1$ as an example of a low level of government spending. Tracing a line from $\psi = 0$ to $\psi = 1$ at $\varsigma = \varsigma_1$ in Figure 1, we see that for every ψ value, $f = (f_1^*, f_2^*)$. Thus when government spending is low, its allocation does not influence the type of equilibrium. Regardless of the allocation of spending, families top-up government spending at both levels. Next consider $\varsigma = \varsigma_2$ as an example of a moderate level of spending. Tracing a line from $\psi = 0$ to $\psi = 1$, we see that for ψ small $f = (f_1^*, 0)$, for ψ large $f = (0, f_2^*)$, and otherwise $f = (f_1^*, f_2^*)$. When this level of spending is sufficiently focused on one stage of education, families spend only on the other stage. When it is split more equally, the dilution results in private spending at both stages. Finally consider $\varsigma = \varsigma_3$ as an example of a high level of spending. With focused spending at this level, families again spend only on the stage neglected by government. However, now with more

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balanced spending $f = (0, 0)$. That is, when spending is high enough, government spending diluted across the two levels is still sufficiently high at both stages to eliminate private spending.

The analysis with $\varsigma = \varsigma_1$ is valid whenever $\varsigma \leq \min \left[\xi \gamma_2 \beta_1^{-1}, \xi \gamma \beta_1^{-1} \right]$ and the analysis with $\varsigma = \varsigma_3$ is valid whenever $\varsigma \geq \xi \left(\gamma + \gamma_2 \right) \beta_1^{-1}$. Otherwise the analysis with $\varsigma = \varsigma_2$ is valid. We can use this to formalize the definitions of high, moderate, and low spending.

Definition 2. Spending is *low* when $\varsigma < \min \left[\xi \gamma_2 \beta_1^{-1}, \xi \gamma \beta_1^{-1} \right]$, *high* when $\varsigma > \xi \left(\gamma + \gamma_2 \right) \beta_1^{-1}$, and *moderate* otherwise.

Furthermore, we can think of government spending as focused on a stage of education when it fully crowds out private spending at exactly one stage of education. In contrast, when spending is balanced, families spend at both or neither stages, depending on the level of government spending. With this, we can state Corollary 1.

Corollary 1. If government spending is low, families always spend on both stages of education. Otherwise, if government spending is focused on one stage of education, families spend only on the other stage. If government spending is balanced, families spend on both stages with moderate government spending and on neither stage with high government spending.

Notice that for moderate levels of spending, the range of ψ values considered balanced spending decreases with ς (i.e. the two bounds are getting closer together). In contrast, when government spending is high, the range is increasing. The intuition for this result is simple. Moderate spending is balanced when both $\varsigma \psi$ and $\varsigma (1 - \psi)$ are small enough that families top-up government spending. Clearly it is easier to satisfy the conditions simultaneously when ς decreases. High spending is balanced when there is sufficient government spending at both levels to fully crowd out both levels of private spending (i.e. when both $\varsigma \psi$ and $\varsigma (1 - \psi)$ are large enough). It is easier to satisfy the conditions simultaneously when ς increases.

3.2 Output

The above discussion clarifies how the equilibrium type depends on the spending level and its allocation. We now consider how these government choices affect output within an equilibrium type. Proposition 2 gives the main result.

Proposition 2. Income is related to government policy according to

$$
I^{1-\gamma-\gamma_2} = \begin{cases}
\bar{A}w\left(\xi\gamma\left(1-\varsigma\left(1-\psi\right)\right)\beta_2^{-1}\right)^{\gamma}\left(\varsigma\left(1-\psi\right)\right)^{\gamma_2} & \text{if} \quad f = (f_1^*, 0) \\
\bar{A}w\left(\xi\gamma\right)^{\gamma}\left(\xi\gamma_2\right)^{\gamma_2}\beta_1^{-(\gamma+\gamma_2)} & \text{if} \quad f = (f_1^*, f_2^*) \\
\bar{A}w\left(\varsigma\psi\right)^{\gamma}\left(\varsigma\left(1-\psi\right)\right)^{\gamma_2} & \text{if} \quad f = (0, 0) \\
\bar{A}w\left(\varsigma\psi\right)^{\gamma}\left(\left(1-\varsigma\psi\right)\beta_3^{-1}\xi\gamma_2\right)^{\gamma_2} & \text{if} \quad f = (0, f_2^*)
\end{cases}
\tag{13}
$$

where $\beta_2 \equiv 1 + \beta + \gamma\xi$ and $\beta_3 \equiv 1 + \beta + \gamma_2\xi$.

The first line of equation (13) corresponds to moderate or high spending which is focused on late childhood education. That is, it considers the case where families spend only on early childhood education. Government spending on early childhood education is $\varsigma\psi$ and output does not depend on this directly. This is because a unit of spending by government offsets a unit that would be spent by the family at this level, leaving total early childhood spending unchanged. Government spending on late childhood is given by $\varsigma\left(1-\psi\right)$. This affects output in two contrasting ways. First, an increase in spending on early childhood increases total education spending as a share of output. If this is accomplished by an increase in ς, the part spent on early childhood is offset by a decrease in private spending. However, the part spent on late childhood does not crowd out private spending since family spending at this stage is already zero. If the increase in late childhood spending is instead accomplished by a decrease in ψ, the result is similar. The decrease in government spending in early childhood causes families to spend more at this stage. However, with families already spending zero on late childhood education, there is not a corresponding decrease in private spending.

The rise in spending relative to output has a positive effect on output. However, another effect works counter to this. A higher *level* of spending can be offset by a less productive *mix* of spending. When families spend on only one stage of education, it is because that stage is more productive at the margin. Thus a reallocation of spending in the other direction reduces the productivity of a given level of spending. Increasing ς can cause such a reallocation. A higher ς, through higher taxation, leaves a smaller share of output with families. This reduces what families allocate to education. Since families are spending only on early childhood, the reduction occurs at this stage. The net result is a shift in overall spending toward late childhood. A smaller ψ is another, more direct, way to switch the mix toward late childhood.

This interplay of the level and mix of expenditures is reflected in the first line of equation (13). Here $\varsigma\left(1-\psi\right)$ has both a positive and negative effect. The effects offset where $\psi\left(1-\varsigma\right) = \gamma_2\left(\gamma+\gamma_2\right)^{-1}$. When this value of ψ lies in the region allowing $f = (f_1^*, 0)$, a local maximum arises at this point.

Figure 2 aids in the discussion. The first panel is equivalent to Figure 1 but further divides the $\varsigma \times \psi$ space into regions where output is increasing, decreasing, and invariant in ψ. The solid curves are as in Figure 1 and thus delineate the four types of equilibria. The dotted lines trace local output maximizing combinations of ψ and ς. The arrows show directions in which output is weakly increasing in ψ and ς. As shown in Figure 1, the lower region to the right of $\xi\gamma_2\beta_1^{-1}$ is where $f = (f_1^*, 0)$. The dashed line in this region is where $\psi(1 - \varsigma) = \gamma_2(\gamma + \gamma_2)^{-1}$. For smaller values of ς in the region, the level effect always dominates, so that output is increased by increasing ς or decreasing ψ. For the larger values, the mix effect dominates and output can be increased by decreasing ς or increasing ψ. For intermediate values of ς, beginning at $\varsigma = \gamma_2(\gamma + \gamma_2)^{-1}$, the effects offset at some point over the range of ψ supporting the equilibrium, giving a local interior maximum.

The second panel gives similar information from another perspective. This graphs normalized output, y, for all ς, ψ pairs. Output is normalized by its value at $\varsigma = 0$. The points of inflection correspond to the regions delineated in Figure 1 and the first panel of Figure 2. The lower right region corresponds to the lower central region of the first panel and thus again considers the case where $f = (f_1^*, 0)$. Consider a value of ς just beyond $\varsigma = \xi\gamma_2\beta_1^{-1}$. Starting at $\psi = 0$ and moving in the direction of an increase in ψ, we see that output is decreasing in ψ. At a larger value of ς, output initially rises and then falls as we increase ψ from zero. This will be true for all values of ς corresponding to those beneath the lower dashed line in the first panel. Beyond this set of ς values, output is increasing in ψ.

Results are symmetric when spending is focused on early childhood (the fourth line of equation (13)) so that families spend only on late childhood education. Government spending on early childhood is $\varsigma\psi$. An increase in this has a level effect and a mix effect analogous to those discussed above. The effects offset where $\varsigma\psi = \gamma(\gamma + \gamma_2)^{-1}$. When this value of ψ lies in the region allowing $f = (0, f_2^*)$, a local maximum arises at this point. In the first panel of Figure 2, the upper region to the right of $\xi\gamma\beta_1^{-1}$ corresponds to $f = (0, f_2^*)$. The dotted curve of Figure 2 plots where $\varsigma\psi = \gamma(\gamma + \gamma_2)^{-1}$. For the lower values of ς in the range, the level effect dominates and lowering ψ or increasing ς increases output as indicated by the arrows. For the higher values of ς in this space, the mix effect dominates and raising ψ or lowering ς increases output. For intermediate values of ς, beginning at $\varsigma = \gamma(\gamma + \gamma_2)^{-1}$, the effects offset.

The above discussion covers focused spending. We now turn our attention to balanced spending.
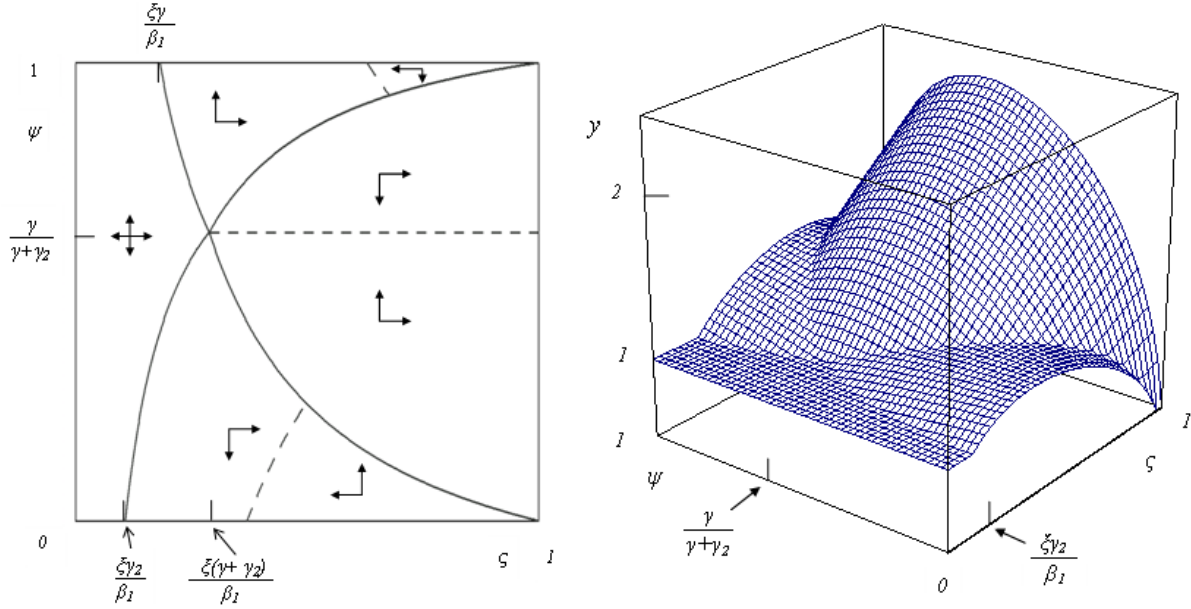
Figure 2: Output. The arrows in the first panel show the direction in which ς and ψ can be changed to increase output. The intersecting arrows on the far left indicate that output is unchanged in each direction. The second panel shows normalized output over the policy space. Here output is normalized by the value it would take at $\varsigma = 0$.

The second line of equation (13) corresponds to the case of low to moderate balanced spending. In this type of equilibrium, output is independent of the mix of spending. Government spending at each level falls below what the family would choose and thus is topped-up with private spending. Since private and public spending are perfect substitutes, a unit more or less of government spending is fully offset by a unit less or more of private spending. Since total spending at each level is unchanged through policy, human capital and hence output are unchanged. In the first panel, the independence of output from policy when $f = (f_1^*, f_2^*)$ is demonstrated by the lack of a partition and by the intersecting arrows. These indicate that output is unchanging in each direction. In the second panel this is demonstrated by the flat area at $y = 1$ for ς small or moderate and balanced.

Finally, consider the third line of equation (13) corresponding to the other possibility with balanced spending (the case of moderate to high spending). Here, both forms of private spending are fully crowded out and government is the sole source of education expenditures. In this case an increase in ς unambiguously increases output. With government providing all education spending, the mix of expenditures is determined solely by ψ and not through any general equilibrium adjustments. Thus government spending no longer has an effect on the mix of spending. Furthermore,

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an increase in ς cannot crowd out any private spending since there is none.

For a given ς, output is maximized when each unit of expenditure is put to its highest use. This requires that the marginal quantity of human capital generated should be the same for both levels of expenditure. This occurs where $\psi = \gamma \left(\gamma + \gamma_2\right)^{-1}$. Note that so long as ς is large and spending is balanced, its optimal allocation is independent of ς. This is reflected in the first panel of Figure 2 by the the horizontal dotted line and in the second by the ridge at $\psi = \gamma \left(\gamma + \gamma_2\right)^{-1}$.

Figure 2 shows that depending on ς there can be several locally optimal values of ψ. Looking at the far right of the first panel, we see that for ς large enough, output is always increasing in the direction of $\psi = \gamma \left(\gamma + \gamma_2\right)^{-1}$ so this is a global maximum. Moving to the left, another local maximum arises with ψ large and further to the left we have yet another local maximum with ψ small. As we move further to the left, past the dashed lines, these local maxima occur at corners where $\psi = 1$ and $\psi = 0$.

The second panel gives clues regarding the globally optimal ψ as a function of ς. As mentioned before, when ς is small its allocation is unimportant. For a range of ς, some sort of focused spending is always best since balanced spending yields $f = \left(f_1^*, f_2^*\right)$, the lowest possible output. For ς in a neighborhood of $\xi \gamma_2 \beta_1^{-1}$ it is best to set $\psi = 0$, and for some values of ς it is best to set $\psi = 1$. Only for ς sufficiently large is it best to have balanced expenditures. Note in particular that when $f = \left(f_1^*, f_2^*\right)$ comes into existence, it is dominated in output by both sorts of focused spending.

Figure 3 provides a more clear summary. The lines show the maximum output attainable in each type of equilibrium over the range of ς for which the equilibrium type exists. That is, it shows output at each of the local maxima existing at each ς. This output value is denoted by y^*. The solid lines correspond to balanced spending and the dashed lines to focused spending. The increasing portion of the $f = \left(f_1^*, 0\right)$ and $f = \left(0, f_2^*\right)$ curves correspond to cases where output is locally maximized at a corner ($\psi = 0$ or $\psi = 1$), and the flat portion is where the local maxima are interior.[10]

The brackets indicate which type of equilibrium globally maximizes output at each level of ς. In the bracketed range furthest to the left, output is maximized where families spend at both stages. In the subsequent bracketed range, an equilibrium where families spend only on early childhood is globally optimal. Next, family spending only on late childhood is globally optimal. Over these two ranges, then, focused spending is preferred (in terms of output). For the range furthest to the

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[10]The downward sloping portion of these curves reflect areas where output is increasing over ψ over the entire range but the equilibrium exists over a smaller range of ψ.
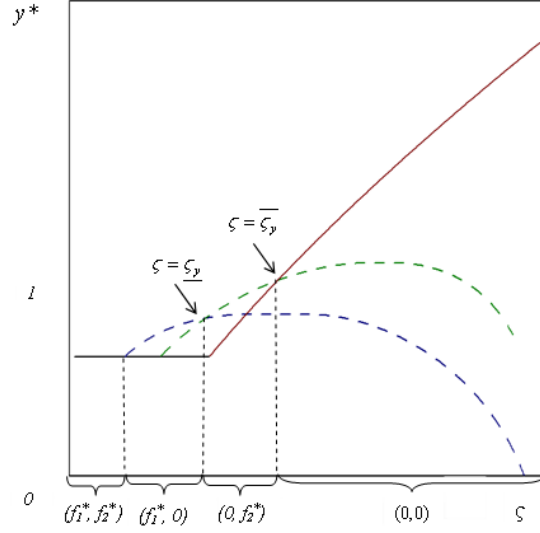
Figure 3: Maximum output. The figure shows normalized output across values of ς in each type of equilibrium when ψ is chosen to yield a local maximum. The brackets show which type of equilibrium maximizes output globally at the relevant value of ς.

right, an equilibrium where families spend at neither level is globally optimal. Only in this range is balanced spending preferred to focused spending. This result is general and the precise cutoff points can be found. The result is stated more precisely in Corollary 2.

Corollary 2. If $\gamma > \gamma_2$ there exists $\underline{\varsigma_y}$ and $\overline{\varsigma_y} > \underline{\varsigma_y}$ such that output is globally maximized at $f = (f_1^*, f_2^*)$ if $\varsigma \leq \frac{\xi\gamma_2}{\beta_1}$, at $f = (f_1^*, 0)$ if $\frac{\xi\gamma_2}{\beta_1} \leq \varsigma \leq \underline{\varsigma_y}$, at $f = (0, f_2^*)$ if $\underline{\varsigma_y} \leq \varsigma \leq \overline{\varsigma_y}$, and at $f = (0, 0)$ if $\varsigma \geq \overline{\varsigma_y}$.

Findings are symmetric if $\gamma \leq \gamma_2$[11]. Thus regardless of the relationship between γ and γ_2, each type of equilibrium is globally optimal for some value of ς. An implication is that focused spending can dominate balanced spending. When focused spending dominates, the corollary also shows which level of education should receive the lion's share of funding. One might expect that with $\gamma > \gamma_2$, education spending should be focused on early childhood where it is more productive. However, the figure shows that this holds only where $\underline{\varsigma_y} \leq \varsigma \leq \overline{\varsigma_y}$. For smaller values, it should be focused on the less productive form of education. To see why, note that we are considering cases where government spends on one stage of education and families spend on the other. The key is to

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[11]For $\gamma < \gamma_2$, the first lower bound is $\frac{\xi\gamma}{\beta_1}$ while $f = (f_1^*, 0)$ and $f = (0, f_2^*)$ switch order in the corollary. For $\gamma = \gamma_2$, $\underline{\varsigma_y} = \overline{\varsigma_y}$ and both are global maxima with $\underline{\varsigma_y} < \varsigma < \overline{\varsigma_y}$.

apply the largest block of funds to its most productive use. Suppose that family spending is higher than government spending. Then output is maximized where families spend on the productive stage indicating that government should fund the unproductive stage of education. If instead government spending exceeds family spending, output is maximized where government spends on the productive stage.

This provides intuition for the main result but ignores one important consideration. The level of spending by families is higher when they fund the more productive type of education. Thus total education spending depends on where families spend. This effect serves to influence the level of government spending at which government should fund the productive stage. However, it does not overturn the key message. For lower levels of government spending, output is higher when government spends on the unproductive stage and vice versa.

In the figure above, interior solutions are never optimal with focused spending. This is not a general result. For different parameter choices, the intersection of the $f = (0,0)$ curve with the $f = (0, f_2^*)$ curve can occur at the flat portion of the latter. However, this does not change the above discussion in a substantive way. The only difference is that in this case focused spending does not imply a corner solution.

3.3 Utility

The analysis above considers the effect of policy on output. While output is a common concern of policy makers, utility comparisons are needed to understand the full effect of policy. As such, we now consider how government choices affect utility within an equilibrium type. Proposition 3 gives the main result.

Proposition 3. Utility is related to government policy according to

$$\bar{U} = \begin{cases} \beta_2^{-(1+\beta)} \left(1 - \varsigma\left(1 - \psi\right)\right)^{1+\beta} I^{\xi+1+\beta} & \text{if} \quad f = (f_1^*, 0) \\ \beta_1^{-(1+\beta)} I^{\xi+1+\beta} & \text{if} \quad f = (f_1^*, f_2^*) \\ \left(1 + \beta\right)^{-(1+\beta)} \left(1 - \varsigma\right)^{1+\beta} I^{\xi+1+\beta} & \text{if} \quad f = (0,0) \\ \beta_3^{-(1+\beta)} \left(1 - \psi\varsigma\right)^{1+\beta} I^{\xi+1+\beta} & \text{if} \quad f = (0, f_2^*) \end{cases} \tag{14}$$

where $\bar{U}$ is a monotonic transformation of U.

The results are clearly closely related to those for output. The difference is that except where $f = (f_1^*, f_2^*)$, utility maximization considers the effect of taxation on consumption. Consider the first line of equation (14). This depends positively on output but is scaled by $(1 - \varsigma\left(1 - \psi\right))^{1+\beta}$. This scalar reflects the extent to which consumption is diminished due to the tax burden. While
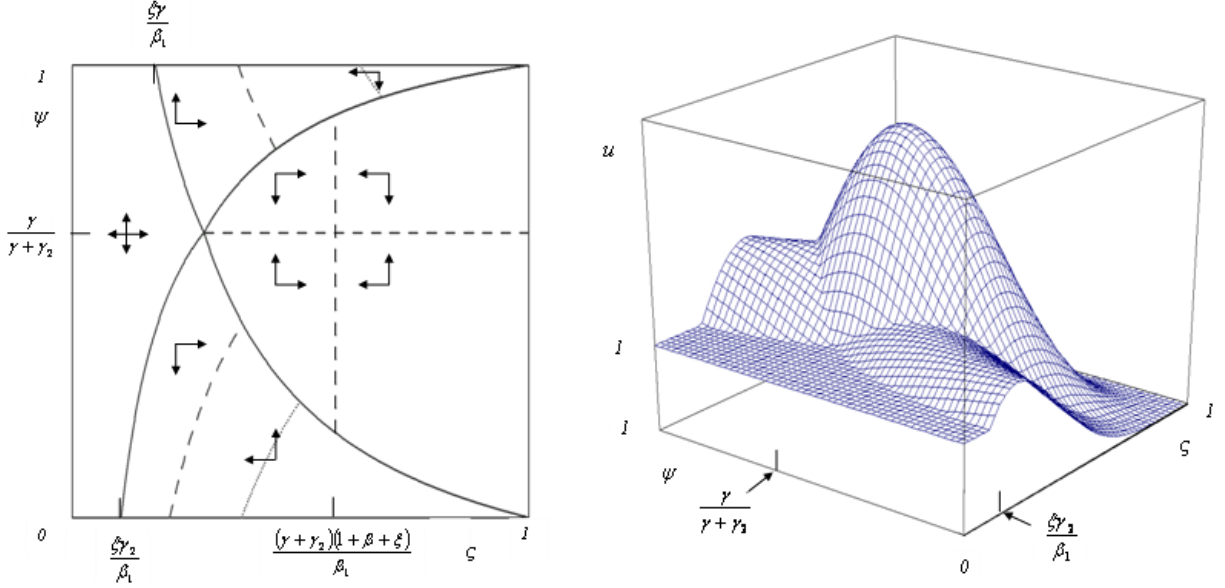
Figure 4: Utility. The arrows in the first panel show the direction in which ς and ψ can be changed to increase utility. The intersecting arrows on the far left indicate that utility is unchanged in each direction. The second panel shows normalized utility over the policy space.

the entire tax burden as a share of income is ς, $\varsigma\psi$ is spent on early childhood education. Since families also spend at this level, a unit of tax expenditure on early childhood offsets a unit of private expenditure leaving the same share of output available for consumption. Thus the scalar only reflects expenditure on late childhood education. The opposite is true when families spend only on late childhood education as in the fourth line. Here the scalar reflects only government spending on early childhood. The second line, where families spend at both levels, does not have a scalar since a unit of government expenditure just offsets a unit of private expenditure. In the third line, the scalar reflects total expenditures since there is no crowding out at the margin.

Figure 4 is analogous to Figure 2 but demonstrates normalized utility, u, rather than output. The dotted lines in the first panel correspond to the dashed lines in Figure 2 and are retained to facilitate a comparison between output and utility maximization. The dashed lines show local optima. When spending is low, output and utility maximization are equivalent since government spending just offsets private spending, leaving all allocations unchanged. With focused spending, the welfare maximizing levels of ς are to the left of those which maximize output. This reflects that some output goes to taxation rather than consumption.

The bigger difference relative to the output discussion occurs with high balanced spending.

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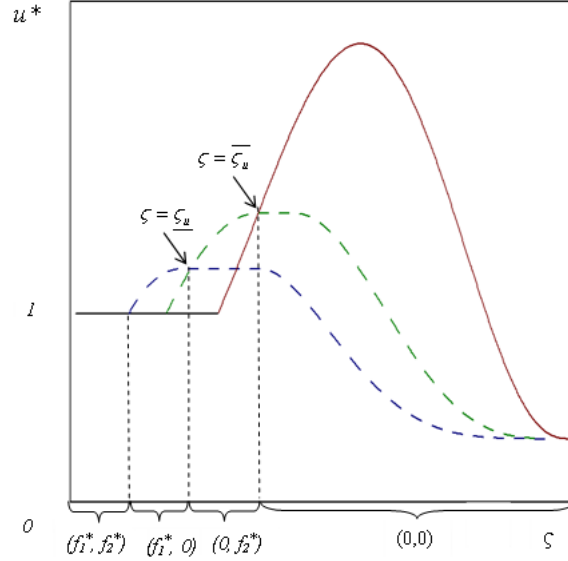
Figure 5: Maximum utility. The figure shows normalized utility across values of ς in each type of equilibrium when ψ is chosen to yield a local maximum. The brackets show which type of equilibrium maximizes utility globally at the relevant value of ς.

Here, the level of ψ that maximizes output also maximizes utility. In the first panel, this is demonstrated by the horizontal line at the same level as in Figure 2. In the second panel, it is demonstrated by the partially visible ridge at this level of ψ. However, utility is not monotonic in high balanced spending. It is straightforward to show that the utility maximizing level of spending is $\varsigma = (\gamma + \gamma_2)(\xi + 1 + \beta)\beta_1^{-1}$. Thus in addition to a ridge of local equilibria along the ς dimension, there is a ridge of local equilibria along the ψ dimension at this value of ς. Utility with high balanced spending is maximized at the intersection of these ridges.

As with Figure 2, we turn to the second panel for insights regarding global maxima as a function of ς. Again each equilibrium type is globally optimal for some range of ς. This is seen also in Figure 5, which shows the maximum utility attainable in each type of equilibrium over the range of ς for which the equilibrium type exists. Thus it is analogous to Figure 3. As with output, utility is maximized first where families spend on both levels, second where they spend on early childhood, third where they spend on late childhood, and finally where they spend on neither.

The generalization of this result and the intuition are similar to those regarding output. For brevity, these are omitted. A key similarity, however, is that for lower levels of spending beyond $\xi\gamma_2\beta^{-1}$ utility, like output, is maximized where families spend on the more productive level of

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education. For a higher level of spending but below a cutoff level, utility is maximized where families spend on the less productive level. Beyond this, it is optimal that families spend on neither level. Thus focused spending is output and utility maximizing for small enough ς and balanced spending is output and utility maximizing for large enough ς. With utility, the cutoff points are different and are denoted by $\underline{\varsigma_u}$ and $\overline{\varsigma_u}$.

4   The General Case

The previous section requires several restrictive assumptions. In this section we relax several items of Assumption 1 and demonstrate that the restrictive model captures much of the key intuition arising in the more general model.[12] Relaxing any of the assumptions requires solving the model numerically. The first order conditions for the more general problem are straightforward extensions of those in the proof to Proposition 1 and are not presented here. For brevity we hereafter focus on output. From the preceding section it is clear that results regarding utility are similar.

In the first panel we set $\eta = .95$ so that private and government spending are imperfectly substitutable in the production of human capital. Results are similar to the second panel of Figure 2. The key difference is a smoothing of the surface between the different regions. With imperfect substitutability, family spending in either category will never go to zero. Thus we no longer have as sharp a distinction across the regions. However, each policy pair yields results that are qualitatively similar to the case with perfect substitutability. In particular, for moderate and high government spending, we have local maxima at several values of ψ. The global maximum again depends on ς and in the same way as before. However, it is straightforward to show that when human capital is a Cobb-Douglas combination of private and government spending, output is always maximized when resources are split relatively equally. From this we conclude that concentrated public spending can maximize output only in the case where private and public spending are relatively close substitutes.

In the second panel of Figure 6 we additionally set $\rho = -1$ so that early and late childhood expenditures are more complementary than in the Cobb-Douglas case. One difference is that the output maximizing level of ψ shifts to the left (when not a corner). This is because early childhood spending now has a larger positive effect on the productivity of later spending. Still, the results mirror those in Figure 2 and the intuition above still serves to understand the results.

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[12]We run a similar experiment to examine changes in r. The results change little, with r simply serving to scale the output effect. For this reason, the results are not presented here.
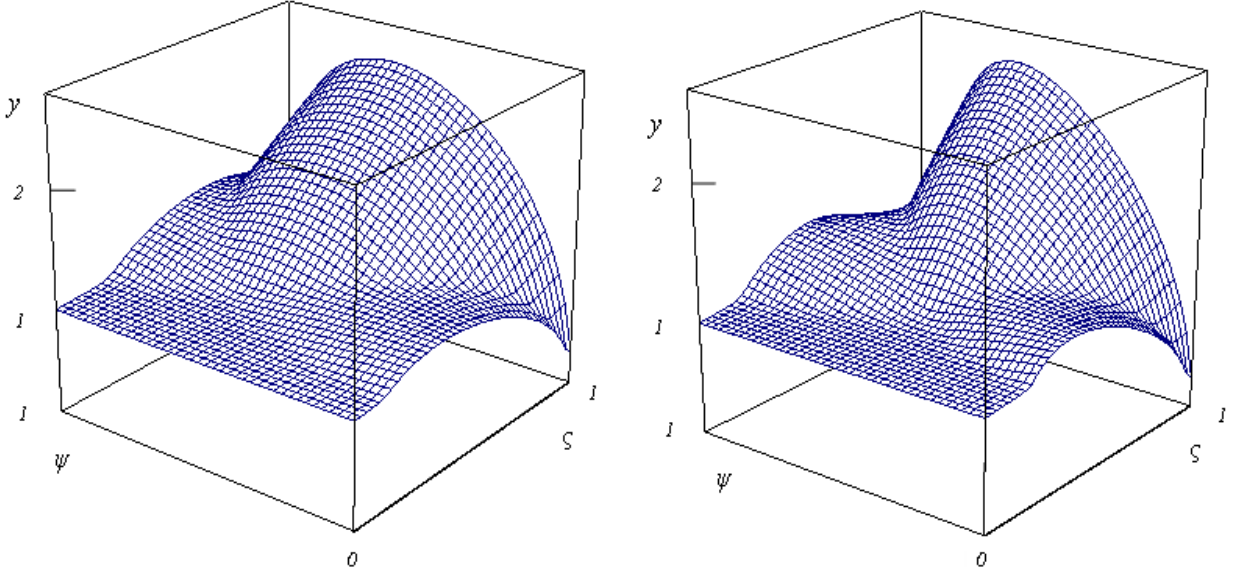
Figure 6: Sensitivity. The first panel sets $\eta = .95$. The second panel additionaly sets $\rho = -1$.

5 Heterogeneity

We now consider the impact of policy across a heterogeneous population. As stated in Section 2, heterogeneity is expressed by different levels of a_j. There are strong similarities between the heterogeneous family economy and the one family economy discussed above. Since the higher indexed families will have a higher value of a_j, in equilibrium they will also have higher income. With heterogeneity, the common level of government expenditure for each family will represent different ratios of government spending to individual income. In particular, a common level of government education spending, ς, will represent lower government spending relative to income for high income families than for low income families. To see it, recall that ς is the share of total output that goes to education. With the population of each generation normalized to 1, lifetime government education spending per family is $\varsigma Z H$. Since the income of family j is $Z h_{2j}$, government spending as a share of own income for family j is

$$\varsigma_j = \varsigma \frac{H}{h_{2j}}. \tag{15}$$

It is this ς_j value that matters to families, rather than ς alone.

The distribution of ς_j clearly depends on ς and the distribution of output. This latter item maps into the distribution of a_j. Stated differently, we can choose the distribution of ς_j through

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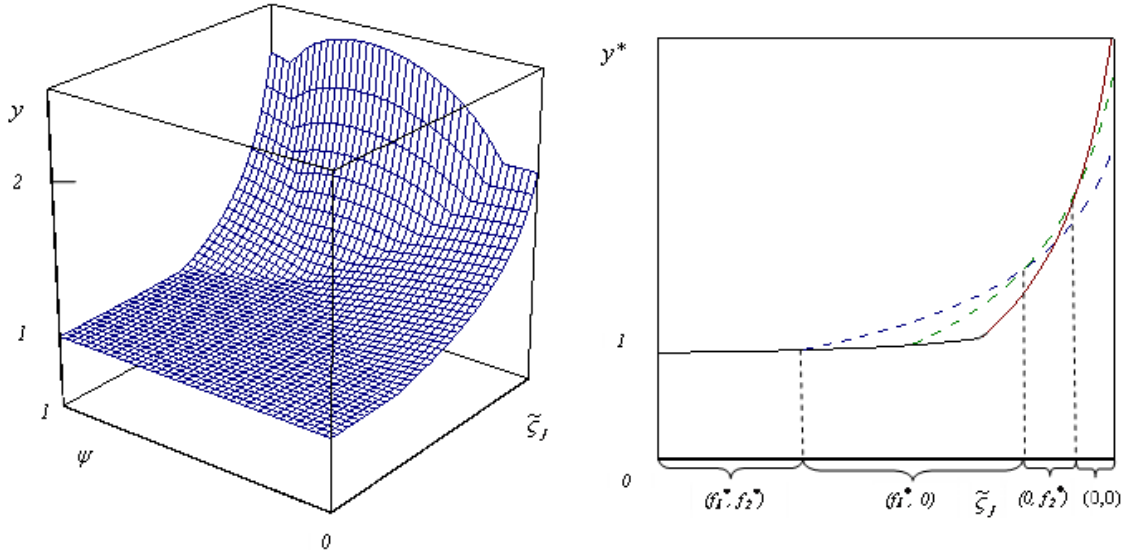
Figure 7: Output and maximum output. The first panel shows normalized output across the income distribution (represented by $\tilde{\varsigma}_j$) as a function or ψ. The second panel shows normalized output across the income distribution when ψ is chosen to yield a local maximum. The brackets show which type of equilibrium maximizes output globally at the relevant point in the income distribution. For each agent, output is normalized by output for that agent when $\varsigma = 0$.

choosing the distribution of a_j. The relationship will be such that the smallest a_j is associated with the largest ς_j.

With a few caveats we can provide a different interpretation of our earlier findings. Rather than considering a representative family at different levels of spending, we can consider different families with common government spending. In the earlier analysis $H = 2h_2$ so differences in ς_j are generated by differences in ς. Now we hold ς constant and allow differences in ς_j though heterogeneity in h_{2j}.

With heterogeneity, we must turn to numerical results even with the parameter restrictions in Assumption 1. These results are presented in Figure 7. The first panel is analogous to the second panel of Figure 2. The difference is that the variation in ς_j is a general equilibrium consequence of variation in ability. Specifically, for this example we assume that ability is uniform over $[.5, 5]$ and $\varsigma = .02$. We then find values of $\{h_{2,j}\}$ $\forall j \in \mathcal{J}$ and other endogenous items such that the definition of an equilibrium is satisfied. Given $\{h_{2,j}\}$ $\forall j$ we know H and thus can use equation (15) to find the distribution of ς_j. For ease of comparison, we plot a monotonic transformation of

ς_j $(\tilde{\varsigma}_j)$ against ψ on the horizontal axes and normalized output along the vertical axis.[13] As before, output is normalized by what it would be with $\varsigma = 0$.

The first panel of Figure 7 shows that there are again four distinct regions. These correspond to the regions in Figure 2. For $\tilde{\varsigma}_j$ small (wealthy families), output is independent of ψ. For larger values of $\tilde{\varsigma}_j$ (less wealthy families), output depends on ψ. In particular, for any level of $\tilde{\varsigma}_j$ there are up to three local maxima. Which of these is the global maximum depends on $\tilde{\varsigma}_j$.

The second panel of Figure 7 shows how. It is analogous to Figure 3 and shows the global maximum income as a function of $\tilde{\varsigma}_j$. Moving right to left, we see that low income families prefer relatively balanced spending. When government focuses spending on one level, these families spend on the other. With low income however, the private spending level is low, resulting in low human capital and output.

Further to the left, agents prefer focused spending. For the lower income families among these, output is highest when government focuses on the more productive form of education (large ψ) and families spend at the other level. This is because family spending is small relative to focused government spending and it is best to have the larger amount of spending allocated to its most productive use. For the next group of families, private spending is large relative to focused government spending. As such, their income is maximized when government spending is focused on the less productive stage. Finally, for the most wealthy agents, government spending at one stage simply displaces private spending so that output is unchanging in ψ.

Because the analogy with the homogeneous case is quite strong, this discussion is quite similar to the discussion after Figure 2. There are, however, some differences. The key qualitative difference is that in Figure 2 output is non-monotonic in ς when $f = (0, f_2^*)$ or $f = (f_1^*, 0)$. This is because in Figure 2 an increase in ς requires an increase in taxes which crowds out private spending. In Figure 7, ς is fixed so this effect does not arise. Also in Figure 7, with $f = (f_1^*, f_2^*)$, y^* increases moderately with ς_j. This reflects that the income tax to finance education is more onerous for those with larger incomes.

Despite these minor differences, we can by and large take the discussion regarding output and utility in the above sections and generalize it to the case where families differ in ability. We need only to recognize that a level of government spending signifies a different relevant ς for the different families. In general, when there are substantial differences in income, there will be differences in

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[13]Specifically, the axis is $\tilde{\varsigma}_j = a(j) \in [.5, 5]$. This allows for easier comparison and provides the same essential information since there is a one-to-one correspondence between $a(j)$ and ς_j.

preferred policies. In particular, focusing expenditures on late childhood may benefit some families at the detriment of others.

6 Conclusion

Early childhood education builds a foundation of knowledge and habits that makes later education more productive. Later education gives this foundation value through a realization of potential. Most prior work abstracts from this hierarchical structure of human capital accumulation. This paper contributes to a nascent literature that instead makes this structure the focal point of its investigations. Our purpose is to evaluate the structure of government education spending in a model of hierarchical human capital accumulation. Currently, government spending favors late childhood over early childhood. We explore whether a reallocation toward early childhood would be beneficial.

Our general equilibrium environment accounts for crowding out of private spending by public spending. In our baseline model, private and public spending are perfectly substitutable so that a unit of government spending offsets a unit of private spending. Only when private spending on at least one stage of education is driven to zero can policy affect output. We show that for low levels of funding, government maximizes output by funding only the less productive type of education. For intermediate levels of funding, government should finance only the more productive type of education. Only when the total level of funding is above a threshold should it fund both.

The first results are derived in a highly stylized setting. This has the advantage of analytical tractability. The stylized model also proves sufficient for demonstrating the key implications of the model. Through sensitivity analyses, we demonstrate that relaxing this strict structure leaves the most interesting results qualitatively unchanged. An exception is the perfect substitutability of private and public resources. When we make these inputs relatively substitutable, but not perfectly so, results are largely unchanged. When the inputs are relatively complementary, output is no longer maximized by concentrated spending.

The final part of the paper shows that these results can be easily generalized to the case of heterogeneous agents. The different levels of spending in earlier sections correspond to different income levels in the final section. With a common level of education spending across agents, there will be agents who privately spend at both stages, one stage, or no stage. The analysis shows that concentrated spending can be best for some part of the population while inappropriate for the lower

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income agents.

Our concern is the theoretical implications of allocating government education expenditures in a hierarchical education system. To maintain focus, even our more general model abstracts from many important considerations. As such, we do not attempt to quantify our findings through a careful calibration. Such a quantitative investigation would be a useful next step. There are a number of issues that might prove interesting in a fuller model. Our model has no physical capital in production. Thus there is no worry of taxation lowering the capital stock. Our model has no credit constraints despite their central role in many other studies of education. We do not consider imperfect inheritance of ability. These omissions could be remedied in a fuller, empirical investigation. However, we expect that the key intuition developed above will continue to hold and thus aid in our understanding of the implications of government education spending.

A more complete analysis might also consider a fuller set of policy options. For brevity, we have restricted attention to the experiments described above. The model, however, is suggestive of other policy implications. Rather than considering spending policies which are symmetric across the population, we could consider the effects of progressive spending where government spends more on those with lower income. This is more reflective of the well-known Perry Preschool Project, the Abecedarian Project (see CHLM (2007)), and Head Start (see Currie (2001b)). Each of these has targeted low income families and has arguably been highly beneficial to the targeted population. In our setup, we would expect to see expenditures at these levels have the largest impact due to diminished crowding out and a higher marginal benefit to an increment in total spending for low income households. This would be consistent with the conclusion by Currie (2001a) that "priority should be given to expanding Head Start rather than funding universal preschool" since children of the lower income parents are more in need of quality preschool. Furthermore, progressive spending may have additional economy-wide benefits when different levels of skill are complements in production. A potentially fruitful direction for future policy analysis, then, is the exploration of optimal spending allocation across the income distribution.

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Appendix

Proof of Propositions 1-3. The agent's problem is to maximize equation (4) subject to the constraints in equation (5) and the relationships in equations (1) and (2). We impose the last two lines of equation (5) to arrive at the following Lagrangian:

$$\mathcal{L} = \ln c_3 + \beta \ln c_4 + \xi \ln \bar{A} w \left(f_1 + g_1\right)^{\gamma} \left(f_2 + g_2\right)^{\gamma_2}$$
$$+ \lambda \left(I \left(1 - \tau\right) - c_3 - c_4 - f_1 - f_2\right).$$

The structure of the problem assures that the first line of equation (5) will hold with equality and that the non-negativity constraints in the second line of equation (5) will not bind in equilibrium.

However, the non-negativity constraints in the third line may bind so we write the Kuhn-Tucker conditions as

$$c_3 \quad : \quad \frac{1}{c_3} - \lambda = 0 \tag{16a}$$

$$c_4 \quad : \quad \frac{\beta}{c_4} - \lambda = 0 \tag{16b}$$

$$f_1 \quad : \quad \frac{\xi\gamma}{f_1+g_1} - \lambda \leq 0, \quad f_1 \geq 0, \quad \text{and} \quad \left(\frac{\xi\gamma}{f_1+g_1} - \lambda\right) f_1 = 0 \tag{16c}$$

$$f_2 \quad : \quad \frac{\xi\gamma_2}{f_2+g_2} - \lambda \leq 0, \quad f_2 \geq 0, \quad \text{and} \quad \left(\frac{\xi\gamma_2}{f_2+g_2} - \lambda\right) f_2 = 0 \tag{16d}$$

$$\lambda \quad : \quad I\left(1-\tau\right) - c_3 - c_4 - f_1 - f_2 = 0. \tag{16e}$$

There are four cases to consider.

Let $f = (f_1^*, 0)$. Equations (16a)-(16c) into equation (16e) and the assumption $f_2 = 0$ give

$$c_3 = \frac{I(1-\tau)+g_1}{\beta_2}, \quad c_4 = c_3\beta, \quad f_1 = c_3\xi\gamma - g_1, \quad f_2 = 0. \tag{17}$$

Let $f = (f_1^*, f_2^*)$. Equations (16a)-(16d) into equation (16e) gives

$$c_3 = \frac{I(1-\tau)+g_1+g_2}{\beta_1}, \quad c_4 = c_3\beta, \quad f_1 = c_3\xi\gamma - g_1, \quad f_2 = c_3\xi\gamma_2 - g_2. \tag{18}$$

Let $f = (0,0)$. Equations (16a) and (16b) into equation (16e) and the assumption $f_1 = f_2 = 0$ give

$$c_3 = \frac{I(1-\tau)}{1+\beta}, \quad c_4 = c_3\beta, \quad f_1 = 0, \quad f_2 = 0. \tag{19}$$

Let $f = (0, f_2^*)$. Equations (16a), (16b), and (16d) into equation (16e) and the assumption $f_1 = 0$ give

$$c_3 = \frac{I(1-\tau)+g_2}{\beta_3}, \quad c_4 = c_3\beta, \quad f_1 = 0, \quad f_2 = c_3\xi\gamma_2 - g_2. \tag{20}$$

With $r = 1$, from equations (3), (6), and (9) and the equilibrium conditions that $H = H_2$ and $w = Z$ we have

$$Y = I = wh_2. \tag{21}$$

From equations (6), (7), (8), and (21) we have

$$\tau = \varsigma, \quad g_1 = \varsigma\psi I, \quad g_2 = \varsigma\left(1-\psi\right) I. \tag{22}$$

Next, using the third and fourth items in equations (17)-(20) along with equations (10) and (22) in equation (11) gives

$$h_2 = \begin{cases} \bar{A}\left(c_3\xi\gamma\right)^\gamma \left(\varsigma\left(1-\psi\right) I\right)^{\gamma_2} & \text{if} \quad f = (f_1^*, 0) \\ \bar{A}\left(c_3\xi\gamma\right)^\gamma \left(c_3\xi\gamma_2\right)^{\gamma_2} & \text{if} \quad f = (f_1^*, f_2^*) \\ \bar{A}\left(\varsigma\psi I\right)^\gamma \left(\varsigma\left(1-\psi\right) I\right)^{\gamma_2} & \text{if} \quad f = (0,0) \\ \bar{A}\left(\varsigma\psi I\right)^\gamma \left(c_3\xi\gamma_2\right)^{\gamma_2} & \text{if} \quad f = (0, f_2^*). \end{cases} \tag{23}$$

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Equations (17)-(20) and (22) give

$$
c_3 = \begin{cases}
I\left(1 - \varsigma\left(1 - \psi\right)\right)\beta_2^{-1} & \text{if} \quad f = (f_1^*, 0) \\
I\beta_1^{-1} & \text{if} \quad f = (f_1^*, f_2^*) \\
I\left(1 - \varsigma\right)\left(1 + \beta\right)^{-1} & \text{if} \quad f = (0, 0) \\
I\left(1 - \varsigma\psi\right)\beta_3^{-1} & \text{if} \quad f = (0, f_2^*).
\end{cases}
\tag{24}
$$

Using equations (21) and (24) in equation (23) gives

$$
h_2 = \begin{cases}
\left(\bar{A}w^{\gamma+\gamma_2}\left(\xi\gamma\left(1 - \varsigma\left(1-\psi\right)\right)\beta_2^{-1}\right)^{\gamma}\left(\varsigma\left(1-\psi\right)\right)^{\gamma_2}\right)^{\frac{1}{1-\gamma-\gamma_2}} & \text{if} \quad f = (f_1^*, 0) \\
\left(\bar{A}w^{\gamma+\gamma_2}\left(\xi\gamma\right)^{\gamma}\left(\xi\gamma_2\right)^{\gamma_2}\beta_1^{-(\gamma+\gamma_2)}\right) & \text{if} \quad f = (f_1^*, f_2^*) \\
\left(\bar{A}w^{\gamma+\gamma_2}\left(\varsigma\psi\right)^{\gamma}\left(\varsigma\left(1-\psi\right)\right)^{\gamma_2}\right)^{\frac{1}{1-\gamma-\gamma_2}} & \text{if} \quad f = (0, 0) \\
\left(\bar{A}w^{\gamma+\gamma_2}\left(\varsigma\psi\right)^{\gamma}\left(\left(1-\varsigma\psi\right)\beta_3^{-1}\xi\gamma_2\right)^{\gamma_2}\right)^{\frac{1}{1-\gamma-\gamma_2}} & \text{if} \quad f = (0, f_2^*).
\end{cases}
$$

Using this in equation (21) and simplifying gives equation (13).

Consider circumstances under which equilibrium types exist.

Let $f = (f_1^*, 0)$. Putting equation (16a) into equation (16d), we see that $f_2 = 0$ if $c_3 \le \frac{g_2}{\xi\gamma_2}$. From the third item in equation (17), $f_1 \ge 0$ requires $c_3 \ge \frac{g_1}{\xi\gamma}$. Using equation (8) and the first line of equation (24) along with $Y = I$, these constraints can be written as

$$
\frac{\varsigma\psi I}{\xi\gamma} \le \frac{I\left(1 - \varsigma\right) + I\varsigma\psi}{\beta_2} \le \frac{\varsigma\left(1 - \psi\right)I}{\xi\gamma_2}.
$$

Solving for ψ, this can be rewritten to give the first line of equation (12).

Let $f = (f_1^*, f_2^*)$. From equation (18), $f_1 \ge 0$ and $f_2 \ge 0$ requires

$$
c_3 \ge \max\left(\frac{g_1}{\xi\gamma}, \frac{g_2}{\xi\gamma_2}\right)
$$

and using equation (8) and the second line of equation (24) this is

$$
I\beta_1^{-1} \ge \max\left(\frac{\varsigma\psi I}{\xi\gamma}, \frac{\varsigma\left(1 - \psi\right)I}{\xi\gamma_2}\right).
$$

Solving for ψ, this can be rewritten to give the second line of equation (12).

Let $f = (0, 0)$. Putting equation (16a) into equations (16c) and (16d), we see that $f_2 = 0$ if $c_3 \le \frac{g_2}{\xi\gamma_2}$ and $f_1 = 0$ if $c_3 \le \frac{g_1}{\xi\gamma}$. Using equation (8) and the third line of equation (24), these constraints can be written as

$$
\frac{I\left(1 - \varsigma\right)}{1 + \beta} \le \min\left[\frac{\varsigma\psi I}{\xi\gamma}, \frac{\varsigma\left(1 - \psi\right)I}{\xi\gamma_2}\right].
$$

Solving for ψ, this can be rewritten to give the third line of equation (12).

Let $f = (0, f_2^*)$. Putting equation (16a) into equation (16c), we see that $f_1 = 0$ if $c_3 \leq \frac{g_1}{\xi\gamma}$. From the fourth item in equation (20), $f_2 \geq 0$ requires $c_3 \geq \frac{g_2}{\xi\gamma_2}$. Using equation (8) and the fourth line of equation (24), these constraints can be written as

$$\frac{\varsigma(1-\psi)I}{\xi\gamma_2} \leq I(1-\varsigma\psi)\beta_3^{-1} \leq \frac{\varsigma\psi I}{\xi\gamma}.$$

Solving for ψ, this can be rewritten to give the fourth line of equation (12). It is straightforward to show that conditions allowing the four cases are mutually exclusive.

Finally, consider utility. From $\hat{I} = I$, equation (4) and equations (18)-(19), $U_j = \ln \beta^\beta c_3^{1+\beta} I^\xi$. Thus equation (14) follows directly from equation (24). $\bar{U} = \exp(U_j)\beta^{-\beta}$ which is a monotonic transformation.

Proof of Corollary 1. Consider the second line of equation (12). The left-hand-side inequality holds for all values of ψ only if $\varsigma \leq \xi\gamma_2\beta_1^{-1}$. The right-hand-side inequality holds for all values of ψ if and only if $\varsigma \leq \xi\gamma\beta_1^{-1}$. Thus both always hold only if $\varsigma \leq \min\left[\xi\gamma_2\beta_1^{-1}, \xi\gamma\beta_1^{-1}\right]$. Along with the definition of low spending, this gives the first line of Corollary 1. The second line of the corollary follows from the first and fourth lines of equation (12) where we see that for ψ small, families spend only on early childhood and with ψ large, families spend only on late childhood. Finally, note that $f = (0,0)$ can exist for some ψ if and only if $\frac{\xi\gamma}{1+\beta}\frac{1-\varsigma}{\varsigma} \leq 1 - \frac{\xi\gamma_2}{1+\beta}\frac{1-\varsigma}{\varsigma}$. This requires $\varsigma \geq \frac{\xi\gamma+\xi\gamma_2}{\beta_1}$. Similarly $f = (f_1^*, f_2^*)$ can exist for some ψ if and only if $1 - \frac{\xi\gamma_2}{\beta_1\varsigma} \leq \frac{\xi\gamma}{\beta_1\varsigma}$. This requires $\varsigma \leq \frac{\xi\gamma+\xi\gamma_2}{\beta_1}$. Along with the definitions of moderate and high spending, this proves the final line.

Proof of Corollary 2. For brevity, we provide only a sketch of the proof. Throughout, we consider $\tilde{I} = (\bar{A}w)^{-1} I^{1-\gamma-\gamma_2}$ rather than I with no loss of generality.

From equation (12), the following equilibria exist for some value of $\psi \in [0,1]$ given the values of ς:

$$f = \begin{cases} (f_1^*, f_2^*) & \text{if} & \varsigma \leq \frac{\xi\gamma_2}{\beta_1} \\ (f_1^*, f_2^*), (f_1^*, 0) & \text{if} & \frac{\xi\gamma_2}{\beta_1} \leq \varsigma \leq \frac{\xi\gamma}{\beta_1} \\ (f_1^*, f_2^*), (f_1^*, 0), (0, f_2^*) & \text{if} & \frac{\xi\gamma}{\beta_1} \leq \varsigma \leq \frac{\xi(\gamma+\gamma_2)}{\beta_1} \\ (0,0), (f_1^*, 0), (0, f_2^*) & \text{if} & \varsigma \geq \frac{\xi(\gamma+\gamma_2)}{\beta_1}. \end{cases}$$

Define $\tilde{I}_{f_1^*,0}$ to be output in $f = (f_1^*, 0)$ when ψ is chosen to locally maximize output. Stated differently, it is the maximum output over the range of ψ supporting $f = (f_1^*, 0)$ given ς. Output is maximized over this range either at $\psi = 0$ or where $\frac{\partial I}{\partial \psi} = 0$, with I given by the first line of equation (13). From choosing the output maximizing level of ψ in equation (13) we find

$$\tilde{I}_{f_1^*,0} = \begin{cases} \left(\xi\gamma(1-\varsigma)\beta_2^{-1}\right)^\gamma \varsigma^{\gamma_2} & \text{if} & \varsigma \leq \frac{\gamma_2}{\gamma+\gamma_2} \\ \left(\xi\frac{\gamma^2}{\gamma+\gamma_2}\beta_2^{-1}\right)^\gamma \left(\frac{\gamma_2}{\gamma+\gamma_2}\right)^{\gamma_2} & \text{if} & \varsigma \geq \frac{\gamma_2}{\gamma+\gamma_2}. \end{cases} \tag{25}$$

Similarly

$$\tilde{I}_{0,f_2^*} = \begin{cases} \varsigma^\gamma \left((1-\varsigma)\,\beta_3^{-1}\xi\gamma_2 \right)^{\gamma_2} & \text{if} \quad \varsigma \le \frac{\gamma}{\gamma+\gamma_2} \\ \left(\frac{\gamma}{\gamma+\gamma_2} \right)^\gamma \left(\frac{\gamma_2^2}{\gamma+\gamma_2}\beta_3^{-1}\xi \right)^{\gamma_2} & \text{if} \quad \varsigma \ge \frac{\gamma}{\gamma+\gamma_2}, \end{cases} \tag{26}$$

$$\tilde{I}_{0,0} = \left(\frac{\varsigma\gamma}{\gamma+\gamma_2} \right)^\gamma \left(\frac{\varsigma\gamma_2}{\gamma+\gamma_2} \right)^{\gamma_2}, \tag{27}$$

and

$$\tilde{I}_{f_1^*,f_2^*} = (\xi\gamma)^\gamma\,(\xi\gamma_2)^{\gamma_2}\,\beta_1^{-(\gamma+\gamma_2)}. \tag{28}$$

Each is continuous. The first two are initially increasing in ς and level out at $\varsigma = \frac{\gamma_2}{\gamma+\gamma_2}$ and $\frac{\gamma}{\gamma+\gamma_2}$.

The third is increasing in ς always and the fourth is independent of ς.

Consider starting with $\varsigma = 0$ and increasing ς. Initially output is globally maximized at $f = (f_1^*, f_2^*)$ since only this equilibrium exists. When $\tilde{I}_{f_1^*,0}$ comes into existence at $\varsigma = \frac{\xi\gamma_2}{\beta_1}$, $\tilde{I}_{f_1^*,0} = \tilde{I}_{f_1^*,f_2^*}$ and the ratio of $\tilde{I}_{f_1^*,0}$ to $\tilde{I}_{f_1^*,f_2^*}$ is increasing in ς. Thus beginning here, $(f_1^*, 0)$ is optimal and beyond this value of ς, $f = (f_1^*, f_2^*)$ can not be globally optimal.

When $\tilde{I}_{0,f_2^*}$ comes into existence at $\varsigma = \frac{\xi\gamma}{\beta_1}$, $\tilde{I}_{0,f_2^*} < \tilde{I}_{f_1^*,0}$. This is because at this value $\tilde{I}_{0,f_2^*} = \tilde{I}_{f_1^*,f_2^*}$ and $\tilde{I}_{f_1^*,0} > \tilde{I}_{f_1^*,f_2^*}$. Also, the ratio of $\tilde{I}_{0,f_2^*}$ to $\tilde{I}_{f_1^*,0}$ is increasing in ς. At their maximum values $\tilde{I}_{0,f_2^*} > \tilde{I}_{f_1^*,0}$. To see this, put $\varsigma = \frac{\gamma_2}{\gamma+\gamma_2}$ into the first line of equation (25) and $\varsigma = \frac{\gamma}{\gamma+\gamma_2}$ into the first line of equation (26) and compare. This is sufficient to show that $\tilde{I}_{0,f_2^*} = \tilde{I}_{f_1^*,0}$ at one value of ς. Call it $\underline{\varsigma_y}$. Beyond $\underline{\varsigma_y}$, $f = (f_1^*, 0)$ cannot be globally optimal.

When $\tilde{I}_{0,0}$ comes into existence at $\varsigma = \frac{\xi(\gamma+\gamma_2)}{\beta_1}$, $\tilde{I}_{0,0} < \tilde{I}_{0,f_2^*}$. This is because at this value $\tilde{I}_{0,0} = \tilde{I}_{f_1^*,f_2^*}$ and $\tilde{I}_{0,f_2^*} > \tilde{I}_{f_1^*,f_2^*}$. Also, the ratio of $\tilde{I}_{0,0}$ to $\tilde{I}_{0,f_2^*}$ is increasing in ς. At their maximum values $\tilde{I}_{0,0} > \tilde{I}_{0,f_2^*}$. To see this, put $\varsigma = \frac{\gamma}{\gamma+\gamma_2}$ into the first line of equation (26) and $\varsigma = 1$ into the first line of equation (27) and compare. This is sufficient to show that $\tilde{I}_{0,0} = \tilde{I}_{0,f_2^*}$ at one value of ς. Call it $\overline{\varsigma_y}$. Beyond $\overline{\varsigma_y}$, $f = (0, f_2^*)$ cannot be globally optimal.

We have shown that in the range $\varsigma \in \left(\frac{\xi\gamma_2}{\beta_1}, \underline{\varsigma_y} \right)$, $\tilde{I}_{f_1^*,0} > \tilde{I}_{f_1^*,f_2^*}, \tilde{I}_{0,f_2^*}$. To assure a global maximum, we need to show that $\tilde{I}_{f_1^*,0} > \tilde{I}_{0,0}$ in this range. Suppose $\tilde{I}_{f_1^*,0} = \tilde{I}_{0,f_2^*} < \tilde{I}_{0,0}$ at $\varsigma = \underline{\varsigma_y}$. Then $\tilde{I}_{0,0} = \tilde{I}_{0,f_2}$ $(\varsigma = \overline{\varsigma_y})$ must occur at a lower value of ς than $\tilde{I}_{0,0} = \tilde{I}_{f_1^*,0}$ and before $\varsigma = \underline{\varsigma_y}$. This is because $\tilde{I}_{0,f_2^*} < \tilde{I}_{f_1^*,0}$ to the left of $\varsigma = \underline{\varsigma_y}$ and their ratio is increasing in ς over this range. At the point where $\tilde{I}_{0,f_2^*} = \tilde{I}_{0,0}$, it must be that $\tilde{I}_{f_1^*,0} > \tilde{I}_{0,0}$ so long as $\varsigma < \underline{\varsigma_y}$. $\tilde{I}_{f_1^*,0} = \tilde{I}_{0,0}$ only at a larger ς.

We show that this cannot hold (a contradiction) and that in fact $\tilde{I}_{0,0} = \tilde{I}_{0,f_2^*}$ occurs at a higher value of ς than $\tilde{I}_{0,0} = \tilde{I}_{f_1^*,0}$. To show this, we find the values of ς that solve $\tilde{I}_{0,0} = \tilde{I}_{f_1^*,0}$ and

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$\tilde{I}_{0,0} = \tilde{I}_{0,f_2^*}$ and then determine that $\tilde{I}_{0,0} = \tilde{I}_{0,f_2^*}$ occurs at a lower value of ς than $\tilde{I}_{0,0} = \tilde{I}_{f_1^*,0}$ only if

$$\frac{1+\beta+\gamma_2\xi}{1+\beta+\gamma\xi} < \left(\frac{\gamma+\gamma_2}{\gamma}\right)^{\frac{\gamma}{\gamma_2}}\left(\frac{\gamma+\gamma_2}{\gamma_2}\right)^{\frac{-\gamma_2}{\gamma}}.$$

The two sides of this are equal at $\gamma = \gamma_2$. The left hand side is decreasing in γ. The right hand side is increasing in γ. This is not obvious but can be shown to hold. Given this, the inequality cannot hold for $\gamma > \gamma_2$. Thus $\tilde{I}_{0,0} = \tilde{I}_{0,f_2^*}$ occurs at a higher value of ς than $\tilde{I}_{0,0} = \tilde{I}_{f_1^*,0}$. With this, we know that $\tilde{I}_{f_1^*,0} > \tilde{I}_{0,0}$ over $\varsigma \in \left(\frac{\xi\gamma_2}{\beta_1}, \underline{\varsigma_y}\right)$ and an equilibrium with $f = (f_1^*, 0)$ is globally optimal in this range.

Since $\tilde{I}_{f_1^*,0} = \tilde{I}_{0,f_2^*} > \tilde{I}_{0,0}$ at $\varsigma = \underline{\varsigma_y}$, by continuity and earlier arguments, we know that in a neighborhood to the right of this $\tilde{I}_{0,f_2^*} > \tilde{I}_{0,0}$ and $\tilde{I}_{0,f_2^*}$ is a global optimum. We also know they cross as some point $\overline{\varsigma_y}$ and beyond this $\tilde{I}_{0,0}$ is globally optimal. This completes the sketch of the proof.

Part II
Chapter 2: Measures of Human Capital in Growth Regressions

7   Introduction

"All who have meditated on the art of governing mankind have been convinced that the fate of empires depends on the education of youth." –Aristotle

"Education is the most powerful weapon which you can use to change the world." –Nelson Mandela

"Our progress as a nation can be no swifter than our progress in education." –John F. Kennedy

"The future belongs to the nation that best educates its citizens. . . " –President Barack Obama

There is no doubt that education is important. The quotations above illustrate this consensus. Formal education is a significant period in most peoples' lives, with the average American spending about 20% of their existence in school[14]. In addition to time, a huge amount of resources is devoted to schooling each year. Spending on public and private education at all levels (pre-kindergarten to graduate school) in the U.S. was approximately $972 billion for the 2006-2007 school year with total education expenditures accounting for about 7.4% of U.S. GDP[15]. In the U.S., local and state governments are the largest source of these funds with the federal government and individuals playing smaller roles.

Education is critical in generating human capital. The Organization for Economic Cooperation and Development (OECD) defines human capital as the "productive wealth embodied in labor, skills, and knowledge"[16]. Human capital is typically considered a main determinant of productivity and economic growth. This follows the notion that more educated and skilled workers will be more productive and innovative. Economists recognized the importance of human capital very early on. In 1776, Adam Smith defined human capital as the "acquired and useful abilities of all the inhabitants or members of the society"[17]. In 1890, Alfred Marshall stressed the importance of human capital by stating, "The most valuable of all capital is that invested in human beings."[18]

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[14]Author's calculation using 2009 estimated U.S. life expectancy (CIA World Factbook. www.cia.gov/library/publications/the-world-factbook/geos/us.html) and 2006 U.S. school life expectancy (UNESCO. www.unesco.org).

[15]U.S. Department of Education, NCES Digest of Education Statistics 2007.

[16]OECD glossary of statistical terms. www.oecd.org/glossary.

[17]Quotation from *An Inquiry into the Nature and Causes of the Wealth of Nations*, originally published in 1776.

[18]From Woessmann (2003)–quotation from *Principles of Economics*, originally published in 1890.

Human capital can be gained through multiple sources, but the focus of most studies is on formal education. Education can be influenced the most by policy and the data is more abundant than for other aspects of human capital such as training, experience, and environment. Most countries recognize the value of education and therefore strive to provide quality schooling for as much of the population as possible. Despite this seemingly common goal, the results across countries are quite different. Governments typically provide the majority of funds to education and set policies that affect education outcomes. Disparities in priorities are evident through differences in spending and its allocation, the organization of the schooling system, and the education services provided. Furthermore, richer countries tend to outperform poorer countries in most education indicators.

The role of human capital is acknowledged in both the theoretical and empirical economic growth literature. As discussed by Engelbrecht (2003), the theoretical literature suggests three main channels through which human capital affects economic growth. First, education increases the human capital of a country's labor force, and the accumulation of human capital over time positively affects growth. Second, increases in human capital lead to greater technological innovation. Finally, higher levels of human capital enhance a country's capacity to understand and implement new technology.

Empirically, the most common approach for examining the impact of human capital on economic growth is to estimate growth regressions. The dependent variable representing economic growth is typically a country's average annual growth rate of real GDP per capita, while the independent variables vary by author and study. Most research now includes a variable representing human capital along with other variables considered important for growth.

Examining the importance of education for economic growth has become increasingly popular. A quick EconLit search with the keywords "human capital" or "education" and "growth" yielded 11,014 articles with 40% of these originating since 2005[19]. While intuition and theory provide strong support for the importance of human capital and education, the empirical findings are less certain. The majority of studies do show that education significantly impacts growth, but there are conflicting results as well. Despite the mixed empirical results, most are still confident that education is a worthwhile endeavor. The World Bank asserts that "education is central for development" and that it "empowers people and strengthens nations"[20]. The United Nations Education, Scientific, and Cultural Organization (UNESCO) provides the same message, stating

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[19]Calculation was based on an EconLit search on March 26, 2010.
[20]World Bank. www.worldbank.org/education.

that education is "key to social and economic development"[21].

The studies of the effect of education on economic growth have a far-reaching impact through the influence on government policy. Governments face numerous education decisions such as those regarding resource allocation, laws and regulations, programs offered, and student and teacher assessment. The results from economic research help guide all of these decisions and can lead to reform in any area of education. Conflicting results make it more difficult for policy makers to determine the most effective strategies.

There are several explanations for the inconsistent findings among the growth literature. A main reason, and the focus of this paper, is the measurement of human capital[22]. Human capital is a complex concept that is difficult to accurately represent with a single measure. Quantifying the knowledge and skills of a nation's citizens is a major challenge faced by researchers.

Including a measure of human capital in growth regressions gained popularity in the 1990's and is now the standard. Over the years human capital has been quantified in many different ways. These measures typically reflect an aspect of formal education, which ignores other sources of human capital such as training and experience as well as the effect of family and peers. The best measure for a growth regression is one that most accurately captures the concept of human capital based on the economic theory to be tested. Unfortunately, the choice of a proxy for human capital is often determined by data collection and availability. There is a general consensus that human capital is poorly proxied in much of the research[23]. While the choice of proxy is critical, few studies give an explanation for why a particular measure is chosen. Here lies the motivation for this paper.

School enrollment rates and years of schooling or educational attainment are the most frequently used proxies for human capital. Over time these measures have been updated, and new proxies have been introduced. Recently, measures that account for the quality of education, not just the quantity, have gained popularity[24]. The evolution has occurred with the increased access to better-quality and expanded data sets. Improving the measurement of human capital has also been the focus of many recent studies[25].

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[21]UNESCO. www.unesco.org.education.

[22]Other sources of inconsistency between growth studies are the model specification, the time period, and the sampled countries.

[23]See, for example, Woessmann (2003) and Temple (1999).

[24]See, for example, Hanushek and Kimko (2000) and Barro and Lee (2001).

[25]Examples include de la Fuente and Domenech (2000) and Cohen and Soto (2007).

The purpose of this paper is to provide a comprehensive review of the human capital proxies employed most often in the empirical growth literature. The rest of this paper is organized as follows. Sections 2 through 8 each give a detailed discussion of a measure of human capital. In each of these sections, there is a description of the measure along with its current trends, a summary of the uses in the literature and the results achieved, a discussion of the advantages and disadvantages, and finally a list of the most common data sets. Section 9 concludes the review.

8 Enrollment

8.1 Description and Trends

Enrollment measures are a common proxy used in the growth literature, especially in earlier studies. Studies generally use total enrollment rates, gross enrollment ratios, or net enrollment ratios for either primary or secondary schooling. According to UNESCO, a gross enrollment ratio measures the ratio of the number of children enrolled at a given level of education regardless of their age to the number of children in the age range officially corresponding to that level of education. A net enrollment ratio, however, only takes into account children enrolled who belong to the official age range for the given level of education regardless of whether younger or older children are also enrolled. Much of the earlier research relied on enrollment measures to proxy human capital because the data was widely available and easy to use. The popularity of enrollment as a proxy has declined with time as data for alternative proxies has become available.

Increasing school enrollment has been a common goal across countries for some time now. On December 10th, 1948, the General Assembly of the United Nations established the Universal Declaration of Human Rights. Article 26 of the Declaration states that, "Everyone has the right to education. Education shall be free, at least in the elementary and fundamental stages. Elementary education shall be compulsory..."[26]. To reaffirm this promise, the 1990 World Conference on Education for All officially declared the commitment of Education for All, which pledged to provide education to "every citizen in every society". One of the goals set forth was to have universal primary education (UPE) in all countries by 2015. Progress was slow in the 1990s, so the commitment was renewed at the World Education Forum in Senegal in 2000. Since this time progress has improved, and the number of children in primary school has greatly increased[27].

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[26]Information is from the United Nations. www.un.org/overview/rights.html.
[27]See the Education for All Global Monitoring Report 2008.

	Total Enroll. (in millions)			Gross Enroll. Ratio			Net Enroll. Ratio		
	1991	1999	2006	1991	1999	2006	1991	1999	2006
World	598	648	688	98%	99%	105%	81%	82%	86%
Developing Countries	508	561	609	97%	99%	106%	78%	81%	85%
Developed Countries	73	70	66	102%	102%	101%	96%	97%	95%
Countries in Transition	18	16	13	97%	104%	99%	89%	88%	90%

Table 1: Primary Education Enrollment. Source: Education for All Gobal Monitoring Report 2009, Table 2.3.

Table 1 shows that about 40 million more children were enrolled in primary education in 2006 than in 1999. This increase was mainly attributable to improvements in sub-Saharan Africa and in South and West Asia[28]. According to the World Bank, 47 out of 163 countries have achieved the goal of UPE, 20 are on track to achieve UPE, but 44 (23 of which are in sub-Saharan Africa) will not meet the goal unless substantial changes are made. So, while access to education is broadening and enrollment is growing, there is still room for improvement.

There are a many factors affecting enrollment across countries. Much of the improvement in access and enrollment is attributable to governments making education a higher priority. Increasing participation in education requires legislation and enforcement along with the allocation of significant resources. Many countries have now passed compulsory education laws and eliminated schooling fees. The health of a country's citizens also influences enrollment. It is not only the well-being of the children that is important for education participation, but also that of their family members. The prevalence of diseases such as HIV/AIDS, tuberculosis, and malaria has prevented many children from entering school and forced others to dropout. Nutrition and immunizations are key for increasing enrollment in developing countries. Population growth and age distribution also affect enrollment rates. Countries with faster population growth and higher percentages of school aged children will likely have increased enrollment. Finally, the structure and economic well-being of families impact enrollment. Children from two-parent homes are more likely to attend school, and children from families where the opportunity cost of their education is highest are less likely[29]. When children are in school, they are not producing or earning money for the family. It is necessary to reduce the opportunity cost of sending children to school, perhaps by offering monetary incentives to parents for their children's attendance.

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[28]Enrollment increased by 42% in sub-Saharan Africa and by a combined 22% in South and West Asia.

[29]From the Education for All Global Monitoring Report 2008.

	Gross Enroll. Ratio			Net Enroll. Ratio		
	1991	1999	2006	1991	1999	2006
World	98%	99%	105%	81%	82%	86%
Developing Countries	97%	99%	106%	78%	81%	85%
Developed Countries	102%	102%	101%	96%	97%	95%
Countries in Transition	97%	104%	99%	89%	88%	90%

Table 2: Secondary Education Enrollment. Source: Education for All Global Monitoring Report 2009, Table 2.7.

Secondary education enrollment has also seen progress. About 513 million students were in enrolled in secondary schooling worldwide in 2006. This accounts for approximately 58% of the population in the corresponding age range and is an increase of 76 million students since 1999. All developed countries and most countries in transition are close to achieving universal secondary enrollment, but the same is not true for developing countries[30]. See Table 2 for secondary education enrollment ratios for countries at different levels of development.

Secondary schooling is often separated into lower and upper levels. Lower secondary along with primary education is compulsory in most countries. Most exceptions to this trend can be found in sub-Saharan Africa and South and West Asia. In countries where secondary enrollment is relatively low, many students dropout after completing lower secondary education[31]. As with primary education, despite recent progress, there is still a long way to go to provide all children with access to secondary education.

8.2 Literature

Enrollment measures have been a popular proxy for human capital, especially in earlier studies. In the seminal growth study by Barro (1991), a country's initial human capital is proxied as enrollment in 1960 at both the primary and secondary level. These give the number of students enrolled in each level relative to the population of the corresponding age group. The study examines the effect of these measures on the growth rate of real GDP per capital from 1960 to 1985 for 98 countries. Barro (1991) concludes that initial human capital, at both the primary and secondary level, is positively related to growth.

Mankiw et al. (1992) also produced an influential growth study using enrollment data to capture

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[30]Countries in sub-Saharan Africa and South and West Asia are furthest from reaching universal secondary enrollment. Information and data is from the Education for All Global Monitoring Report 2008.

[31]See the Education for All Global Monitoring Report 2005.

a country's human capital. Their paper centers on an augmented Solow model with both physical and human capital as explanatory variables. Human capital is represented by the fraction of the working age population enrolled in secondary education. The study's cross-country regressions show, like Barro (1991), that this measure of human capital has a significant positive effect on growth from 1960 to 1985. Mankiw et al. (1992) also find that adding human capital to the model reduces the impact of physical capital and improves the overall performance of the model.

Empirical studies with cross-country growth regressions have found numerous variables to be significant for growth. Levine and Renelt (1992) perform a robustness check on some of the early findings to determine how sensitive these results are to changes in model specification. Specifically, their extreme bounds analysis examines the significance of variables as different variables are included in the growth regression. The results show that the significance of most results is very sensitive to small changes in the model. However, the analysis does confirm the findings of the two papers above by showing that the 1960 secondary enrollment rate is positively and robustly related to growth.

Like Levine and Renelt (1992), the purpose of the study by Sala-i-Martin et al. (2004) is to explore the robustness of explanatory variables used in cross-country growth regressions. They develop an approach called Bayesian Averaging of Classical Estimates, which is less strict than extreme bounds analysis. BACE creates estimates by averaging coefficients from OLS regressions across different models. Sala-i-Martin et al. (2004) test 67 explanatory variables found to be significant in the literature and discover that 18 are significantly and robustly related to growth. The primary education enrollment rate in 1960 is shown to be highly important for growth, ranking 2nd based on a goodness-of-fit measure. Other education measures are also tested. The higher education enrollment rate in 1960 ranked 25th, and public education spending in 1960 ranked 48th.

The positive relationship between enrollment and growth has been verified by other studies. Bils and Klenow (2000) reproduce the results of Barro (1991) using updated data. They confirm that primary and secondary enrollment rates in 1960 have a positive effect on GDP growth between 1960 and 1990. Bils and Klenow (2000) extend their study to investigate the causality of this relationship. They conclude that the results partly reflect the impact of growth on schooling, not just the effect of schooling on growth.

Kalaitzidakis et al. (2001) take a different approach and examine nonlinearities in the relationship between human capital and growth. They use enrollment rates at the primary and secondary

level to make the results comparable with earlier studies. The findings show that enrollment rates positively influence growth from 1960 to 1990 and that the effect is linear.

Webber (2002) also finds enrollment to be a significant determinant of growth. His study shows that secondary education enrollment is the most important, followed by primary, and then tertiary. Agiomirgianakis et al. (2002) also proxy human capital using enrollment at the primary, secondary, and tertiary levels of education. Their analysis focuses on economic growth from 1960 to 1987 for 93 countries. All three measures give positive and highly significant coefficients with larger effects for higher levels of education.

Finally, a recent study by Keller (2006) examines growth using enrollment data for 1960 to 2000. She finds that enrollment rates in both secondary and higher education have a significant positive effect on growth. However, she finds a negative effect for primary education enrollment.

The review above shows that studies using enrollment as a proxy for human capital generally find a significant positive relationship with economic growth. However, as alternative measures of human capital have been developed and new data has become available, enrollment rates are used less in the growth literature.

8.3 Advantages and Disadvantages

The primary reason for the use of enrollment data is the accessibility of data sets. Enrollment data is readily available for a large number of countries and for a long period of time. Enrollment is easy to measure and less subjective than other human capital variables. For these reasons, enrollment data exhibits less measurement error than other education data. Another benefit of using enrollment measures is the straightforward interpretation of results.

Many criticisms have been voiced about the use of enrollment as a proxy for human capital. It is even common for studies using enrollment measures to discuss the weaknesses of the proxy. One of these is an issue surrounding most human capital proxies. Human capital is comprised of the knowledge and skills obtained through schooling, experience, training, family, and peers. However, enrollment captures only formal education. This focus on formal schooling is mostly attributable to data limitations.

Enrollment is a quantitative measure of education. Quantitative measures of education are typically described as either flow variables or stock variables. The two types of variables differ in their contribution to the labor force. Enrollment rates are an educational flow variable that

Source	Details
Mankiw et al. (1992)	Enrollment rate at secondary level; 98 counties; 1960 to 1985
Barro and Lee (1993)	Enrollment rates at primary, secondary, and tertiary level; 98 countries; 1960 to 1985
Barro and Lee (2000)	Update to 1993 dataset; enrollment rates at primary, secondary, and tertiary level; 98 countries; 1960 to 1995
Agiomirgianakis et al. (2002)	Enrollment rates at primary, secondary, and tertiary level; 93 countries; 1960 to 1987
Keller (2006)	Enrollment rates at primary, secondary, and tertiary level; 93 countries; 1960 to 2000

Table 3: Commonly Used Enrollment Data Sets.

only measure access to education and ignore the cumulative benefits of completing additional years of schooling. The consensus among the literature is that stock variables are more appropriate for growth models[32]. There is a considerable lag between the time of enrollment in school and the subsequent addition to the human capital of the labor force. Students enrolled in school may or may not go on to enter the country's labor force. There could also be additions to the labor force over time that are not represented in the enrollment data. Furthermore, Bassanini and Scarpetta (2001) claim that reverse causality is less of an issue with stock variables than with flow variables.

Another major issue with enrollment measures is that they do not take into account the quality of education. As pointed out by Hanushek and Kimko (2000), using enrollment rates to measure human capital implies that being enrolled in school in Australia is the same as being enrolled in Zimbabwe or any other country. This is clearly not reality. The quality of schooling varies drastically across countries. As discussed above, Barro (1991) initially uses enrollment data to examine the role of human capital in growth. However, in later studies Barro departs from enrollment and turns to measures that account for the quality of education. Barro and Lee (2001) state that previous studies using enrollment were flawed by ignoring educational quality. Hanushek and Kimko (2000) also stress that differences in quality cannot be ignored.

8.4   Data and Summary

As discussed above, enrollment data is readily available. Table 3 lists the most popular enrollment data sets from the cross-country growth literature. The data sets most frequently cited are those from Barro and Lee (1993, 2000).

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[32]See, for example, Kalaitzidakis et al. (2001) and Hanushek and Kimko (2000).

The discussion of the literature shows that enrollment measures are generally positively and significantly related to economic growth. The two seminal papers by Barro (1991) and Mankiw et al. (1992) both find a significant relationship between enrollment and growth from 1960 to 1985. Sala-i-Martin et al. (2004) test the robustness of this result and find that primary education enrollment in 1960 is a robustly significant determinant of growth.

Enrollment was considered an adequate proxy for human capital in earlier growth studies. However, it seems that this acceptance was driven primarily by the accessibility of the data. As data for alternative measures has become available, the satisfaction with enrollment as a proxy has declined. Temple (1999) states that enrollment rates should not be used now that other data is available. A key drawback is that enrollment rates measure access to education rather than the knowledge and skill accumulated throughout schooling. High enrollment rates do not necessarily translate into a highly educated labor force. While the trend over time has been to move away from enrollment measures toward stock and quality measures, some studies still employ enrollment rates because of the data availability or for comparability reasons.

9 Literacy

9.1 Description and Trends

Literacy rates are common in earlier growth studies, but are now rarely used to measure human capital. Literacy is most often defined as the ability to read and write, with understanding, a short, simple statement about everyday life[33]. From this it is clear country's literacy rate reflects only the basic skills of the labor force. As suggested by Woessmann (2003), literacy rates, like enrollment rates, are used to proxy human capital mainly because the data is widely available for many countries and years.

Both UNESCO and the World Bank assert that literacy was largely neglected in the past. However, literacy is now a part of the United Nations' Millennium Development Goals as well as the Education for All Goals. The Millennium Development Goal of universal primary education contains the objective that all children will attend school and learn basic literacy skills. The Education for All Goal is to reach 50% improvement in adult literacy levels by 2015. Literacy remains a serious problem worldwide, but especially in the poorest countries.

Large strides have been made, but global literacy progress has recently slowed. The percent of

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[33]The World Bank. www.worldbank.org.

	Adult Lit. Rates (1985-1994)	Adult Lit. Rates (1995-2004)
Developing Countries	68%	77%
Developed Countries	99%	99%
Countries in Transition	98%	99%
Sub-Saharan Africa	54%	59%
Arab States	58%	70%
Central Asia	99%	99%
East Asia and Pacific	82%	92%
South and West Asia	48%	60%
Latin America and Caribbean	88%	90%
North America and West Europe	99%	99%
Central and East Europe	96%	97%

Table 4: Adult (15 and older) Literacy Rates. Source: Education for All Global Monitoring Report 2008, Table 2.15.

the world population over the age of 15 with basic reading and writing skills increased from 10% in the mid-nineteenth century to over 80% in 2005[34]. According to UNESCO, there are currently 776 million adults without fundamental literacy skills, and if countries continue on the same track, there will still be about 700 million illiterate adults in 2015. The highest levels of illiteracy are found in sub-Saharan Africa and South and West Asia where 19 countries have literacy rates below 55%. Table 4 gives literacy rates across different regions of the world between 1985 and 2004.

Approximately 80% of adult illiteracy is concentrated in only 20 countries, and more than half is found in just 4 countries–China, India, Bangladesh, and Pakistan. Illiteracy is strongly linked to poverty and disadvantage. Illiteracy rates are higher where access to schooling is limited and the quality of education is low. There is also a sizeable gender gap in literacy levels in many countries with women accounting for 64% of global illiteracy[35]. This reflects the limited access to education for females in some countries.

The typical literacy measures are based on the percentage of the adult population that is either literate or not. A new measure was introduced in 1994 with the first comparative survey of adult literacy. The International Adult Literacy Survey (IALS) was a combined effort by governments, statistical agencies, and the OECD. The IALS measures literacy proficiency in several skill categories along a continuum. The IALS tests individuals between the ages of 16 and 65 and assesses their literacy skill over three areas–prose, document, and quantitative. The study was

[34]Education for All Global Monitoring Report 2006.
[35]Education for All Global Monitoring Report 2009.

administered in 1994, 1996, and 1998 starting with 7 countries in 1994 and building to 23 countries in 1998. The results from the study show large differences within and between countries with all populations showing a significant proportion of low literacy. The results also show a link between literacy and family background factors and educational attainment[36].

The literacy rate now tends to be higher for the younger generation than for the older. This attributable to the increased enrollment in schooling along with improvements in the quality of education. There is a new focus on increasing literacy levels through the expansion of quality schooling. In addition to providing high-quality primary education, literacy programs need to be available for adults who never attended school or failed to obtain literacy skills[37].

9.2 Literature

Literacy rates are used relatively sparsely in the growth literature. Romer (1989) provides the most influential paper using literacy to proxy human capital. However, he stresses that this analysis could easily be performed with other measures of human capital. He uses the literacy rate of a country's population to proxy human capital for three main reasons. First, the data is easy to compile for a large number of countries whereas data for other measures is more limited. Second, literacy is straightforward to compare across countries. Finally, Romer (1989) ignores other measures of higher levels of human capital and focuses on literacy to "keep the project manageable". The results show the initial level literacy (in 1960) has a positive relationship with growth between 1960 and 1985. This is confirmed using consumption of newsprint per capita as an instrumental variable. In contrast, to the significant relationship for the level of literacy, Romer (1989) finds that the change in the level of literacy between 1960 and 1980 is not important for growth.

Due to a lack of data, Azariadis and Drazen (1990) use literacy of a country's population aged ten and older as a proxy for investment in human capital. The authors clearly state that this was not their ideal proxy, "...realizing that reliable data on some higher level of educational attainment might be preferable if available". Their study covers 32 countries from 1940 to 1980. The results show that literacy has no effect on growth in the higher income countries in the sample, but has a significant positive effect for the low and middle income countries.

Barro's (1991) study investigates the effect of human capital on growth for 1960 to 1985. Here he focuses on enrollment as the proxy for human capital, but also examines the effect of other human

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[36]Information regarding the IALS is from the OECD. www.oecd.org.
[37]See the World Bank Development Report 2007: *Development and the Next Generation.*

capital measures such as the adult literacy rate in 1960. He comments that literacy is an appealing measure because it is a stock measure instead of a flow measure as is enrollment. However, he recognizes the shortcomings, stating that literacy rates are inconsistent and often inaccurate for less developed countries. Barro's (1991) results show that when enrollment is included in the regression, the effect of literacy on growth is negative. But when enrollment is excluded, literacy has a significantly positive effect.

In a later study, Barro and Lee (2000) examine the effect of human capital on growth using educational attainment as their main proxy for human capital. They use IALS scores as a comparison measure for their results. Barro and Lee (2000) find a significant relationship between IALS scores and growth.

Coulombe and Tremblay (2006) also make use of the new IALS data to see the effect of human capital on growth for 14 OECD countries. They utilize the IALS results to develop a time series of the literacy level of a country's cohort of labor market entrants in each five year period between 1960 and 1995. The study shows that literacy has a significant positive impact on growth. Furthermore, Coulombe and Tremblay (2006) conclude that their measure of literacy explains growth better than measures of educational attainment.

A recent paper by Vinod and Kaushik (2007) examines the impact of human capital on economic growth for 18 large developing countries from 1982 to 2001. They use a country's adult literacy rate to proxy human capital. Their analysis indicates that human capital, as measured by illiteracy, is important for growth.

Recognizing the limitation of basic literacy rates, Baten and van Zanden (2008) present a new data set to proxy more advanced skills. They propose using book production per capita rather than the usual literacy rates. The time period of their data also makes their study unique. The authors introduce book production data for 8 European countries from 1454 to 1800. With their new data set, Baten and van Zanden conclude that human capital has a strong positive influence on economic growth prior to 1800.

9.3 Advantages and Disadvantages

As discussed in the literature review, the key advantage of literacy rates is the widespread availability of data covering many years and a large sample of countries. This accessibility stems from the ease of measurement at any point in time. In addition, the definition of literacy is common

across countries. Another benefit is that the concept of literacy is easy to interpret and the results are straightforward to understand.

More importantly, however, is that literacy does appear to give a good indication of human capital accumulation, especially for developing countries[38]. Rather than just measuring access to education as with enrollment rates, literacy provides an outcome measure of schooling. It reflects a country's investment in basic human capital relative to other countries.

In contrast to schooling measures based on student data, much of the literacy data is based on adults. This has the advantage of translating more directly to a country's labor force. This reduces error that can arise from students not becoming part of the labor force or others entering the labor force that did not attend school.

Most studies that employ literacy rates as the measure of human capital do so because of data limitations. Romer (1989) and Azariadis and Drazen (1990) make it clear that literacy rates were utilized simply for the ease of use and availability. Both affirm that subsequent work would employ different measures.

Literacy is proxy for very basic levels of human capital. This is a more acceptable measure for developing countries where primary education is still expanding and improving. However, in more developed countries the literacy rate is often near 100%. So, literacy rates do not reflect investments in human capital beyond basic skills. Basic literacy is only a small part of total human capital. Using literacy rates ignores the importance of skills and knowledge obtained beyond basic literacy and assumes that human capital remains constant over time. The IALS data aids in addressing these deficiencies.

There are also concerns about the quality of literacy data, particularly in less developed countries. In addition, the IALS data is still very limited in terms of the number of participating countries and time period covered.

9.4 Data and Summary

Data availability is one of the advantages of literacy as a measure of human capital. Several different measures have been used in the literature representing various levels of literacy, from very basic to more advanced skills. See Table 5 for list of literacy data sets used throughout the growth literature.

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[38]See Judson (2002) for a discussion.

Source	Details
Romer (1989)	Literacy rate; 1960; 94 countries
Romer (1989)	Consumption of newsprint per capita; 1960; 94 countries
Barro (1991)	Literacy rate; 1960; 98 countries
Azariadis and Drazen (1990)	Literacy rate of population aged 10 and older; 32 countries; 1940 to 1980
Barro and Lee (2000)	IALS scores; 12 OECD countries; 1994 to 1995
Coulombe and Tremblay (2006)	IALS scores; 14 OECD countries; 1994 to 1998
Vinod and Kaushik (2007)	Literacy rate of population aged 15 and older; 18 large developing countries; 1982 to 2001
Baten and vanZanden (2008)	Book production per capita; 8 European countries; 1454 to 1800

Table 5: Commonly Used Literacy Data Sets.

All in all, the studies that employ a measure of literacy for human capital find a significant positive relationship with growth. The influential paper by Romer (1989) shows that a country's initial level of literacy positively impacts growth from 1960 to 1985, but the change in literacy between 1960 to 1980 has no impact on growth.

As with enrollment rates, fewer studies use literacy rates as their sole measure of human capital since data for alternative measures has become more widely available. The fact that literacy rates reflect only very basic skills is a main issue. An important study by Azariadis and Drazen (1990) illustrates this by finding that literacy is important for growth in low and middle income countries but not for higher income countries. The adult literacy rate for most developed countries is close to 100%, so the measure cannot capture differences in human capital across these countries. However, recent studies are making use of IALS data as it becomes more widely available. Whereas literacy rates measure only basic literacy and individuals are classified as either literate or not, the IALS provides a measure of more advanced literacy skills and gives an individual a score within a continuum. Coulombe and Tremblay (2006) conclude that IALS scores have a positive effect on growth in OECD countries.

10   Educational Attainment

10.1   Description and Trends

Educational attainment is the most frequently used human capital proxy in the growth literature. Attainment variables are stock measures that quantify the accumulation of education. Like enrollment, educational attainment focuses only on the formal education aspect of human capital.

Educational attainment measures gained popularity as problems with enrollment and literacy rates were discovered and reported. In addition, attainment data is widely available and comprehensive.

Worldwide, educational attainment has seen improvement in recent years. As mentioned previously, the United Nations Millennium Summit developed 8 development goals in 2000 to be reached by 2015 with the purpose to end extreme poverty. One of the goals was to ensure that all children complete a full course of primary schooling[39]. It is not enough to just get children enrolled, they also need to stay in school. Many developing countries experience high rates of grade repetition and dropouts along with late entry into schooling. Therefore, most children in developing countries are not in the appropriate grade for their age. Students that are older than the appropriate age are more likely to dropout early, while students that are younger are more likely to repeat grades. In sub-Saharan Africa, there are 11 countries that have repetition rates for first grade above 20%. However, most countries have increased the number of children reaching the last grade of primary school. In developing countries, the percentage of children that complete primary education increased from 79% in 1999 to 85% in 2006. Despite the improvements, some countries are still struggling. The primary school completion rate is less than 87% in about half of the countries with data in 2004, with the lowest rate of 63% in sub-Saharan Africa followed by South and West Asia at 79%. The highest levels of completion occur in North America and Western Europe along with Central and Eastern Europe with a median rate of over 98%[40].

The increase in primary education attainment means that more students are making the transition to secondary education. With the exception of South and West Asia and sub-Saharan Africa, the median transition rate to secondary schooling is above 90% for all regions. This is due, in large part, to the elimination of primary school exit exams and the fact that lower secondary education is now compulsory in many countries. While many students make the transition from primary to lower secondary schooling, fewer make the transition to upper secondary. Worldwide, the gross enrollment ratio is 78% for lower secondary education, but just 53% for upper. Students in sub-Saharan Africa receive, on average, five to six years less primary and secondary education than students in Western Europe or the Americas[41].

Following the upward trend in primary and secondary schooling, more students are participating

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[39]See United Nations' The Millennium Development Goals Report 2008 for more information regarding the development goals. www.un.org/millenniumgoals.

[40]Information and data is from the Education for All Global Monitoring Report 2008.

[41]See UNESCO's Education for All Global Monitoring Report 2009 for more information.

	Yrs. of Sch. Life Exp. (2001)			Change Since 1990
	Prim. and Sec.	Post-Sec.	Total	Total
World	9.2	1.1	10.3	+1.0
Sub-Saharan Africa	6.8	0.2	7.0	+1.0
Arab States	9.0	1.0	10.0	+1.4
Central Asia	10.1	1.3	11.4	-0.2
East Asia and Pacific	10.0	0.9	10.9	+1.3
South and West Asia	8.0	0.6	8.6	+1.0
Latin America and Caribbean	11.6	1.4	13.0	+2.6
North America and West Europe	12.8	3.5	16.3	+1.5
Central and East Europe	10.2	2.5	12.7	+1.3

Table 6: Expected Years of Schooling. Source: Education for All Global Monitoring Report 2005, Table 3.4.

in tertiary education. 51 million more students were enrolled worldwide in 2006 than in 1999, yet overall the proportion of students with access to tertiary education remains small. Tertiary gross enrollment ratios range from 70% in North America and Western Europe to 5% in sub-Saharan Africa[42].

In addition to the large differences in educational attainment across countries, there are also significant differences within countries. Children from low income families complete fewer years of schooling. Differences in education systems also affect attainment. A shortage of schools, low quality education, and a lack of resources can reduce the number of years of schooling children complete. Other reasons for low attainment levels include poor health, pregnancy, and child labor[43].

School life expectancy is a common education statistic defined as the total number of years of schooling that a child can expect to receive. The measure includes years of schooling completed at all levels. Repetition adds to school life expectancy in many countries. Throughout the 1990s, school life expectancy increased by about one year worldwide. The most significant progress occurred in countries that already had high school life expectancy, while progress was slower in sub-Saharan Africa and South and West Asia[44]. Table 6 shows years of school life expectancy in 2001 for different regions in the world.

There have been many efforts to measure educational attainment. The most common measure is the average years of schooling of a country's labor force. Different age groups are examined,

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[42]Data is from the Education for All Global Monitoring Report 2009.
[43]Information is from UNESCO's Education for All Global Monitoring Report 2009.
[44]See the Eduation for All Global Monitoring Report 2005 for more information about school life expectancies.

but typically the measure is focused on either adults fifteen years and older or adults twenty-five and older. This is typically calculated using the share of a country's population that successfully completed a certain level of schooling along with the length of that level. Enrollment rates are regularly utilized to fill in for missing data. Woessmann (2003) summarizes some of the methods used to create educational attainment data sets. Attainment and enrollment data can be collected directly from national surveys and censuses. The perpetual inventory method is often used to transform school enrollment ratios into average years of education while taking into account data on repetition and dropout rates and the probability of completion. Finally, the projection method can be used to forecast average years of schooling based on lagged enrollment ratios.

Barro and Lee (1993, 2000) provide the most commonly used data sets for cross-country educational attainment. Their measures of average years of schooling are constructed from national census and survey data. There have been many attempts in the growth literature to update and improve these data sets[45].

10.2 Literature

The majority of empirical growth studies use measures of educational attainment to proxy human capital. There are numerous data sets covering most countries and different periods of time. Furthermore, a great deal of research is devoted to constructing and improving attainment data sets.

Psacharopoulos and Arriagada (1986) make one of the first efforts to create an educational attainment measure using census data. They provide a data set of years of schooling for the population aged 25 and older for 99 countries from 1960 to the early 1980's.

Barro and Lee (1993) continue the work of Psacharopoulos and Arriagada (1986) with their years of schooling data set. They use national census and survey data, filling in the missing data using literacy and enrollment rates. Barro and Lee (1993) find that their attainment measure is significantly positively related to economic growth. Barro and Lee (2000) update their previous data set by expanding the number of countries to 142 and the years covered to 1960 through 2000. They construct their data set using the perpetual inventory method. The years of schooling measure is based on data for the percentage of a country's adult population who successfully completed a particular level of schooling along with the typical duration of that level of education.

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[45]Examples include de la Fuente and Domenech (2000) and Cohen and Soto (2007), both of which are discussed below.

Kyriacou (1991) also develops a data set that has been used in the growth literature. He uses data from Psacharopoulos and Arriagada (1986) to estimate years of schooling in the labor force for 120 countries from 1970 to 1985. Kyriacou (1991) examines the importance of initial human capital as well as the growth of human capital for economic growth. The regression results show a significant positive relationship with initial human capital but an insignificant negative relationship with the change in human capital. This indicates that the level but not the growth of human capital matters for growth. Kyriacou (1991) gives two possible explanations for the findings. He suggests that the output of elasticity of human capital could be positively related to the level of human capital or that the level of human capital could proxying technology growth.

Lau et al. (1991) use the perpetual inventory method to construct a measure of educational attainment for 58 developing countries from 1960 to 1986. They use time series data to calculate the number of years of school completed by the population aged 15 to 64. Using their data, Lau et al. (1991) conclude that education is an important determinant of growth but that the effect differs across countries.

The seminal studies by Benhabib and Spiegel (1992a, 1992b) are widely cited. They proxy human capital with educational attainment data from Kyriacou (1991) for 42 countries. The studies use two different approaches to examine the effect of human capital on growth. They first look at the role of human capital as a normal input into production. The results from this specification match those from Kyriacou (1991), showing that the change in human capital has an insignificant or negative effect on growth. Next, Benhabib and Spiegel (1992a, 1992b) investigate the role of the level of human capital in technological progress. The results here suggest a significant positive role for human capital. So, the main findings from Benhabib and Spiegel's (1992a, 1992b) work is that the level of human capital rather than the change is important for growth.

Nehru et al. (1993) follow the trend of developing new educational attainment data sets by constructing years of schooling estimates for 85 countries from 1960 to 1987. They use the perpetual inventory method adjusting for repetition, dropouts, and mortality to find the accumulated years of schooling at all levels of education for the population aged 15 to 64. The adjustment for mortality improved the accuracy of their measure as a proxy for the human capital of a country's labor force.

Gemmell (1996) also develops a data set with attainment measures representing the level of human capital in 1960 and the change in human capital from 1960 to 1985. In contrast to Kyriacou (1991) and Benhabib and Spiegel (1992a, 1992b), Gemmell (1996) concludes that both the initial

stock and the accumulation of human capital are important for growth. More specifically, he finds that primary educational attainment is most important for the poorest countries in the sample, secondary education is most important for the middle income countries, and higher education is most important for the OECD countries.

The purpose of Bils and Klenow's (2000) study is to challenge earlier findings that human capital leads to economic growth. They calibrate a model to examine how much of this relationship is actually due to growth leading to increases in a country's stock of human capital. Using a measure of average years of schooling, Bils and Klenow (2000) conclude that only one-third or less of the relationship is explained by schooling causing growth. Instead, they find that the majority of the relationship is explained by growth causing increased schooling. Therefore, the authors stress the need to exercise caution when interpreting the results from growth regressions.

Many recent studies have focused on improving the educational attainment data, both in terms of the quality and the method of construction. De la Fuente and Domenech (2000) modify Barro and Lee's (1993) data set for 21 OECD countries from 1960 to 1990. Their measure is the fraction of the country's population aged 25 and older that started each level of education. In order to develop a higher quality data set, de la Fuente and Domenech (2000) employ new sources of information and eliminate breaks in the data caused by changes collection standards. Their revised data set yields a positive relationship with growth for a variety of model specifications and passes a robustness check. De la Fuente and Domenech (2006) provide a further update of their data set and compare the quality to other data sets. They construct informational content indicators for the alternative data sets and compare the performance in several specifications of growth regressions. The results show a significant positive correlation between the quality of the data set as given by the indicators and the importance of educational attainment in the growth regressions.

Like de la Fuente and Domenech (2000), Bassanini and Scarpetta (2001) develop an average years of schooling data set focused on OECD countries. Their data covers 21 countries from 1971 to 1998. They also find that human capital has a significant positive effect on economic growth in the OECD countries.

Barro (2001) examines the effect of educational attainment on growth based on gender and level of education for 1965 to 1995. The only significant positive effect found is for male attainment at the secondary and higher level. Female attainment at all levels of education is found insignificant along with male attainment at the primary level. Petrakis et al. (2002) explore the effect of

educational attainment on growth based on the level of economic development across countries. They find that the relationship varies with the level of development. Specifically, primary and secondary education appear to be more important for growth in less developed countries, while higher education is more important in developed countries.

Pritchett (2001) uses educational attainment data sets from both Barro and Lee (1993) and Nehru et al. (1993) to construct estimates of the growth of per worker human capital. Using this measure, he finds that human capital has no effect on growth from 1960 to 1987. He gives three possible explanations for the differences in the effect of human capital on growth across countries. First, Pritchett (2001) suggests that not all knowledge gained from schooling is used productively. Second, the demand for educated labor varies across countries. Finally, he states that the differences could arise from disparity in countries' education quality.

Bosworth and Collins (2003) continue the discussion of the inconsistencies in the empirical growth literature. Some of the reasons they give for the varying results are differences in the countries in the sample, the time period examined, the specification of the growth model, and the measurement error in the educational attainment data. They run multiple growth regressions and use two different educational attainment data sets–Barro and Lee (2000) and Cohen and Soto (2001)[46]. Cohen and Soto's (2001) data set includes 95 countries from 1960 to 2000 and contains more recent census data than Barro and Lee's (2000). The two data sets are highly correlated but Cohen and Soto's years of schooling tend to be higher. Bosworth and Collins (2003) find the coefficient on the Barro and Lee (2000) measure to be positive and the coefficient on the Cohen and Soto (2001) measure to be negative. However, both are statistically insignificant. The authors also combine the measures to form a composite variable, which did not produce satisfactory results. Bosworth and Collins (2003) also calculate a reliability measure for each data set[47]. Cohen and Soto's (2001) measure shows higher reliability with a score of 0.63 compared to 0.43 for the Barro and Lee (2000) measure.

The purpose of Portela et al. (2004) is to show flaws in the method used by Barro and Lee (2000) to develop their educational attainment data set is flawed. As mentioned above, Barro and Lee (2000) and others construct data sets using the perpetual inventory method. Portela et al. (2004) show that there is a significant difference between data directly from census or survey data and that derived from enrollment data using the perpetual inventory method. They find that

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[46]An updated version (2007) is discussed later in the section.
[47]The reliability measure was based on the covariance with the alternative measures divided by its variance.

the perpetual inventory method causes education to be underestimated, which can lead to biased regression results. The authors conclude that once the source of information and measurement error are taken into account, both the level and the change in education have a significant effect on growth.

Baier et al. (2006) also seek to improve Barro and Lee's (2000) data set by incorporating more years of data. Some of the countries included in their sample have data for as far back as 1900. In addition, their measure of human capital reflects not only average years of schooling but average years employed as well. The authors calculate years of schooling for an employed person from enrollments at each level of education and the age distribution of the population. Average experience is calculated as average age less average years of schooling and six years before attending school. The human capital measure is derived from estimated parameters of earnings regressions. Baier et al. (2006) conclude that their measure of human capital is important for growth.

Like others, Cohen and Soto (2007) stress that the quality of education data affected previous regression results. They attempt to improve the quality of the data by using education information available by age group. This allows them to rely less on assumptions as in some previous data sets and more on data actually observed. Their measure of average years of schooling is calculated in the common way by multiplying the population's shares of educational attainment by the appropriate duration of each education level. They state that their data is similar to that of Barro and Lee's (2000), but performs better by taking into account the population's age structure and mortality rates. Cohen and Soto's (2007) growth regressions produce a significant positive relationship between human capital and growth from 1960 to 2000.

Hanushek and Woessmann (2008) employ a version of Cohen and Soto's (2007) average years of schooling data set to estimate multiple growth models. While they conclude that average years of schooling is important for growth, they find that the effect is sensitive to how the model is specified. For example, when the effect of institutional differences (reflected by openness and security of property rights measures) of a country are controlled for, the effect of years of schooling decreases and becomes insignificant.

Morrisson and Murtin (2009) seek to fill a gap in the attainment data. There is little data that exists for early periods of time, so Morrisson and Murtin (2009) gather data for as far back in time as possible. They develop a data set of educational attainment for 74 countries from 1870 to 2010. The authors use the perpetual inventory method to construct data for years prior to 1960 and use

Cohen and Soto's (2007) data set for years after 1960.

10.3   Advantages and Disadvantages

The popularity of educational attainment as a human capital proxy indicates advantages over other measures. First of all, attainment data is easily obtainable for a broad number of countries and years and is more complete than most other education data. Furthermore, it is a stock rather than a flow measure, which is more compatible with economic theory. It accounts for the accumulation of education across different levels rather than just access to education as with enrollment rates. Finally, educational attainment is easy to measure and to interpret. Since years of schooling is a fairly straightforward measurement, the data is more abundant and can be more accurate than that of measures that are more difficult to quantify.

Despite being the most popular measure, educational attainment has its shortfalls. Many of the criticisms parallel those encountered with enrollment measures. Measures of attainment focus only on the formal education aspect of human capital, ignoring skills and experience gained outside of schooling. Perhaps the most important problem, however, is that educational attainment does not take into account the quality of the education received. Hanushek and Kimko (2000) stress that quantity measures do not accurately reflect cognitive skill, which is most important for productivity. As mentioned with enrollment, disregarding education quality assumes that a year of schooling is equal in all countries. In addition, Woessmann (2003) points out that the years of schooling measure suggests that the same amount of human capital is gained in the first year of schooling as in the 15th. Neither of these assumptions reflect reality.

The quality of the data is another issue commonly discussed in the literature. De la Fuente and Domenech (2000), Portela et al. (2004), and Cohen and Soto (2007) all maintain that the poor quality of the data biased the results of previous studies. Much of the data relies heavily on assumptions and backward extrapolation for missing data. However, data sets have improved as new historical data has become available. There has also been some criticism of the perpetual inventory method, which was employed by Barro and Lee (2000) in the construction of their popular data set. Portela et al. (2004) estimate that the method could underestimate education by about 1/5 of a year for every five year period.

A number of factors have to be accounted for when constructing an educational attainment data set. It is important that years of schooling be adjusted for grade repetition, especially in

less developed countries where repetition rates are higher. Nehru et al. (1993) state that ignoring repetition can cause enrollment rates, which are often used to calculate attainment, to be overstated by as much as 25% in some developing countries. Cohen and Soto (2007) acknowledge the importance of accounting for differences in classification systems for education levels. Finally, overlooking mortality rates can cause an upward bias. Failure to make these adjustments can lead to inaccurate results.

Another concern, as pointed out by Bosworth and Collins (2003), is that years of schooling changes slowly, and therefore, growth effects could be difficult to identify in cross-country studies. This could be a reason why some researchers fail to find a relationship between educational attainment and growth.

10.4 Data and Summary

Educational attainment is the most popular measure of human capital, and as such there are numerous data sets available. Most of these provide measures of years of schooling completed at different levels of education. Barro and Lee (1993, 2001) provide the most widely used data sets across the growth literature. A list of the most commonly data sets is given in Table 7.

The review above illustrates the popularity of educational attainment as a proxy for human capital. It has been utilized more often than any other measure mostly because of the availability of data and easy interpretation of results. As shown above, measures of educational attainment are used in earlier studies and continue to be used frequently in recent studies. The seminal study by Barro and Lee (1993) shows a positive relationship between years of education attained and cross-country economic growth from 1960 to 1985. In the influential papers by Benhabib and Spiegel (1992a, 1992b) the level of attainment is shown to have a positive impact on growth whereas the change in attainment is shown to have an insignificant or negative impact.

There have been many attempts to improve the educational attainment data sets. De la Fuente and Domenech (2000, 2006) and Cohen and Soto (2007) provide improve data sets that are widely cited in the growth literature. De la Fuente and Domenech (2000, 2006) find a positive relationship between their attainment measure and growth in OECD countries, while Cohen and Soto (2007) also find a positive relationship but for a broader sample of countries. Barro and Lee (2000) update their data set to include average years of schooling for 142 countries from 1960 to 2000. This has become the most frequently used data set in the growth literature. Overall, studies examining the

Source	Details
Psacharopoulos and Arriagada (1986)	Educational attainment of population aged 25 and older at six levels of education; 99 countries; 1960 to early 1980s
Kyriacou (1991)	Average years of schooling of labor force at primary, secondary, and tertiary level; 111 countries; 1965 to 1985
Lau et al. (1991)	Total years of schooling completed for working age population at primary, secondary, and tertiary level; 58 countries; 1960 to 1986
Barro and Lee (1993)	Educational attainment of population aged 25 and older at primary, secondary, and tertiary level for 152 countries; 1960 to 1985
Nehru et al. (1995)	Total years of schooling completed for working age population at primary, secondary, and tertiary level;85 countries; 1960 to 1987
Barro and Lee (2000)	Update to 1993 dataset; educational attainment of population aged 25 and older at primary, secondary, and tertiary level; 142 countries; 1960 to 2000
de la Fuente and Domenech (2000)	Educational attainment of population aged 25 and older at primary, secondary, and tertiary level; 21 OECD countries; 1960 to 1990
Cohen and Soto (2007)	Educational attainment of 5-year age groups; 95 countries; 1960 to 2000
Morrisson and Murtin (2009)	Educational attainment; 74 countries; 1870 to 2010

Table 7: Commonly Used Educational Attainment Data Sets.

effect of educational attainment on growth find a positive relationship.

Measures of educational attainment reflect the average amount of schooling attained by a country's labor force, but ignores the quality of that education. Failing to account for quality differences is the primary drawback to using attainment to measure human capital. Many current growth studies discuss this shortcoming and propose solutions.

11 Test Scores

11.1 Description and Trends

The majority of early growth studies rely on quantitative measures of human capital such as enrollment or attainment. As discussed above, these were often employed because of the ease of use and availability. Recently, these measures have been criticized for ignoring the quality of education. Hanushek and Kimko (2000) stress that quantitative measures assume the amount of human capital gained from one year of schooling is equal across countries. However, there is huge disparity in the quality of schooling across countries, and students in different school systems will obtain different knowledge and skills. In addition, quantity measures such as years of schooling are bounded at an upper limit and do not fully reflect students' cognitive skill. In contrast, test scores are less bounded, which allows variation to be more fully reflected. Furthermore, the scores represent cognitive skill from schooling as well as from other sources such as family and peers.

Quality of education is difficult to measure, and multiple methods have been proposed. Barro and Lee (2001) identify two main types of quality measures–education inputs and education outcomes. Standardized test scores are a main outcome measure of students' cognitive skills and achievement. Measures of cognitive skill align best with the concept of human capital in economic theory. Because of this and the increasing availability of data, test scores are now the most popular qualitative measure of education. International test score data is becoming more widely available as more countries participate in testing, but the data is still somewhat limited. The majority of the tests focus on math, science, and reading. Overall, international test scores show that low academic achievement is a widespread problem, especially in developing countries.

International standardized testing began in the 1950's with relatively few countries taking part. The earlier participants were mostly higher income countries, but over time more countries are participating, including those of low and middle income. The tests are typically administered by international agencies and most contain both academic questions and life skills questions. The

three most commonly used tests in the literature are the Trends in Mathematics and Science Study (TIMSS), the Progress in International Reading Literacy Study (PIRLS), and the Program for International Student Assessment (PISA). The TIMSS and PIRLS are conducted by the International Association for the Evaluation of Educational Achievement (IEA), while the PISA is administered by the OECD. The TIMSS tests the mathematics and science skills of fourth and eighth graders every four years. Forty-five countries participated in 1995, and this number grew to over 60 for the 2007 tests. Asian countries had the highest percentages of students reaching the advanced international benchmark in both math and science. The median percentage of students reaching the advanced international benchmark in math was 7% for fourth grade and 2% for eighth grade. The median reaching the science benchmark was 7% for fourth grade and 3% for eighth grade. Overall, there has been steady improvement in both disciplines at the fourth grade level since 1995, but there has been little change at the eighth grade level[48]. The International Assessment of Educational Progress (IAEP) also conducted two international tests for math and science in 1988 and 1991. These are used frequently in the literature as well.

The PIRLS tests the reading skills of fourth graders and is conducted every 5 years in 40 participating countries. In 2006, 95% of participants showed at least some basic reading skills, 75% reached an intermediate benchmark, and 20% met the advanced international benchmark[49]. The PISA assesses the science, math, and reading abilities of 15 year olds. In 2000, 43 countries participated, followed by 41 in 2003, and 57 in 2006. While some countries have shown improvement, progress has been flat overall for OECD countries[50].

Intelligence quotient (IQ) tests are another form of standardized testing designed to assess cognitive ability. Psychologists created these tests and have made improvements throughout the twentieth century. IQ test scores are obtained from several standardized tests that cover a broad range of skills[51].

11.2 Literature

Recognizing the importance of distinguishing between the quantity and quality of education is becoming increasingly common. While it is clear that the quality of education differs across countries, quality is difficult to measure. On way to reflect the quality of education is through direct measures

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[48]This data was obtained from the IEA website. www.iea.nl.
[49]IEA PIRLS 2006 International Report. www.iea.nl.
[50]More information regarding PISA can be found on the OECD website. www.oecd.org.
[51]See Lynn and Vanhanen (2002) for a detailed discussion of IQ tests.

of cognitive skills. International standardized test scores and IQ test scores have both been used to measure cognitive skills.

Most of the studies that employ test scores as a proxy for human capital are relatively recent. International test score data is still limited but is becoming more readily available for a larger sample of countries.

An early study by Lee and Lee (1995) compares quantity and quality measures in growth models. They use data from the 1970 to 1971 First International Science Study conducted by the IEA to measure human capital along with quantitative measures. The test scores reflect science achievement in secondary school for 17 countries. The authors find that the quantitative measures of education become insignificant after including the test score measure in the model. In addition, the inclusion of test scores substantially improves the performance of the model.

Hanushek and Kimko (2000) stress the importance of taking the quality of education into account when examining economic growth. They assert that cognitive skill, math and science knowledge in particular, is the most relevant component of human capital. This cognitive skill is not fully captured in quantitative measures of human capital such as enrollment and attainment. Hanushek and Kimko (2000) develop a measure of cognitive skill using international test scores in math and science. They combine all math and science test score data available for each country from 6 standardized tests from 1965 through 1991. Complete test score data was only available for 31 countries, so the authors expand the sample by imputing missing values from test score regressions. Hanushek and Kimko (2000) first examine test scores as the dependent variable. They find the main determinants to be primary school enrollment, population growth, and regional differences, while the quantity of schooling, education expenditures and resources, and pupil-teacher ratios are unimportant. Hanushek and Kimko (2000) next examine economic growth as the dependent variable and conclude that test scores have a "consistent, stable, and strong relationship with economic growth". Furthermore, they find that the quality (test score) coefficient remains significant even when the coefficient on the quantity measure of schooling becomes insignificant. Their results survive robustness checks and different empirical specifications.

The purpose of Barro and Lee's (2000) study is to provide a new and improved data set for educational attainment. They examine the impact of this measure of human capital on economic growth from 1960 to 1995 and compare the results to those using alternative human capital measures. One of these alternative measures is international test scores. Like Hanushek and Kimko

(2000), Barro and Lee use only math and science scores. More specifically, their data set is comprised of scores from the TIMSS for 7th grade students in 1994 and 1995. The sample of countries is substantially smaller when test scores are used as the human capital proxy compared to when years of schooling are used. Barro and Lee (2000) conclude that both years of schooling and test scores are important for growth, with both giving valuable information concerning a country's stock of human capital.

The primary goal of Barro and Lee's (2001) study is to find the determinants of education quality. They expand on Hanushek and Kimko's (2000) test score data set. The analysis examines the factors affecting a country's quality of education as measured by international test scores as well as dropout and repetition rates. The test score data is compiled from scores on exams conducted in various years between 1964 and 1998 in science, math, and reading for several different age groups in primary and secondary schooling. Barro and Lee (2001) estimate an education production function where test scores are a function of a variety of family factors and resources devoted to schools. They find that family factors such as income have a strong effect on test scores. Years of education attained by adults also shows a significant positive effect. Pupil-teacher ratios have a negative relationship with test scores, and primary school teacher salaries have a positive but less significant relationship. Education spending per student and school term length are found to be insignificant.

Barro's (2001) study recognizes the importance of considering quality when examining the effect of human capital on growth. He compares the regression results when using years of schooling to proxy human capital to the results when using test scores. Barro (2001) utilizes the test score data from Barro and Lee (2001) described above. His study shows that science and math scores have a significant positive effect on growth. Reading scores alone show a negative effect but it becomes positive when included along with math or science scores. Barro (2001) concludes that while both the quantity and quality measures are important for growth, quality (as measured by test scores) is much more important than quantity (as measured by years of schooling).

Bosworth and Collins (2003) expand the Hanushek and Kimko (2000) math and science test score data set to include 48 countries over 1960 to 2000. Bosworth and Collins (2003) find that test scores have a significant positive effect on growth. They also find that the inclusion of the quality measure eliminates the significance of educational attainment, a result similar to Hanushek and Kimko (2000). However, Bosworth and Collins (2003) show that the significance of the quality measure is not robust to the inclusion of certain explanatory variables. For example, the test scores

become insignificant when a variable measuring the quality of governing institutions is added.

Woessmann (2003) presents a review of human capital proxies commonly used in the growth literature. He affirms that it is important to account for cross-country quality differences through measures of cognitive skill. Woessmann (2003) develops a quality weight by normalizing Hanushek and Kimko's (2000) test score measure for each country to the measure for the U.S. This gives a quality-adjusted measure of human capital by weighting each year of schooling in a country. Woessmann (2003) concludes that differences in human capital measured by the quality-adjusted years of schooling explain more than half of the differences in growth across countries. This is substantially higher than for measures not adjusted for quality.

Jamison et al. (2007) contribute to the test score literature by using a larger sample of countries and allowing for heterogeneity in country effects. Their test score data set includes 62 countries from 1960 to 2000. The larger sample of countries is indicative of the growing availability of test score data. The study examines the effect of two quality measures–math test scores and U.S. labor market returns to education by country of immigrant origin. The test score data used is the average of math scores on all international tests in which a country participated. Jamison et al. (2007) find the test score measure to have a significant positive effect on growth, while the returns to education measure is found to be insignificant.

In a recent, Hanushek and Woessmann (2008) expand the Hanushek and Kimko (2000) test score data set to encompass 50 countries. Their measure of cognitive skills is an average of a country's math and science scores on all available international tests. Hanushek and Woessmann (2008) find that test scores have a strong and statistically significant positive effect on growth between 1960 to 2000 when controlling for initial GDP and years of schooling. This result passes extensive robustness checks.

In addition to the standardized tests discussed above, IQ tests are also used as a measure of human capital. Lynn and Vanhanen (2002) provide the most popular IQ data set. They assemble a data set of national average IQ scores across the 20th century for 81 countries. Ram (2006) uses this data in the augmented Solow model from Mankiw et al. (1992). He compares the growth effects of three alternative human capital proxies–IQ, life expectancy, and secondary school enrollment. Ram deduces that IQ is the strongest of these for explaining growth. When both IQ and the secondary enrollment are included in the model, IQ exhibits high significance while secondary enrollment is insignificant.

Jones and Schneider (2006) also make use of Lynn and Vanhanen's (2002) IQ data set. They show that the IQ data is positively correlated with both Barro and Lee's (2001) and Hanushek and Kimko's (2000) test score measures, which indicates that they measure similar skills. Furthermore, they point out that IQ has been ignored as a measure of human capital even though the data is more widely available than international standardized test score data. Jones and Schneider (2006) use the Bayesian Averaging of Classical Estimates (BACE) approach introduced by Sala-i-Martin et al. (2004) to determine the significance of IQ for economic growth. The BACE results show that IQ is highly robustly significant for economic growth.

11.3 Advantages and Disadvantages

International test scores are thought to indicate differences in the quality of education across countries. This is a considerable advantage over quantitative measures since ignoring quality differences can lead to inaccurate results. Using measures that only account for the quantity, and not the quality, of education makes the incorrect assumption that the benefits received from education are equal across all countries. In addition, test scores have the benefit of being able to capture aspects of human capital gained from sources outside of schooling such as parental and environmental factors.

Furthermore, the quantitative measures of years of schooling and enrollment rates are restricted by an upward bound that many developed countries have met or are close to meeting. This restricts the amount of variation that these measures can reflect. Test scores are less bounded and therefore have another advantage of allowing the dispersion that exists across countries to be more fully reflected.

The most noteworthy problem with test scores as a proxy for human capital is the limited availability of the data. International standardized testing is a relatively recent development and while the number of participating countries is increasing, data is still sparse. Barro and Lee (2001) point out several other issues with international test score data. First, countries have differing education curricula, and test scores can reflect these differences. Multiple concerns arise from the sample of students being tested. It is difficult to test a nationally representative sample of students in each country, which can lead to biases from sample selection. In addition, it is tough to monitor how the tests are administered to students and to control for quality. In other words, it is a big challenge to standardize standardized tests. Finally, as with any type of data, errors can arise

Source	Details
Hanushek and Kimko (2000)	International math and science test scores; 39 countries; 1965 to 1991
Barro and Lee (2001)	International math, science, and reading test scores; 58 countries; 1964 to 1998
Lynn and Vanhanen (2002)	Average IQ test scores; 81 countries; 1910 to 1990
Bosworth and Collins (2003)	International math and science test scores; 84 countries; 1970 to 2000
Jamison et al. (2007)	International math test scores; 62 countries; 1960 to 2000
Hanushek and Woessmann (2008)	International math and science test scores; 77 countries; 1960 to 2000

Table 8: Commonly Used Test Score Data Sets.

due to problems with data collection. This becomes an even bigger problem since sample sizes are relatively small.

Concerns have also been raised regarding the use of IQ scores as a measure of human capital. Perhaps the most notable criticism is from Gould (1981), who claims that IQ tests are based on incorrect assumptions and that general intelligence cannot be accurately reflected in a single number. He further suggests that IQ scores can be used for "scientific racism". While there is a large literature suggesting that IQ and other standardized tests are racially biased, there is also a large literature disputing the claim[52].

11.4 Data and Summary

The limited nature of test score data is the primary problem with using test scores as a measure of human capital. Standardized testing is relatively new, so data is limited in both the number of countries and years covered. Furthermore, few countries participated in these tests early on and most of those participating were highly developed countries. Over time, more countries have started to take part, and data for a broader set of countries is becoming available. Table 8 gives sources for test score data sets used in growth studies.

The use of test scores to proxy human capital is becoming increasingly popular. The largest problem with measures used earlier in the growth literature is that they only account for a country's quantity of education, and not the quality. However, the consensus is that measures of human capital need to reflect quality. Test scores are thought to account for the quality of education by measuring cognitive skills. The influential paper by Hanushek and Kimko (2000) stresses the

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[52]See Jencks and Phillips (1998) for more information about racial bias in testing. Neisser et al. (1995) is an example of a study concluding that IQ tests are not racially biased.

importance of accounting for the quality of education through the use of test score data. They show that math and science test scores have a strong positive impact on cross-country growth from 1965 to 1991. Barro (2001) also provides an important study showing that test scores are a more important determinant of growth than is educational attainment. In general, the studies that employ test scores to measure a country's human capital find a significant positive relationship with economic growth.

12   Pupil-Teacher Ratios

12.1   Description and Trends

Teachers are the most valuable resource in a student's education. Therefore, it seems that smaller class sizes would be beneficial for students. Small classes give students more opportunity for participation and interaction with the teacher. The pupil-teacher ratio reflects the total number of students relative to the total number of teachers at a given level of education. According to the United Nations, the target pupil-teacher ratio for reaching universal primary education by 2015 is 40:1 or lower.

When used as a proxy for human capital, the pupil-teacher ratio is typically intended to reflect the quality of education. It is often considered an objective input measure that reflects how education resources are invested. The use of the pupil-teacher ratio did not arise until later in the literature due to data limitations.

There are considerable differences in pupil-teacher ratios across and within countries. Developing countries tend to have higher ratios than developed and transition countries. The disparity within countries is generally due to differences between areas that are rich or poor and urban or rural[53]. Pupil-teacher ratios have fallen significantly over time for OECD countries. For primary education, the ratio decreased from 30 to 16 between 1960 to 1990 and from 18 to 13 for secondary education. Developing countries did not experience the same level of improvement. From 1960 to 1990, the primary pupil-teacher ratio dropped from 38 to 33, but increased from 19 to 21 for secondary education[54]. Recently, progress has slowed in all countries with little change in the ratios since 1999.

It is clear from Table 9 that there are severe shortages of teachers in sub-Saharan Africa and

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[53]See UNESCO's Education for All Global Monitoring Report 2009 for more details about differences in pupil-teacher ratios across countries.

[54]Data is from Barro and Lee (2001).

	Primary PT Ratio		Secondary PT Ratio	
	1999	2006	1999	2006
Developing Countries	27	28	21	20
Developed Countries	16	14	13	13
Countries in Transition	20	18	11	10
Sub-Saharan Africa	41	45	24	27
Arab States	23	22	16	16
Central Asia	21	19	11	12
East Asia and Pacific	22	20	17	17
South and West Asia	37	40	33	30
Latin America and Caribbean	26	23	19	16
North America and West Europe	15	14	14	13
Central and East Europe	19	18	13	11

Table 9: Pupil-Teacher Ratios. Source: Education for All Global Monitoring Report 2009, Table 2.18.

South and West Asia. These high ratios are partly attributable to the failure to keep up with the rising school enrollment levels. Afghanistan, Chad, Mozambique, and Rwanda each have primary pupil-teacher ratios greater than 60:1[55].

High ratios typically indicate insufficient expenditure on education or weak incentives for teachers such as low salaries. It is important to remember that it is not just the number of teachers that is important but the quality of those teachers as well. Many countries are hiring unqualified contract teachers to reduce costs and increase the teaching force[56].

12.2 Literature

There are obvious differences in the quality of schooling across countries. Quality is typically proxied using measures of cognitive skill or using measures of education inputs. Pupil-teacher ratios are one of these input measures. It seems intuitive that resources devoted to schools should improve the quality of education received. Specifically, we would expect that students in schools with smaller class sizes to have higher achievement. However, the empirical literature investigating the importance of pupil-teacher ratios has produced mixed results.

While this review centers on cross-country growth, studies focusing on the U.S. provide useful insight into the impact of pupil-teacher ratios. Card and Krueger (1992) find that men born between 1920 and 1949 who attended schools with lower pupil-teacher ratios experience a higher

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[55]Statistics are from UNESCO's Education for All Global Monitoring Report 2009.
[56]Information is from Education for All Global Monitoring Report 2009.

return to education. Bratsberg and Terrell (2002) also discover an important role for class size in their study of U.S. immigrants. They show that U.S. immigrants from a source country with low pupil-teacher ratios achieve a higher return to education. A recent study by Baldwin and Borrelli (2008) corroborate this result by finding a negative relationship between pupil-teacher ratios and economic growth in the U.S. between 1998 and 2005. In contrast, Betts (1995) concludes that pupil-teacher ratios and other input measures are not an important source of disparity in quality across schools in the U.S. Heckman et al. (1996) also fail to find a relationship between pupil-teacher ratios and earnings of white males born in the U.S. between 1910 and 1959.

As just mentioned, pupil-teacher ratios are typically used to reflect the quality of education. Several studies examine whether the ratios are actually an important determinant of quality at all. Barro and Lee (2001) demonstrate that school resources do in fact improve school quality as measured by international test scores. In particular, they find lower pupil-teacher ratios to be especially important for student achievement. Hanushek and Kimko (2000) also investigate the determinants of test scores, but reach different conclusions. They find various measures of school resources to be relatively unimportant for student performance. An unexpected positive relationship is shown to exist between pupil-teacher ratios and test scores. From this result, the authors deduce that it is unlikely that pupil-teacher ratios reflect any quality differences across schools. Hanushek (2004) reiterates this finding by pointing out that despite considerable decreases in pupil-teacher ratios along with other increases in resources, student achievement has not improved.

There are relatively few cross-country economic growth studies that use pupil-teacher ratios as the sole proxy for human capital. Barro (1991) tests the impact of human capital on growth using enrollment rates to proxy a country's human capital. Acknowledging the importance of differences in education quality, Barro (1991) furthers the study by examining the relationship between pupil-teacher ratios and growth. His results indicate that primary school pupil-teacher ratios are significantly negatively related to growth, while secondary school ratios are insignificant. Subsequent work by Barro (2001) that examines the impact of education on growth shows similar results regardless of the proxy employed–test scores, pupil-teacher ratios, years of schooling, or dropout rates. He finds that each of these plays an important role in explaining economic growth.

Hanushek and Kimko (2000) compare the results of different model specifications for determining the effect of education on growth. They look at models with and without test scores as a measure of school quality and with and without school input measures. They find a significant negative

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Source	Details
Barro (1991)	Pupil-teacher ratio at primary and secondary level; 88 countries; 1960
Barro and Lee (2001)	Pupil-teacher ratio at primary and secondary level; 105 countries; 1960 to 1990

Table 10: Commonly Used Pupil-Teacher Data Sets.

coefficient for primary school pupil-teacher ratios when the test score measure of quality is omitted, while the coefficient for secondary school pupil-teacher ratios is positive and insignificant. When test scores are included in the model, the effect of primary school pupil-teacher ratios becomes insignificant.

12.3   Advantages and Disadvantages

Pupil-teacher ratios can be used as qualitative measure of education, and as pointed out earlier, it is important to account for the quality of education in a proxy for human capital.   Baldwin and Borrelli (2008) call attention to the fact that pupil-teacher ratios help signal how education spending is allocated. While much of the literature suggests that test scores are the better measure of quality, it is possible that pupil-teacher ratios and other input measures capture some aspects of education that test scores do not. Furthermore, students' test scores can be influenced by many other factors such as various family characteristics, making it difficult to discern how much of the effect on growth is attributable to education.   Another benefit of pupil-teacher ratios is that they are easy to measure and not subjective.   This helps reduce measurement error in the data.

The inconsistent results regarding the importance of pupil-teacher ratios for education quality and growth reduce confidence in the measure. Heckman et al. (1996) suggest that measures of school quality may simultaneously change due to budget constraints, and as a result, give conflicting information. They use the example that an increase in teacher salaries may occur at the same time as an increase in pupil-teacher ratios so that schools can stay within their budget. In this case, one measure signals an increase in the quality of education while the other signals a decrease.

12.4   Data and Summary

Barro and Lee's (2001) widely used data set provides cross-country data for a variety of human capital related measures.   This data set is the main source for pupil-teacher ratio data.   Details regarding pupil-teacher ratio data sets can be found in Table 10.

Relatively few studies use pupil-teacher ratios to measure human capital in cross-country growth regressions. The seminal work of Barro (1991) finds a significant negative relationship between primary education pupil-teacher ratios and growth from 1960 to 1985, but finds an insignificant relationship for secondary education pupil-teacher ratios. Another important study by Hanushek and Kimko (2000) shows that primary education pupil-teacher ratios are important for growth until test scores are added to the growth regressions. Hanushek and Kimko (2000) agree with Barro (1991) that secondary education pupil-teacher ratios are unimportant for cross-country economic growth. Overall, the growth literature shows a negative relationship between primary education pupil-teacher ratios and a country's economic growth.

Whereas pupil-teacher ratios are seldom used as the sole proxy for human capital in growth studies, the measure has been used often as a determinant in studies of the return to education in the U.S. The results of these studies are inconsistent. Some find a significant negative relationship between pupil-teacher ratios and the return to education, while an equal number find an insignificant relationship.

13   Education Expenditures

13.1   Description and Trends

Spending on education is another class of measures frequently used to proxy the quality of education. These measures typically focus on government expenditures rather than household spending for several reasons. First, governments provide the largest share of education funds. Second, studies tend to focus on government spending because it can be affected most by changes in policy. Finally, data for government expenditures is more readily available than that for household expenditures.

Governments of all countries play an important role in providing education. As mentioned already, governments are the main source of education resources. There are many uses and types of public education expenditures. For example, money spent on education can be used for teacher and staff salaries and benefits, school buildings and facilities, services such as meals and transportation, various education programs, and materials such as textbooks and computers[57]. However, most studies do not distinguish between the different types of education spending. An exception is that some studies use only teacher salaries as that is where the largest proportion of education spending

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[57]The OECD Education At a Glance 2008 lists types and uses of education spending.

	Total Govt. Exp. on Educ. (% GNP 2006)			Total Govt. Exp. on Educ. (% Total Govt. Exp. 2006)		
	Min.	Median	Max.	Min.	Median	Max.
Developing Countries	1.4	4.4	10.8	4	16	31
Developed Countries	1.2	5.3	8.3	6	12	17
Countries in Transition	2.4	3.9	6.6	9	17	20
Sub-Saharan Africa	1.4	4.4	10.8	4	18	30
Arab States	1.6	4.6	7.7	10	21	31
Central Asia	2.4	3.4	5.3	9	-	19
East Asia and Pacific	1.8	-	10.8	9	-	25
South and West Asia	2.6	3.3	8.3	11	15	19
Latin America and Caribbean	1.2	4.1	10.8	9	15	26
North America and West Europe	2.3	5.5	8.3	9	12	20
Central and East Europe	3.6	5.3	6.6	6	13	20

Table 11: Total Government Expenditure on Education. Source: Education for All Global Monitoring Report 2009, Tables 3.1 and 3.2.

is devoted[58]. Like other measures of quality, expenditure data has become more abundant over time but is still limited.

Increasing the amount of government spending allocated to education is priority for achieving universal primary education and the Education for All goals. There are large differences in public education expenditures across countries. Low income levels and poverty lead to budget constraints, and can limit resources allocated to education. Low levels of education spending can also reflect a lack of government commitment to education. UNESCO asserts that a minimum threshold must be met to provide students with adequate materials facilities. However, high levels of spending do not guarantee successful student outcomes.

In general, higher income countries tend to devote about the same share of government budget to education. Governments in developing countries have made education a higher priority and have devoted more resources, but spending in some countries is still very low.

Table 11 shows education expenditures for different regions. The table should, however, be interpreted with caution because there are many countries without data. Lower income countries tend to spend substantially less on education primarily because tax revenue is lower. In addition to the amount spent, the allocation is also important. The distribution of resources among different levels of education is strongly related to enrollment. In countries where post-primary enrollment is small, most of the education budget is allocated to primary education. Conversely, countries

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[58]Examples include Card and Krueger (1992) and Heckman et al. (1996).

with high post-primary enrollment devote less to primary education. The proportion of spending devoted to primary education is about 50% for low income countries, but just 25% for high income.

Teacher salaries account for the largest share of education spending. UNESCO reports that about half of the countries for which they had data in 2006 spent more than 75% of their education budget on teacher salaries. However, this large proportion does not mean that teachers are overpaid, but rather that education is underfunded. In general, teacher pay is lower than comparable jobs and is often at or below the poverty line. Low salaries compromise the quality of education for several reasons. Some teachers are forced to take on second jobs, which reduces time devoted to instruction. Low pay can also lead to low motivation and morale. Finally, low salaries do not attract the highest quality applicants. So, governments face an important trade-off between cost and quality. Paying low salaries allows for the hiring of more teachers but at the expense of the quality of education.

The salaries of teachers are very low in many developing countries in particular. In most sub-Saharan African countries and in South and West Asia, teacher pay is below the poverty level. In addition, salaries in Latin America and Central Asia are typically above the poverty line but are significantly lower than those for comparable professions[59].

13.2   Literature

The recent growth literature stresses the importance of incorporating the quality of education into measures of human capital. It seems natural to assume that resources devoted to education would have an effect on schooling quality. Hence, it is quite common for researchers to use a measure of education resources to proxy the quality of education. There have been various measures of education resources used, with education expenditures among the most popular. While the intuition that resources should increase education quality seems logical, the empirical relationship is somewhat controversial given the conflicting results.

Many studies that argue against the importance of education resources for student outcomes. In Hanushek's (1986) study of schooling in the U.S., the relationship between resource measures of school and teacher characteristics and academic achievement is explored for the time period of 1960 to 1983. He finds that there is no relationship with resource measures such as expenditures per student. Hanushek and Kimko (2000) reiterate this finding and stress that school resources are not

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[59]See the Education for All Global Monitoring Report 2009 for more information regarding teacher pay across countries.

an appropriate proxy for education quality. Their study explores the determinants of education quality by testing the effect of multiple measures of schooling resources along with test scores. The coefficients on both measures of expenditures–current public expenditure per student and total education expenditure as a share of GDP–are statistically significant but with an unexpected negative sign. Hanushek and Kimko (2000) conclude that while quality is an important determinant of growth, education resources are not an important determinant of quality.

In their sensitivity analysis, Levine and Renelt (1992) test the robustness of education spending as a determinant for growth. The extreme bounds analysis shows that the ratio of government education expenditures to GDP is not robust to changes in model specification. Therefore, Levine and Renelt (1992) conclude that spending is not a significant determinant of growth for the time period between 1960 and 1989.

Barro and Lee (2000) also investigate the factors that contribute to differences in education quality. They examine the effect of various education resources on test scores. Total education spending per student is shown to have a positive effect, but is statistically insignificant. When three more measures are added (pupil-teacher ratio, teacher salaries, and school term length), the coefficient on the spending variable is still insignificant but becomes negative.

Kalaitzidakis et al. (2001) reach similar conclusions by examining the effect of multiple human capital proxies on growth. They find an insignificant effect for low levels of government education spending and a negative effect for higher levels.

In contrast to the studies discussed so far, Oketch (2002) finds a significant role for education expenditures in his study of African growth. He examines how spending on basic and advanced education as a percent of GDP affects growth for 47 African countries from 1960 to 1998. The results show that spending at both levels of education has a positive and statistically significant effect on growth.

Keller (2006) also finds a significant role for spending. She studies the importance of three different human capital measures–enrollment rates, government expenditures as a percent of GDP, and government expenditures per student as a percent of GDP per capita. The regression results show that expenditures per student is positive and significant at the primary level, positive but less significant at the secondary level, and negative and significant at the higher level. In regards to overall government education spending, the results are mostly insignificant with a positive coefficient at the primary level but negative coefficients at the secondary and higher levels. Keller

(2006) concludes that expenditures are better targeted towards primary education, especially when resources are scarce.

Blankenau et al. (2007) examine the relationship between government education expenditures and growth while taking into account the government's budget constraint. They find that including the budget constraint has important implications for the relationship. When the budget constraint is not considered, government education expenditures appear to have no effect on growth. However, when the budget constraint is accounted for, public education spending is shown to have a significant positive effect on growth for high income countries. They find no relationship between spending and growth for poorer countries.

The goal of Al-Yousif (2008) is to determine if a relationship exists between human capital as measured by education spending and growth for six Gulf Cooperation Council (GCC) countries. He employs two measures of spending–government education spending per worker and the ratio of government education spending to GDP. The results from the Johansen Cointegration tests indicate that human capital is cointegrated with growth regardless of which measure is used. The Granger-Causality tests give mixed results regarding the relationship between human capital and growth. Al-Yousif (2008) summarizes that the results are country-specific and also vary depending on which spending measure is utilized.

As mentioned above, some studies use teacher salaries as a measure of education spending. The majority of these examine the relationship with individual earnings rather than overall economic growth. Yet, these studies can provide useful insights regarding the importance of teacher pay. Card and Krueger (1992) use teacher salaries in their analysis of the effect of schooling quality on the rate of return to education for men born in the U.S. between 1920 and 1949. They hypothesize that higher salaries would attract better teachers thereby improving schooling quality and increasing the return to education. The findings confirm their hypothesis.

Betts (1995) tests the effect of schooling quality on earnings in the U.S. between 1979 and 1990. He uses three measures of quality including the salary of beginning certified teachers with a bachelor's degree. He finds each of his quality measures to be insignificant for earnings. This conclusion is echoed by Heckman et al. (1996). Their study focuses on the choice of the functional form for modeling the effect of schooling quality on earnings. They include four measures of quality–two pupil-teacher ratio measures, term length, and relative teacher pay. None of these measures prove to be significant for earnings.

The main purpose of the study by Barro and Lee (2001) is to find the significant determinants of education quality by examining the relationship between test scores and a variety of school and family input measures. They use real primary teacher salaries as one of their input measures. The motivation behind this measure is that higher salaries should attract higher quality teachers who will have a larger impact on student achievement. The results support this notion, showing that primary teacher salaries have a significant positive effect on test scores. In addition to test scores, repetition and dropout rates are also used as measures of quality. The use of these measures leads to different results. Teacher salaries are found to be insignificant for the repetition rate and significant but negative for the dropout rate.

13.3   Advantages and Disadvantages

Employing a measure of education spending as a proxy for human capital is considered a way to account for quality differences in education across countries. It makes sense intuitively that spending on education should affect quality and therefore growth. However, the effect of education spending on the quality of schooling is controversial topic considering the mixed results from studies over time.

Government spending on education is an objective measure that is easier to quantify than many other human capital variables. Spending measures are also straightforward to interpret and compare across countries.

Rangazas (2005) highlights that education spending is likely to be allocated quite different between poor and rich countries. In poorer countries, increases in spending would probably be used hire teachers, increase the length of schooling, or provide basic supplies. In richer countries, increases in spending would more likely be used for increasing technology or decreasing class sizes. Furthermore, spending in poorer countries is more focused on younger students since there are fewer students attending secondary and higher education.

Overall spending on education is difficult to measure for several reasons. Mankiw et al. (1992) point out that difficulty arises because education spending comes from many sources including all levels of government and from families. These various sources cause discrepancies in spending data in used in the literature. Family spending data in particular is scarce primarily due to measurement difficulty.

A major drawback of education spending measures is that they do not reflect the effectiveness

Source	Details
Levine and Renelt (1992)	Ratio of government education expenditures to GDP; 119 countries; 1974-1989
Barro and Lee (2001)	Expenditures on public education and subsidies for private education from all levels of government for primary, secondary, and tertiary schooling; 105 countries; 1960 to 1990
Barro and Lee (2001)	Ratio of real expenditures on education per pupil to real GDP per capita; 105 countries; 1960 to 1990
Barro and Lee (2001)	Average real salary of primary school teachers; 105 countries; 1960 to 1990
Keller (2006)	Public education expenditures as a share of GDP at primary, secondary, and tertiary levels; 74 countries; 1960 to 2000
Keller (2006)	Public expenditure per student as a share of GDP per capita at primary, secondary, and tertiary levels; 93 countries; 1960 to 2000

Table 12: Commonly Used Education Expenditure Data Sets.

of how the resources are used. The allocation and use of funding is important, not just the amount. Additionally, Woessmann (2003) and Hanushek (2004) both suggest that teacher salaries are not good proxies for education quality since there is limited evidence of a positive relationship with test scores.

13.4 Data and Summary

As with other measures, Barro and Lee (2001) provide the main source for education spending data. This data set includes cross-country data for both government education expenditures and teacher salaries. Keller (2006) provides government spending data for a longer time period. See Table 12 for more information about these data sets.

The results from examining the effect of education spending on growth are quite mixed, with multiple studies finding an insignificant or negative relationship. This has led many to discount education spending as an appropriate proxy for schooling quality. Funds for education come from a variety of sources, including state, local, and federal governments as well as from private sources. Most spending measures focus on government spending since this data is easier to collect than that for family education spending. Furthermore, most spending data reflects the amount of resources devoted to education, but not how efficiently these funds are used. These complexities likely contribute to the inconsistent results in the growth literature.

Human Capital Measure	Articles Reviewed	% Finding Sign. Growth Rel.
Enrollment	9	100%
Literacy	7	100%
Educational Attainment	25	90.5%
Test Scores	12	100%
Pupil-Teacher Ratio	10	100%
Education Expenditures	12	57%
Overall	81	91.2%

Table 13: Summary–Number of Articles Reviewed and the Percent Finding a Significant Relationship with Growth.

Studies examining the determinants of education quality typically find that education expenditures are not a significant factor. For example, the influential work by Hanushek (1986) shows that education spending is unimportant for U.S. student achievement. Barro and Lee (2000) come to the same conclusion for cross-country test scores.

14 Other Measures

A variety of other measures are used to proxy human capital in the literature, but are used with less frequency than those discussed above. These proxies are typically other measures of teacher or school characteristics such as teacher education level and certification, teacher experience, term length, and compulsory schooling laws. The focus of this review is on the most popular human capital measures, and as such, these are omitted from this paper.

15 Conclusion

The notion that human capital is important for growth is certainly not new. The 1776 work of Adam Smith introduces the concept and describes the importance of an individual's human capital as, "Those talents, as they make a part of his fortune, so do they likewise that of the society to which he belongs." Becker (1964) later coined the term human capital and pioneered the inclusion of human capital in a theoretical model of growth. As discussed in Agiomirgianakis et al. (2002), Lucas (1988) and Romer (1989) were also influential in modeling the relationship of human capital and economic growth. However, it was not until the 1990's that studying the empirical relationship became popular.

A proxy for human capital must be chosen in order to examine the empirical relationship

between human capital and economic growth. This is a difficult task due to the complex and intangible nature of human capital. There has been a progression over time in growth models from simply including a measure of human capital to including the best measure that most closely matches with the theory. In early studies, the choice of proxy was limited by data availability. As time has passed, more data has become accessible, and existing measures of human capital have been improved, and new measures have been introduced.

Table 13 summarizes the review. The most popular proxies for human capital are enrollment rates, measures of educational attainment, and, more recently, test scores. Enrollment rates were prevalent in early studies mainly because it was the measure for which the most data was available. However, there are problems with using enrollment rates to proxy human capital. Enrollment rates measure only the access to education and do not reflect the completion or accumulation of schooling. Therefore, the human capital of a country's labor force is not likely to be accurately reflected. Furthermore, enrollment rates give no indication of the quality of schooling to which the students have access.

Measures of educational attainment were developed to reflect the accumulation of human capital. These are the most commonly used proxies for human capital. Measures of attainment typically give the average years of schooling completed for a country's adult population. This measure aligns better with economic theory than do enrollment rates, but the quality of schooling is still not taken into consideration. The important work of Hanushek and Kimko (2000) emphasizes that ignoring quality implicitly assumes that a year of schooling in every country provides the same benefit to growth. This is certainly not the case as there are vast differences in the quality of education received across countries.

It seems clear that quality should be considered, but quality is very difficult to measure. For this reason, many studies still employ educational attainment measures and, to a lesser extent, enrollment rates in growth models. However, many recent studies focus on accounting for quality when examining the impact of human capital on growth. Currently, the most common way to measure the quality of a country's education is through international test scores. The main problem with test scores is the lack of data. International standardized testing is a relatively new concept with very few countries participating early on. As more data becomes available and more countries participate, test scores will be used more often, and the results will be more reliable.

This review serves multiple purposes. It provides a reference for future studies of growth. It

will aid in the selection of a human capital proxy by giving the pros and cons of the alternative measures and the data sources available. Very few studies offer an explanation of their choice of human capital proxy. It is the hope that this review will give authors a basis for their selection.

A main conclusion to be drawn from this survey is that human capital matters for growth. Regardless of which measure is used, the majority of studies find a significant relationship between education and economic growth. It is clear that a measure of human capital should be included in growth models.

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Part III

Chapter 3: Determining the Importance of Human Capital for Growth Using a Bayesian Averaging of Classical Estimates Approach

16   Introduction

The literature aimed at finding the determinants of economic growth is vast. Much of this empirical research follows the seminal work of Barro (1991). The basic methodology is to estimate cross-country growth regressions where growth is a function of a variety of independent variables. Economic growth is typically measured as a country's growth rate of real GDP per capita. However, the possible explanatory variables for growth are virtually unlimited. As pointed out by Sala-i-Martin et al. (2004), which will hereafter be referred to as SDM (2004), the number of possible regressors is greater than the number of countries for analysis. This makes model specification extremely difficult. Researchers are left to select, often arbitrarily, a few explanatory variables to include in growth regressions. This relatively small number of regressors is used to determine the statistical significance of a particular variable for growth.

The growth literature has produced a large number of variables deemed significant for growth. Durlauf, Johnson, and Temple (2005) count 145 different variables found to be significant at least once in the literature. Brock and Durlauf (2001) attribute this multitude of regressors to the "open-endedness" of economic growth theories. In other words, the theoretical growth literature is not specific or clear enough about the determinants of growth.

Estimating growth regressions started gaining popularity in the 1950's and continues to be popular today. Dobra et al. (2005) find that the empirical growth research from the 1950's through the 1980's, focused on only five explanatory variables. Eicher et al. (2007) state that this changed in the 1990's as the number of possible explanatory variables increased rapidly due to the rush of new growth theories. Model uncertainty has been a major issue in the growth literature ever since.

It is difficult to have confidence in the results from empirical growth studies given the overwhelmingly large number of different variables found to be significantly related to growth. Classical approaches involve including all possible independent variables in the regression and then letting

the data work through them. This is not viable for cross-country growth since the number of potential regressors is greater than the number of countries with sufficient data. Hence, there is no consensus on how to model economic growth.

There have been multiple attempts to solve this model uncertainty problem. Some of these studies propose methods to assess how confident we should be in the results from growth regressions. Leamer (1983, 1985) stresses that the sensitivity of results to changes in model specification needs to be studied in a systematic way. In regards to findings from previous growth studies, Leamer (1985) states that, "A fragile inference is not worth taking seriously." He proposes a method called "global sensitivity analysis" to examine whether results hold up to changes in the explanatory variables included in the model. His method is a form of extreme bounds analysis where results are determined to be robust or fragile based on the interval of inferences derived from different model specifications. A variable is deemed robustly significant for growth only if the number of alternative specifications tested is "wide enough to be credible" and the resulting interval of inferences is "narrow enough to be useful" (Leamer 1985).

Granger and Uhlig (1990) extend the work of Leamer (1983, 1985) by introducing "reasonable extreme bounds analysis". Their method is similar in examining the extreme values of coefficient estimates for a certain variable when different independent variables are included in the model. However, Granger and Uhlig (1990) point out that some of the estimates examined in Leamer's work come from models with a low R^2. They attempt to improve the extreme bounds analysis by focusing only on models that have a good fit[60].

Levine and Renelt (1992) also perform a version of extreme bounds analysis to determine if results from previous growth studies are robust to changes in regressors. They identify the highest and lowest coefficient estimates from all possible linear combinations of explanatory variables[61]. They conclude that a variable is robustly related to growth if the two extreme bounds values of the coefficient are significant and of the same sign. Levine and Renelt (1992) find that virtually none of the variables are robust to changes in model specification.

Levine and Renelt's (1992) results can be interpreted as an indication that very few variables are important for growth. Sala-i-Martin (1997) gives an alternative explanation—that the extreme bounds test is too strong for variables to pass. Instead of labeling variables as "robust" or "not

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[60]Models with an R^2 above a certain threshold are considered a good fit.

[61]The regressions are comprised of a set of independent variables that are always included and a combination of up to three other independent variables.

robust", he assigns a level of confidence to each potential determinant. The entire distribution of coefficients from regressions including different combinations of independent variables is examined[62]. Sala-i-Martin (1997) finds 22 out of 59 variables to be significantly correlated with growth, compared to only one variable when using the extreme bounds test.

SDM (2004) further update the literature by proposing another way to overcome the model uncertainty problem. The starting point of their method is to admit that there is not just one "true" growth model. So, rather than trying to find a single correct model, they find probabilities of being correct for different possible models. This is clearly a deviation from classical approaches that focus on a single model. SDM (2004) develop a technique called Bayesian Averaging of Classical Estimates (BACE). This method combines the Bayesian method of averaging estimates across models with classical ordinary least squares (OLS) estimation. A fully Bayesian approach requires specifying the prior distribution of all variables in each model. This is very difficult and has prevented Bayesian methods from gaining widespread popularity. BACE avoids this problem by requiring the specification of only one prior—mean model size. This relies on the assumption of diffuse priors for the rest of the variables[63]. Two advantages result from this assumption. First, classical OLS estimation stems from the assumption of diffuse priors. So, this makes the results from BACE easier to understand since they are derived from familiar OLS estimates. Second, diffuse priors limit the effect prior information has on results. This is a benefit because prior information tends to be somewhat arbitrary.

SDM (2004) use BACE to examine the importance for growth of 67 variables previously found to be significant in the literature. A variable is deemed robustly significant for growth if the probability that a variable should be included in the model increases after the prior inclusion probability has been updated with the data. In other words, a variable is significant for growth if confidence of its inclusion in the model grows after seeing the data. SDM (2004) find 18 of the variables to be important for growth.

For this paper, I employ the BACE method, but with a sharper focus on the importance of human capital for growth. SDM (2004) include only three human capital variables in their analysis with two of these being enrollment measures. The recent human capital literature has shown that enrollment rates do not accurately represent a country's human capital. Therefore, it

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[62]Like Levine and Renelt (1992), Sala-i-Martin has a set of three variables that are included in every regression and the remaining regressors vary.

[63]Diffuse priors indicate there are no prior beliefs.

is necessary to include other measures of human capital into the BACE framework to determine the effect of human capital on growth. To do this, I develop a new data set of 35 human capital measures. Using this additional human capital data set, I find that some of these measures are indeed important for growth and should therefore be considered for inclusion in growth models. These significant human capital variables include IQ scores, average years of higher education for the female population, average years of primary education, duration of primary and secondary education, and higher education enrollment.

16.1   Importance of Human Capital

Human capital is the knowledge and skills embodied by a country's labor force, and economists recognized its importance very early on. Adam Smith first defined human capital in 1776, and Alfred Marshall stressed its value in 1890 saying, "The most valuable of all capital is that invested in human beings."[64] Human capital is attained through a variety of sources—education, training, experience, peers, and family. However, most of the focus is on the formal education aspect since education can be influenced the most by policy and data is more abundant.

Few would argue with the fact that education is important. The World Bank asserts that "education is central for development" and that it "empowers people and strengthens nations"[65]. Education is critical in generating human capital, and human capital is typically considered a main determinant of productivity. This follows the notion that more educated and skilled workers will be more productive and innovative.

The role of human capital is acknowledged in both the theoretical and empirical economic growth literature. As discussed by Engelbrecht (2003), the body of theoretical research indicates three main channels through which human capital, and education in particular, affects economic growth. First, education increases the human capital of a country's labor force, and the accumulation of human capital over time positively affects growth. Second, increases in human capital lead to greater technological innovation. Finally, higher levels of human capital enhance a country's capacity to understand and implement new technology. In line with growth theory, most empirical growth research now includes a variable representing human capital along with other variables considered important for growth.

What is less certain is how to measure human capital. Human capital is complex and therefore

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[64]From Woessmann (2003)–quotation from Principles of Economics, originally published in 1890.
[65]World Bank. www.worldbank.org/education.

difficult to accurately represent in a single measure. Including a human capital measure in growth regressions became increasingly popular in the 1990's with the emergence of new growth theories. Since this time, human capital has been measured in many different ways[66]. As just mentioned, these measures typically reflect some facet of formal education. The two used most often have been school enrollment rates and years of schooling or educational attainment. Over time these measures have been updated, and alternatives have been introduced. Recently, measures that take into account the quality of education, not just the quantity, have gained popularity[67]. The measurement of human capital has evolved over time as access to better-quality and expanded data sets has increased. Furthermore, improving the measurement of human capital has been the focus of many studies[68].

Multiple measures of human capital have been found to have a significant relationship with growth. As discussed above, the wide variety of results makes it difficult to be confident in any one study. The goal of this paper is to determine which of the many measures of human capital are robustly significant for growth within the BACE framework. The rest of the paper is organized as follows. Section 2 provides a description of the data used in the analysis, followed by Section 3 which discusses the BACE methodology. Section 4 gives the results, and Section 5 concludes.

17   Data

The data used in this analysis is from multiple sources. I use SDM's (2004) data set of 67 possible growth determinants along with my newly compiled human capital data set. The human capital data set is comprised of 35 variables including measures such as enrollment rates, years of education attained, pupil-teacher ratios, and IQ scores. When possible, these measures are decomposed by level of schooling and gender. The BACE model developed by SDM (2004) imposes some constraints on the data used for analysis. The data used for my study follow these restrictions laid out by SDM (2004). First, the explanatory variable data needs to be from the beginning of the time period examined, or as close as possible to that year. The time period for this analysis is from 1960 to 1996, so all variables are 1960 values (or the closest year available). As suggested by SDM (2004), this constraint makes the regressors "state variables" and helps avoid endogeneity in the model. The downside of this restriction is that some variables have to be ignored or excluded if data is only

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[66]See my dissertation chapter titled "Measures of Human Capital in Growth Regressions" for a review.
[67]See, for example, Hanushek and Kimko (2000) and Barro and Lee (2001).
[68]Examples include de la Fuente and Domenech (2000) and Cohen and Soto (2007).

available for later years. The most notable exclusion in my analysis due to this restriction is that of test scores. International standardized testing has only recently become widespread. In 1960, very few countries participated in these tests, so data is extremely limited. This omission of this variable is a concern because test scores to measure human capital has become increasingly popular. However, my analysis does include a measure of average IQ scores, which is a good alternative for international test score data.

The second constraint imposed on the data is the requirement of a balanced data set. This assures an equal number of observations (countries) for each possible regression. Making the data set balanced means dropping any observation that has missing data for any of the variables included in the analysis. Therefore, all countries included in the analysis have data for every explanatory variable (and dependent variable). Some variables with a large amount of missing data are omitted because they lower the sample size too much. Some of these human capital variables are repetition rates, measures of government spending, teacher salaries, and test scores. The balanced data set requirement causes the sample size of countries to be relatively low. There is a trade-off between the number of countries in the sample and the number and variety of independent variables included in the analysis.

The dependent variable is the typical measure of growth used in the literature—the annualized growth rate of real GDP per capita. This is the same measure used in SDM (2004) and measures the rate of economic growth from 1960 to 1996. The data originally comes from the Penn World Table Version 6.0 from Heston et al. (2001). Set 1 and Set 3 regressions include all of SDM's (2004) variables, while Set 2 includes the variables found significant. SDM's (2004) data set encompasses a wide variety of variables covering topics such as location, government, religion, language, education, and economy. See Table A1 of the appendix for the list and description of the SDM (2004) variables[69].

The new human capital data set includes an array of education related measures from multiple sources. I divide these into 3 categories–attainment and enrollment variables, input and policy variables, and outcome variables. The attainment and enrollment category includes two popular quantitative measures of schooling–educational attainment and school enrollment rates. Educational attainment is the measure of human capital used most often in the growth literature. It typically reflects the amount of education accumulated in a country's labor force, but ignores the

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[69]See SDM (2004) for more details about their data set.

quality of that education. The attainment measure compiled for this data set is the average years of schooling completed by a country's population aged 25 and older. There are separate variables for the male and female population and each level of education–total, primary, secondary, and higher. The attainment data is from the widely used data set from Barro and Lee (2000). SDM (2004) do not use any measures of educational attainment, but do include two enrollment measures–the primary education enrollment rate and the higher education enrollment rate. Enrollment rates give the percentage of the appropriate aged population enrolled in the corresponding level of schooling. Enrollment rates also ignore quality, and reflect only access to schooling, not the accumulation of education. Enrollment measures have become less popular in growth studies as new data and measures have been introduced. SDM (2004) exclude the enrollment rate in secondary education even though several important studies have found the variable to be important for growth[70]. My data set includes the secondary education enrollment rate from Sala-i-Martin (1997). See Table 14 for the list of attainment and enrollment variables included in the human capital data set. The table gives each variable's description, source, and summary statistics.

The input and policy category includes a variety of measures reflecting educational policies and resources devoted to schooling. The data set includes variables regarding government education spending, teacher salaries, pupil-teacher ratios, and time spent in school. Input and policy measures are typically used to represent the quality of education received in a country. They are thought to reflect government commitment to education. SDM (2004) include one measure of government education spending in their analysis. My human capital data set includes 14 of these measures compiled from UNESCO and Barro and Lee (2001). See Table 15 for a list of these variables along with the description, source, and summary statistics.

The last category of human capital variables includes schooling outcome measures. These are also often used to reflect a country's quality of education and are gaining popularity in the growth literature as more data becomes available. The recent literature is moving away from strictly quantitative measures of education to those that account for quality. In particular, test scores are now the most popular outcome measures. However, test score data is still limited both in terms of the number of countries and years covered. My human capital data set includes outcome measures such as repetition and drop-out rates, IQ scores, standardized test scores, and illiteracy rates. See Table 16 for details regarding these variables.

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[70]See, for example, Mankiw et al. (1992).

Human Capital Variable	Description and Source	Mean	Std. Dev.	Min.	Max.
Sec. Educ. Enroll. Rate	Enrollment rate in secondary educ. in 1960. Sala-i-Martin (1997).	0.21	0.21	0.00	0.86
Avg. Years Educ.	Avg. years of educ. in population aged 25+ in 1960. Barro and Lee (2000).	3.35	2.52	0.07	9.56
Avg. Years Prim. Educ.	Avg. years of primary educ. in population aged 25+ in 1960. Barro and Lee (2000).	2.60	1.85	0.05	7.32
Avg. Years Sec. Educ.	Avg. years of secondary educ. in population aged 25+ in 1960. Barro and Lee (2000).	0.66	0.82	0.01	4.59
Avg. Years High. Educ.	Avg. years of higher educ. in population aged 25+ in 1960. Barro and Lee (2000).	0.08	0.10	0.00	0.53
Female Avg. Years Educ.	Avg. years of educ. in female population aged 25+ in 1960. Barro and Lee (2000).	2.92	2.59	0.01	9.47
Female Avg. Years Prim. Educ.	Avg. years of educ. in female population aged 25+ in 1960. Barro and Lee (2000).	2.31	1.96	0.01	7.33
Female Avg. Years Sec. Educ.	Avg. years of secondary educ. in female population aged 25+ in 1960. Barro and Lee (2000).	0.55	0.75	0.00	3.93
Female Avg. Years High. Educ.	Avg. years of higher educ. in female population aged 25+ in 1960. Barro and Lee (2000).	0.05	0.09	0.00	0.49
Male Avg. Years Educ.	Avg. years of educ. in male population aged 25+ in 1960. Barro and Lee (2000).	3.78	2.54	0.14	9.65
Male Avg. Years Prim. Educ.	Avg. years of primary educ. in male population aged 25+ in 1960. Barro and Lee (2000).	2.88	1.80	0.08	7.30
Male Avg. Years Sec. Educ.	Avg. years of secondary educ. in male population aged 25+ in 1960. Barro and Lee (2000).	0.78	0.95	0.02	5.48
Male Avg. Years High. Educ.	Avg. years of higher educ. in male population aged 25+ in 1960. Barro and Lee (2000).	0.10	0.12	0.00	0.60

Table 14: Attainment and Enrollment Human Capital Variables.

Human Capital Variable	Description and Source	Mean	Std. Dev.	Min.	Max.
Prim. Educ. PT Ratio	Pupil-teacher ratio in primary educ. in 1960. Barro and Lee (2001).	36.90	11.05	18.60	95.30
Sec. Educ. PT Ratio	Pupil-teacher ratio in secondary education in 1960. Barro and Lee (2001).	19.13	6.03	6.60	34.30
Govt. Prim. Educ. Spend.	Real govt. current primary educ. spending per pupil in 1965. Barro and Lee (2001).	377.16	504.23	33.00	3,241.00
Govt. Sec. Educ. Spend.	Real govt. secondary educ. spending per pupil in 1965. Barro and Lee (2001).	826.19	623.06	47.00	2,852.00
Govt. Prim. Educ. Spend. to GDP	Ratio of govt. primary educ. spending to real GDP per capita in 1965. Barro and Lee (2001).	13.35	7.07	4.00	33.50
Govt. Sec. Educ. Spend. to GDP	Ratio of govt. secondary educ. spending to real GDP per capita in 1965. Barro and Lee (2001).	61.67	79.16	3.80	364.50
Prim. Educ. Days	Number of school days per year in primary educ. in 1960. Barro and Lee (2001).	197.48	16.18	135.00	240.00
Prim. Educ. Hours	Number of school hours per year in primary educ. in 1960. Barro and Lee (2001).	983.47	156.43	589.00	1,600.00
Prim. Educ. Avg. Teacher Sal.	Avg. real salary of primary educ. teachers in 1965. Barro and Lee (2001).	8,584.62	7,398.59	810.00	4,7391.00
Prim. Educ. Avg. Teacher Sal. to GDP	Avg. real salary of primary educ. teachers to GDP in 1965. Barro and Lee (2001).	425.04	312.57	54.00	1,948.00
Prim. Educ. Entrance Age	Primary educ. entrance age in 1970. UNESCO.	6.17	0.63	5.00	7.00
Prim. Educ. Duration	Primary educ. duration in 1970. UNESCO.	5.96	0.72	4.00	8.00
Sec. Educ. Entrance Age	Secondary educ. entrance age in 1970. UNESCO.	12.19	0.97	10.00	14.00
Sec. Educ. Duration	Secondary educ. duration in 1970. UNESCO.	6.19	0.89	4.00	9.00

Table 15: Input and Policy Human Capital Variables.

Human Capital Variable	Description and Source	Mean	Std. Dev.	Min.	Max.
Prim. Educ. Rep. Rate	Repetition rate of primary educ. in 1965. Barro and Lee (2001).	11.49	9.10	0.00	29.00
Sec. Educ. Rep. Rate	Repetition rate of secondary educ. in 1970. Barro and Lee (2001).	10.00	6.53	0.00	30.00
Prim. Educ. Drop Rate	Drop-out rate of primary educ. in 1970. Barro and Lee (2001).	29.35	25.39	0.00	92.00
IQ	National avg. IQ from 1910 to 1990's. Lynn and Vanhanen (2002).	83.28	11.95	63.00	107.00
Test Scores	Avg. test scores in math and science for primary to secondary educ. Hanushek and Woessmann (2009).	4.51	0.60	3.09	5.45
Illiteracy Rate	Illiteracy rate in 1970 of population aged 15+. UNESCO.	48.83	27.58	1.80	94.25
Male Illiteracy Rate	Illiteracy rate in 1970 of male population aged 15+. UNESCO.	40.58	25.30	1.18	89.45
Female Illiteracy Rate	Illiteracy rate in 1970 of female population aged 15+. UNESCO.	57.09	30.72	2.28	98.77

Table 16: Schooling Outcome Human Capital Variables.

Three sets of regressions are examined in this analysis. The first includes all SDM (2004) variables along with the additional human capital variables. The second set includes only the variables SDM (2004) found significant and the human capital variables. The data set for the first set of regressions has a total of 92 variables. The sample size for this set of regressions is 50 countries. The data set for the second set of regressions has 45 variables and a sample size of 51 countries. The balanced data set requirement is the main reason for the relatively small sample of countries examined in these sets of regressions. Countries with missing data for any of the variables are dropped, which led to the exclusion of about 90 countries. The majority of countries remaining in these samples are considered developing or emerging as opposed to advanced[71]. Eighty-four percent and 82% of the countries included in Set 1 and Set 2 respectively are classified as developing or emerging. The list of countries for each data set are similar and can be seen in Table A2 of the appendix. The composition of the sample of countries should certainly be considered when evaluating the results. In follow-up work, it would be useful to fill in missing data so the analysis could examine a more complete and representative sample of countries.

The third set of regressions examines each additional human capital variable individually. Each is added separately to the full set of SDM (2004) variables. Therefore, 35 sets of regressions are run–one for each new human capital variable. The sample of countries differs by the human capital variable added. Again, each set of regressions includes only the countries for which data is available for all variables. The sample sizes for these sets of regressions are notably larger than Set 1 and 2 since their are fewer explanatory variables. The number of countries examined in each set of regressions is shown in Table 19 in the Results section. The sample of all possible countries includes 139 countries of which 98 (71.5%) are considered developing or emerging. The list of all possible countries is shown in Table A3 of the appendix. Each set of regressions in Set 3 includes a sub-sample of these countries.

18 Methodology

The goal of this paper is to find which human capital variables are robustly significant for cross-country economic growth. As discussed above, model specification uncertainty exists in empirical studies of growth because the number of possible explanatory variables exceeds the number of

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[71]This based on classifications by the IMF. The IMF divides countries into two major groups: advanced or emerging and developing. The main criteria for the classification are income per capita, export diversification, and degree of integration into the global financial system.

countries. I use SDM's (2004) BACE approach to address this problem. The BACE methodology acknowledges and integrates model uncertainty into the framework.

As the name implies, BACE is a blend of Bayesian and classical estimation techniques. More specifically, BACE combines the Bayesian concept of averaging across models with classical OLS estimation. In contrast to the classical approach which conditions on one "true" model, BACE does not declare a single model as correct. Instead, BACE gives probabilities for the different possible models.

The methodology below is restated from SDM (2004). BACE is a form of Bayesian Model Averaging, which is a framework based around model uncertainty. Bayesian approaches are an extension of Baye's Rule, which is given by

$$g(\beta \mid y) = \frac{f(y \mid \beta)g(\beta)}{f(y)} \tag{29}$$

where $g(\beta \mid y)$ is the posterior density of β, $f(y \mid \beta)$ is the likelihood function summarizing the information about β contained in the data, $g(\beta)$ is the prior density of β, and $f(y)$ is the prior density of the data.

Baye's Rule illustrates how probabilities are updated with additional information. Bayesian Model Averaging is a special case of Baye's Rule researchers use when faced with model uncertainty. The Bayesian Model Averaging approach requires attaching a prior probability to each possible model that reflects the researcher's beliefs before seeing the data about the model being true. Next, regressions are run for each possible model. Finally, the probabilities of a model being true are updated using some function of each regression's summary statistics.

A first step in deriving the BACE method is to rewrite Baye's Rule in terms of posterior probabilities for the alternative models. Following Bryant and Davis (2008), the posterior probability for the jth model is given as

$$P(M_j, y) = \frac{P(M_j)P(y \mid M_j)}{\sum\limits_{i=1}^{N} P(M_i)P(y \mid M_i)} \tag{30}$$

where

$$P(y \mid M_i) = \int L(y, \theta_i)P(\theta_i, M_i)d\theta_i \tag{31}$$

where $\theta_i = k_i$ is the parameter vector associated with model M_i, $P(\theta_i, M_i)$ is the prior density function for θ_i under M_i, $L(y, \theta_i)$ is the likelihood function for M_i, and $P(M_i)$ is the prior probability of M_i.

Equation (30) gives the probability of model j being the true model relative to all other possible models. Equation (31) will be analytically intractable, so SDM (2004) uses Schwarz's (1978) approximation. In log form this is

$$\log P(y \mid M_i) = \log L(y, \widehat{\theta}_i) - 0.5 k_i \log T \tag{32}$$

where the right hand side is the Bayesian Information Criterion (BIC), $L(y, \widehat{\theta}_i)$ is the estimated log-likelihood function for model M_i, and T is the number of observations. When the model is estimated by OLS, $\log L(y, \widehat{\theta}_i)$ becomes $-0.5 T \log SSE_i$, where SSE_i is the sum of squared errors for model i. This gives

$$\log P(y \mid M_i) = -0.5 T \log SSE_i - 0.5 k_i \log T. \tag{33}$$

As shown in Bryant and Davis (2008), exponentiating Equation (33) and plugging the result into Equation (30) gives

$$P(M_j, y) = \frac{P(M_j) T^{\frac{-k_j}{2}} SSE_j^{\frac{-T}{2}}}{\sum\limits_{i=1}^{2^K} P(M_i) T^{\frac{-k_i}{2}} SSE_i^{\frac{-T}{2}}} \tag{34}$$

where y is the observed data, T is the sample size (number of countries), K is the number of possible regressors, k_j is the number of regressors included in model j, and $P(M_j)$ is the prior probability of model j being true. Equation (34) gives the posterior probability of each model, which is a weighted likelihood formula where the weight of a given model is normalized by the sum of the weights of all possible models. This measure reflects the contribution of the variable to the goodness-of-fit of a model. The posterior inclusion probability gives the probability that the variable is included in the true model (has a nonzero coefficient).

Prior probabilities, $P(M_j)$'s, need to be specified for each model. These reflect the researcher's belief about the probability that the model is correct. The main difficulty in the standard Bayesian approach, and the reason it has not gained widespread popularity, lies in the specification of prior probabilities. Bayesian Model Averaging requires giving a prior distribution to all variables for each possible model. So, as the number of explanatory variables increases, specifying priors becomes more cumbersome. Due to the complexity of this task, many researchers apply prior information that is essentially arbitrary. A major advantage of BACE is that it avoids this problem by assuming diffuse priors for the explanatory variables. This assumption implies that the researcher has no prior beliefs about the probability of a variable being included in the "true" model. This is where BACE

connects to classical estimation—OLS is based on the assumption of diffuse priors. Furthermore, diffuse priors reduce the effect of a researcher's prior information, which as just mentioned, is often arbitrary anyway. In contrast to fully Bayesian methods that require priors for all variables, BACE requires only one prior for mean model size, $\overline{k}$. SDM (2004) refer to this as the "hyperparameter". I will follow SDM (2004) and set the prior mean model size to seven, $\overline{k} = 7$. This reflects the belief that models include an average of seven regressors. So, it follows that each explanatory variable has a prior probability of $\frac{\overline{k}}{K}$ of being included, independent of the inclusion of other variables. K is the total number of possible regressors.

With such a large number of explanatory variables, running every possible regression is not feasible. Therefore, only a random sample of regressions for the possible models is run. Models are selected by randomly including each variable with an independent sampling probability of $P_s(\beta_i)$. The larger the number of random draws, the closer the posterior inclusion probability, mean, and variance will be to their true values.

BACE takes into account estimates from all possible models, and a weighted average of regression coefficients across all these models is generated. The posterior probability of each model, given by Equation (34), gives the weights for the different models. Following SDM (2004), the weighted average of each variable's coefficient estimates are calculated with the OLS regression estimates weighted by the posterior model probabilities. This is given as the expected value of β_j conditional on inclusion in the model, or the posterior mean of the variable

$$E(\beta \mid y) = \sum_{j=1}^{2^K} P(M_j, y)\widehat{\beta}_j \tag{35}$$

where $\widehat{\beta}_j$ is the OLS estimate of β_j. The OLS estimate of β_j is written as

$$\widehat{\beta}_j = E(\beta \mid y, M_j). \tag{36}$$

The variance of β_j is also calculated. The posterior variance of the coefficient estimates is the sum of the variance within a model and the variance between the different models. The square root of the posterior variance is the standard deviation reported in the results section . The posterior variance is computed as

$$var(\beta \mid y) = \sum_{j=1}^{2^K} P(M_j, y)var(\beta \mid y, M_j) + \sum_{j=1}^{2^K} P(M_j, y)(\widehat{\beta}_j - E(\beta \mid y))^2. \tag{37}$$

The BACE results give the posterior mean and standard deviations conditional on the variable being included in the true model along with the unconditional mean and standard deviation. The unconditional mean is the weighted average of OLS estimates for all models including those that do not include the variable (zero coefficient)[72].

As mentioned in Section 2, there are 3 sets of regressions run using the BACE method outlined above. Set 1 includes all of the variables included in SDM (2004) along with the additional human capital variables. Set 2 includes only the variables found to be significant by SDM (2004) in addition to the human capital variables. Set 3 examines each additional human capital variable individually by adding each one separately to the full set of SDM (2004) variables.

18.1   Significance Criteria

The goal when using the BACE method is to determine which of the many possible explanatory variables are significantly related to economic growth. This analysis focuses on using the BACE approach to find which human capital variables are important. Following SDM (2004), the posterior inclusion probability of a variable is compared to the prior model probability to determine whether or not the variable has a significant relationship with growth. Variables that are declared robustly significant have a posterior inclusion probability that is greater than its prior probability. This indicates that the variable has a higher probability of being included in the true model after the prior probability is updated with the data. In other words, the belief that the variable belongs in the model is stronger after seeing the data. A high posterior probability reflects that models including the variable perform better than those without the variable. A posterior inclusion probability that is less than the prior probability indicates that there is little or no support for including the variable in a growth model.

19   Results

The results of the two sets of regressions are reported separately in Table 17, Table 18, and in the appendix. The tables give the results in rank order based on the variable's posterior inclusion probability. The expected mean and standard deviation of the variable's coefficient conditional on inclusion in the true model are given as well. A variable is considered significant for growth if the posterior inclusion probability is greater than the prior inclusion probability. An asterisk indicates

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[72]The unconditional mean and standard deviation are not reported in this paper.

that it is a human capital variable added for this analysis.

19.1   Set 1 Results

The first set of results, shown in Table 17 and Table A4 of the appendix, is for the set of regressions run with the data set including all of SDM's (2004) and the additional human capital variables. The prior probability of a variable being included in the true model for this set of variables is equal to 0.076[73]. Variables considered significant for growth have posterior inclusion probabilities greater than 0.076. When interpreting the results, it is important to consider the high proportion of developing countries in the sample.

The BACE results show that 23 variables are robustly significant for growth. Of these variables, 5 are from the additional human capital data set and 18 are from the SDM (2004) data set. The higher education enrollment rate is the only SDM (2004) human capital variable that I find to be significant. SDM's (2004) analysis shows that the primary education enrollment rate is the only significant education variable, whereas my analysis shows this variable to be insignificant[74].

The most significant variables according to posterior inclusion probabilities are GDP in 1960, IQ, the fraction of GDP in mining, real exchange rate distortions, and life expectancy. All of these except IQ, which I added, are found to be at least marginally significant in SDM (2004). However, my study finds none of SDM's (2004) top 3 variables to be significant[75]. Overall, there are four variables that both SDM (2004) and I find to be robustly significant for growth. I also consider 8 variables to be marginally significant[76]. Out of these variables, 2 are from the additional human capital data set and 3 are variables found significant by SDM (2004).

Of the variables shown to be significant or marginally significant, there are 4 from the attainment and enrollment category, 2 from the input and policy category, and just one from the outcome category. All of the significant and marginally significant variables are shown in Table 17, and the insignificant variables are listed in Table A4 of the appendix. Each significant or marginally significant human capital variable is described below[77].

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[73]The prior probability is equal to $\frac{\bar{k}}{K}$, which is equal to 7/92.

[74]SDM (2004) find the higher education enrollment rate and government education spending to be insignificant for growth.

[75]SDM's (2004) top three variables are East Asian dummy, primary education enrollment rate, and investment price.

[76]Variables are considered marginally significant if the posterior inclusion probability is greater than 0.060.

[77]See SDM (2004) for a discussion of the variables used in their analysis.

Rank	Variable	Post. Incl. Prob.	Cond. Post. Mean	Cond. Post. Std. Dev.
1	GDP in 1960 (log)	0.972	-0.018882	0.005719
2	IQ*	0.968	0.001272	0.000384
3	Fraction GDP in Mining	0.728	0.047400	0.034902
4	Real Exch. Rate Distortions	0.605	-0.000083	0.000076
5	Life Expectancy	0.603	0.000633	0.000585
6	Govt. Share of GDP	0.290	-0.017673	0.030522
7	Govt. Cons. Share of GDP	0.266	-0.014095	0.026859
8	Sec. Educ. Duration*	0.189	0.001406	0.003301
9	Public Investment Share	0.171	-0.011761	0.033792
10	Higher Educ. Enroll. Rate	0.142	-0.020845	0.057780
11	Nom. Govt. Share of GDP	0.142	-0.008278	0.022727
12	Female Avg. Years High. Educ.*	0.116	-0.009479	0.030997
13	Political Rights	0.116	-0.000436	0.001376
14	Landlocked Country Dummy	0.112	-0.001232	0.003887
15	Fraction Catholic	0.099	-0.000989	0.003442
16	Fraction Pop. Less than 15	0.099	0.008049	0.028027
17	Fraction Pop. in Tropics	0.095	-0.001098	0.003912
18	Religious Intensity	0.094	-0.001730	0.006128
19	Hydrocarbon Deposits	0.087	0.000086	0.000322
20	Avg. Years Prim. Educ.*	0.083	0.000627	0.011336
21	Civil Liberties	0.082	-0.001203	0.004654
22	English Speaking Pop.	0.082	0.001761	0.006888
23	Prim. Educ. Duration*	0.080	0.000754	0.002994
24	Avg. Years of Educ.*	0.075	0.000212	0.011066
25	Fraction Pop. Over 65	0.074	-0.019260	0.081965
26	Male Avg. Years Prim. Educ.*	0.072	0.000392	0.005481
27	Fraction of Tropical Area	0.072	-0.000580	0.002546
28	Fraction Muslim	0.072	0.000776	0.003367
29	Fraction Hindu	0.065	0.001493	0.006689
30	African Dummy	0.062	-0.000839	0.003944
31	Pop.	0.061	0.000000	0.000000

Table 17: Set 1 Significant and Marginally Significant Variables.

19.1.1 Significant Human Capital Variables

IQ: The IQ score data is from Lynn and Vanhanen (2002). Their IQ measure is a country's national average IQ score over the twentieth century with most scores from the 1950's to 1990. I include this measure as an alternative to international standardized test scores which are excluded due to limited data. The IQ measure is positively correlated with data from the two most popular test score data sets–Barro and Lee (2001) and Hanushek and Kimko (2000)–indicating that IQ and other tests measure similar skills. It is important to include the IQ measure even though it is not strictly a 1960 measure. The current human capital literature stresses the need to account for differences in the quality of education received across countries. Most agree that measures of cognitive ability, namely standardized tests, are the best indicators of education quality[78]. Test scores also have an advantage over other measures by reflecting not just the effects of formal education but also that of family, peers, and environment.   As such, my analysis would be incomplete without a measure of cognitive skill.

The sample of countries in this set of regressions has an average IQ score of 83.4 with a minimum score of 64 and a maximum score of 105. IQ has the highest posterior inclusion probability of all the human capital variables and ranks second overall. The high posterior inclusion probability of 0.968 indicates that IQ has a large marginal contribution to the regression model's goodness-of-fit. The positive posterior conditional mean suggests that higher IQ scores are related to higher economic growth. This positive relationship could signal that schooling quality is important for growth. In addition, the positive significance might reflect that individuals with higher IQ scores are more productive or contribute more to innovation and technology. Jones and Schneider (2006) examine the importance of IQ scores for economic growth using the BACE framework and also find a robustly positive significant relationship.

Secondary Education Duration: The secondary education duration data comes from UNESCO's Institute for Statistics. It gives the duration of compulsory general secondary education in years according to regulations in place in each country in 1970. Most countries distinguish between two levels of secondary schooling–lower and upper. Some amount of lower secondary education is compulsory in most countries, but upper secondary education is often not required. The secondary education duration measure reflects the number of years required in both lower and upper secondary

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[78]See, for example, Hanushek and Kimko (2000).

schooling.

Secondary education duration is the second most significant human capital variable and ranks eighth overall. Countries in this sample require an average of 5.98 years of secondary education with a minimum of 4 years and a maximum of 8 years. The posterior inclusion probability is 0.189 indicating that there is an 18.9% chance that secondary education duration is included in the true model. The posterior conditional mean is positive, which suggests that the more years of secondary education required, the faster a country's economic growth. The positive significance of this variable reflects the importance of time spent in school. Higher years of compulsory education also reflect a greater commitment to education by a country's government. Government commitment to education will most likely translate into other areas of education such as quality. Furthermore, a longer length of required secondary education could reflect the goal of better preparing students for the labor market.

Higher Education Enrollment Rate: The higher education enrollment rate in 1960 is the only SDM (2004) variable related to human capital that I find robustly significant for growth. The sampled countries have an average higher education enrollment rate of 0.027 with a minimum of 0 and a maximum of 0.13. This variable ranks tenth overall with a posterior inclusion probability of 0.142. The posterior conditional mean is negative, which is somewhat unexpected. There are several possible explanations for the negative relationship shown between enrollment levels in higher education and growth. First, many students enrolled in higher education will not complete their education, so high enrollment rates do not necessarily translate into a more educated and productive labor force. Second, as suggested by Mamuneas et al. (2006), structural obstacles exist (particularly in developing countries) that can prevent the educated labor force from being efficiently employed. Much of the human capital gained from higher education requires complementary technologies that are scarce in many countries. This can lead to an unproductive use of educated labor. The third explanation expands on this idea. Kalaitzidakis et al. (2001) discuss evidence that higher levels of education in some countries, particularly those with lower incomes, may be used for rent-seeking activities or in the illegal economy. These explanations are especially relevant considering the large number of developing countries examined in the analysis.

Female Average Years of Higher Education: The data for female average years of higher education is from the widely used Barro and Lee (2000) data set. The measure reflects the average

years of higher education attained by the female population aged 25 and older in 1960. This is the fourth most significant human capital related variable and ranks twelfth out of all variables. The average years of higher education for females in the sample countries is 0.029, the minimum years is 0, and the maximum is 0.222. The posterior inclusion probability is 0.116, and the average coefficient across models is negative. This negative relationship between female average years of higher education and growth is again somewhat unexpected, but the finding is not uncommon[79].

There are still clear disparities between males and females in terms of education and labor market experiences. The negative coefficient indicates that highly educated women are not being used efficiently in the labor force. There are several possible explanations for this inefficiency. First, as suggested by Barro (2001), women might face discrimination that prevents them from holding productive positions. Second, women are still mostly responsible for childcare and housework, which can also prevent them from holding productive jobs or working as many hours as their male counterparts. Finally, this result could again be a reflection of the inefficient use of higher education in developing countries.

Average Years of Primary Education: This variable is a measure of average years of primary education attained by a country's total population aged 25 and older in 1960 and is also from the Barro and Lee (2000) data set. The measure is calculated using the percentage of the adult population that completed primary education along with the duration of primary education. This is one of the most popular measures of a country's human capital.

Universal primary education is a goal in all countries and has been reached in most developed countries. Therefore, years of primary education mainly reflects differences in less developed countries. For the countries in this set of regressions, the average years of primary education is 2.107, the minimum is 0.191, and the maximum is 5.471. Average years of primary education ranks twentieth overall with a posterior inclusion probability of 0.083. The posterior conditional mean is positive reflecting the importance of primary education for growth. In particular, the more years of basic education a country's population receives, the faster its economic growth. More years of primary education could be important for growth for several reasons. As students complete more years of primary education, they are more likely to continue on to secondary education and therefore gain more human capital. Also, primary education provides a foundation of education that can make subsequent schooling more productive. This concept of complementarity between

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[79]See, for example, Kalaitzidakis et al. (2001) and Barro (2001).

levels of education is discussed in Cunha et al. (2006).

Primary Education Duration: Primary education duration is the number of years of compulsory primary schooling based on regulations in each country in 1970. The number of years of primary education required signals the importance placed on basic education by a country's government. These lengths have expanded as countries continue to strive for universal primary education.

The average duration of primary education for countries in this set of regressions is 6.06 with a minimum of 5.0 and maximum of 8.0. Primary education duration is the last variable considered to be robustly significant for growth in this set of results. The posterior inclusion probability is 0.080. The positive posterior conditional mean again reflects the importance of primary education for economic growth. A longer duration of primary school required could positively impact growth because of the stronger government commitment it reflects and the higher level of human capital it leads to.

19.1.2 Marginally Significant Human Capital Variables

Average Years of Education: Average years of education is again from Barro and Lee's (2000) popular data set. It is a measure of total education attained at all levels of education (primary, secondary, and higher) of the total population aged 25 and older in 1960. It is a quantitative measure of education reflecting the average number of years of schooling completed by the labor force. As with the other quantitative measures discussed so far, average years of education does not account for differences in quality of schooling across countries.

The average years of education for countries in the sample is 2.534, the minimum number of years is 0.203, and the maximum is 6.988. The posterior inclusion probability ranks 24th at 0.075, which barely misses the cutoff for significance of 0.076. The average coefficient is positive, which implies that a more educated labor force leads to higher economic growth. This finding reinforces the importance of education in general.

Male Average Years of Primary Education: The average years of primary education measure is from Barro and Lee (2000). Like the other attainment measures, data for years of male primary education comes from national census and survey data. This measure gives the average years of primary schooling attained by the male population aged 25 and older. The average for the countries in this set of regressions is 2.443 with a minimum of 0.309 and a maximum of 6.059. The

posterior inclusion probability is 0.073, and the posterior conditional mean is positive. This again reflects the importance of primary education for growth. The positive effect of male education in particular could again reflect the gender disparity in the labor market as discussed earlier.

19.2   Set 2 Results

The second set of results, shown in Table 18 and Table A5 of the appendix, is for the regressions run with the data set including only SDM's (2004) significant variables and the additional human capital variables. The prior probability of a variable being included in the true model for this set of variables is equal to 0.156[80]. This larger prior reflects the increase in probability due to the smaller number of possible explanatory variables in this set of regressions. Variables that are considered robustly significant for growth have posterior inclusion probabilities greater than 0.156. It is again important to take into account the high percentage of developing or emerging countries included in the sample of countries.

The BACE results show that 9 variables are significant for growth. Of these, 2 are from the additional human capital data set. Of the 7 SDM (2004) variables found significant, none are related to human capital. The top 4 variables based on posterior inclusion probability are GDP in 1960, IQ, life expectancy, and fraction of GDP in mining. IQ is the most important human capital variable in both Set 1 and Set 2. I also consider 4 variables to be marginally significant for growth[81]. Of these variables, 2 are from the additional human capital data set.

Of the variables shown to be significant or marginally significant, there are 2 from the attainment and enrollment category, one from the input and policy category, and one from the outcome category. The significant and marginally significant variables are shown in Table 18, and each human capital variable is described below[82]. The variables found to be insignificant are listed in Table A5 of the appendix.

19.2.1   Significant Human Capital Variables

IQ: As with the first set of regressions, IQ is the highest ranking human capital variable in terms of posterior probability and second in rank overall. See the discussion above for details regarding this IQ measure. In this set of regressions, the sampled countries have an average IQ score of 84.1, a minimum score of 64, and a maximum score of 107. The posterior inclusion probability

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[80]The prior probability is $\frac{\bar{k}}{K}$, which is equal to 7/45.

[81]Variables are marginally significant if the posterior inclusion probability is greater than 0.10.

[82]See SDM (2004) for a discussion of the variables used in their analysis.

Rank	Variable	Post. Incl. Prob.	Cond. Post. Mean	Cond. Post. Std. Dev.
1	GDP in 1960 (log)	0.954	-0.019283	0.006522
2	IQ*	0.890	0.001180	0.000522
3	Life Expectancy	0.826	0.001010	0.000566
4	Fraction of GDP in Mining	0.712	0.040106	0.030300
5	East Asian Dummy	0.246	0.003932	0.008195
6	Female Avg. Years High. Educ.*	0.227	-0.019297	0.047764
7	Govt. Cons. Share of GDP	0.205	-0.009348	0.021179
8	African Dummy	0.205	-0.002865	0.006713
9	Fraction Muslim	0.163	0.001926	0.005221
10	Prim. Educ. Entrance Age*	0.128	-0.000702	0.002190
11	Investment Price	0.121	-0.016398	0.052926
12	Spanish Colony	0.111	-0.000865	0.003024
13	Avg. Years High. Educ.*	0.109	-0.007160	0.052417

Table 18: Set 2 Significant and Marginally Significant Variables.

is 0.890, which again suggests that models including IQ perform much better than models without IQ. The average coefficient across models is positive as expected, indicating a higher average IQ score contributes to higher economic growth.

Female Average Years of Higher Education: In line with the first set of results, female average years of higher education is found to be robustly related to growth. The average years of female higher education for countries in this sample is 0.030 with a minimum of 0 and a maximum of 0.222. The posterior inclusion probability is 0.227, and the average coefficient is again negative. Refer to the Set 1 Results section for a discussion of the measure and an interpretation of the similar results.

19.2.2 Marginally Significant Human Capital Variables

Primary Education Entrance Age: Primary education entrance age is the average entrance age into primary school in 1970. This data was collected from UNESCO's Institute for Statistics. The average age for the countries in the sample is 6.235 with a minimum age of 5 and maximum age of 7. This variable ranks tenth with a posterior probability of 0.128. The posterior conditional mean is negative, which implies that the lower the entrance age the better for economic growth. This again reflects the importance of primary education and the early years in particular. Recently there has been a surge in research stressing the importance of a child's early years for learning. For example, most research shows that IQ is essentially set by the age of 10 and is therefore most

impressionable before that time[83]. Furthermore, it is likely that if a student starts schooling at an earlier age they will ultimately receive more years of education.

Average Years of Higher Education: This attainment measure again comes from Barro and Lee (2000) and is computed from the percentage of the total population aged 25 and older that has completed higher education and the duration of higher education. The measure reflects the average number of years of higher education attained by the total adult population in 1960. The sample countries average 0.049 years with a minimum of 0 years and a maximum of 0.291 years.

The posterior inclusion probability for average years of higher education is 0.109 and its overall ranking is 13th. The average coefficient across regressions is negative, which is somewhat surprising but not unheard of in the literature[84]. This negative relationship with economic growth indicates that additional education is not being put to good use. As discussed earlier with the relationship between female higher education and growth, there is evidence from some countries that higher levels of education is used for rent-seeking activities or in other unproductive ways. Furthermore, many low income countries lack the technology to accommodate highly educated workers. In developing countries, it is not uncommon for individuals with high levels of education to be unemployed or working in the underground economy.

19.3 Set 3 Individual Results

Multicollinearity is a concern that is often raised when a large number of variables that are possibly related are analyzed at once. It is likely that some of the human capital variables are correlated with each other. This could cause these variables to show an insignificant effect when they are actually important for growth. To account for this issue, each human capital variable is added separately to SDM's (2004) original data set. Set 3 is comprised of individual sets of regressions for each human capital variable. Thirty-five sets of regressions are run–one set for each new human capital variable. A variable is considered significant for growth if its posterior probability is greater than 0.103[85].

The BACE results show that 5 additional human capital variables are significant for economic growth in their individual sets of regressions–government secondary education spending, IQ, test scores, primary education teacher salaries, and government secondary education spending to GDP.

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[83]See, for example, discussions in Jensen (1980) and Cunha et al. (2006).
[84]See, for example, Kalaitzidakis et al. (2001).
[85]The prior probability is $\frac{k}{K}$, which is equal to 7/68.

I also find 5 additional human capital variables to be marginally significant–secondary education repetition rate, female illiteracy rate, total illiteracy rate, primary education teacher salary to GDP, and female average years of primary education[86]. These results show that only one variable in the education and attainment category is significant or marginally significant, while there are 4 from the input and policy category, and 5 from the outcome category. The primary education enrollment rate is the only human capital related variable found significant by SDM (2004). This measure tends to remain significant as an additional human capital variable is added to the set of regressions. The primary enrollment rate is significant for growth in 19 out of the 35 individual sets of regressions and marginally significant in another 8 sets.

The results from the individual regressions in Set 3 are quite different from Set 1 and Set 2 results. The only similar result is that all three sets of regressions find IQ to have the highest significance of all the human capital variables. One reason for the differing results for Set 3 is the inclusion of variables that were excluded from Set 1 and Set 2 due to missing observations. These include the spending and salary variables as well as the repetition rates. Table 19 shows the human capital variables in rank order by posterior inclusion probability for their individual sets of regressions. The significant and marginally significant variables are described below.

19.3.1 Significant Human Capital Variables

Government Secondary Education Spending: This spending variable is from Barro and Lee's (2001) popular data set and measures government expenditures per student in secondary education in 1960. This measure was excluded from the previous sets of regressions because missing values caused the sample size of countries to be too low to analyze. The total sample of countries for the individual set of regressions averages $826.20 per student with a minimum of $47.00 and a maximum of $2,852.00. The individual BACE results show that this is the most important human capital variable. The high posterior inclusion probability of 0.495 indicates that there is a 50% chance that secondary government spending is in the true growth model.

The average regression coefficient for this spending measure is negative, which suggests a that increases in secondary government spending decreases growth. This negative relationship is not uncommon in the growth literature where findings are mixed regarding the impact of education spending on growth[87]. Education spending is typically used to reflect the quality of schooling in

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[86]Variables are considered marginally significant if the posterior inclusion probability is greater than 0.07.

[87]For example, Hanushek and Kimko (2000) find an insignificant negative relationship between education spending

Rank	Human Capital Variable	Post. Incl. Prob.	Cond. Post. Mean	Cond. Post. Std. Dev.	Coun- tries
1	Govt. Sec. Educ. Spend.	0.495	-0.000007	0.000003	69
2	IQ	0.460	0.000990	0.000307	88
3	Test Scores	0.322	0.009629	0.004606	47
4	Prim. Educ. Avg. Teacher Sal.	0.119	-0.000001	0.000000	70
5	Govt. Sec. Educ. Spend. to GDP	0.105	-0.000045	0.000024	68
6	Sec. Educ. Rep. Rate	0.082	0.000445	0.000307	46
7	Female Illiteracy Rate	0.077	-0.000214	0.000152	70
8	Illiteracy Rate	0.074	-0.000284	0.000184	70
9	Prim. Educ. Avg. Teacher Sal. to GDP	0.072	-0.000009	0.000006	69
10	Female Avg. Years Prim. Educ.	0.072	-0.002281	0.001339	75
11	Govt. Prim. Educ. Spend. to GDP	0.055	-0.000349	0.000273	75
12	Male Illiteracy Rate	0.050	-0.000218	0.000171	70
13	Sec. Educ. Enroll. Rate	0.041	-0.018371	0.014249	86
14	Avg. Years Prim. Educ.	0.035	-0.001780	0.001445	75
15	Prim. Educ. Hours	0.029	-0.000006	0.000008	55
16	Female Avg. Years Educ.	0.028	-0.001095	0.001064	75
17	Govt. Prim. Educ. Spend.	0.024	-0.000004	0.000005	75
18	Male Avg. Years Sec. Educ.	0.022	0.001391	0.001573	79
19	Female Avg. Years High. Educ.	0.022	-0.014162	0.015845	80
20	Sec. Educ. Duration	0.021	0.001205	0.001651	85
21	Prim. Educ. Duration	0.021	0.000671	0.002873	84
22	Male Avg. Years Prim. Educ.	0.020	-0.000964	0.001417	75
23	Sec. Educ. PT Ratio	0.020	-0.000169	0.000223	85
24	Sec. Educ. Entrance Age	0.019	-0.000342	0.001958	85
25	Prim. Educ. PT Ratio	0.019	-0.000102	0.000165	87
26	Avg. Years Sec. Educ.	0.018	0.001371	0.001976	79
27	Avg. Years Educ.	0.018	-0.000508	0.001109	75
28	Prim. Educ. Days	0.017	-0.000059	0.000084	88
29	Prim. Educ. Drop Rate	0.017	0.000000	0.000088	81
30	Prim. Educ. Rep. Rate	0.016	0.000033	0.000130	55
31	Avg. Years High. Educ.	0.016	-0.008025	0.015481	80
32	Female Avg. Years Sec. Educ.	0.016	0.000646	0.002396	79
33	Prim. Educ. Entrance Age	0.015	0.000222	0.002527	84
34	Male Avg. Years Educ.	0.015	0.000058	0.000996	75
35	Male Avg. Years High. Educ.	0.015	-0.001415	0.014039	80

Table 19: Individual Results.

a country. While the measure reflects the amount of resources devoted to education, it does not reflect how efficiently these resources are used. The negative coefficient suggests that spending at the secondary level is not being spent in an efficient way.

IQ: All three sets of regressions show that it is important to include IQ in a growth model. As discussed above, Lynn and Vanhanen's (2202) measure gives a country's national average IQ score. The sample of countries has an average IQ score of 82.28 with a minimum score of 63 and a maximum score of 107. IQ ranks second among the human capital variables in the individual regressions with a posterior inclusion probability 0.460. This high posterior inclusion probability suggests that IQ has a large marginal contribution to the regression model's goodness-of-fit. The posterior conditional mean is positive, indicating that increases in IQ scores can increase economic growth. This supports the work of Jones and Schneider (2006) who also find a significant positive relationship between IQ and growth using the BACE framework.

Test scores: International standardized test scores are becoming a popular proxy for human capital as more data becomes available. Many feel that these scores are the best measure of human capital since they best reflect cognitive ability[88]. The test score measure from this analysis is from Hanushek and Woessmann (2009) and is a composite of average standardized test scores in math and science from primary through secondary schooling for all years available. This variable was excluded from Set 1 and Set 2 because of the large number of missing observations. The individual set of regressions had the lowest sample size of all the variables. The average test score for this sample is 4.51, the minimum is 0.60, and the maximum is 5.45.

The BACE results indicate that test scores are an important determinant of growth with a posterior inclusion probability of 0.322. The average coefficient on the test score variable is positive indicating that increasing test scores can lead to higher economic growth. This finding provides more support for using test scores to measure the quality of a country's education.

Primary Education Teacher Salary: This spending variable from Barro and Lee (2001) measures the average real salary of primary school teachers in 1965. Teacher salary measures are often used in place of total education spending since salaries represent the largest component of spending. Like other spending measures, teacher salaries are commonly used to proxy the quality of schooling

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and growth while Keller (2006) finds a significant positive relationship.

[88]See, for example, Hanushek and Kimko (2000) and Barro and Lee (2001).

received in a country. The total sample of countries pays their primary school teachers an average of $8,584.62, with a minimum of $810.00, and a maximum of $47,391.00.

The BACE results give a posterior inclusion probability of 0.119 and a negative posterior conditional mean. As discussed above, this negative coefficient could be an indication of inefficient spending. The salary measure shows how much is spent on teachers, but does not reflect the quality of teachers or instruction.

Government Secondary Education Spending to GDP: This measure is the ratio of the government secondary education spending variable above to real GDP per capita in 1965. The sampled countries have an average ratio of 61.67, a minimum of 3.80, and maximum of 364.50. The posterior inclusion probability of 0.105 barely passes the cutoff for significance. Like the spending variables above, the coefficient on the ratio of public secondary spending to GDP is negative.

19.3.2   Marginally Significant Human Capital Variables

Secondary Education Repetition Rate: The repetition rate in secondary education in 1970 is another variable that had to be excluded from the previous sets of regressions. Repetition rates are considered education outcome variables and are used to reflect the quality of a country's schools. The countries in the total sample have an average secondary repetition rate of 10.0%, a minimum rate of 0%, and a maximum rate of 30.0%. The BACE results give a posterior inclusion probability of 0.082 and an unexpected positive average coefficient. A possible explanation for this positive coefficient is that by repeating a grade of secondary schooling a student becomes better prepared for the labor force or additional education than had they dropped out of school.

Female Illiteracy Rate: This education outcome measure from UNESCO is the percentage of the female population aged 15 and older in 1970 that is unable to read and write a simple sentence about everyday life. High illiteracy rates reflect a deficiency in very basic skills. The sample countries have an average female illiteracy rate of 57.09% with a minimum of 2.28% and a maximum of 89.77%. There is clearly a large disparity across countries in women's literacy skills, reflecting differences in access to basic education.

The posterior inclusion probability is 0.077, and the posterior conditional mean is negative. The negative average coefficient suggests that increases in female illiteracy decreases a country's rate of economic growth.

Total Illiteracy Rate: This illiteracy rate reflects the percentage of a country's total population aged 15 and older in 1970 that is illiterate. The summary statistics show that the average illiteracy rate is 48.83%, the minimum rate is 1.80%, and the maximum rate is 94.25%. Comparing these to the female rates above, indicates that illiteracy is a larger problem for females than for males. As mentioned previously, this suggests that males have higher access to basic education than do females. The BACE regressions give a posterior inclusion probability of 0.074 and the expected negative average coefficient.

Primary Education Teacher Salary to GDP: The data for the measure of average real salary of primary education teachers to GDP per capita in 1965 is from Barro and Lee (2001). The sampled countries have an average ratio of 425.04 with a minimum ratio of 54.0 and a maximum ratio of 1,948.0. Like the salary and spending variables already discussed, the posterior conditional mean for this salary ratio is negative. This, again, reflects inefficient spending and emphasizes that the salary measure does not accurately reflect the quality of teachers or instruction.

Female Average Years of Primary Education: This attainment variable is a measure of average years of primary education attained by a country's female population aged 25 and older in 1960 from Barro and Lee's (2000) data set. The measure is calculated using the percentage of the female adult population that completed primary education along with the duration of primary education. For the countries in this set of regressions, the average years of female primary education is 2.31, the minimum is 0.01, and the maximum is 7.33. The posterior inclusion probability is 0.072, and the posterior conditional mean is negative. As with female years of higher education discussed in Set 1 and Set 2, the negative coefficient reflects that educated women are not used efficiently in the labor force. This coefficient could also be an indication that females are less likely to gain additional education, perhaps due to limited access in some countries.

20   Conclusion

For this paper I employ the BACE methodology developed by SDM (2004) to determine which of a variety of human capital related variables are robustly significant for economic growth. The BACE technique is ideal for addressing model uncertainty that arises from an extraordinarily large number of possible explanatory variables. Rather than declaring a single model as correct as in classical approaches, BACE gives each possible model a probability of being correct.

The BACE approach has several advantages over other estimation methods. First, as just mentioned, it is not conditional on one model. Settling on one model of economic growth is very difficult given the large number of possible regressors. This is displayed in the empirical growth literature where the model specification varies across papers and authors. The concept of assigning probabilities to handle model uncertainty comes from the standard Bayesian framework. Bayesian methods, while appealing, have failed to gain widespread popularity due to the difficulty in specifying priors for all parameters. Overcoming this difficulty is another advantage of BACE, which only requires the specification of one prior–mean model size. Finally, the methodology and results are intuitive and easy to interpret even for those who are not Bayesian experts. This is attributable to the fact that BACE combines Bayesian methods with the more familiar classical OLS estimation.

I extend the work of SDM (2004) by focusing on human capital as a determinant of growth. The main issue when studying the relationship between human capital and growth is the measurement of human capital. There is no consensus in the literature as to the best way to quantify a country's human capital, and therefore, many different measures have been used. I compile a data set of a variety human capital related variables to add to the BACE analysis of economic growth.

Whether or not a variable is considered robustly significant for growth is determined by the variable's posterior inclusion probability calculated in the BACE analysis. The posterior inclusion probability indicates the variable's marginal contribution to the growth model's goodness-of-fit. A high posterior inclusion probability indicates that models with the variable perform better than models without. Specifically, it gives the probability that the variable should be included in the model after seeing the data. A variable is considered significant for growth its posterior probability is greater than its prior probability. The prior probability is based on the expected model size and the total number of explanatory variables. A posterior inclusion probability that exceeds the prior probability indicates the belief that the variable belongs in the model is stronger after seeing the data.

I run three sets of BACE analyses. The first includes all variables from SDM (2004) plus the additional human capital variables, and the second includes only significant SDM (2004) variables plus the additional human capital variables. The findings from both of these sets of regressions are similar. In the first set of regressions, 6 human capital variables are significant for growth– IQ, secondary education duration, higher education enrollment, female average years of higher

education, average years of primary education, and primary education duration. In the second set of regressions, 2 human capital variables are significant–IQ and female average years of higher education.

The measure of IQ scores is the highest ranking human capital variable in both Set 1 and 2 and ranks second overall based on posterior inclusion probability. This finding provides more evidence that measures of cognitive skills have an important relationship with growth. This idea can be seen in the current growth literature where there is an emphasis on using test scores to measure of human capital. There are several advantages and disadvantages of using IQ to measure human capital. The main advantage is that IQ is a measure of cognitive ability, which aligns best with economic theory and may reflect the quality of early education. The main disadvantage is the limited nature of the data and the possibility of biases that arise from the sample selected for testing and the tests themselves. See my dissertation chapter titled "Measures of Human Capital in Growth Regressions" for more details.

Several measures regarding higher education are found significant or marginally significant for growth, however, for each the average coefficient across models is negative. The negative coefficient indicates an inefficient use of higher levels of education. This is likely to be the result of the sample of countries examined, which is largely comprised of developing or emerging rather than advanced countries.

In general, measures of years of education are found to be significant more than any other type of human capital variable in the analysis. These quantitative measures continue to be the most common human capital measure used in the empirical growth literature. My findings from Set 1 and Set 2 give additional support to this practice.

The third set of regressions examines the effect of each human capital variable individually. This produces differing results from the first two sets BACE results. One reason is that examining the variables individually allows for the inclusion of some measures that were excluded from Set 1 and Set 2 because of missing observations. The sample of countries included in these regressions is also larger than in the first two sets. Five of human capital variables–test scores, government secondary education spending, government secondary spending to GDP, secondary education repetition rate, primary education teacher salary, and primary education teacher salary to GDP–are found significant or marginally significant for growth. Surprisingly, no attainment variables are found to be significant in Set 3. The similar result from all sets of regressions is the importance of

IQ for economic growth.

Taken together, the BACE analyses indicate that IQ should be included in models of economic growth. Perhaps the most general conclusion from this analysis is that human capital is indeed important for growth, and therefore, models should always include a measure of human capital.

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Appendix

SDM (2004) Variable	Description
Abs. Latitude	Absolute latitude.
Air Dist. to Big Cities	Log of min. distance (in km) from New York, Rotterdam, or Tokyo.
Ethnoling. Fraction.	Avg. of 5 indices of ethnolinguistic fractionalization.
British Colony Dummy	Dummy for former British colonies after 1776.
Fraction Buddhist	Fraction of pop. that is Buddhist in 1960.
Fraction Catholic	Fraction of pop. that is Catholic in 1960.
Civil Liberties	Index of civil liberties in 1972.
Colony Dummy	Dummy for former colonies.
Fraction Confucian	Fraction of pop. that is Confucian.
Pop. Density	Pop. per area in 1960.
Pop. Density Coastal	Coastal (within 100 km of coastline) pop. per coastal area in 1965.
Interior Density	Interior (more than 100 km from coastline) pop. per interior area in 1965.
Pop. Growth Rate	Avg. growth rate of pop. between 1960 and 1990.
E. Asian Dummy	Dummy for East Asian countries.
Capitalism	Degree of capitalism index.
English Speaking Pop.	Fraction of pop. speaking English.
European Dummy	Dummy for European countries.
Land Area	Land area in square km.
Landlocked Country Dummy	Dummy for landlocked countries.
Hydrocarbon Deposits	Log of hydrocarbon deposits in 1993.
Life Expectancy	Life expectancy in 1960.
Fraction Land Area Near Navigable Water	Proportion of land area within 100 km of an ocean or an ocean-navigable river.
Malaria Prevalence	Index of malaria prevalence in 1966.
Fraction of GDP in Mining	Fraction of GDP in mining.
Fraction Muslim	Fraction of pop. that is Muslim.
Timing of Independence	Timing of national independence.
Oil Producing Country Dummy	Dummy for oil producing countries.

Table 20: SDM (2004) Variables

SDM (2004) Variable	Description
Openess	Avg. ratio of exports plus imports to GDP from 1965 to 1974.
Fraction Othodox	Fraction pop. that is Orthodox in 1960.
Fraction Speaking Foreign Language	Fraction of pop. speaking a foreign language.
Prim. Educ. Enroll. Rate	Enroll. rate in prim. educ. in 1960.
Avg. Inflation	Avg. inflation rate between 1960 and 1990.
Square of Inflation	Square of avg. inflation rate between 1960 and 1990.
Political Rights	Political rights index.
Fraction Pop. Less than 15	Fraction of pop. younger than 15 years old in 1960.
Pop.	Pop. in 1960.
Fraction Pop. Over 65	Fraction of pop. over 65 years old in 1960.
Primary Exports	Fraction of primary exports in total exports in 1970.
Fraction Protestants	Fraction of the pop. that is Protestant in 1960.
Real Exch. Rate Distortions	Real exchange rate distortions.
Revolutions and Coups	Number of revolutions and military coups.
African Dummy	Dummy for Sub-Saharan African countries.
Outward Orientation	Measure of outward orientation.
Size of Economy	Log. of aggregate GDP in 1960.
Socialist Dummy	Dummy for countries under Socialist rule for considerable time during 1950 to 1995.
Spanish Colony	Dummy for former Spanish colonies.
Terms of Trade Growth	Growth of terms of trade in the 1960's.
Terms of Trade Ranking	Terms of trade ranking.
Fraction of Tropical Area	Proportion of land area within geographical tropics.
Fraction Pop. In Tropics	Proportion of pop. living in geographical tropics.
Fraction Spent in War	Fraction of time spent in war between 1960 and 1990.
War Particpation	Indicator for countries that participated in an external war between 1960 and 1990.
Years Open	Number of years economy has been open between 1950 and 1994.
Tropical Climate Zone	Fraction of tropical climate zone.

Table 21: SDM (2004) Variables Continued.

Set 1		Set 2	
Algeria	Malawi	Algeria	Malawi
Argentina	Malaysia	Argentina	Malaysia
Bolivia	Mauritius	Bolivia	Mexico
Botswana	Mexico	Botswana	Nepal
Cameroon	Netherlands	Cameroon	Netherlands
Central Afr. Rep.	Niger	Central Afr. Rep.	Niger
Chile	Pakistan	Chile	Pakistan
Colombia	Panama	Colombia	Panama
Costa Rica	Pap. N. Guinea	Costa Rica	Pap. N. Guinea
Dominican Rep.	Paraguay	Dominican Rep.	Paraguay
Ecuador	Peru	Ecuador	Peru
El Salvador	Philippines	El Salvador	Philippines
Ghana	Senegal	Ghana	Senegal
Greece	Spain	Greece	Spain
Guatemala	Sri Lanka	Guatemala	Sri Lanka
Haiti	Syria	Haiti	Syria
Honduras	Thailand	Honduras	Thailand
India	Togo	Hong Kong	Togo
Indonesia	Trin. and Tob.	India	Trin. and Tob.
Israel	Tunisia	Indonesia	Tunisia
Italy	Turkey	Israel	Turkey
Jamaica	Uganda	Italy	Uganda
Jordan	Uruguay	Jamaica	Uruguay
Korea	Venezuela	Jordan	Venezuela
Lesotho	Zambia	Korea	Zambia
		Lesotho	

Table 22: Countries Included in Each Set of Regressions.

Afghanistan	Denmark	Israel	Oman	Tanzania
Algeria	Dominica	Italy	Pakistan	Thailand
Angola	Dominican Rep.	Jamaica	Panama	Togo
Argentina	Ecuador	Japan	Pap. N. Guinea	Tonga
Australia	Egypt	Jordan	Paraguay	Trin. and Tob.
Austria	El Salvador	Kenya	Peru	Tunisia
Bahamas, The	Ethiopia	Korea	Philippines	Turkey
Bahrain	Fiji	Kuwait	Poland	Uganda
Bangladesh	Finland	Lesotho	Portugal	Unit. Arab Emir.
Barbados	France	Liberia	Rwanda	United Kingdom
Belgium	Gabon	Luxembourg	Samoa	United States
Benin	Gambia	Madagascar	Saudi Arabia	Uruguay
Bolivia	Germany, West	Malawi	Senegal	Vanuatu
Botswana	Ghana	Malaysia	Seychelles	Venezuela
Brazil	Greece	Mali	Sierra Leone	Yemen, N.Arab
Burkina Faso	Grenada	Malta	Singapore	Yugoslavia
Burundi	Guatemala	Mauritania	Solomon Islands	Zaire
Cameroon	Guinea	Mauritius	Somalia	Zambia
Canada	Guinea-Bissau	Mexico	South africa	Zimbabwe
Cape verde	Guyana	Morocco	Spain	
Cental Afr. Rep.	Haiti	Mozambique	Sri Lanka	
Chad	Honduras	Myanmar	St.Lucia	
Chile	Hong Kong	Namibia	St.Vin. and Gren.	
China	Hungary	Nepal	Sudan	
Colombia	Iceland	Netherlands	Suriname	
Comoros	India	New Zealand	Swaziland	
Congo	Indonesia	Nicaragua	Sweden	
Costa Rica	Iran, I.R. of	Niger	Switzerland	
Cote d'Ivoire	Iraq	Nigeria	Syria	
Cyprus	Ireland	Norway	Taiwan	

Table 23: All Possible Countries.

Rank	Variable	Post. Incl. Prob.	Cond. Post. Mean	Cond. Post. Std. Dev.
32	Fraction Confucian	0.0574	0.002216	0.010900
33	Terms of Trade Ranking	0.0548	-0.001066	0.005488
34	Spanish Colony	0.0498	-0.000314	0.001817
35	Air Dist. to Big Cities	0.0482	0.000000	0.000000
36	E. Asian Dummy	0.0481	0.000578	0.003268
37	Pop. Density	0.0463	0.000000	0.000005
38	Illiteracy Rate*	0.0444	0.000000	0.000071
39	Outward Orientation	0.0422	-0.000233	0.001359
40	Prim. Educ. Enroll. Rate*	0.0389	0.000436	0.003931
41	Avg. Years High. Educ.*	0.0377	-0.002053	0.026452
42	Primary Exports	0.0371	-0.000442	0.002902
43	Fraction Buddhist	0.0370	0.000552	0.003570
44	Male Avg. Years Educ.*	0.0361	0.000090	0.005261
45	Capitalism	0.0337	0.000032	0.000304
46	Latin Amer. Dummy	0.0335	-0.000248	0.001952
47	Fraction of Land Area Near Navigable Water	0.0305	0.000198	0.001610
48	Land Area	0.0303	0.000000	0.000000
49	British Colony Dummy	0.0303	0.000155	0.001183
50	Female Avg. Years Prim. Educ.*	0.0302	0.000063	0.002356
51	Female Illiteracy Rate*	0.0297	0.000000	0.000043
52	Avg. Inflation	0.0295	-0.000004	0.000030
53	Prim. Educ. Entrance Age*	0.0290	-0.000111	0.000861
54	Square of Inflation	0.0281	0.000000	0.000000
55	Years Open	0.0278	0.000255	0.002114
56	Terms of Trade Growth	0.0271	0.001452	0.011840
57	Size of Economy	0.0269	0.000036	0.000396
58	Fraction Speaking Foreign Language	0.0267	0.000024	0.000887
59	Investment Price	0.0266	0.000001	0.000016
60	Govt. Educ. Spend. Share of GDP	0.0264	0.001704	0.031751
61	Timing of Independence	0.0264	0.000055	0.000602
62	Female Avg. Years Educ.*	0.0261	-0.000055	0.002300
63	Ethnoling. Fraction.	0.0251	-0.000186	0.002095
64	Male Illiteracy Rate*	0.0250	-0.000002	0.000046
65	Colony Dummy	0.0247	-0.000162	0.001460
66	Prim. Educ. Days*	0.0242	-0.000003	0.000023
67	Pop. Density Coastal	0.0235	0.000000	0.000001
68	Sec. Educ. Enroll.*	0.0234	-0.000360	0.005541
69	Fraction Protestants	0.0231	0.000166	0.002836
70	Female Avg. Years Sec. Educ.*	0.0228	-0.000167	0.002999
71	Abs. Latitude	0.0225	0.000003	0.000044

Table 24: Set 1 Insignificant Variables.

Rank	Variable	Post. Incl. Prob.	Cond. Post. Mean	Cond. Post. Std. Dev.
72	Fertility	0.022	5.23E-05	0.002481
73	Avg. Years Sec. Educ.*	0.022	-0.000151	0.011277
74	European Dummy	0.022	-9.85E-05	0.001603
75	Fraction Spent in War	0.022	-0.000344	0.003415
76	Interior Density	0.020	-3.88E-07	0.000005
77	Male Avg. Years Sec. Educ.*	0.019	-5.33E-05	0.005471
78	Malaria Prevalence	0.019	-9.17E-05	0.001202
79	Male Avg. Years High. Educ.*	0.019	0.000449	0.014160
80	Revolutions and Coups	0.019	-4.28E-05	0.001153
81	Sec. Educ. Entrance Age*	0.019	6.29E-08	0.000378
82	Sec. Educ. PT Ratio*	0.018	3.12E-06	0.000045
83	Pop. Growth Rate	0.018	0.000287	0.058801
84	War Particpation	0.017	3.59E-05	0.000562
85	Defense Spend. Share	0.017	1.34E-05	0.011951
86	Tropical Climate Zone	0.016	-4.40E-05	0.001155
87	Socialist Dummy	0.016	8.12E-05	0.001345
88	Prim. Educ. Drop Rate*	0.016	-5.94E-07	0.000014
89	Openess	0.015	1.34E-06	0.000995
90	Prim. Educ. PT Ratio*	0.014	-4.34E-07	0.000022
91	Oil Producing Country Dummy	0.014	2.95E-05	0.000953
92	Fraction Othodox	0.013	4.85E-05	0.001702

Table 25: Set 1 Insignificant Variables Continued.

Rank	Variable	Post. Incl. Prob.	Cond. Post. Mean	Cond. Post. Std. Dev.
14	Fraction of Tropical Area	0.088	-0.000867	0.003740
15	Fraction Buddhist	0.088	0.001379	0.005517
16	Latin Amer. Dummy	0.078	-0.000640	0.003306
17	Prim. Educ. Enroll. Rate	0.069	0.001429	0.006928
18	Illiteracy Rate*	0.068	-0.000019	0.000164
19	Fraction Confucian	0.066	0.002056	0.010286
20	Female Avg. Years Educ.*	0.061	-0.000214	0.012470
21	Sec. Educ. Duration*	0.058	0.000189	0.001167
22	Malaria Prevalence	0.058	-0.000457	0.002640
23	Pop. Density Coastal	0.057	0.000000	0.000002
24	Male Avg. Years Prim. Educ.*	0.057	0.000281	0.015950
25	Female Illiteracy Rate*	0.056	-0.000007	0.000095
26	Ethnoling. Fraction.	0.055	-0.000588	0.003872
27	Male Illiteracy Rate*	0.051	-0.000009	0.000092
28	Male Avg. Years High. Educ.*	0.050	-0.000802	0.029429
29	Female Avg. Years Prim. Educ.*	0.050	-0.000124	0.012504
30	Avg. Years Prim. Educ.*	0.049	0.000225	0.013939
31	Sec. Educ. PT Ratio*	0.048	0.000007	0.000091
32	Male Avg. Years Educ.*	0.047	0.000043	0.015832
33	Avg. Years Educ.*	0.046	-0.000015	0.013618
34	Years Open	0.044	0.000311	0.002236
35	Prim. Educ. Days*	0.044	-0.000005	0.000031
36	Sec. Educ. Entrance Age*	0.041	-0.000060	0.000682
37	Female Avg. Years Sec. Educ.*	0.040	-0.000151	0.012765
38	High. Educ. Enroll. Rate	0.040	-0.000002	0.000018
39	Prim. Educ. Duration*	0.038	0.000065	0.000901
40	Sec. Educ. Enroll. Rate*	0.038	-0.000389	0.006251
41	Avg. Years Sec. Educ.*	0.037	-0.000092	0.014052
42	Prim. Educ. Drop Rate*	0.035	-0.000002	0.000023
43	Male Avg. Years Sec. Educ.*	0.034	0.000010	0.015969
44	Govt. Educ. Spend. Share in GDP	0.031	0.002728	0.042292
45	Prim. Educ. PT Ratio*	0.029	-0.000001	0.000035

Table 26: Set 2 Insignificant Variables.