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MEASURING HUMAN CAPITAL: ALTERNATIVE METHODS AND INTERNATIONAL EVIDENCE

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Human capital is increasingly believed to play an important role in the growth process, however, adequately measuring its stock remains controversial. This paper identifies three general approaches to human capital measurement; cost-based, income-based and education-based, and presents a critical review of the theories and their applications to data from a range of countries. Emphasis on empirical evidence will be given to the case of New Zealand.

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I. INTRODUCTION

According to Schultz (1961a), economists have long recognised that people are an important component of the wealth of nations. Schultz cited Smith (1776) who included all acquired and useful abilities of a country's inhabitants as part of capital. Even prior to that, Petty (1690), in an attempt to demonstrate the power of England, estimated the total human capital of that country to be £520 million, or £80 per capita. In a similar exercise, Farr (1853) estimated that the average net human capital

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of an English agricultural labourer was £150.

Today, with the importance of ‘knowledge’ in the economy, human capital has increasingly attracted both academic and public interest. Human capital theory suggests that it is human capital -- the knowledge and skills embodied in people -- rather than physical capital, that is vital to a country’s economic prosperity. In practice, private and public investment in human capital, in the form of expenditure in education and training, accounts for over 10 percent of national income in most OECD countries (Healy, 1998). Understanding human capital must, therefore, be of great interest to politicians, economists and development strategists.

In the recent economic literature, interest in human capital revolves around economic growth. Traditionally, the focus on boosting growth was to give workers access to more physical resources, like land, factories and machines. But modern theories of economic growth, such as those of Romer (1986), Lucas (1988) and Jones and Manuelli (1990), emphasise human capital. According to these theories, human capital can foster growth through stimulating technological creation, invention and innovation, as well as facilitating the uptake and imitation of new technologies. Numerous empirical studies have sought to establish a relationship between human capital and economic growth. Although human capital has been found to enhance growth in some cases, positive results have failed to prevail in others. The hypothesis that human capital plays a significant role in the growth process is, therefore, not empirically validated.

It has been suggested that a major reason for the mixed evidence is that human capital has been poorly measured (Krueger and Lindahl, 2001). It may be either because the proxies that have been used do not capture key elements of human capital, or because the data on the proxies are erroneous. Consequently, measurement error may account for the somewhat surprising finding that greater investment in human beings does not appear to be associated with faster economic growth. This concern with measurement error, therefore, brought up a question that has occupied economists in the last several decades -- how to measure human capital adequately?

Following the insights of Adam Smith, the creation of specialised labour is seen to require the use of scarce inputs, typically education/learning. This emphasis on 'education' has led to a research agenda where human capital is proxied by some measure of school experience. However, this is only one of several approaches to the measurement of human capital. There are alternative methods which build upon Smith, Ricardo and modern labour economics more generally. In particular, these are measures of human capital which are based on the cost of production or the expected earnings of heterogeneous labour. These approaches have a rich and long intellectual pedigree and the advantages of easily permitting monetary values to be assigned to the stock and thus enabling comparisons with other types of capital.

As can be expected, the impact that human capital has on economic growth is sensitive to the measures or proxies of human capital. It is necessary that there be an accurate and consistent measure of human capital, which will facilitate cross-sectional and temporal comparisons. Only when human capital is adequately and consistently measured can we understand how it affects the growth process and how governments or firms can influence its quantity or quality. The need for a reliable measure of human capital is reinforced by the fact that even in countries where attempts are made to estimate the value of human capital it is not yet standard practice for official statistical agencies to include human capital in their capital stock measures. This is a surprising omission because estimates of the value of human capital, as mentioned above, predate the formal development of National Accounts statistics.

In this paper we identify three general approaches to human capital measurement; cost-based, income-based and education-based, and present a critical review of the theories and their applications to data from a range of countries.

The rest of the paper proceeds as follows. Section 2 provides some definitions of human capital. The major approaches to human capital measurement will be presented in the next four sections. Section 7 concludes by summarising the international literature on human capital measurement.[1]

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[1] Part of the current paper has been published in Le et al. (2003).

II. DEFINITIONS OF HUMAN CAPITAL

Schultz (1961a) classified skills and knowledge that people acquire as a form of human capital, and in so doing he sparked the revival of interest in the notion of human capital. A variety of definitions of human capital have since prevailed. For example, the Penguin Dictionary of Economics defines human capital as “the skills, capacities and abilities possessed by an individual which permit him to earn income.” This concept has been extended to incorporate non-market activities, and a broader definition of human capital is “the knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being” (OECD, 2001, p18). Laroche et al. (1991) further extend the notion to include innate abilities. By definition, human capital is a complex concept; it has many dimensions and can be acquired in various ways (at home, at school, at work, and so on).

Clearly, human capital is *intangible*, the stock of which is not directly observable like that of physical capital. Therefore, estimates of the human capital stock must be constructed indirectly. Common approaches to human capital measurement include the cost-based approach, the income-based approach and the education-based approach.

III. THE COST-BASED APPROACH

A very common approach to the measurement of human capital is the cost-of-production method originated by Engel (1883), who estimated people’s human capital based on rearing costs to their parents. Engel considered a person to be fully produced by the age of 26, so the cost of rearing a person would equal the summation of costs required to raise him from conception to the age of 25. Assuming that the cost of rearing a person aged $x < 26$, belonging the i^{th} class at birth of c_{oi} and annual costs of $c_{oi} + k_i c_{oi}$ a year, Engel arrived at this formula:

$$c_{xi} = c_{0i} + xc_{0i} + \sum_{1}^{x} k_i c_{0i} = c_{0i}\left\{1 + x + \frac{k_i x(x+1)}{2}\right\} \qquad (1)$$

However, as Dagum and Slottje (2000) point out, this model should not be taken as an estimation of human capital; it is merely a summation of historical costs and ignores the time value of money as well as the social costs that are invested in people. More recently, Engel's approach has been augmented based on the assumption that the depreciated value of the dollar amount spent on investment in human capital is equal to its stock value.

Kendrick (1976) and Eisner (1985, 1989) were among the seminal examples of systematically measuring the stock of human capital by a cost-based approach. Kendrick divided human capital investments into tangible and intangible. The tangible component consists of the costs required to produce the physical human being. Intangible investments, by contrast, aim at enhancing the quality or productivity of labour. They include expenditures on health and safety, mobility, education and training, plus the opportunity costs of students attending school.

This approach provides an estimate of the resources invested in the education and other human capital related sectors, which can be useful for cost-benefit analyses. It is also easy to apply, thanks to the ready availability of data on public and private spending.

However, as is well known with physical capital, there is no necessary relationship between investments and the quality of output: the value of capital is determined by the demand for it, not by the cost of production. This problem is more serious with human capital and thus renders cross-sectional and temporal comparisons unreliable. For example, an innately less able and less healthy child is more expensive to raise, so the cost-based approach will overestimate his human capital while underestimating well endowed children who, all else equal, should incur less rearing and educational expenses.

Secondly, the components entering into the production of human capital and their prices can not be easily identified. In particular, since how increases in each type of spending contribute to change in the human capital stock is not observable, it is difficult to distinguish between investment expenditures and consumption expenditures. For example, Kendrick classified costs of raising children to the age of 14 as human capital investments, reasoning that these expenses, typically on necessities such as food and clothing, compete with other types of investment. This contradicts Bowman (1962) who argued against treating those costs as investments unless the men were slaves. Machlup (1984) concurred with this view, maintaining that basic expenditures should be considered consumption. There is a similar problem with determining the marginal contribution of each type of investment. Given the lack of empirical evidence, the researcher may have to allocate household spending quite arbitrarily between investment and consumption. Kendrick, for instance, assigned 50 percent of outlays for health and safety to human capital investment. Since most expenditures on people have both *consumption* effect (satisfying consumer preferences) and *investment* effect (enhancing productivity), cost-based measures are sensitive to assumptions about the type of spending and the share of various household and public expenditures that should be regarded as human capital investment. The difficulty in separating consumption effect from investment effect of ‘expenditures on man’ means that what should be considered human capital investment is controversial.[2]

Thirdly, the depreciation rate matters a great deal. Kendrick estimated depreciation in human capital by the (modified) double declining balance method. This is because physical capital depreciates faster in early years of life, so the double declining balance schedule is appropriate. To be consistent across different types of capital, Kendrick applied this method to depreciate human capital. By contrast, Eisner used the straight-line practice. Appreciation is often ignored, despite empirical evidence which showed that human capital appreciates at younger ages (Mincer, 1958, 1974). Graham and Webb (1979), who found evidence of human capital appreciation, criticised Kendrick for understating human capital by not allowing for appreciation while over-depreciating it.

There is ample empirical evidence on measures of human capital based on the cost approach, especially for the US. Schultz (1961a), for example, estimated that the stock of human capital of the US labour force increased by eight and a half times during 1900-1956 while the stock of reproducible capital grew only half as fast. Kendrick (1976) and Eisner

[2] See, for example, Schultz (1961a,b) and Shaffer (1961), who discussed the difficulties in distinguishing between consumption and investment expenditures in the formation of human capital.

(1985, 1989) provided more comprehensive estimates, opening the way to the construction of human capital time series using the perpetual inventory method.

Kendrick found that during 1929-1969, the stock of human capital often exceeded that of physical capital. In 1969, the US non-human capital stock totalled $3,220 billion, whereas human capital was valued at $3,700 billion. In constant prices, the stock of human capital tripled over the period 1929-1969, at a growth rate of 6.3 percent a year, compared with an annual growth rate of 4.9 percent for non-human capital. Education and training accounted for 40-60 percent of the stock of human capital and this share increased consistently over time.[3]

Eisner (1985) departed from Kendrick's approach by allowing for the value of non-market household contribution to investment in child rearing. Investment in research and development also counted as human capital investment. While Kendrick divided human capital into tangibles and intangibles, Eisner classified it all as intangibles. His results showed that of the $23,746 billion worth of total capital in 1981, $10,676 billion was human capital. In real terms, human capital grew at 4.4 percent a year during 1945-1981 while capital in general increased at 3.9 percent a year. When put in the same price base, Kendrick's and Eisner's estimates are broadly similar, except that Kendrick's estimates of human capital often exceeded those of physical capital stocks, whereas the opposite was true of Eisner's.

IV. THE INCOME-BASED APPROACH

4.1 Early studies

The income-based approach to human capital measurement even predates the cost-of-production method. Petty (1690) was the first to use this framework. He calculated the human capital stock of England by capitalising to perpetuity the wage bill, defined as the difference between the estimated national income (£42 million) and property income (£16 million), at a 5 percent interest rate. This gave a result of £520 million,

[3] All figures quoted in this sub-section are net stocks of capital.

or £80 per capita. Petty's method was simplistic as it did not account for the heterogeneity of the population. Crude as it was, it raised the issue of estimating the money value of a country's labourers and gave an answer with a meaningful economic interpretation.

The first truly scientific model to estimating the value of a human being, according to Kiker (1966), was developed by Farr (1853). Farr calculated the earning capacity as the present value of an individual's future earnings net of living expenses, adjusted for deaths in accordance with a life table. Using a discount rate of 5 percent, Farr estimated the average net human capital of an agricultural labourer to be £150, which is the difference between the average gross value of £349 and the average maintenance cost of £199. Farr 's procedure laid a sound base for the income approach to human capital measurement. The underlying principle is to value people's human capital as the total income that could be generated in the labour market over their lifetime.

Dublin and Lotka (1930) followed Farr and devised a formula for calculating the value of an individual at birth, V_0, as:

$$V_0 = \sum_{x=0}^{\infty} \frac{S_{0,x}(W_x Y_x - C_x)}{(1+i)^x} \tag{2}$$

where i is the interest rate, $S_{0,x}$ is the probability of living to age x, W_x is the employment rate at age x, Y_x is the individual's annual earnings from age x to $x+1$, and C_x is the annual cost of living.

Equation (2) is a formal statement of Farr's method, except that Dublin and Lotka made allowance for unemployment. It can be extended to obtain the value of an individual at a given age a:

$$V_a = \sum_{x=a}^{\infty} \frac{S_{a,x}(W_x Y_x - C_x)}{(1+i)^{x-a}} \tag{3}$$

Similarly, the net cost of rearing a person up to age a is:

$$C_a = \sum_{x=0}^{a-1} \frac{S_{a,x}(C_x - W_x Y_x)}{(1+i)^{x-a}} \tag{4}$$

The right-hand side of equation (3) can be expanded:

$$
\begin{aligned}
V_a &= \sum_{x=0}^{\infty} \frac{S_{a,x}(W_x Y_x - C_x)}{(1+i)^{x-a}} - \sum_{x=0}^{a-1} \frac{S_{a,x}(W_x Y_x - C_x)}{(1+i)^{x-a}} \\
&= \sum_{x=0}^{\infty} \frac{S_{0,x}(W_x Y_x - C_x)(1+i)^a}{S_{0,a}(1+i)^x} + \sum_{x=0}^{a-1} \frac{S_{a,x}(C_x - W_x Y_x)}{(1+i)^{x-a}} \\
&= \frac{(1+i)^a}{S_{0,a}} \sum_{x=0}^{\infty} \frac{S_{0,x}(W_x Y_x - C_x)}{(1+i)^x} + \sum_{x=0}^{a-1} \frac{S_{a,x}(C_x - W_x Y_x)}{(1+i)^{x-a}}
\end{aligned} \tag{5}
$$

Combining (5) with (2) and (4), we have:

$$V_a = \frac{(1+i)^a}{S_{0,a}} V_0 + C_a \tag{6}$$

Equivalently,

$$C_a = V_a - \frac{(1+i)^a}{S_{0,a}} V_0 \tag{7}$$

This formula has a very intuitive interpretation: the cost of producing a person up to age a is equal to the difference between his current value and the present value, at age a, of his value at birth, adjusted for his survival probability to age a.

Other researchers also made important contributions. Wittstein (1867) combined Engel’s cost-of-production approach with Farr’s prospective method to evaluate the human capital of an individual at different ages. However, he was criticised for unjustifiably assuming lifetime earnings and lifetime maintenance costs of an individual to be equal.

Nicholson (1891) derived the human capital stock by capitalising the wage bill, earnings of management, earnings of capitalists, earnings of salaried government officials, and the so-called “domesticated humanity” (the costs of producing wage earners). He claimed that the United Kingdom’s stock of living capital was worth five times that of conventional capital. But by combining the prospective and retrospective methods like that, Nicholson was criticised for duplicating values. Specifically, the costs of producing wage earners, which were already counted in the "domesticated humanity," also appeared in the capitalised value of their earnings.

De Foville (1905) believed that the prospective method overstates human capital by not deducting consumption expenditures from earnings. He, therefore, estimated the stock of human capital for France by applying Petty's approach to earnings net of maintenance. Another French researcher, Barriol (1910) used Farr's approach to evaluate the "social value" of French male labourers. Assuming that lifetime income equals lifetime expenditures, Barriol computed this value by discounting their future expenditures, adjusted for deaths, at a 3 percent interest rate. This method differed from Farr's in that maintenance costs were not subtracted from earnings. But what made Barriol's work innovative was that he estimated the social value by age group.

In the US, experimental studies on this subject date back to the early twentieth century. Fisher (1908) used Farr's approach to measure human capital in order to assess the costs of preventable illness and death. Also based on a Farr-type method, Huebner (1914) found the US stock of human capital to be worth 6-8 times the stock of conventional capital. Woods and Metzger (1927) used five methods, including those due to Petty and Farr, to tackle this issue. But these analyses, as pointed out by Kiker (1966), contained several erroneous assumptions.

Treadgold (2000) identified Wickens (1924) as a pioneer in human capital measurement. Wickens evaluated the stock of wealth in Australia's population by estimating the total discounted value of all future streams of services expected to be generated by the country's citizens. He divided the population into three groups: adults of working age (males aged 18-64 and females aged 18-59), juveniles (younger than 18), and the aged. The value of the annual services a person brings to the society was assumed to equal the weighted average gross earnings. These figures, corresponding to £ 133 and £ 65 for males and females respectively, were calculated from official weekly rates, with four weeks deducted from the working year to account for such factors as unemployment and unpaid holidays. Wickens further assumed that all surviving men would continue to earn £133 a year and women £65 until the retirement age. For the aged, old-age pensions were used in place of earnings. The "juveniles" were assumed to render no services before 18 and "adult services" subsequently. Combining these numbers with a life table and a discount rate, human wealth values would be obtainable for men and women at every age from 0 to 104.

Having human wealth values by age and gender, Wickens identified a median age for each of the three new groups (under 15, 15-64, and above 64) then multiplied the per capita wealth estimate of the median age by the population size of that group. He found that in 1915 Australia's human capital totalled £6,211 million, or £1,246 per capita. This stock value was three times the stock of physical capital. However, Wickens's estimates were questionable, since he used such an unjustifiable shortcut to obtain the aggregate value and ignored the value of individuals in older age groups when deriving the value of people in younger age groups.

4.2 Critique

The income-based approach measures human capital by summing the discounted values of all future income streams that all individuals in the population expect to earn throughout their lifetime. This method is 'forward-looking' (prospective) because it focuses on expected returns to investment, as opposed to the 'backward-looking' (retrospective) method whose focus is on the historical costs of production.

The prospective approach seeks to evaluate a person's earning power. It values human capital at market prices, since the labour market more or less accounts for many factors, including ability, effort, productivity and education, as well as the institutional and technological structures of the economy (Dagum and Slottje, 2000). Also, there is no need to assume an arbitrary rate of depreciation, as depreciation is already implicitly captured. This method provides the most meaningful results if required data are available.

Indeed, accurate and timely life tables are readily available, and (un)employment rates and earnings by age and education level can be obtained from relevant surveys. The choice of a discount rate involves some subjective judgment, but this should not be a problem. Above all, since the approach based on income is forward-looking, a dynamic economy wanting to evaluate its future productive capacities would be more interested in this approach than the historical cost approach (Graham and Webb, 1979).

But this approach is not free from drawbacks. Most notably, the model rests crucially on the assumption that differences in wages truly reflect differences in productivity. In practice, wages may vary for other reasons. For example, trade unions may be able to command a premium wage for their members, or real wages may fall in economic downturns. Under such circumstances, income-based measures of human capital will be biased. These measures are also very sensitive to the discount rate and the retirement age.

Whether maintenance costs should be deducted is contentious. On the one hand, some authors argue that physical capital estimates are net of maintenance costs, thus human capital should also be net. De Foville (1905) and Eisner (1988), for example, criticised the income-based method for not deducting maintenance costs from gross earnings. Weisbrod (1961) attempted to account for maintenance, but he encountered many difficulties. What types of expenditures should be classified as maintenance, and how to account for economies of scale and ‘public’ goods when estimating per capita consumption for different members in the same household are problems that are not easily resolved. On the other hand, others maintain that consumption is an end, rather than a means, of investment and production, so gross earnings are more relevant to human capital derivation. It is argued that net productivity is a more adequate measure of a person’s value to others; whereas gross productivity is a superior estimate of his total output to the society (Graham and Webb, 1979).

Another disadvantage of the income-based method is that data on earnings are not as widely available as data on investment. This is especially the case for developing countries, where the wage rate is often not observable. In the early studies reviewed above, the major problem lies in the lack of reliable data on earnings and the unjustified assumption about future earnings.

4.3 The revived interest in the income-based approach

Despite its merits, data constraints had prevented early researchers from utilising the income-based approach. Weisbrod (1961) was among the first to use cross-sectional micro data. He adopted Dublin and Lotka's (1930) formula:

$$V_a = \sum_{x=a}^{74} \frac{S_{a,x} W_x Y_x}{(1+i)^{x-a}} \tag{8}$$

where V_a is the present value of expected future earnings of a person at age a. The retirement age is 75, at which earnings are nil.

The use of cross-sectional data necessitates assuming that in n years, those currently aged x would earn an income equal to what people aged $x+n$ now earn. A similar logic applied to employment rates and survival probabilities. Weisbrod showed that in 1950, average human capital for US males aged 0-74 was $17,000 at a discount rate of 10 percent and $33,000 at 4 percent. Netted of maintenance costs, the corresponding figures would be $13,000 and $26,000 respectively. Apparently, even the lowest estimate of (male) human capital exceeded the stock of non-human assets of $881 billion, consistent with the fact that labour income exceeded property income. Based on these results, the author claimed that the society was paying too much attention to non-human capital, while it was human capital that deserved greater investment.

Weisbrod cautioned that such use of cross-sectional data overlooks changes in age-specific values over time. Since such changes tend to be positive, estimates of human capital under static age-specific conditions are likely to be biased downwards. Another source of underestimation was that median earnings were used, because mean earnings were not available.[4]

Houthakker (1959) and Miller (1965) argued that in a growing economy, everyone should benefit from an expected increase in their earnings on top of the gains in experience, seniority and other age-related

[4] As is widely known, for most earnings distributions, the mean is often greater than the median.

factors. Also using data from the 1950 US Census, Miller demonstrated that by accounting for economic growth, estimates of lifetime income based on cohort analyses well exceeded those based on cross-sectional patterns.

Recognising the major limitation in Weisbrod (1961), Graham and Webb (1979) adjusted the framework to incorporate economic growth. They also departed from earlier studies by controlling for education. Equation (8) is then modified as follows:

$$V_a^i = \sum_{x=a}^{75} \frac{S_{a,x}^i W_x^i Y_x^i (1+g_k^i)^{x-a}}{(1+i_k^i)^{x-a}} \tag{9}$$

where the superscript i denotes a vector of personal characteristics and i_k^i and g_k^i are respectively the interest rate and growth rate in earnings that apply to type i individuals at the k^{th} year of life. The underlying assumption here is that a person aged x with characteristics i will base his expectation of earnings n years from now on what is earned by those who are currently $x+n$ years old and who possess the same basic characteristics.

Graham and Webb found that lifetime wealth rises with education at all ages and is concave in age at all education levels. Throughout the life cycle, human wealth initially rises, then approaches zero at retirement. The income-based framework implicitly allows for depreciation, so there is no need to assume an arbitrary depreciation rate. In aggregate, the stock of capital embodied in US males aged 14-75 in 1969 ranged from $2,910 billion at a 20 percent discount rate to $14,395 billion at a 2.5 percent rate. According to Kendrick’s (1976) cost-based method, human capital in 1969 totalled $3,700 billion. Taken into account the difference in population bases, Kendrick’s estimate was still comparatively lower than Graham and Webb’s at the highest discount rate of 20 percent. They believed that Kendrick’s estimates are biased downwards due to the incorrect assumption about depreciation.

4.4 The Jorgenson and Fraumeni method

4.4.1 Model

Graham and Webb's (1976) study was far more sophisticated than earlier ones, but it still contained methodological limitations and covered barely half of the US population. Jorgenson and Fraumeni (1989, 1992) augmented the method and proposed a new system of national accounts. They estimated the human capital of everyone in the US population classified by the two sexes, 61 age groups, and 18 education groups (0-17+ years of schooling) for a total of 2,196 cohorts.

Jorgenson and Fraumeni's most significant contribution was in simplifying the procedure for discounting future income streams to the present value. Specifically, they noted that the present value of lifetime labour income for an individual of a given age is just his current annual labour income plus the present value of his lifetime income in the next period weighted by survival probabilities. By backwards recursion it is possible to calculate the present value of lifetime income at each age. For example, if people retire at 75, then for a 74-year-old person, the present value of lifetime labour income is simply his current labour income. The lifetime labour income of a 73-year-old individual is equal to his current labour income plus the present value of lifetime labour income of the 74-year-old, and so forth. Formally, the lifetime income V of an individual with sex s, age a, education e is given by:

$$V_{s,a,e} = Y_{s,a,e} + S_{s,a+1} V_{s,a+1,e} (1+g)/(1+i) \qquad (10)$$

where Y is annual earnings and S_{a+1} is the probability that the person will survive another year. Jorgenson and Fraumeni identified five stages of the life cycle: no school and no work (ages 0-4), school but no work (5-13), school and work (14-34), work but no school (35-74), and no school or work (75 and older). By assumption, the lifetime income for the oldest group is zero, so is the annual income of those in the first two stages.

Also notably, Jorgenson and Fraumeni's method incorporates the potential value created by people who are currently attending school.

Such inclusion of enrolment affects the lifetime income of those in the second and third stages of the life cycle. For these people, lifetime income is:

$$\begin{aligned} V_{s,a,e} = Y_{s,a,e} \quad & +\{E_{s,a,e}S_{s,a+1}V_{s,a+1,e+1} \\ & +(1-E_{s,a,e})S_{s,a+1}V_{s,a+1,e}\}(1+g)/(1+i) \end{aligned} \tag{11}$$

where E denotes the school enrolment rate. Working backwards from the lifetime incomes of the most educated people, we can obtain lifetime income for individuals who are still at school.

Arguing that human capital is not restricted to market activities, Jorgenson and Fraumeni imputed the value of labour compensation for non-market activities (excluding schooling). They defined full labour income as the sum of market and non-market labour compensation after taxes. The formulae above apply similarly to both market income and non-market income. How income is divided between market and non-market depends on how much time is allocated to 'maintenance.' For example, Jorgenson and Fraumeni assumed 10 hours maintenance a day, so if a person works 40 hours a week, he would have $40 \times 52 = 2080$ hours for market activities and $(14 \times 7 - 40) \times 52 = 3016$ hours a year for non-market activities. Annual earnings, market and non-market, are derived from after-tax hourly labour compensation for each sex-education-age cohort.

Jorgenson and Fraumeni (1989) found that in 1982 prices the US stock of human capital almost doubled, from \$92 trillion in 1949 to \$171 trillion in 1984. In the later study (1992), the estimates were 20 percent higher, due to allowance being made for school enrolment. Population growth accounted for most of the increase, as per capita human capital went up by only 15 percent. Women accounted for about 40 percent of the stock of human capital and this proportion remained fairly stable throughout the period. The share of human capital due to market activities was around 30 percent.

While cost-based studies found the human capital stock to be of similar value to the physical capital stock and while earlier income-based studies observed the former to be 3-5 times greater than the latter, Jorgenson and

Fraumeni (1989) showed that human capital was worth 12-16 times more than physical capital. For the period 1948-1969, their (1992) estimates were from 17.5 to 18.8 times higher than Kendrick's (1976). According to Jorgenson and Fraumeni, this is because their estimates incorporates all sources of lifetime labour income, including investment in education, the value of rearing, and the lifetime incomes of individuals added to the population, prior to any investment in education or rearing. On the one hand, Kendrick was criticised for underestimating human capital by over-depreciating it. On the other hand, critics argue that Jorgenson and Fraumeni overestimated human capital through the treatment of non-market activities.

Even when biases are minimised, disparities in results from the two methods can hardly be avoided. As Graham and Webb (1979) pointed out, in a competitive equilibrium the value of a capital asset can be determined both by summing the costs of production and by discounting future returns. These two methods are equivalent in a world of complete certainty, perfect capital markets and no externalities. In reality, estimates from the two approaches can differ markedly since seldom do these conditions prevail.

4.4.2 Critique

The most controversial point of Jorgenson and Fraumeni's model is the assumption that human capital raises the productivity of time spent at leisure and at work equally. Rothschild (1992) refutes this argument. Their way of imputing non-market activities means that unemployment matters to the division of human capital between market and non-market activities but does not affect total human capital. As Conrad (1992) stresses, there would be no change in the human capital stock if the population is fully employed or only half employed, since non-work time will be fully imputed anyway. Besides, average earnings of workers are used to impute the value of non-market time for non-workers and this creates a sample selection bias problem. Aulin-Ahmavaara (2002) questions the full imputation of non-work time, seeing as at least some leisure time is necessary to prepare for work.

Dagum and Slottje (2000) also point out that Jorgenson and Fraumeni's model contains ability bias because it does not allow for variations in endowment among individuals of the same sex and education. Furthermore, the retirement age is set too high (Conrad, 1992); overvaluing older people's productivity results in overstating lifetime incomes for all other ages.

4.4.3 Applications to other countries

Wei (2003) applies Jorgenson and Fraumeni's framework to Australian data. Focusing on the working population, Wei only distinguishes two life-cycle stages: work and study (ages 25-34) and work only (35-65). The author identifies four education levels, based on qualifications, rather than 18 levels based on years of formal schooling as in Jorgenson and Fraumeni. Like Graham and Webb (1979), Wei finds that education and human capital are positively related and that lifetime labour income initially rises then falls for all education levels. In 2001 prices, the stock of Australia's working-age human capital increased from $3.2 trillion in 1981 to $5.6 trillion in 2001, most of which growth was caused by rising number of educated individuals. Women accounted for approximately 40 percent of the total stock of human capital. Even for such a small population base, the stock of human capital always exceeded that of physical capital, and this ratio has been rising, from 2.8:1 in 1981 to 3.1:1 in 2001.

Ahlroth et al. (1997) show that Jorgenson and Fraumeni's model can also work with micro survey data. Since their data only have 6,000 individuals for 2,196 cohorts, most cohorts have few observations and some are even empty. Ahlroth et al. (1997) resolve this problem by using regression techniques to predict the values of hourly compensation, working hours, school hours, employment rates and school enrolment rates. They found that even the lowest estimates of Sweden's human capital stock (after-tax, excluding leisure income) were 6-10 times higher than the stock of physical capital.

4.5 The income-based index method

Also basing on income to estimate human capital, some authors seek to obtain an index value instead of a monetary measure. For example, Mulligan and Sala-i-Martin (1997) measure human capital as the total labour income per capita divided by the wage of the uneducated. The rationale for this method is that labour income incorporates not only the workers' human capital but also the physical capital available to them, such that for a given level of human capital workers in regions with higher physical capital will tend to earn higher wages. Therefore, to obtain a 'pure' measure of human capital, the effect of physical capital should be netted out. Formally, the average human capital h of state i at time t is:

$$h_i(t) = \left\{ \int_0^{\infty} w_i(t,s)\eta_i(t,s)ds \right\} / w_i(t,0) \tag{12}$$

where $w_i(t,s)$ is the wage rate of a person with s years of schooling, $w_i(t,0)$ the wage rate of a zero-schooling worker, and $\eta_i(t,s)$ the fraction of people with s years of schooling. This method assumes that uneducated workers always have the same human capital, although they do not necessarily earn the same income. According to Mulligan and Sala-i-Martin, if schooling has quality and relevance that vary across time and space, any amount of schooling will introduce inter-temporal and interregional differences in an individual's level of skills. Hence, the only sensible *numeraire* is the uneducated worker. The wage rate of such a worker is estimated by the exponential of the constant term from a Mincer wage regression.

Results indicated that the US stock of human capital shrank drastically during 1940-1950, then trended upwards until 1990. Interestingly, the human capital stock expanded by 52 percent between 1980 and 1990, whereas over the four preceding decades it grew by only 17 percent. Mulligan and Sala-i-Martin also find that although their measure of human capital correlates well with average years of schooling, this correlation is not perfect. Their estimates of human capital increased much faster than schooling which, in the authors' view, was due to the improved quality and relevance of schooling.

Mulligan and Sala-i-Martin's measure clearly has some advantages.

First, by netting out the effect of physical capital on labour income, this measure captures the variation in quality and relevance of schooling across time and space. Second, this method does not unrealistically impose equal amounts of skills on workers with equal amounts of schooling. Finally, it does not demand much data. However, this model relies heavily on the assumptions that zero-schooling workers are identical and that these workers are perfectly substitutable for the rest of the labour force. These assumptions, according to Wachtel (1997), are questionable. Moreover, this method neglects the contribution to human capital by factors other than formal schooling, such as informal schooling, on-the-job training and health.

Jeong (2002) departs from Mulligan and Sala-i-Martin in that he uses as the *numeraire* the industrial labourer, as classified by the International Labour Office. According to Jeong (2002), industrial labourers, who primarily supply their physical effort with little skill, are more comparable across countries than any other types of workers. By not using schooling as a basis for comparing workers, Jeong's method avoids the problems that are inherent in education-based measures of human capital, namely the failure to account for schooling quality, for skills that are acquired outside formal schooling, and for variable rates of return to schooling across levels.

Not surprisingly, poorer countries use less human capital inputs in economic production and that the richest countries have from 2.2 to 2.8 times as much human capital as the poorest countries. These figures, however, pale into insignificance in comparison with cross-country differences in years of schooling and in output levels.

In a study on Austria and Germany, Koman and Marin (1999) construct a measure of human capital stock by weighting workers of different schooling levels by their wage income. First, based on a perpetual inventory method, the number of individuals aged i whose highest level of schooling at time t is j is computed as:

$$H_{i,j,t} = H_{i-1,j,t-1}(1-\delta_{i,t}) + H^{+}_{i,j,t} - H^{-}_{i,j,t} \tag{13}$$

where $H^{+}_{i,j,t}$ is the number of people aged i who completed education level j at time t, $H^{-}_{i,j,t}$ is the number of individuals aged i whose highest level of education was j in time $t-1$ and who completed a higher schooling level in time t, and $\delta_{i,t}$ is the probability that those aged $i-1$ in time $t-1$ died before reaching age i. After converting each schooling level j into years of schooling, the authors use a Cobb-Douglas aggregator to relate workers with different educational attainment to human capital h:

$$h = \ln\left(\frac{H}{L}\right) = \sum_{s} \omega_s \ln(\rho(s)) \tag{14}$$

where $\rho(s) = \frac{L(s)}{L}$ is the share of working-age individuals with s years of schooling; $\omega_s = \frac{e^{\gamma s} L(s)}{\sum_{s} e^{\gamma s} L(s)}$, the share of the wage income of workers with s years of schooling in the total wage bill of the economy, is the efficiency parameter of those workers; and γ 's, the slope coefficients that capture the effect of schooling on earnings, are obtained from a Mincer wage regression.

Koman and Marin's framework measures workers' productivity by their wage income. Similar to Mulligan and Sala-i-Martin's (1997) approach, Koman and Marin's efficiency parameter ω_s nets out the effect of physical capital on wages (and hence on human capital). The use of a non-linear aggregator also avoids assuming that different education levels are perfectly substitutable. A limitation remains, however, as the model assumes that one year of schooling yields the same amount of skills over time. Koman and Marin find that their measure of human capital grew faster than average years of schooling and that the time-series evidence is not consistent with a human capital augmented Solow model. Interestingly, with the inclusion of human capital, factor accumulation is less able to explain cross-country growth performance of Austria and Germany.

Laroche and Merette (2000) adopt Koman and Marin's model but additionally account for work experience. Canada's human capital, as defined by average years of schooling, increased by 15 percent during 1976-1996. The growth is 33 percent higher when human capital is measured using Koman and Marin's income-based approach, as higher education levels command rising premia. When experience is considered, average human capital grew by up to 45 percent. While the two human capital measures (including and excluding experience) were virtually the same from 1976 to 1981, they diverged afterwards. According to Laroche and Merette, this is because before 1981 schooling contributed more to human capital than work experience whereas after that the reverse was true. This pattern is reinforced by the fact that the Canadian population has grown older and as this greying trend is expected to persist, the gap between the two measures is likely to widen.

4.6 Other income-based methods

Also income-based, but Macklem's (1997) measure has a macro focus. He calculates human capital as the expected present value of aggregate labour income net of government expenditures, based on an estimated bivariate vector autoregressive model. This method requires little data. According to the author, it also permits greater recognition of the joint statistical properties of innovations in income and interest rates. These advantages are, however, counteracted by the less disaggregated information.

Macklem finds that in per capita terms, human wealth in Canada rose steeply during 1963-1973, then fell until the mid-1980s, but has picked up since. First, this was because the real interest rate was very low in the mid-1970s and high in the 1980s -- a higher interest rate reduces the cumulative growth factor and thus human wealth. Second, net income in the early 1980s was lowered by the increases in government expenditures and the drop in labour income due to the recession in the same period. Third, in the second half of the 1980s real interest rates were falling while net income was growing strongly, reversing the earlier downward trend in human wealth. Since this human wealth (capital) measure is income-based, it has a pro-cyclical pattern with economic downturns. However, Dagum and Slottje (2000) criticise Macklem's estimation for containing large, unacceptable and unsubstantiated fluctuations, in a period when Canada experienced steady economic growth. In the critics' view, this paradox is caused by the limitations in the exogenous variables specified in the bivariate autoregressive model.[5]

V. THE EDUCATION-BASED APPROACH

Unlike the 'conventional' approaches which measure capital by cost or by yield, the educational approach estimates human capital based on such educational output indicators as literacy rates, enrolment rates, dropout rates, repetition rates, average years of schooling and test scores. This method builds on the grounds that these indicators are closely related to investment in education and that (investment in) education is a key element in human capital formation. Educational indicators are, therefore, proxies for, not direct measures of, human capital. Of course, human capital encompasses more dimensions, but education is arguably the most important component. Indeed, for individuals, education can enhance well-being not only by opening up broader economic opportunities but also through non-market benefits such as improvements in health, nutrition, fertility, upbringing of children, opportunity for self-fulfilment, enjoyment and development of individual capabilities (Haveman and Wolfe, 1984). For the society, education plays a central role in economic, institutional, social and technological development.

5.1 Adult literacy rates

Typically defined as the proportion of the population aged 15 and older who are able to "read and write a simple statement on his or her everyday life" (UNESCO, 1993, p24),[6] adult literacy rates convey meaningful information about a country's general educational status. This indicator has been used in early empirical studies that control for human capital in growth equations, including Romer (1989) and Azariadis and Drazen

[5] A summary of studies that use cost-based, income-based and integrated approaches to human capital measurement is provided in Appendix Table 1.

[6] This is a rather 'narrow' definition of literacy; various definitions of literacy are discussed in Chowdhury (1995).

(1990).

As can be expected, the so-defined human capital variable has shown limited explanatory power in cross-country growth regressions. One, perhaps minor, reason lies in the fact that literacy is not objectively and consistently defined across countries and thus creates biases in international comparisons. A more important reason is, despite reflecting a fundamental component of human capital, adult literacy rates miss out most of the elements that extend beyond that elementary level, such as numeracy, logical and analytical reasoning and scientific and technological knowledge. Using adult literacy as a proxy for human capital thus ignores the contribution of more advanced skills and knowledge to productivity. As Judson (2002) assesses, literacy rates might be a good proxy for human capital in countries where the populace has little education, but not for those with universal primary education.

5.2 School enrolment rates

School enrolment rates measure the number of students enrolled at a given level relative to the population of the age group who, according to national regulation or custom, should be attending school at that level. Net and gross enrolment rates are distinguished by the numerator of the ratio. Specifically, gross enrolment rates use the total number of students enrolled at the given level, whereas net enrolment rates exclude those students who do not belong to the designated age group.

Studies that use school enrolment rates as proxies for human capital in augmented growth models include Barro (1991), Mankiw et al (1992), Levine and Renelt (1992) and Gemmell (1996). Such use is justified by the notion that the enrolled population represents the flow that adds to the existing stock of education to establish subsequent stocks. That is, enrolment rates measure the current investment in human capital that will be reflected in the stock of human capital sometime in the future.

However, enrolment rates prove poor proxies for the present stock of human capital. First, being measures of flows, enrolment rates only capture part of the continuous accumulation of the stock of human capital. Second, there is a long lag between investment in education and additions to the human capital stock; hence, current enrolment rates are indicators of the schooling level of the future, rather than current, labour force. Third, the education of current students may not be fully added to the (future) productive human capital stock because graduates may not partake in the labour force and because investment may partially be wasted through grade repetition and dropouts. Fourth, change in the stock of human capital is the difference between the human capital of those who enter and those who exit the labour force, but school enrolment rates take no account of the latter. Therefore, school enrolment rates do not even accurately reflect future flows of the human capital stock, let alone current flows or the current stock itself.

Moreover, data on school enrolment in developing countries often lack reliability. According to Barro and Lee (1993), UNESCO enrolment data primarily come from annual surveys of educational institutions in each country and reporters often overstate enrolment figures for the sake of their institutions. Besides, there could be a reverse causality between enrolment rates and productivity growth -- high enrolment may result from high productivity growth, rather than vice versa (Wolff, 2000).

In view of the pros and cons, school enrolment rates can be at best satisfactory proxies for human capital in some countries but not in others. For example, secondary enrolment rates will only be good proxies for human capital accumulation in countries where secondary education is expanding the most rapidly (Judson, 2002). Indeed, this author observes positive correlations between growth and human capital accumulation at the primary level for poor countries, at the secondary level for middle-income countries, and at the higher levels for rich countries, but no relationship between growth and human capital is found for the pooled sample.

5.3 Average years of schooling

Average years of schooling has several advantages over literacy rates and school enrolment ratios. First, it is a valid stock measure. Second, it quantifies the accumulated educational investment in the current labour force. Wachtel (1997) shows that under some reasonable assumptions, the number of schooling years is equivalent to cost-based measures of human capital.

Since primary data on years of schooling are not normally available at the country level, researchers have to construct their own data. Typically, UNESCO data on enrolment and attainment levels are used in the estimation. The studies that have attempted to develop data series on years of schooling can be divided into three groups based on the method they employ: the census/survey-based estimation method, the projection method, and the perpetual inventory method.[7]

5.3.1 The census/survey-based estimation method

Psacharopoulos and Arriagada (1986, 1992) were the first to compile data on average years of schooling for countries:

$$\overline{S} = \sum L_i D_i \tag{15}$$

where L_i is the proportion of labour-force participants with the i^{th} level of schooling and D_i the duration in years of the i^{th} level. Data on L_i were available directly from national censuses and surveys for 66 countries. For another 33 countries, the corresponding statistics had to be derived based on the educational composition of the population classified by sex and age.

Average educational attainment ranged from a low of 0.5 for Mali (1976) to a high of 12.6 for the US (1981). In addition to Mali, labour-force participants in Nigeria (1967) and Maldives (1977) had also attained on average less than one year of schooling. Mali and Nigeria, indeed, belonged to the region (West Africa) where workers were the least educated, having only 1.8 years of schooling on average. By contrast, workers in Eastern European countries and developed countries had over 10 years of schooling each. With 11.7 years per person in the labour force, New Zealand (1981) ranked third, next to the US (12.6 years) and East Germany (11.9).

For those who did not complete each schooling level, it was not known how many years they had finished. The authors thus assumed that these

[7] This classification is similar to that of Wößmann (2003).

individuals have attended half of the duration of the corresponding level. This arbitrary assumption is a potential source of measurement error, since dropout rates vary considerably across countries. Moreover, of the 99 countries covered, only for 34 countries were more than one observation available. Cross-country comparisons are further hampered by the fact that the year of observation varies from country to country, extending from 1960 to 1983 and that labour force is defined differently across countries.

5.3.2 The projection method

Kyriacou (1991) sought to overcome limitations in Psacharopoulos and Arriagada's (1986) study by using a projection method. He regressed the years of schooling data available from Psacharopoulos and Arriagada (1986) for 42 countries in the mid-1970s (from 1974 to 1977) on lagged gross enrolment ratios obtained from UNESCO Statistical Yearbook:

$$S_{1975} = \beta_1 + \beta_2 Prim_{1960} + \beta_3 Sec_{1970} + \beta_4 High_{1970} \tag{16}$$

where $Prim$, Sec and $High$ denote enrolment ratios for primary, secondary and higher education. Observing a high R^2 coefficient (0.82), Kyriacou used the estimated coefficients to predict average years of schooling for other years (1965, 1970, 1980, 1985) and other countries. In that way, five observations were obtainable for most of the 113 countries covered. This data set shows even larger dispersion in schooling attainment than in Psacharopoulos and Arriagada's data, ranging from 0.15 for Chad in the mid-1960s to 12.1 for the US in the mid 1980s. For New Zealand, the estimate increased from 8.0 to 9.3, while the country's rank fell from 5 to 12 over the period studied.

The richness in Kyriacou's data comes at the expense of substantial measurement error. His model assumed that the relationship between lagged enrolment ratios and years of schooling was stable across time and countries when in practice it never was UNESCO78. Similarities in the length of each schooling level, dropout rates and repetition rates were also implied. These strong assumptions explain why the estimates correlate well with the original data for the mid-1970s but differ massively for other periods.

5.3.3 The perpetual inventory method

Lau et al (1991) used a perpetual inventory method, which computes the stock of education S at year T by summing the enrolments E at all grade levels g for all age cohorts:

$$S_T = \sum_{T-a_{\max}+6}^{T-a_{\min}+6} \sum_{g=1}^{g_{\max}} E_{g,t}\theta_{g,t} \tag{17}$$

where $\theta_{g,t}$ is the probability that an enrolee in grade g at time t will survive to the year $T, a_{\min} = 15$ and $a_{\max} = 64$ are respectively the youngest and oldest working ages. Setting the age of school entry at six, we have $T - 64 + 6$ as the year when the oldest cohort entered school, whereas the youngest cohort started school in year $T - 15 + 6$.

This method is very data demanding. Estimating the total years of schooling for the population aged 15-64 during 1965-1985 requires data on school enrolment and mortality probabilities that go as far back as 1907. Substantial measurement error is likely, because pre-1950 and post-1980 data on enrolment were not available and thus needed to be extrapolated, and data gaps needed to be filled by interpolation. The heavy reliance on 'fabricated' statistics and the lack of benchmarking against census data is probably the major reason why Lau et al's estimates are poorly correlated with those from Psacharopoulos and Arriagada (1986). More biases could also result from ignoring dropouts, grade repetition and migration.

Nehru et al (1995) modified Lau et al's method to correct for dropouts and repetition:

$$S_T = \sum_{T-a_{\max}+6}^{T-a_{\min}+6} \sum_{g=1}^{g_{\max}} E_{g,t}(1 - r_{g,t} - d_{g,t})\theta_{g,t} \tag{18}$$

where $r_{g,t}$ and $d_{g,t}$ are repetition rates and dropout rates, which are assumed to be constant over time and across grade levels, due to data constraints. Another merit of this study is that it collected enrolment data that go as far back as 1930 for most countries and in some cases to 1902, thereby reducing the errors caused by backwards extrapolation.

Nehru et al found that workers in sub-Saharan Africa were the least educated, having acquired only 2.5 years of schooling per person by 1987. Along with East Asia, sub-Saharan Africa experienced the fastest growth in schooling, averaging 4.2 percent per annum during 1960-1987. By contrast, the corresponding growth was only 0.3 percent for industrial countries. This is because workers in these countries had received as many as 10 years of schooling per person. New Zealand performed somewhat below the industrial countries' average, with only 8.9 years per worker in 1987.

Nehru et al (1995) chose to ignore census data on attainment levels because most countries in their sample have more than one census observation and they could not determine what data point to benchmark their estimates against. Moreover, they argued that census-based estimates are not necessarily superior to estimates based on a perpetual inventory method. As a result, their study has been criticised by de la Fuente and Domenech (2000), who claim that disregarding the only direct information available on the variable of interest is hardly justifiable.

5.3.4 The Barro and Lee studies

Barro and Lee (1993) combined the three estimation methods. In fact, they applied essentially the same approach as Psacharopoulos and Arriagada's (1986, 1992); the departure in their study is on how missing data are filled.

Since census and survey data on attainment levels are available for only 40 percent of the observations, data gaps needed to be closed using other sources. Observing a high correlation (0.95) between adult illiteracy rates and the share of uneducated individuals for 158 observations, Barro and Lee used the former to fill missing data on no schooling. This exercise provided another 16 percent of the observations. Next, to impute missing data at the other broad categories (first level total, second level total and higher) the authors applied a perpetual inventory method which involves using census/survey data on attainment rates as benchmarks and estimating changes from these benchmarks on the basis of school enrolment ratios and the age structure of the population. Estimates for the sub-categories (incomplete/complete) of each level (primary, secondary and higher) were next obtained by regressing the observed completion ratios on five- and ten-year lagged values or lead values and on regional dummies. Incompletion ratios were eventually determined using various ways. With sufficient information on attainment rates, average years of schooling can be computed using a similar formula to (15).

Ahuja and Filmer (1995) built on Barro and Lee's (1993) data but used a different method to impute missing enrolment data and corrected enrolment rates for repetition and dropouts. For 1985, their estimates of average years of schooling show high correlation (from 0.88 to 0.95) with those from Kyriacou (1991), Barro and Lee (1993) and Nehru et al (1995). Their projections suggest that the strongest growth in human capital will be seen in the Middle East and North Africa, whereas sub-Saharan Africa, already the least educated region, will experience the lowest growth.

Barro and Lee (1996) also extended to ages 15-24 and used net enrolment ratios to avoid overstating enrolments. In the most recent revision (2001), gross enrolment ratios adjusted for repetition are used, so that children who enter school earlier or later are not incorrectly missed out. Allowance is also made for variations in the duration of schooling levels over time.

The Barro and Lee studies show that South Asia did not only have the lowest average years of schooling but also the highest gender inequality in education. In 1960, females in this region received 28 percent as much schooling as males, rising to 48 percent in 1985. By contrast, in OECD countries the gender ratio has stabilised around 94 percent. Interestingly, while New Zealand never got to the top 10 in Kyriacou's and Nehru et al's data sets, it frequently tops Barro and Lee's lists. Besides, Barro and Lee's (1993) estimates for some countries (Portugal, Spain and Turkey) appear substantially lower than the corresponding estimates from Kyriacou (1991) which, according to Wolff (2000), is too large to be attributable to the difference in population bases alone. However, Wolff observes that Barro and Lee's data show greater internal consistency over time than Kyriacou's. This view is shared by de la Fuente and Domenech

(2000), who assess that Barro and Lee's procedure should be theoretically superior to Kyriacou's because it utilises more information and avoids making strong implicit assumptions.

But de la Fuente and Domenech point out that the widely used Barro and Lee data contain a lot of noise, leading to unjustifiable inconsistencies in country rankings across data sets as well as implausible jumps and breaks in the time-series patterns. To make their case, the critics draw on attainment data from previously unexploited sources to revise Barro and Lee's (1996) data for OECD countries. They use interpolation and extrapolation, rather than the perpetual inventory method, to impute missing observations. These authors rely on subjective judgment to select the most 'plausible' figure in the presence of multiple observations or sharp breaks. According to their estimates, in 1990 New Zealanders aged 25 and above had on average 12.1 years of schooling, compared with 11.2 as in Barro and Lee (1996), yet the country's ranking in the OECD went from third place down to sixth place.

Most interestingly, de la Fuente and Domenech's estimates outperform those developed by Barro and Lee (1996) or Nehru et al (1995) in several growth specifications. Although de la Fuente and Domenech's method involves considerable guesswork and lacks scientific underpinning, their results lend support to the argument that poor data quality is a principal cause behind the 'growth puzzle' -- the lack of relationship between economic growth and human capital formation -- in the recent literature.

Also critical of Barro and Lee's estimates, Cohen and Soto (2001) seek to minimise potential error by obtaining as much observable data as possible. Missing data are imputed based on the assumption that the school attainment of the population aged T in one census is equal to the school attainment of the population aged $T-n$ in the census conducted n years earlier or, when this information is not available, the attainment of the population aged $T+m$ in the census conducted m years later. Only in the absence of relevant census information do Cohen and Soto (2001) resort to enrolment data and the perpetual inventory method.

Cohen and Soto's estimates correlate well (about 90%) with Barro and Lee's (2001), but the correlation drops to below 10 percent in first differences. The authors maintain that this disagreement is caused by

Barro and Lee's estimates being plagued with measurement error, which is most visible from the several 'implausible' figures. Cohen and Soto also believe that while Barro and Lee's estimates are biased downwards, de la Fuente and Domenech's (2000) are biased in the opposite direction, even though very high correlation (94%) is observed between the latter and their results.

5.3.5 Summary

The sound theoretical grounds and reasonable availability of data are major reasons why years of schooling has been widely used in human capital studies, at both micro and macro levels. Years of schooling has become the most common proxy for human capital in growth models.[8] However, it does not seem to improve the explanatory power of cross-country growth regressions. Such a disappointing outcome is often attributable to many imperfections inherent in this indicator.

First, years of schooling fails to account for the fact that costs and returns of education vary hugely from level to level. This measure incorrectly assumes that one year of schooling always raises human capital by an equal amount. For example, a worker with 10 years of schooling is assumed to have 10 times as much human capital as a worker with one year of schooling. This assumption is at odds with the empirical literature which has typically documented diminishing returns to education (Psacharopoulos, 1994).

Second, no allowance is made for differences in quality of education across time and space. Behrman and Birdsall (1983), based on some Brazilian evidence, found that neglecting quality of schooling biased returns to schooling. Since the quality of schooling varies more considerably across countries than within one country, overlooking quality is likely to create more severe biases.

Third, this measure unrealistically assumes that workers of different education categories are perfect substitutes for each other, as long as their years of schooling are equal. As Judson (2002) puts it, using years of schooling as a human capital stock measure is analogous to estimating

[8] Examples include Barro (1997, 1999), Barro and Sala-i-Martin (1995), Benhabib and Spiegel (1994), Islam (1995), Krueger and Lindahl (2001), Temple (1999) and Wolff (2000).

physical stocks by counting the number of buildings, rather than valuing different kinds of buildings differently.

Fourth, it is debatable whether or not schooling raises productivity. Starting from Arrow (1973), there has been evidence that schooling does more to 'signal' abilities to employers than to truly enhance skills. If this was the case, years of schooling may increase even when the true (but unobservable) human capital remains the same. In reality, the effect of schooling may be less extreme, but to the extent that schooling has a 'signalling' effect, years of schooling will be a biased measure of human capital.

Moreover, years of schooling completely ignores all human capital elements other than formal schooling, including health, on-the-job training, informal schooling and work experience. A clear example is that this measure treats uneducated individuals as having no human capital, even though in practice they are economically valuable as long as they work.

Data quality introduces another source of measurement error. As reviewed earlier, the methods that have been used to estimate schooling years are more or less flawed. Many authors, including de la Fuente and Domenech (2000), Krueger and Lindahl (2001) and Cohen and Soto (2001), argue that it is the lack of good data, rather than the characteristics of the variable itself, that has rendered years of schooling a poor proxy for human capital. This is quite clear from the discrepancies in New Zealand's rankings across data sets, ranging from top positions in Barro and Lee (1993, 1996, 2001) to 21st place in Nehru et al (1995).

According to Krueger and Lindahl (2001), until recently, the macro literature had not paid adequate attention to potential problems caused by measurement error in education. These authors show that country-level schooling data are no more reliable than micro data. For example, the correlation between schooling data from Barro and Lee (1993) and Kyriacou's (1991) in 1985 is 0.86, dropping to 0.34 for changes between 1965 and 1985. Additional estimates of the reliability of country-level data further confirm their belief that measurement error in education severely distorts results from growth regressions that control for human capital (Krueger and Lindahl, 2001).[9]

5.4 Quality of schooling

According to Hanushek and Kimko (2000), quality issues have been neglected because it is taken for granted that variations in the quality of human capital are of much less importance than variations in its quantity. Such an omission has proved a mistake.

Recognising the limitations that contaminate measures of quantity of schooling, Barro and Lee (1996) and Lee and Barro (2001) allow for the quality dimension. They consider such input indicators as public educational spending per student, pupil-teacher ratios, salaries of teachers and length of the school year, and such outcome indicators as repetition and dropout rates. In fact, these measures are more or less a version of the cost-based approach to human capital evaluation.

As summarised in Appendix Table 4, not only does New Zealand lag behind the OECD average but it also ranks very low by international standards, especially on pupil-teacher ratios at the secondary level, ratios of government educational spending per pupil to GDP per capita and ratios of primary school teachers' salaries to GDP per capita. However, the country fares much better on the outcome measures (repetition rates and dropout rates). While New Zealand's rankings on the input indicators have improved over time, its rankings on the outcome side have worsened.

Barro and Lee (2001) introduce another 'quality' measure: test scores. In theory, test scores are good human capital indicators because they measure educational outcome, cognitive skills, and they ensure international comparability. Until the early 1990s, New Zealand students scored well in mathematics, science and reading. Yet their performance is more disappointing in the most recent test (the Third International Mathematics and Science Study, TIMSS, 1994-1995), where New Zealand ranked 23rd out of the 37 participating countries (see Appendix Table 5).

Unlike tests for students, the International Adult Literacy Test (IALS)

[9] Appendix Tables 2-3 contain a summary of studies that measure the stock of human capital based on average years of schooling.

directly measures the human capital of labour-force participants, and unlike other schooling indicators, this test captures the knowledge that is gained outside formal education. Therefore, IALS test scores have attracted considerable interest, as well as criticism, in human capital measurement. New Zealand performs poorly in this test, ranking from seventh on prose literacy to 13th on quantitative literacy out of a sample of 20 countries. These results put New Zealand on par with Australia and the US but well below the top performers (Sweden, Norway, Finland and Denmark). Overall, there is huge variation in literacy scores across OECD countries, despite the similarity in average years of schooling in their labour force. Barro and Lee (2001) also notice a large discrepancy in achievement between students and adults. For example, the correlation between the TIMSS mathematics score for seventh grade students and the IALS quantitative literacy score for adults, in the common sample of 17 countries, is only 0.32.

The existence of so many ‘quality’ measures, most of which are poorly correlated with each other and with quantity measures of schooling, seems to create confusion rather than to resolve the human capital measurement puzzle. Those education-based measures of human capital, the most widely used measures of this variable, produce results that are often at odds with each other. The case of New Zealand provides a telling example: ranking for this country varies wildly not only across indicators, from first to 117th, but also across different data sets of the same indicator, from first to 20th (see Appendix Tables 3-6).

To settle this problem, Hanushek and Kimko (2000) develop a measure that incorporates all available information on international mathematics and science test scores. Data are available for 26 performance series for different ages, sub-test scores, and various years from 1965 to 1991. For their first measure (QL1), data on each of the series are transformed to having a world mean of 50. The second measure (QL2) adjusts all scores according to the US international performance, modified for the national temporal pattern of scores provided by the National Assessment of Educational Progress (NAEP). These national tests serve as an absolute benchmark to which the US scores on international tests can be keyed, whereby the mean of each international test series is allowed to drift in reference to US NAEP score drift and to the mean US performance on each international comparison. Measures of schooling quality for each country are then constructed by averaging all available transformed test scores, weighted by the normalised inverse of the country-specific standard error for each test.

Hanushek and Kimko's measure has the advantage of combining various indicators of quality in one index, but it can be misleading because test scores do not just reflect schooling quality -- they may also pick up unobserved variables, such as innate abilities. Besides, a measure of schooling quality is not necessarily a good measure of labour-force quality, as past and current students may be quite different from current workers. Moreover, because data on internationally comparable test scores are limited, Hanushek and Kimko have to impute missing values and in that way can not escape from the second type of measurement error, namely low data quality.

Wößmann (2003) makes further improvements by incorporating Hanushek and Kimko's quality measure into stock measures. First, the author expresses Hanushek and Kimko's estimate for each country as a ratio to the estimate for the US. This relative measure can be used as quality weights for a year of schooling in a country, with the weight for the US being unity. World average rates of return to education are finally integrated to arrive at a quality-adjusted measure of human capital stock:

$$h_i^Q = e^{\sum_a r_a Q_i s_{ai}} \tag{19}$$

where r_a denotes the world average rate of return to education at level a, Q_i refers to Hanushek and Kimko's educational quality index for country i relative to the US value, and s_{ai} is average years of schooling at level a in country i.

Employing data from Barro and Lee (2001) for average years of schooling, from Psacharopoulos (1994) for average rates of return to education, and from Hanushek and Kimko (2000) for a of schooling quality, Wößmann shows that New Zealand is the richest country in the world in terms of human capital, having 150% more human capital per person than the US (see Appendix Table 6).

Wößmann's measure allows human capital to rise continually, just like physical capital, instead of being bound by a limit like other quantity measures of human capital. Furthermore, this measure captures quantity as well as some aspects of schooling quality in one single number. However, this method is very data demanding, and to the extent that the estimates in Barro and Lee (2001), Psacharopoulos , and Hanushek and Kimko are biased by mismeasurement, Wößmann's measure will also be biased.

5.5 Summary of education-based measures

Education-based measures of human capital, including literacy rates, school enrolment rates and average years of schooling, are easy to quantify and have good international data coverage. These measures give a rough idea of how much human capital a country has. However, they have been criticised for not adequately reflecting key aspects of human capital and for emphasising quantity over quality. By being based upon some crude proxy for education so far experienced, these measures neither capture the richness of knowledge embodied in humans nor quantify the flow of future benefits of the knowledge accrued. Indeed, they have been found to be at best relevant to one group of countries but not to another group that is at a different stage of development. The use of these indicators has also been hampered by deficiencies in the data. Recently, ample evidence has been gathered which shows that it is how they are measured, rather than what they measure, that renders these indicators poor proxies for the true stock of human capital.

Although Barro and Lee (1996, 2001) and Lee and Barro (2001) account for quality of schooling, their method has complicated the matter. Since quality is multidimensional, many indicators of quality have to be considered, yet estimates across indicators are very poorly correlated. Hanushek and Kimko (2000) combine several test scores in an index of schooling quality and Wößmann (2003) incorporates this indicator, together with average rates of returns to education, in a comprehensive quality-adjusted measure of human capital. However, as with pure quantity measures of schooling, errors in recording data and imputing missing data on the quality indicators are a potential source of bias. Given the dubious quality of his data, the reliability of Wößmann's estimates of human capital is not warranted.

VI. THE INTEGRATED APPROACH

Recognising that no single approach to human capital measurement is free from limitations, some researchers combine different methods in order to exploit their strengths and neutralise their weaknesses.

Tao and Stinson (1997) integrate the cost and income methods. They note that investments in human capital determine the human capital stock, which can be established by the cost method. Human capital, in turn, determines earnings through the income-based approach:

$$Y_{s,a,e} = w_t h_{s,a,e} \tag{20}$$

where h and Y are respectively human capital and earnings, s, a and e denote the sex, age and education level of an individual, and w_t is the human capital rental rate in year t.

Since both of the right-hand side variables are unobservable, one of them must be standardised. Tao and Stinson choose to standardise the human capital stock of base entrants. This group is selected because they enter the labour force straight after leaving high school, thus no allowance needs to be made for the impact that experience, on-the-job training and the cost of training have on their human capital. The ability of these base entrants can be determined from the Scholastic Aptitude Test (SAT) scores. This test provides a consistent measure of the ability of high school graduates and SAT results are available for many years.[10]

The human capital stock of base entrants is estimated as the accumulated real expenditures on their general education. Once the human capital of these individuals is defined, the human capital rental rate w can be estimated by applying earnings data to equation (20). That

[10] The SAT data suffer from a self-selection bias, since students have the choice whether or not to take the test. Tao and Stinson (1997) have, however, corrected for this problem.

rental rate, which is assumed to be constant across cohorts, can then be plugged into equation (20), together with earnings, to derive the human capital stock for other cohorts.

It is found that the human capital stock of the US employed work force expanded sixfold between 1963 and 1988. When differences in the abilities of base entrants are considered, specifically, when entry-level wages are assumed to match the SAT scores of base entrants, the growth reduced to less than 100 percent. The increase was greater for females (135%) than for males (75%), largely due to rising labour supply by the former.

Tao and Stinson claim that by using the cost method to estimate human capital for only base entrants, their framework avoids the problem of what constitutes an investment in human capital in the population. Besides, this approach requires no assumptions about depreciation in human capital. However, a problem of the cost method remains unsettled. Specifically, how good are educational expenses at measuring the human capital of base entrants? Moreover, this model assumes that base entrants are paid according to their ability as measured by the SAT score, but whether or not SAT scores are a good indicator of ability is open to question.

Also combining various methods, Dagum and Slottje (2000) define human capital as a dimensionless latent variable:

$$z = L(x_1, x_2, x_3, \ldots, x_p) \tag{21}$$

where z is a standardised (zero mean and unit variance) human capital latent variable, and x_1, x_2, x_3, ..., x_p are standardised indicators of human capital. An accounting value of human capital for the i^{th} economic unit is given as:

$$h_i = e^{z_i} \tag{22}$$

Dagum and Slottje then adopt Jorgenson and Fraumeni's (1989) method to estimate H_x, the human capital of the average economic unit aged x. The monetary value of human capital of the i^{th} sample observation is:

$$H_i = h_i \frac{\overline{H}}{\overline{h}} \tag{23}$$

where $\overline{h}$ and $\overline{H}$ are respectively the average values of h_i and H_x. Intuitively, the monetary value of a person’s human capital is equal to the average lifetime earnings of the population, weighted by the level of human capital that he has relative to the average human capital of the population.

Dagum and Slottje estimate that per capita human capital ranged from $239,000 to $365,000 in 1982, depending on the choices of the discount rate and the economic growth rate. In real terms, their lowest estimate is still twice Kendrick’s (1976) estimate for 1969, yet they are only a fraction of those obtained by Jorgenson and Fraumeni (1989, 1992) because the latter incorporate non-market human capital.

While previous studies only estimated average human capital of cohorts, Dagum and Slottje are able to estimate the human capital of individuals. Theoretically, the latent variable approach can remove the omitted variable bias of the income-based method. However, this innovation is hampered by the lack of data on intelligence, ability, or hard work. Besides, their model assumes a standardised normal distribution of human capital; whether or not human capital is normally distributed is controversial. Furthermore, as with the income-based method, results obtained from this integrated framework are very sensitive to assumptions regarding the retirement age, discount rate and real income growth rate.

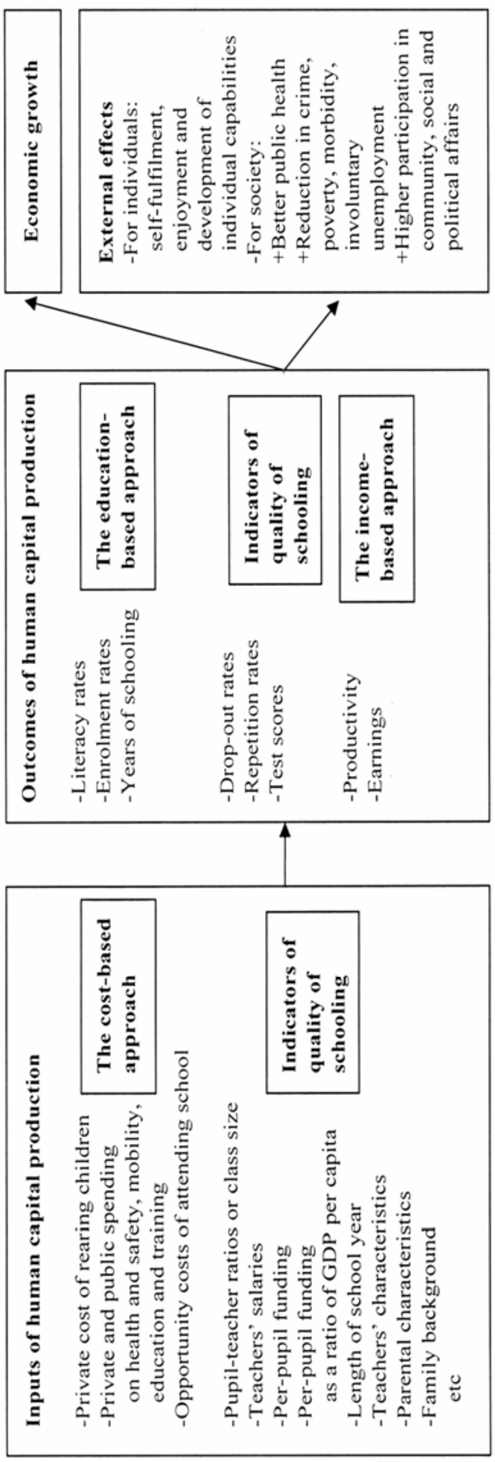
VII. SUMMARY OF APPROACHES TO HUMAN CAPITAL MEASUREMENT

Different as they may seem, the cost-, income- and education-based approaches are not unrelated. Figure 1 shows how these models are connected. In words, inputs in the human capital production process, such as costs of rearing and educating people, form the basis for the cost method. The income method builds on individuals’ earnings, whereas such indicators as literacy rates, school enrolment rates and average years of schooling have widely been used as education-based measures of human capital.

There has been a radical change in the motivation behind human capital valuation. Early studies were more concerned with demonstrating the power of a nation, with estimating the money values of human loss from wars and plagues, and with developing accurate measures of human wealth in national accounts. Recently, the focus has switched to using human capital as a tool to explain economic growth across countries. Human capital is believed to play a critical role in the growth process, as well as producing positive external effects such as enhanced self-fulfilment, enjoyment and development of individual capabilities, reduction in poverty and delinquency, and greater participation in community and in social and political affairs.

However, the impact of human capital on economic growth has not been empirically supported. The lack of empirical consensus arises because approaches to human capital valuation build on sound theoretical underpinning, yet none of them is free from shortcomings. Each approach is more or less subject to two types of measurement error: the measure does not adequately reflect key elements of human capital, and data on the measure are of poor quality. Therefore, properly measuring human capital remains a challenge.

[Figure 1] Human capital production and common approaches to human capital measurement



Appendix

Appendix Table 1: Summary of studies on measuring human capital using cost-based, income-based, and integrated approaches

Source	Method	Country, time	Motivation	Results
Petty (1690)	Income-based	England and Wales	-Interest in public finance -To evaluate the power of England, the economic effects of migration, the loss caused by a plague or by men killed in war	Aggregate stock was about £520 million, or £80 per capita.
Farr (1853)	Income-based	England	Interest in public finance: taxing human capital	Net value of per capita human capital was about £150.
Engel (1883)	Cost-based	Germany		
Wittstein (1867)	Income-based (Farr's approach), combined with cost-based (Engel's approach)	Germany	To determine a guide to be based on for claims for compensation from loss of life	
Nicholson (1891, 1896)	Income-based, combined with cost-based	United Kingdom, 1891	To estimate the stock of "living" capital	The stock of living capital was about 5 times that of conventional capital.
De Foville (1905)	Income-based (Petty's approach)	France, around 1900		
Fisher (1908)	Income-based (Farr's approach)	United States (US), 1907	To estimate the cost of preventable illness and death	The stock of human capital exceeded all other wealth.
Barriol (1910)	Income-based (Farr's approach)	France and other selected countries	To estimate the social value of an individual	

Huebner (1914)	Income-based (Farr's approach)	US, around 1914		The stock of human capital was 6-8 times that of conventional capital.
Wickens (1924)	Income-based (Farr's approach)	Australia, 1915		The human capital stock of £6,211 million (or £1,246 per capita) was about 3 times as large as the physical capital stock.
Woods and Metzger (1927)	5 different methods, including -Farr's approach -Petty's approach	US, 1920	To show the importance of the nation's population	
Dublin (1928)	Unknown	US, 1922		The stock of human wealth was about 5 times that of material wealth.
Dublin and Lotka (1930)	Income-based (improved from Farr's approach)		-To estimate how much life insurance a man should carry -To estimate the economic costs of preventable disease and premature death	
Schultz (1961a)	Cost-based	US, 1900-1956	Economic growth, productivity	The stock of human capital grew twice as fast as that of physical capital.
Weisbrod (1961)	Income-based	US, 1950, males aged 0-74	To estimate the value of the human capital stock	-Gross: \$1,335b at $i = 10\%$, \$2,752b at $i = 4\%$ -Net (of consumption): \$1,055b and \$2,218b respectively -Compared with non-human assets of \$881b
Kendrick (1976)	Cost-based	US, 1929-1969	To develop national wealth estimates to complement estimates of the physical stock in the national accounts	The stock of human capital was often greater and grew faster than that of physical capital.
Graham and Webb (1979)	Income-based	US, 1969, males aged 14-75	National accounts	The stock of human capital ranged from \$2,910 billion at 20% discount rate to \$14,395 billion at 2.5% discount rate. This contrasted with an estimate

				of $3,700 billion that Kendrick (1976) obtained based on the cost method.
Eisner (1985)	Cost-based	US, 1945-1981 (selected years)	To implement the total incomes system of accounts	The stock of human capital was almost as large as that of physical capital.
Jorgenson and Fraumeni (1989, 1992)	Income-based	US, 1947-1986	-To present a new system of national accounts for the US economy -To measure the output of the education sector	The stock of human capital almost doubled between 1949-1984. Per capita human capital grew by only 15% during 1947-1986. Women's share was around 40%. The share of human capital based on market activities was around 30%. Human capital was 12-16 times greater than physical capital in size. For the period 1948-1969, their (1992) estimates were from 17.5 to 18.8 times higher than Kendrick's (1976).
Ahlroth et al (1997)	Income-based (Jorgenson and Fraumeni's method)	Sweden, 1968, 1974, 1981 and 1991	To derive the aggregate measures of the output of the Swedish education sector that can serve as alternatives to the input-based measures that are traditionally used in the national accounts	Even the lowest estimates of the human capital stock (after taxes, excluding leisure income) were 6-10 times higher than the stock of physical capital.
Macklem (1997)	Income-based (macro focused)	Canada, 1963-1994, quarterly	To provide a comprehensive measure of aggregate private sector wealth that includes both human and non-human components	Per capita human wealth rose steeply from 1963 to 1973, then decreased well into the mid-1980s, but has picked up since. The ratio of aggregate human wealth to non-human wealth fell from 8:1 in the early 1960s to about 3:1 in the 1990s.
Mulligan and Sala-i-Martin (1997)	Income-based	48 US continental states, 6 census years (1940, 1950, 1960, 1970, 1980,	To provide an alternative measure of human capital	The stock of human capital shrank substantially between 1940 and 1950, then rose steadily to 1990. Between 1980 and 1990, the stock of human capital increased by 52%, whereas over the 4 earlier

		1990)		decades it grew by only 17%.
Tao and Stinson (1997)	Integrated	US, 1963-1988, employed work force	To provide an alternative approach to human capital measurement which circumvents the problems of the cost- and income-based approaches	The effective human capital stock expanded by 6 times. When differences in the abilities of base entrants are considered, the growth dropped to less than 100%. The expansion was greater for females (135%) than for males (75%), largely due to the increased labour-force participation by the former.
Koman and Marin (1999)	Income-based	Austria and Germany, aged 15 and over, 1960-1997	To assess the impact of human capital on economic growth	Human capital grew over twice as fast as average years of schooling.
Dagum and Slottje (2000)	Integrated	US, 1982	To estimate the monetary value of personal human capital and to examine its size distribution	Average human capital ranged from $239,000 to $365,000. In real terms, their lowest estimate is still twice Kendrick's (1976) estimate for 1969, but well below those obtained by Jorgenson and Fraumeni (1989, 1992) and Macklem (1997).
Laroche and Merette (2000)	Income-based (Koman and Marin's (1999) method)	Canada, aged 15-64, 1976 to 1996	To provide an alternative measure of human capital	While average years of schooling increased by 15%, human capital, as measured by Koman and Marin's method, grew by 33%. When experience is accounted for, average human capital increased by up to 45%.
Jeong (2002)	Income-based (Mulligan and Sala-i-Martin's (1997)	45 countries	To compare human capital inputs for countries of diverse output levels	The richest countries have from 2.2 to 2.8 times as much human capital as the poorest countries.
Wei (2003)	Income-based (Jorgenson and Fraumeni's method)	Australia, aged 25-65, 1981-2001 quinquennially	To present systematic estimates of the stock of human capital for Australia	The stock of human capital increased by 75%. Women's share was approximately 40%. The stock of human capital was 3 times as large that of physical and this ratio has been rising.

Appendix Table 2: Summary of studies on measuring human capital using an education-based approach

Source	Data coverage	Population base	Method of constructing average years of schooling	Highlighted results
Psacharopoulos and Arriagada (1986)	99 countries, various years from 1960 to 1983	Labour force	$\overline{S} = D_p(\frac{1}{2}L_{p1} + L_{p2}) + (D_p + \frac{1}{2}D_s)L_{s1} + (D_p + D_s)L_{s2}$ $+(D_p + D_s + D_h)L_h$ where $\overline{S} =$ average years of schooling, $L_i =$ share of the labour force with the i^{th} level of schooling, $i = p1$ for incomplete primary, $p2$ for complete primary, $s1$ for incomplete secondary, $s2$ for complete secondary, and h for higher, $D =$ duration in years of the i^{th} level, and i refers to primary (p), secondary (s) and higher education (h)	Top 5 countries: US 12.6 D R Germany 11.9 Canada 11.7 **New Zealand** 11.7 Czechoslovakia 11.5
Kyriacou (1991)	113 countries, for 1965, 1970, 1975, 1980, 198	Labour force	$S_{1975} = \beta_1 + \beta_2 \times Prim_{1960} + \beta_3 \times Sec_{1970} + \beta_4 \times High_{1970}$ where $Prim, Sec, High =$ enrolment ratios for primary, secondary and higher education respectively, $\beta_1 = 0.052$, $\beta_2 = 4.439$, $\beta_3 = 2.665$, $\beta_4 = 8.092$	Top 5 countries in 1985: US 12.09 Finland 10.83 Germany 10.33 Israel 10.03 Canada 9.98
Lau et al. (1991)	58 developing countries, from 1965 to 1985	Working age population (15-64)	$S_T = \sum_{T-a_{max}+6}^{T-a_{min}+6} \sum_{g=1}^{g_{max}} E_{g,t}\theta_{g,t}$ where $S_T =$ total stock of education at year T $E =$ enrolment number of grade g at time t $\theta_{g,t} =$ probability that an enrolee will survive to year T	

			a_{min} = 15, youngest working age a_{max} = 64, oldest working age 6 = school entry age	
Barro and Lee (1993) [a]	129 countries, 5-yearly periods from 1960 to 1985	Population aged 25 and over	$\overline{S} = D_p(\frac{1}{2}h_{ip} + h_{cp}) + (D_p + D_{s1})h_{is} + (D_p + D_{s1} + D_{s2})h_{cs}$ $+(D_p + D_{s1} + D_{s2} + \frac{1}{2}D_h)h_{ih} + (D_p + D_{s1} + D_{s2} + D_h)h_{ch}$ where h_j = share of the adult population with the highest level of schooling j, $j = ip$ for incomplete primary, cp for complete primary, is for first cycle secondary, cs for second cycle secondary, ih for incomplete higher, and ch for complete higher, D = duration in years of the i^{th} level, and i refers to primary (p), first cycle secondary ($s1$), second cycle secondary ($s2$) and higher education (h)	Top 5 countries in 1985: **New Zealand** 12.04 USA 11.79 Hungary 10.75 Norway 10.38 Canada 10.37
Nehru et al. (1995) [b]	85 countries, 1960-1987	Working-age population (15-64)	$S_T = \sum_{T-a_{max}+6}^{T-a_{min}+6} \sum_{g=1}^{g_{max}} E_{g,t}(1 - r_{g,t} - d_{g,t})\theta_{g,t}$ where $r_{g,t}$ = repetition rates $d_{g,t}$ = dropout rates	Top 5 countries in 1987: Israel 12.58 US 11.62 Japan 10.99 Great Britain 10.21 Canada 10.01

Ahuja and Filmer (1995)	81 developing countries, for 1985, 1990, 1995	Population aged 6-60	Built on data from Barro and Lee (1993)	In 1995: High: 6.9 (East Asia and the Pacific Low: 4.0 (Sub-Saharan Africa)
Barro and Lee (1996) [c]	126 countries, 5-yearly periods from 1960 to 1990	Population aged 15 and over	Revised from Barro and Lee's (1993) data	Top 5 countries in 1990: USA 11.74 **New Zealand** 11.25 Denmark 10.7 U.S.S.R. 10.50 Australia 10.39
de la Fuente and Doménech (2000)	21 OECD countries, 5-yearly periods from 1960 to 1990	Population aged 25 and over	Revised from Barro and Lee's (1996) data	Top 5 countries in 1990: Germany 12.99 USA 12.91 Canada 12.8 Switzerland 12.53 Australia 12.28
Cohen and Soto (2001) [d]	95 countries, 10-year intervals from 1960 to 2010	Population aged 15-64		Top 5 countries in 2000: UK 13.12 Australia 13.09 Canada 13.07 Germany 12.95 Switzerland 12.73

Barro and Lee (2001)[e]	142 economies, 5-yearly periods from 1960 to 2000	Population aged 15 and over	Revised from Barro and Lee's (1996) data	Top 5 countries in 2000: USA 12.05 Norway 11.85 **New Zealand** 11.74 Canada 11.62 Sweden 11.41
Krueger and Lindahl (2001)	34 countries, mostly surveyed in 1990	Labour Force	Derived from The World Values Survey	Top 5 countries: Norway 13.43 USA 13.26 Sweden 12.79 Finland 12.61 Canada 12.6

Sources:

a *Barro-Lee Data Set: Educational Attainment Data, 1960-1985, International Comparisons of Educational Attainment*

b *Nehru and Dhareshwa Data Set*

c *Barro-Lee Data Set, International Measures of Schooling Years and Schooling Quality*

d Data available at http://www.oecd.org/dataoecd/33/13/2669521.xls

e Data available at http://www.cid.harvard.edu/ciddata/ciddata.html

Appendix Table 3: Average years of schooling: New Zealand in comparison with Australia and the United States

Source	Year	Countries	New Zealand	Australia	United States
Psacharopoulos and Arriagada (1986)	1981*	99	11.7 (3)	11.1 (8)	12.6 (1)
Kyriacou (1991)	1965	80	7.97 (5)	6.91 (8)	9.82 (1)
	1970	89	7.94 (6)	7.39 (10)	10.40 (1)
	1975	109	8.31 (9)	7.81 (15)	11.95 (1)
	1980	109	8.79 (11)	8.26 (15)	12.02 (1)
	1985	113	9.28 (12)	8.72 (18)	12.09 (1)
Barro and Lee (1993)	1960	101	9.61 (1)	8.93 (3)	8.67 (4)
	1965	98	9.54 (1)	8.94 (4)	9.36 (3)
	1970	102	9.69 (3)	10.09 (2)	10.14 (1)
	1975	108	11.16 (1)	10.01 (4)	10.77 (2)
	1980	110	12.14 (1)	10.08 (7)	11.89 (2)
	1985	106	12.04 (1)	10.24 (7)	11.79 (2)
Barro and Lee (1996) (Population aged 25+)	1960	107	9.55 (2)	9.03 (3)	8.66 (5)
	1965	107	9.42 (2)	8.94 (4)	9.25 (3)
	1970	109	9.37 (4)	10.09 (1)	9.79 (3)
	1975	114	11.00 (1)	9.81 (4)	10.01 (3)
	1980	113	11.94 (1)	10.02 (6)	11.91 (2)
	1985	113	11.88 (1)	10.06 (5)	11.71 (2)
	1990	112	11.18 (3)	10.12 (8)	12.00 (1)
Barro and Lee (1996) (Population aged 15+)	1960	107	9.7 (3)	9.28 (4)	8.49 (5)
	1965	107	9.74 (2)	9.18 (4)	9.09 (5)
	1970	109	9.72 (3)	10.24 (1)	9.56 (5)
	1975	114	11.27 (1)	10.14 (2)	9.69 (6)
	1980	114	11.94 (1)	10.29 (4)	11.86 (2)
	1985	114	11.91 (1)	10.32 (4)	11.56 (2)
	1990	113	11.25 (2)	10.39 (5)	11.74 (1)
Nehru et al (1995)	1960	83 each year	5.7 (21)	6 (19)	10.73 (2)
	1961		5.76 (21)	5.98 (19)	10.72 (2)
	1962		5.82 (21)	5.97 (19)	10.7 (2)
	1963		5.89 (21)	5.96 (20)	10.68 (2)
	1964		5.96 (21)	5.96 (20)	10.67 (2)
	1965		6.03 (20)	5.97 (22)	10.66 (2)
	1966		6.14 (21)	5.99 (22)	10.67 (2)
	1967		6.26 (21)	6.03 (22)	10.68 (2)
	1968		6.38 (21)	6.07 (22)	10.69 (2)
	1969		6.46 (20)	6.12 (22)	10.7 (2)
	1970		6.55 (20)	6.16 (22)	10.71 (2)
	1971		6.66 (20)	6.24 (22)	10.74 (2)
	1972		6.76 (20)	6.31 (21)	10.75 (2)
	1973		6.88 (20)	6.39 (21)	10.77 (2)
	1974		6.99 (19)	6.46 (21)	10.78 (2)

	1975		7.11 (19)	6.54 (21)	10.8 (2)
	1976		7.24 (17)	6.63 (21)	10.84 (2)
	1977		7.38 (17)	6.72 (21)	10.88 (3)
	1978		7.53 (17)	6.81 (21)	10.92 (2)
	1979		7.68 (17)	6.91 (21)	10.96 (2)
	1980		7.82 (17)	6.98 (22)	10.98 (2)
	1981		7.97 (17)	7.08 (22)	11.09 (2)
	1982		8.11 (16)	7.16 (22)	11.19 (2)
	1983		8.24 (14)	7.24 (23)	11.28 (2)
	1984		8.38 (13)	7.32 (24)	11.35 (2)
	1985		8.51 (13)	7.4 (24)	11.41 (2)
	1986		8.68 (11)	7.5 (24)	11.52 (2)
	1987		8.85 (11)	7.6 (25)	11.61 (2)
de la Fuente and Domenech (2000)	1960	21 each year	10.46 (3)	10.15 (4)	11.44 (2)
	1965		10.72 (3)	10.67 (4)	11.69 (2)
	1970		10.98 (4)	11.15 (3)	11.93 (2)
	1975		11.3 (4)	11.43 (3)	12.24 (1)
	1980		11.6 (5)	11.71 (3)	12.53 (2)
	1985		11.86 (6)	12.00 (4)	12.74 (1)
	1990		12.11 (6)	12.28 (5)	12.91 (2)
Barro and Lee (2001) (Population age 25+)	1960	99	9.55 (1)	9.43 (2)	8.66 (4)
	1965	99	9.42 (1)	9.3 (2)	9.25 (3)
	1970	101	9.36 (3)	10.09 (1)	9.79 (2)
	1975	106	11 (1)	9.81 (3)	10.01 (2)
	1980	105	11.43 (2)	10.02 (5)	11.91 (1)
	1985	105	11.43 (2)	10.06 (4)	11.71 (1)
	1990	107	11.18 (2)	10.12 (6)	12 (1)
	1995	104	11.31 (3)	10.31 (6)	12.18 (1)
	2000	104	11.52 (3)	10.57 (6)	12.25 (1)
Barro and Lee (2001) (Population age 15+)	1960	99	9.7 (2)	9.73 (1)	8.49 (5)
	1965	99	9.74 (1)	9.57 (2)	9.09 (3)
	1970	101	9.72 (2)	10.24 (1)	9.53 (4)
	1975	106	11.27 (1)	10.14 (2)	9.69 (4)
	1980	106	11.47 (2)	10.29 (5)	11.87 (1)
	1985	107	11.5 (2)	10.32 (4)	11.57 (1)
	1990	109	11.25 (3)	10.38 (5)	11.74 (1)
	1995	105	11.49 (3)	10.67 (6)	11.89 (1)
	2000	105	11.74 (3)	10.92 (6)	12.05 (1)
Cohen and Soto (2001)	1960	95 each year	8.98 (10)	9.82 (3)	10.18 (2)
	1970		9.87 (11)	11.04 (4)	11.27 (2)
	1980		10.72 (11)	12.2 (3)	12.19 (4)
	1990		11.02 (11)	12.76 (3)	12.62 (4)
	2000		12.09 (11)	13.09 (2)	12.63 (6)
	2010		12.48 (10)	13.25 (4)	13.24 (5)

Notes: Entries for each country are respectively average years of schooling and ranking for the applicable year. * 1981 for these 3 countries, but other years may apply to others.

Appendix Table 4: Lee and Barro's data on indicators of schooling inputs and outcomes

Indicator	1960		1965		1970		1975		1980		1985		1990	
	NZ	OECDA vg	NZ	OECD Avg	NZ	OECDA vg	NZ	OECD Avg	NZ	OECDA vg	NZ	OECD Avg	NZ	OECD Avg
No. of sch. days per year (Primary)	200 (44)	195	(in general, not indicative of year 1960)											
No. of sch. hours per year (Primary)	1000 (30)	980												
Pupil/Teacher ratio (Primary)	30.9 (38)	29.3	25.2 (25)	25.8	21.3 (14)	24.1	18.5 (11)	21.1	16.7 (13)	19.0	19.9 (30)	17.5	18 (28)	15.7
Pupil/Teacher ratio (Secondary)	19.4 (67)	18.2	25.2 (113)	17.2	24.4 (107)	16.2	29.1 (117)	16.2	26.3 (104)	15.2	18.8 (61)	13.6	17.2 (52)	12.7
Govt. Edu. Exp. per pupil (Primary) (1)	407 (10)	546	747 (15)	1,010	1,031 (10)	1,180	1,359 (14)	1,687	1,680 (10)	2,239	1,730 (15)	2,472	1,894 (16)	2,796
Govt. Edu. Exp. per pupil (Secondary) (2)	743 (24)	757	648 (43)	1,287	810 (42)	1,515	1,025 (29)	1,885	1,490 (23)	2,277	1,243 (27)	2,485	1,665 (22)	2,697
(1) to GPD per capita	5.1% (58)	9.22%	8.2% (73)	13.2%	11% (45)	13.2%	13% (40)	17.1%	16.4% (28)	19.9%	15.3% (30)	20.0%	16.5% (15)	20.1%
(2) to GPD per capita	9.4% (62)	12.9%	7.2% (83)	17.9%	8.7% (86)	17.8%	9.8% (81)	19.2%	14.5% (67)	20.6%	11% (69)	20.7%	14.5% (58)	20.2%
Avg. real salary of teachers (Primary) (3)	8,676 (15)	10,428	13,921 (14)	17,873	16,461 (16)	19,811	21,813 (12)	25,922	24,327 (10)	25,725	25,903 (12)	28,821	18,279 (25)	28,372

(3) to GDP per capita	1.09 (65)	1.89	1.54 (82)	2.48	1.76 (79)	2.31	2.08 (65)	2.73	2.37 (50)	2.44	2.29 (53)	2.51	1.59 (57)	2.10
Repetition rate (Primary)	.	.	0 (1)	5.65%	0 (1)	5.48%	0 (1)	4.26%	4% (35)	3.91%	3% (30)	3.77%	3% (28)	3.14%
Repetition rate (Secondary)	.	.	.	.	3% (9)	8.31%	.	9.50%	3% (16)	9.28%	2% (10)	12.1%	2% (13)	11.3%
Dropout rate (Primary)	.	.	.	.	3% (17)	3.58%	3% (18)	3.37%	3% (19)	3.36%	3% (20)	3.33%	3% (21)	2.95%

Source: Lee and Barro (2001), and Barro-Lee Data Set, International Measures of Schooling Years and Schooling Quality.

Notes: Overall sample size is 145 countries, but data on the indicators are not always available for all countries. OECD averages are unweighted averages over 23 OECD countries. Numbers in brackets under NZ estimates are ranking for New Zealand; the lower the rank, the better New Zealand performs relatively to other countries. Statistics in (1), (2), and (3) are in 1985 US dollars adjusted for PPP.

Appendix Table 5: Barro and Lee's data on test scores

Test	Test participants	Top 5 countries	Results for NZ	
			Test Score	Rank[a]
Mathematics (1982-83)	13 year-old students	Japan, Netherlands, Hungary, France, Belgium	46.4	10/17
Mathematics (1982-83)	FS students[b]	Hong Kong, Japan, Finland, Sweden, New Zealand	49.8	5/12
Mathematics (1993-98)	13 year-old students	Singapore, Korea, Japan, Hong Kong, Belgium	47.2	23/37
Science (1970-72)	14 year-old students	Japan, Hungary, Australia, New Zealand, Germany	30.3	4/16
Science (1970-72)	FS students	New Zealand, Germany, Australia, Netherlands, UK	48.3	1/16
Science (1993-98)	13 year-old students	Czech, Bulgaria, Singapore, Slovak, Russia	48.1	26/37
Reading (1990-91)	9 year-old students	Finland, US, Sweden, France, Italy	52.8	6/26
Reading (1990-91)	13 year-old students	Finland, France, Sweden, New Zealand, Switzerland	54.5	4/30
TIMSS[c] (1994-95): Math	7th grade students	Singapore, Korea, Japan, Hong Kong, Czech	472	23/37
TIMSS: Science	(as above)	Singapore, Korea, Czech, Japan, Bulgaria	481	23/37
IALS: Prose	Adults aged 16-65[d]	Sweden, Finland, Norway, Netherlands, Canada	275.2	7/20
IALS: Document	(as above)	Sweden, Norway, Denmark, Finland, Netherlands	269.1	12/20
IALS: Quantitative	(as above)	Sweden, France, Denmark, Norway, Germany	270.7	13/20

Source: Barro-Lee Data Set, International Measures of Schooling Years and Schooling Quality, and Barro and Lee (2001, Table 6).

Notes: Overall sample size is 58 countries, but data on the tests are not always available for all countries. Scales: TIMSS: 0-1000, IALS: 500, others: 0-100.

a New Zealand's rank out of participating countries.

b FS denotes final year of secondary schooling.

c Third International Mathematics and Science Study.

d Several countries have a higher upper age limit.

Appendix Table 6: Quality-adjusted measurs of human capital

Source	Construction method	Coverage	Top 5 countries
Hanushek and Kimko (2000)[a]	For QL1, data on each of the series are transformed to having a world mean of 50. QL2 adjusts all scores according to the US international performance modified for the national temporal pattern of scores provided by the National Assessment of Educational Progress. QL1 and QL2 are then constructed by averaging all available transformed test scores, weighted by the normalised inverse of the country-specific standard error for each test.	Including 37 countries participating in at least one international test during 1961-1965, but test scores can be imputed using a regression method for another 49 countries (QL1) or 52 countries (QL2).	**QL1** Japan 60.7 China 59.3 West Germany 59.0 Hong Kong 65.9 Netherlands 56.8 **QL2** Singapore 72.1 Hong Kong 71.9 **New Zealand** 67.1 Japan 65.5 Norway 64.6
Wößmann (2003)	$h_i^Q = e^{\sum_a r_a Q_i s_{ai}}$ where r_a = world average rate of return to education at level a (20% for primary level, 13.5% for secondary level, 10.7% for higher level) from Psacharopoulos (1994) Qi = QL2 from Hanushek and Kimko (2000) s_{ai} = average years of schooling for population aged 15 and over, from Barro and Lee's (2001) estimates for 1990	151 countries, missing data imputed	**New Zealand** 2.47[b] Norway 2.23 Poland 1.67 Hong Kong 1.56 Australia 1.43

Notes: [a] The 6 tests used were: IEA Math 1964-1966, IEA Science 1966-1973, IEA Math 1980-1982, IEA Science 1983-1986, IAEP 1988 and IAEP 1991, where IEA refers to the tests administered by the International Association for the Evaluation of Educational Achievement and IAEP to International Assessment of Educational Progress. [b] These figures refer to the country's estimate relative to the US value.

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