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Human capital and endogenous growth
Evidence from Taiwan

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Abstract

We examine the empirical implications of models that display perpetual growth through human capital accumulation in a case study of Taiwan. Our results show that incorporating a labor quality index into the labor input improves the performance of the growth model in Taiwan over the 1965–89 period. The results are robust to alternative enhancements to raw labor input measures and to the inclusion of additional relevant variables often correlated with economic growth in developing countries. The evidence supports the theoretical suggestion that labor skill is a useful augmentation of the raw labor measure commonly used in empirical growth studies.

Key words: Human capital; Endogenous growth; Economic development

JEL classification: O40; J24; I20

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1. Introduction

The neoclassical growth model of Solow (1956), which has been for the past thirty years the central framework to account for economic growth, focuses on exogenous technological/population factors that determine output–input ratios. Despite the widespread use of the model in various applications, Lucas (1988) and Romer (1989) emphasize the major drawback that in empirical applications over half of the growth in output remains unexplained.[1] More than thirty years ago, Schultz (1961) noted that the growth rate of output exceeded the growth rate of the relevant input measures (employment and physical capital), suggesting that '[i]nvestment in human capital is probably the major explanation for this difference'. Uzawa (1965) and Rosen (1976) also stress the important role of human capital accumulation in driving economic growth.

In this paper, we postulate that human capital is the engine of growth and argue that government policies, the improvement of financial markets, and the opening of international trade play a role in motivating and supporting human capital accumulation. The endogenous enhancement in human capital in turn generates a big push, allowing countries to industrialize successfully.[2] Focusing on the embodied manifestation of labor quality improvement, recent empirical work employs various education measures to indicate the initial human capital skill level. Despite the growing literature, the results of existing cross-country studies present conflicting evidence so that the explicit effect on output growth from human capital remains inconclusive.[3]

As a complement to cross-country studies, the present paper adopts an alternative empirical strategy to investigate the importance of human capital evolution on economic growth by focusing on a single, newly industrialized country. The main advantages of analyzing growth in a case study framework are: (i) a more careful and in-depth examination of institutional and historical characteristics of a particular country, (ii) the use of a data set comprised of the most appropriate and highest quality measures unconstrained by the need for measurement consistency across countries, and (iii) a more detailed exposition of the dynamic evolution of the economy. We employ data for Taiwan, the most feasible among several candidates, covering the period 1965 to 1989.[4] Although the data series begin in the early 1950s, we restrict our sample to begin in 1965 to avoid the period of transition from an agricultural society to an industrializing

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[1] See also Romer (1986, 1990b), Barro (1990, 1991), Becker, Murphy, and Tamura (1990), King and Rebelo (1990), Rebelo (1991), Tamura (1991), and Lucas (1993).

[2] For discussion on the big push issue from a different perspective, see Murphy, Shleifer, and Vishny (1989).

[3] See Section 2 below for extended discussion on this point.

[4] We choose to investigate the Taiwan economy, based on the availability of good human capital proxy measures. See Section 2 below for extended discussion.

Table 1
Summary statistics of elements of growth for Taiwan, 1966–89

Variable	Mean growth rate (%)	Variance	Standard error of the mean
Output	6.78	10.04	0.647
Employment	1.34	2.43	0.318
Capital (private and public enterprise)	6.52	2.93	0.345
Labor skill (education)			
Higher	6.30	20.10	0.915
Secondary	4.81	23.96	0.999
Primary	0.96	1.27	0.230
Literacy rate	0.79	1.25	0.228
Net export ratio	1.32	68.96	1.695
Government consumption	5.00	17.74	0.869
Government capital	6.94	7.67	0.565
Birth rate	− 3.06	32.54	1.164
Money to output ratio	5.80	35.91	1.223

Output, capital, government capital, and government consumption are real per capita measures. Employment is also in per capita terms. Labor skill indicators (educational achievement measures) are relative to the total population at and over the age of 6.

economy. (Table 1 presents summary statistics that describe the growth experience of Taiwan.)

We delineate the main features of Taiwan's development, recognizing the constructive role of its government sector and the positive contribution of its market-oriented development policies. The Taiwan government since the early 1950s has stressed the importance of improving the human capital stock of its population (see Li, 1988). Also, the market-oriented policies and consistent trend toward economic liberalization in Taiwan have provided a fertile environment for its economic development (see Tsiang, 1980), enhancing the expected returns to human capital.

The empirical study uses the Solow–Swan type aggregate production function as the organizing framework of the investigation. We begin by examining the first moments of the data and applying linear regression techniques to check for consistency with a constant-returns-to-scale production technology. We compare results using a raw labor input measure with those employing labor input measures that reflect labor quality (human capital) as well as labor quantity (employment). The true specification of aggregate production remains uncertain, so we conduct the empirical analysis using traditional log-level as well as first-differences.[5] We find that for all alternative specifications human-capital-embodied effective labor performs better than traditional employment

[5] We also consider linear time trend, autoregressive correction, and cointegrated specifications.

data in estimating potential output growth. We examine the explanatory power of additional alternative factors in economic growth in a robustness test of the extended aggregate production function including quality-adjusted labor input and find no significant changes in the role of human capital.[6] We regard this result as a formal econometric accounting of the value of labor or man-hours (see Kydland and Prescott, 1988).

Section 2 provides background information on why we chose to focus on a single country for our study. Section 3 describes Taiwan's economic development, emphasizing the role of government policy initiating and supporting improvements in labor quality. In Section 4, we present an aggregate production model that provides structure for the subsequent empirical work on the role of quality measures in the labor input. We then investigate the contribution of human capital accumulation to aggregate output empirically in Section 5, examining the explicit role of government, financial innovation, fertility, and the opening of international trade. We also examine some alternative specifications as well as a variety of human capital measures. Section 6 concludes the paper.

2. Why study Taiwan as a case of human capital engendered growth?

The large proportion of empirical evidence on the effect of human capital on growth are studies that use data on a cross-section of countries and try to link some initial level of human capital with subsequent real output growth performance. In general, the results from existing theoretical models suggest a positive impact of human capital on real growth. However, the individual empirical studies, though they provide numerous intriguing findings, differ substantially on their predictions – there is no consensus on the overall implications of the results.[7]

The lack of consistency in the existing results is not surprising given the difference in the data samples and the chosen proxy measures for the desired

[6] For example, we employ measures of tax distortion and the extent of government physical capital stock to proxy for fiscal policy and also test the role of trade, of fertility, and of financial innovation in Taiwan's growth experience.

[7] For example, research by Barro (1991), Romer (1990a), and Mankiw, Romer, and Weil (1992) investigates the impact of the initial human capital level on subsequent economic growth using cross-country analysis. Barro finds that primary/secondary school enrollment rates in 1960 have significant explanatory power in the (per capita) output growth regression, but the same enrollment measures for 1950 or 1970 have no predictive value. Romer concludes that if one corrects for measurement error, human capital measured by the literacy rate in 1960 adds no additional explanatory power to output growth beyond its effect on investment. Mankiw, Romer, and Weil find a significant role of human capital measured by the secondary school enrollment rate, but find production to exhibit diminishing returns in physical and human capital inputs.

variables. In addition, there are a number of drawbacks to current implementations of cross-country analysis. Levine and Renelt (1992) perform sensitivity analysis on the observed correlations between long-run growth and policy variables in cross-country studies. Their results indicate that regressions that display a positive relationship between human capital and growth are not robust to the inclusion of other relevant variables. They recommend a reasonable degree of skepticism about inferences from empirical studies linking human capital to growth.

Cross-country studies may also fail to capture important country-specific characterstics that may be crucial to their economic development.[8] For example, using Summers–Heston data (averaged for 1960–85), we find that certain countries with extremely high investment to GDP ratios of more than 25 percent, such as Argentina, Chile, the Congo, and Zambia, have not experienced high output growth. Moreover, Jordan, Jamaica, Panama, and the Philippines were among the top 15 percent in both the investment ratio and the secondary school enrollment rate, but they have not advanced to the high-income nation status. It may be the failure of government interventions, the absence of a stimulative infrastructure or learning environments, and the lack of political or socioeconomic stability that apparently result in development slowdown in these economies.

Cross-country studies more or less suffer from measurement problems, especially with regard to production inputs. In the absence of consistent employment series, adult population (age 15–64) often approximates the labor effort input. The investment to GDP ratio, a flow measure, proxies for the physical capital stock because the latter is unavailable for most countries. The use of these proxies for the desired measures may certainly be questionable. Also, the school enrollment or literacy rate data used in the above-mentioned cross-country studies do not measure the stock of human capital. They may proxy adequately for labor quality to distinguish undeveloped, low-income from middle- or high-income countries. Such human capital proxies, however, may be inappropriate for distinguishing between growth in developed and growth in newly industrializing economies, in which development may rely on 'advanced' knowledge accumulation that cannot be captured by primary or secondary education measures.[9]

Alternatively, one may study the role of human capital evolution in the rapid and sustained growth experience of newly industrializing countries, such as Hong Kong, Korea, Singapore, and Taiwan. In an independent study,

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[8] In the presence of multiple steady states and hence multiple convergence groups (see a discussion in Becker, Murphy, and Tamura, 1990, and Tamura, 1991), cross-country analysis is generally subject to sample selection bias (see comments by De Long, 1988, on Baumol, 1986).

[9] For developed economies, human capital is diversified and more specialized which may not be precisely captured by standard educational category levels.

Table 2a
Educational attainment as percent of population over 6 years

Year	Literacy	Years of schooling completed		
		6 or more	12 or more	15 or more
1954	60.3	56.4	10.9	1.6
1959	71.1	66.8	13.5	1.8
1964	77.5	73.6	17.6	2.3
1969	84.7	80.8	28.9	3.5
1974	86.6	83.8	33.9	4,8
1979	89.3	86.6	42.6	6.8
1984	91.2	89.0	49.6	8.7
1989	92.9	91.7	55.4	10.5

Table 2b
Higher educational degrees conferred in three general fields as a percent of total

Period	Social sciences	Natural sciences	Engineering
1965–66	38.4	6.5	15.1
1975–76	31.8	4.8	30.3
1985–86	30.3	6.3	35.3
1989–90	30.5	6.9	35.9

Following 1982–83, the categories are comprised of several subcategories. For example, social sciences include social science and behavior, mass communication, service trade, home economics, and commerce and business administration. Natural sciences also includes math and computer science. Engineering includes transportation and communication as well as architecture and town planning.

Young (1992) employs this strategy in an investigation of the economic miracles of Hong Kong and Singapore. It is, however, noteworthy that precise capital stock data for Hong Kong and Singapore are unavailable; education measures for Korea are limited to literacy and primary/secondary school enrollment rates. Among others, Taiwan has the most complete data for our study.

For our case study of Taiwan, we use an explicit employment measure and calculate a physical capital stock series adapted directly from an input–output survey.[10] We combine a human capital measure and employment to create an effective labor input. Further, the human capital proxies are educational

[10] In contrast, Young (1992) constructs capital stock measures for Hong Kong and Singapore by assuming a zero capital stock at some previous date, accumulating investment and assuming a fixed geometric depreciation rate.

'achievement' (instead of enrollment) measures, more closely approximating the stock of human capital proposed in theory. More specifically, the Taiwan data for educational achievement in Table 2a displays the percentage of the population at and over the age of six that has completed a) primary education, b) secondary education, and c) at least three years of post-secondary school education (such as colleges, universities, and institutes of technology). The last measure indicates the proportion of advanced and technical human capital that the economy has accumulated; most of those are in the areas of engineering, computer science, and business administration rather than in rent-seeking activities (see Table 2b).

We present this research as a complement to cross-country research on growth and human capital accumulation and suggest that there are some questions that are addressed more effectively by the appropriate choice of research strategy. We are aware of the limitations of a single-country study that could be country-specific and not representative of the general development pattern worldwide. Nevertheless, in the current stage of empirical research, the results on Taiwan appear to add insights to the existing cross-country evidence.

3. Recent history of Taiwan's economic development

Taiwan is a small island economy with an extremely high population density and with very few natural resources. Yet the country in the past few decades has experienced rapid output growth with moderate inflation. Its real gross domestic product (GDP) per capita has increased by more than six-fold since 1954 with an average annual growth rate of over 6 percent, while its personal income distribution index measured by the ratio of household income share of the richest to the poorest quintile decreased from 5.33 to 4.94 over the 1964–89 period.[11] The government role in supporting human capital accumulation and in providing market-oriented development strategies that create ample economic opportunities have been essential to its industrialization process.

3.1. Early development

Taiwan's modern economic history began following WWII, a war which destroyed an estimated 75 percent of its industrial capacity, two-thirds of its power generation, and 50 percent of its transportation facilities. Following WWII, the Kuomingtang (KMT) dismantled factories and raided for raw materials to support its fight with the Communists on Mainland China. The

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[11] Taiwan's remarkable economic development has interested many economists. For a comprehensive survey of the related literature, see the bibliographic essay in Clark (1989).

Table 2c
Employment (*EM*) and output (*YD*) by industry (in percentages)

Year	Primary industry		Manufacturing		Commerce	
	EM	*YD*	*EM*	*YD*	*EM*	*YD*
1952	56.1	32.2	12.4	12.9	10.6	17.9
1960	50.2	28.5	14.8	19.1	10.0	15.3
1970	36.7	15.5	20.9	29.2	13.6	14.5
1980	19.5	7.7	32.6	36.0	16.0	13.1
1989	12.9	4.9	33.9	35.6	19.5	14.6

Primary industry contains mainly agriculture, forestry, fisheries, and livestock. Commerce is mainly retail trade.

hyperinflation that afflicted the mainland from 1946 to 1949 passed on to Taiwan. In reaction to the existing economic problems, the KMT enacted several stabilization policies, especially monetary and land reform. In 1953, the KMT initiated the first economic development plan, emphasizing price stability, rebuilding infrastructure, and increasing agricultural and industrial productivity. There were nine consecutive economic plans put forward by the government over the span of thirty years. Government plans for the economy centered on promoting the production of high value-added exports as a replacement for production of import substitutes. In addition, the government attempted to smooth the transition from a primarily agricultural economy to a newly industrialized manufacturing economy.[12]

3.2. Economic take-off

The Taiwan economy began to take off in the years from 1963 to 1965.[13] Between these years, the per capita growth in real GDP increased from less than 3 percent to more than 6 percent; the investment to NNP ratio increased from roughly 6 percent to above 10 percent; the net saving to NNP ratio rose from below 8 percent to about 13 percent. The rate of domestic savings increased from 13 percent in the early 1960s to 20 percent by the late sixties, and reached 30 percent through the 1970s and 1980s. Also, the output of industrial sectors began to exceed the output of agricultural sectors, and employment started moving from agriculture to other industries (see Table 2c).

[12] In the early 1950s, Taiwan seemed a prototypical agricultural economy: raw and processed agricultural products comprised over 40 percent of output; the associated employment share exceeded two-thirds; and the resulting exports accounted for more than 90 percent of the total.

[13] To determine whether an economy starts taking off, one can adopt various criteria proposed by Rostow (1961), Tsiang (1964), and Kuznets (1966).

3.3. Educational improvement

The improvement of labor quality in Taiwan was a major concern of the government and its development plans often directly addressed education and human capital issues.[14] First, the government focused on reducing the illiteracy rate from the 40 percent level of the early 1950s.[15] In response to a shortage of skilled workers, the Ministry of Education in 1962 contracted with Stanford Research Institute to conduct a study on education and development. The economic plans focused on upgrading the efficiency of the workforce, viewing manpower as Taiwan's only abundant resource. The first Manpower Development Plan in 1966 required 9 years of education for boys and girls (mandatory since 1968), increased the number of industrial and vocational schools, and guided colleges and universities to put major emphasis on training and development of scientists, technologically-skilled engineers, and business managers.

The expansion of vocational schools and the focus on higher education and scientific learning came after the initial policies were implemented and economic progress took hold. In 1979, the government introduced the Science and Technology Development program that focused on high-level education and training, with key emphasis on technologies that would be needed by industry. As an indicator of their success, the ratio of students majoring in engineering and science to those majoring in social science and liberal arts rose from 0.4 in 1965 to 1.2 in 1989. Vocational school degrees conferred in industrial areas grew from approximately 2.6 percent in 1965 to between 11 and 12 percent in the 1980s.

The government role in enhancing educational development in Taiwan demonstrated the conscious effort to give education a leading role in its national development policies. The statistical data supports the view of active government participation in education. Government expenditure on education (and culture) as a percent of total government expenditure grew from 14 percent in the 1950s and 1960s, to 16 percent in the 1970s, to about 20 percent in the 1980s. As the educational policy focus shifted toward the more expensive higher education, real government spending per student in 1981 New Taiwan dollars (NT$) increased from 4,500–5,000 in the 1950s and 1960s, to 10,000 in the 1970s, to approximately 20,000 in the 1980s. The government took the lead in establishing an Industrial Technology Research Institute that conducts advanced research and development activities, arranges technology transfer, and searches for new technologies worldwide. There has also been some transfer of technology through the foreign investments made in Taiwan indicating a degree of overlap among educational policies, government infrastructure spending, and trade policies that enhances the stock of available and implementable knowledge in the Taiwan economy.

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[14] Li (1988) stresses this point in his Harvard lectures. See also Clark (1989).

[15] The illiteracy rate fell to 20 percent by 1963 and to 6.4 percent by 1989.

3.4. Fertility, trade, financial innovation, and the role of government

The Taiwan government engaged in planned parenthood activities in the early 1950s, which reduced the crude birth rate (total number of live births during a woman's reproductive life) from 3.5 to less than 2 in the 1980s. The trade and financial development policies implemented by the government have contributed substantially to the industrialization of Taiwan.[16]

In April 1958, the government instituted the program for Foreign Exchange Adjustment and Trade Control Reductions, which offered major changes in laws and regulations in foreign exchange markets, tariffs, and export incentives. For example, it abolished the import quota system and it reduced protectionist measures for domestic industries to reduce inefficiency. To further the movement toward export industries, the government provided free export-related services, including technical and management consulting. The government also removed obstacles to foreign investment in Taiwan by building three tax- and duty-free export processing industrial zones that contain all relevant government adminstrative offices for import and export licensing. The industrial production share of exports grew from 11 in 1954 to over 50 percent in 1965 and to over 95 percent in 1989. Increasing net exports and foreign investment offered the prospect of better job opportunities and greater returns from investments in human capital.

Heavier trading activity helped integrate the domestic economy with the rest of the trading nations. As a result, Taiwan improved its access to the world stock of knowledge, thus increasing the likelihood for knowledge spillovers. As development in Taiwan progressed, the government added support for a shift in export production toward goods with higher value added. In the early 1980s, the government provided funding for venture capital, financed high-tech research and development, and offered management and marketing support to firms in selected high-technology industries.

The Hsinchu Science Park established in 1980 is a prime example of the government's investment in infrastructure to support trade as well as to enhance knowledge accumulation, making human capital investment less expensive and removing market frictions so that the citizens reap the rewards of their human capital. The goal of the infrastructure has been to support rapid economic growth, and the Ten Major Development Projects, announced in 1973, substantially improved the transportation infrastructure. The Twelve New Projects followed, adding further to the public capital stock. In the 1970s, infrastructure investment accounted for as much as 30 percent of Taiwan's total fixed capital formation. These projects also provided knowledge spillover effects whereby Taiwanese engineers gained experience from working with foreign consultants

[16]The importance of trade promotion, financial market innovation, and government support of these actions is discussed at length in Li (1988) and Hwang (1991).

on the major developments. The data on economic development spending by the government reflect these expenditure decisions. As a percent of total government spending, economic development was 10 percent in the 1950s, 15 percent in the 1960s, peaking in the 1970s at near 35 percent, and receding to between 25 and 30 percent in the 1980s.

The Taiwan financial market was initially closed and controlled largely by the government. Over time, the market has become increasingly liberalized, and the impact of these steps on economic growth may be substantial, although difficult to measure directly. Three particular moves are noteworthy. In 1976, there became established a money market independent of the government-controlled banking system with a market-determined interest rate. In 1980, commercial banks were allowed some degree of freedom in determining bank lending rates. Commercial banks became able to act as agents for buying and selling foreign exchange in 1983. Further liberalization encouraged the establishment of foreign bank branches in Taiwan, opening financial markets in Taiwan and promoting the financing of additional growth.

In summary, the economic development of Taiwan relied on numerous market-oriented government policies, many of which focused on supporting the accumulation of human capital in the labor force. Policies geared toward growth recognized the necessity of maintaining a skilled labor force and increasing its high-technology capabilities. It is notable that progress in trade, government infrastructure, and financial liberalization enhanced the returns gained from human capital investment and likely increased the accumulation of human capital in Taiwan.

4. Empirical model and data measurement

We employ the standard aggregate production theory as a unifying framework for the empirical work to focus the study on the traditional input measures of capital (K) and labor (L). Our extension from the typical Solow–Swan growth framework arises from the arguments of Lucas–Romer endogenous growth models that suggest that endogenously accumulated human capital has a direct impact on the productivity of labor. As a result, it seems informative to augment the labor input by characterizing the degree of labor skill in the economy. We assume that human capital is specific to the individual, leaving innovation in the stock of knowledge as an exogenous factor.

The growth model used in the empirical study is

$$Y_t = A_t K_t^{\alpha} (H_t L_t)^{\beta}, \qquad H = E^{\delta}, \tag{1}$$

where Y is real output, K is the physical capital stock, L is raw labor input, H is the level of human capital, E is the measure of education level, δ is the return to education relative to raw labor input, A is an exogenous knowledge and technological factor, and α and β are the capital and labor shares, respectively. In the typical empirical implementation of these models, we can take natural logs and derive the following estimable form:

$$\log(Y_t) = \alpha \log(K_t) + \beta[\log(L_t) + \delta \log(E_t)] + \log(A_t)\,. \tag{2}$$

It is notable that if there are constant returns to scale in both reproducible (physical and human) capital stocks (i.e., $\alpha + \beta = 1$), the model can generate perpetual growth.

We examine the importance of human capital accumulation for economic growth in Taiwan for the years 1965–89. We rely on several data series, listed with sources in the Appendix, for our analysis. For our output measure, we use real gross domestic product per capita (YD). The input measures are each to some degree created by transforming raw data. We create the capital stock measure, gross capital stock per capita (K), using an input–output survey of the Taiwan economy. Specifically, we aggregate the physical capital stock from the input–output survey for 1975 that contains a net capital stock series and accumulated depreciation at the two-digit industry level. After aggregation, we then add and subtract investment and depreciation flow measures to get our series. It is worth noting that our capital stock measures include those from private and public enterprise sectors and, separately, the government sector. The raw labor input is employment per capita (EM). The human capital stock (H) is measured by various educational attainment measures (E) discussed below.

In an economy with a Cobb–Douglas production function as specified in (1), we should have growth rates in capital and labor roughly equal along balanced growth paths (see King, Plosser, and Rebelo, 1988). As shown in Table 1, gross output per capita grew at an average annual rate of 6.78 percent from 1966 to 1989, and (gross) capital per capita grew at an average rate of 6.52 percent, whereas employment per capita grew at an average annual rate of only 1.34 percent. Assuming a labor income share of 60 percent, straightforward application of standard Denison Accounting will leave 3.37 percent (or approximately one-half) of the annual rate of output growth unexplained by growth in the two major inputs. If capital and labor are complementary (as in the standard neoclassical growth theory), the mismatch of the two major factor inputs should not have generated such rapid output growth. It is our claim that the accumulation of labor skill improvements, omitted from the measured labor input, is responsible for the apparent incompatibility between the input growth rates and the output growth rate.

Conventional cross-country studies use education enrollment rates to account for labor quality changes. In contrast, we employ data on the educational achievement of the Taiwan population to proxy for embodied human capital, which measures the stock of human capital available to the labor market. Lucas (1993) suggests that on-the-job training or experience is most likely the source of 'miraculous' labor productivity enhancement. Yet, as Rosen (1976) suggested, advanced education enhances the speed of labor skill accumulation. Thus, a true measure of embodied human capital likely includes education achievement as a determining factor.

Table 2a presents educational attainment as a percent of the population at and over the age of 6. The Taiwanese data examines educational achievement for the population that is at and over the age of 6 years of age. Clearly, it would be preferable to have educational attainment data for the workforce age of 25 and over. Unfortunately, such data are unavailable. Nevertheless, we can glean useful information from the available measures.[17] The breakdown in the table shows the percent of the population achieving literacy as well as the percent completing primary, secondary, and higher educational degrees. For example, the second column reports the percent of the population over the age of 6 that have completed at least six years of schooling. Similarly, the third and fourth columns present data describing the percentage of the population over the age of 6 completing at least 12 and 15 years of schooling, respectively. These are also figures on the numbers of people educated in specific fields, as in Table 2b, allowing analysis of the distribution of human capital and the allocation of talent in the economy. These rich data enable us to formulate reasonable proxy measures for the average, aggregate educational level of the Taiwan economy.

Over the sample period, the various education achievement measures grew at average annual rates from as low as 0.8 percent for literacy, to as high as a rate of 6.3 percent for higher education. Using the growth rate for the higher education measure combined with that of employment, the resulting labor input measure grew at an annual average rate of 7.7 percent, much closer to the capital growth rate and more consistent with the neoclassical presumption. We need a straightforward and reasonable way to combine human capital proxies and labor to form effective labor input. For our purposes, we employ a simple transformation function relating human capital to our education level or labor skill proxy: $H = E^{\delta}$. We determine a value for δ by choosing the value that makes the average annual growth rate of the effective labor input, LE^{δ}, equal to the average annual growth rate for the capital input, K, over the period from 1966 to 1989.

We examine as additional relevant variables in an empirical study of growth two measures of government activity, an indicator of financial market innovation, birth rate data, and a measure of the economy's openness to trade. We use

[17] The population at and over the age of 5 and under 25 in Taiwan over the sample period 1965 to 1989 hovers between 38 and 48 percent of the total population. Thus, the educational attainment percentages are underestimated in comparison to the desired workforce measures. Yet, we focus our analysis on the growth rates of these measures so that level differences between the workforce and the available measures should not alter our conclusions. Also, there appears to be no systematic mismeasurement in the available data that would affect our results adversely.

real government consumption spending relative to output as a measure of the impact of distortionary taxes on economic growth. The ratio of government relative to private (and public enterprise) physical capital represents government infrastructure as a complement to the private capital in promoting output growth. Financial innovation may explain improvements in capital allocation; we employ the ratio of a money supply measure (*M1B*) to nominal output (used by King and Levine, 1992) as a proxy measure. A higher birth rate increases demand for dependent care, thus reducing the available labor force and retarding human capital accumulation. Finally, we use the export to import ratio as our proxy of the openness of the economy to trade. We discuss these robustness test results following our initial specification estimates.

The profitability of improved or additional human capital underlies the incentive to invest in human capital. Thus, the rewards to human capital enhancement are the higher returns to the possessor of the assets. Our perspective toward these other variables correlated with output growth is that better government infrastructure, increasing trade, decreasing fertility, and a more developed financial market all lead to increased returns to human capital accumulation. To find that these variables have significant correlations with output is no surprise. However, we suggest that the correlation is primarily in support of the underlying reationship between the accumulation of broadly defined capital and output growth.

5. Empirical results

The empirical estimates presented below provide insights into the relationships between measures of physical and human capital and growth. However, these regressions should not be misinterpreted as causality tests; in particular, we acknowledge a substantial feedback effect from output growth toward the inputs, as emphasized in the endogenous growth literature. These estimates are not simple correlations because the input measures directly impact the production process so that the measures are related directly. Rather, we view the evidence as indicating whether our human capital proxies measuring embodied knowledge improve upon traditional growth measurement.

5.1. Raw versus human-capital-enhanced labor input

The results in Table 3 provide evidence on the log-level Cobb–Douglas specification of output using inputs of physical capital and a variety of labor inputs imposing constant returns to scale (*CRTS*). When raw labor measures labor input, the labor share estimate for the log-level specification is 0.04, an unusually low value. In contrast, all effective labor measures including educational achievement in the log-level specifications have labor share estimates that

Table 3
Output estimates, raw and education-enhanced labor input, log-linear and difference specifications

Education measure	Constant	Labor	Physical capital	*SEE*	*D–W*
		Log-linear			
None (raw labor)	− 0.670	0.038	0.962	0.0532	0.442
	(3.98)	(1.43)	(35.9)		
Primary	− 5.50	0.254	0.746	0.0362	0.789
	(6.68)	(5.57)	(16.4)		
Secondary	− 0.395	0.308	0.692	0.0378	0.697
	(3.96)	(5.16)	(11.6)		
Higher	0.425	0.475	0.525	0.0372	0.724
	(1.69)	(5.31)	(5.87)		
		First-differences			
None (raw labor)	0.065	1.216	− 0.216	0.0254	1.85
	(4.70)	(4.80)	(0.85)		
Primary	0.0041	0.222	0.777	0.0325	1.50
	(0.61)	(2.34)	(8.19)		
Secondary	0.0037	0.279	0.721	0.0319	1.62
	(0.57)	(2.53)	(6.54)		
Higher	0.0036	0.363	0.637	0.0317	1.90
	(0.56)	(2.63)	(4.62)		

'Primary' refers to the education measure that indicates completion of at least 6 years of schooling. 'Secondary' reflects completion of at least 12 years of schooling. 'Higher' refers to at least 15 years of schooling. Each of these education measures is used to enhance the raw labor using the specification given in Eq. (1). Absolute values of t-statistics for regression coefficient estimates are in parentheses.

move in the direction of values typically estimated.[18] The labor share estimates vary from 0.254 for effective labor using primary education levels up to 0.475 for effective labor with higher education.

The first-difference specifications in Table 3 present additional evidence supporting the inclusion of educational achievement in the labor effort measure. In Table 3, the labor share estimates using a raw labor input measure in a first-difference specification imposing the same restrictions exceeded unity

[18]The time trend variable that normally represents exogenous technical progress is not significant in any log-linear specification. Adjusting for autocorrelation using the Cochrane–Orcutt procedure generates results that are qualitatively similar to the regression results in Table 3.

(1.22), assigning a negative share to the capital input.[19] The inconsistency of the labor share estimates with typical reasonable measures in addition to the dramatic changes in the estimated share value in the two specifications suggests that the model estimates using a raw labor input measure are suspect. In contrast, across all the estimated first-difference specifications using a human capital adjusted labor input, the estimated shares for the effective labor input start from a low of 0.22 in the primary education case to 0.36 for the higher education measure.[20] These preliminary results indicate that there is some benefit to including educational achievement levels as proxies for human capital, but there are likely better ways to employ the data.

5.2. Construction of aggregate human capital skill indexes

To exploit more fully the information in the educational achievement data, we create two indexes of educational achievement that employ each component of the education level, that is, the population completing only primary school, those completing both primary and secondary school, and finally those finishing primary, secondary, and higher educational degrees.

First, we approximate the increased productivity of additional education by weighting the educational levels assuming that more educated workers are more productive. Specifically, we attach weights of 1 to workers completing only a primary education, 1.4 to those completing secondary education, and 2 for those completing higher education in the first index measure of human capital. This weighting scheme is typical in the literature of the economics of growth and education (Maddison, 1987; Pencavel, 1991), under which the computed value of δ is 1.27. We construct a second index with weights of 1 for primary, 2 for secondary, and 4 for higher educated workers, it is selected such that the value of δ is close to 1 (1.07). In this latter case, a δ value of 1 implies that raw labor employment and the human capital education index are essentially perfect substitutes, as in Lucas (1988) and Rebelo (1991) , and we do not have to distinguish the measure of education (E) from the hypothesized human capital measure (H) [see Eq. (1)]. The measures span the existing levels of education and likely provide a better gauge of aggregate level of education and skill accumulation of the Taiwanese population. We will refer to these indexes as index 1 (with weights of 1, 1.4, and 2) and index 2 (with weights of 1, 2, and 4) in the results presented in Tables 4 through 6. Over the sample period from 1966 to 1989, index 1 grew at an average annual rate of 4.0 percent, whereas index 2 grew at 4.8 percent.

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[19] We found no evidence of significant cointegration among the variables in this study.

[20] We find similar results when we assume a cointegration specification. However, the estimated cointegrating vector was not significantly different from zero at the 5 percent level in any cointegrating specification. Thus, we do not include those results.

Table 4
Human capital enhancement of labor input, using the aggregate education indexes

Education index	Constant	Effective labor	Physical capital	*SEE*	Test of CRTS	
		Contemporaneous physical capital stock				
Index 1	0.0032	0.553	0.447	0.0286	$F(1, 21)$	0.411
	(0.55)	(3.66)	(2.95)		P-value	(0.528)
Index 2	0.0033	0.546	0.454	0.0288	$F(1, 21)$	0.651
	(0.57)	(3.61)	(3.00)		P-value	(0.429)
		Lagged physical capital stock				
Index 1	0.0029	0.617	0.383	0.0294	$F(1, 20)$	0.275
	(0.47)	(4.43)	(2.75)		P-value	(0.606)
Index 2	0.0029	0.612	0.388	0.0294	$F(1, 20)$	0.373
	(0.47)	(4.44)	(2.82)		P-value	(0.548)

Index 1 is an aggregate educational attainment measure with weights of 1, 1.4, and 2 assigned to primary, secondary, and higher educated workers, respectively; index 2 has weights of 1, 2, and 4 corresponding to the specified education levels. CRTS denotes constant returns to scale. See also note to Table 3.

The estimates of labor share using the raw labor input were unsatisfactory, but we can use the data to infer the contribution of educational proxy measures for helping explain growth. We generate a Solow residual using the raw inputs and compare it to our educational attainment measures. To produce the residual, we assign the standard shares of 0.6 for labor and 0.4 for capital, estimate the growth rate of output given the growth rate of the inputs, and then take the difference between the predicted growth rate from actual output growth.[21] Regressions of the Solow residual on the growth rate of the two weighted education attainment measures generate coefficient estimates of approximately 0.4 to 0.5, which are statistically significant at the 5 percent level.

Table 4 lists the results of output growth regressions using the educational achievement indexes to enhance the labor input measures. The first set of results employs a contemporaneous physical capital stock growth rate in the regression, whereas the second set assumes a time-to-build production technology, as suggested in Kydland and Prescott (1982), so that only the one-year-lagged growth rate of capital affects contemporaneous output.[22] In addition to the share

[21] The results reported below are not sensitive to the value of the labor income shares in the range from 0.5 to 0.65.

[22] We do not lag our measure of human capital because as educational achievement data these educated individuals are available for current labor input.

estimates, we test the imposition of the constant-returns-to-scale restriction. The statistics suggest that the restriction is not rejected at conventional 5 or 10 percent significance levels for any of the regressions, thus lending support to the sustained growth models of Romer (1986, 1990b), Lucas (1988), and Rebelo (1991).[23]

Regressions using contemporaneous physical capital produce estimates of labor shares that are an improvement over share estimates using raw labor, although estimated values of approximately 0.55 are still somewhat less than typical labor shares. However, the share estimates for effective labor employing lagged physical capital are between 0.6 and 0.65, close to the values typically assigned in growth accounting studies.[24] These results are consistent across both indexes of aggregate educational achievement. Thus, the indexes of educational achievement help explain the apparent empirical deviation from the neoclassical production function using raw labor input in the Taiwanese growth miracle.

5.3. Robustness tests

Research by Levine and Renelt (1992) suggests that many of the observed correlations between output growth and policy variables are not robust to the inclusion of additional relevant variables. We use the empirical correlations between the first-difference of the Solow residual that we generated from the raw labor input and (one-year-lagged) physical capital and the rates of change of several variables that we suspect may have an important relationship to economic growth. We find a significant correlation between the Solow residual and (a) the (one-year-lagged) birth rate (LBR) of -0.33, (b) the export–import ratio (XB) of 0.32, and two measures of government activity, (c) the government consumption–output ratio (GCY) of -0.27, and (d) the (one-year-lagged) government to private physical capital stock ratio ($LGKR$) of 0.32. We also examine the financial innovation proxy measured by the rate of change of the ratio of a monetary aggregate to output (MY); we find only a correlation of 0.16 between it and the differenced Solow residual, but we examine it in regressions for completeness.[25]

Table 5 lists the robustness tests using the proposed financial (MY), fertility (LBR), and international trade (XR) variables. We find that these additional variables add little explanatory power to regressions using the indexes of

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[23] We note that in our framework, we cannot test the presence of increasing returns to scale because δ cannot be identified empirically in the latter case. See Benhabib and Speigel (1992) for treatment of positive production externalities.

[24] Young (1992) finds the labor share in Hong Kong to be between 0.58 and 0.67; for Singapore, he finds a lower value ranging from 0.44 to 0.51.

[25] We have also examined alternative monetary aggregate measures of financial activity and obtained qualitatively similar results.

Table 5
Roustness tests on first difference specifications

Education index	Constant	Effective labor	Physical capital	Added variable	*SEE*	Test of CRTS
			Money to output ratio (*MY*) as additional variable			
Index 1	– 0.0044	0.631	0.369	0.124	0.0291	*F*(1, 18) 0.103
	(0.52)	(4.57)	(2.68)	(1.22)		*P*-value (0.75)
Index 2	– 0.0037	0.620	0.380	0.112	0.0292	*F*(1, 18) 0.222
	(0.43)	(4.51)	(2.77)	(1.10)		*P*-value (0.64)
			Birth rate (*LBR*) as additional variable			
Index 1	– 0.0006	0.571	0.429	– 0.13	0.0292	*F*(1, 18) 0.243
	(0.94)	(3.97)	(2.98)	(1.13)		*P*-value (0.63)
Index 2	– 0.00085	0.567	0.433	– 0.14	0.0290	*F*(1, 18) 0.292
	(0.13)	(4.02)	(3.07)	(1.22)		*P*-value (0.59)
			Export to import ratio (*XR*) as additional variable			
Index 1	0.0024	0.608	0.392	0.069	0.0295	*F*(1, 18) 0.788
	(0.38)	(4.34)	(2.79)	(0.89)		*P*-value (0.39)
Index 2	0.0024	0.602	0.398	0.064	0.0296	*F*(1, 18) 0.930
	(0.39)	(4.32)	(2.85)	(0.81)		*P*-value (0.35)

When we test the exclusion restrictions, we impose constant returns. For brevity, we report only tests using one-year-lagged physical capital. See also note to Table 4.

education measures to enhance the labor input. While the insignificance of the financial variable is not surprising given the correlation analysis mentioned above, it is useful to discuss first why the other correlations fail to hold up in the presence of other regressors. On the one hand, the export–import ratio does not have a significant impact on growth after physical capital and human capital adjusted labor measures are included in the regression. We believe that much of the correlation between the export–import ratio and output growth could be captured by the human capital measure. As an economy becomes more open, individuals are further exposed to the larger world stock of knowledge; the external effects of additional knowledge thus raises the expected returns to human capital accumulation. On the other hand, an increase in the birth rate not only reduces raw labor but also hinders the accumulation of human capital in both learning-by-doing and education.[26] Thus, employment and human capital could capture the birth rate effect.

[26] The negative impact of the birth rate on growth reflects similar intuition as found in Brander and Dowrick (1993).

Table 6
Government activity and output growth

First-difference specifications with government consumption to output (*GCY*) and government to private physical capital stock ratios (*LGKR*) as additional variables

Education index	Constant	Effective labor	Physical capital	*GCY*	*LGKR*	*SEE*	Test of CRTS	
Index 1	−0.0047	0.663	0.337	−0.232	0.844	0.0236	$F(1, 19)$	0.676
	(0.86)	(5.73)	(2.19)	(2.00)	(3.18)		P-value	(0.42)
Exclusion restriction for government variables: $F(2, 19) = 6.75$, with a P-value of 0.0061, suggesting rejection of the null hypothesis								
Index 2	−0.0046	0.641	0.359	−0.241	0.784	0.0242	$F(1, 19)$	1.10
	(0.81)	(5.50)	(3.08)	(2.03)	(2.90)		P-value	(0.30)
Exclusion restriction for Government variables: $F(2, 19) = 5.95$, with a P-value of 0.0099, suggesting rejection of the null hypothesis.								

See notes to Tables 4 and 5.

Table 6 shows, in contrast, the two government variables (*GCY* and *LGKR*) in first-differences retain significant explanatory power in these output growth regressions. The negative (and statistically significant) coefficient on the government consumption to output ratio suggests the detrimental impact of distortionary taxes, as suggested in Barro (1990).[27] The positive (and statistically significant) coefficient on the government to private capital stock ratio implies that government infrastructure spending leads to additional future output, which is consistent with the hypothesis of Barro and Sala-i-Martin (1992). Despite the instances in which the additional government variables add explanatory power, the human-capital-embodied labor input measures retain statistical significance for weighting schemes 1 and 2 and are both associated with labor share estimates close to two-thirds.

The coefficient estimates in the test for robustness are quantitatively close and comparable to the estimates in the simple first-difference specification. This observation lends additional support to suggest that the estimated share coefficients are robust and that the relationships hold up in the presence of additional development and policy variables usually considered in growth studies. The results in Table 6 enable us to perform a growth accounting; for comparison, we employ the results using the second weighting scheme for human capital. We find that (a) traditional major factor inputs, physical capital and raw labor, account for 32 percent and 13 percent, respectively, of output growth; (b) two

[27] This result is not surprising because it measures only government consumption; government investment spending is in the government capital stock measure.

government variables, reduction in tax distortion and improvement in government infrastructure, account for 10 percent of output growth; (c) human capital alone accounts for 45 percent of output growth. Young (1992) finds similar evidence in his investigation of the growth experience of Singapore, in which he finds that quality-adjusted labor and physical capital input measures explain output growth satisfactorily. Our results contrast, however, with Young's results regarding Hong Kong, a growth experience that appears to rely more heavily on exogenous technological innovation.

6. Conclusions

Overall, the empirical evidence supports the use of educational attainment measures as human capital proxies to augment the labor input measure in an aggregate production function. We show that using reasonable proxies of human capital enhances our ability to account for economic growth in a developing economy. On a basic level, we suggest that the growth rates of output, physical capital, and labor input are more in line with a Cobb–Douglas specification when the labor measure incorporates a human capital proxy than with a raw labor measure. We provide evidence in a regression framework that constant-returns-to-scale restrictions are not rejected and share estimates are more comparable with typically assumed values using a quality-adjusted (for human capital) labor input than with a raw labor input. These results are robust to alternative specifications and to inclusion of additional variables. We find that output growth is best captured by five factors, including raw labor, one-year-lagged physical capital, human capital approximated by two constructed education achievement indexes, and two government variables that measure tax distortion and government infrastructure, respectively. Simple growth accounting indicates human capital alone accounts for about 45 percent of output growth in Taiwan over the past three decades.

The focus on one country, Taiwan, enabled us to gather a variety of educational attainment measures to proxy for embodied human capital. Our results show that human capital evolution plays a crucial role in the miraculous development of the Taiwan economy, consistent with the recent endogenous growth theory pioneered by Lucas (1988) that hypothesizes human capital as the main engine of growth. Our study suggests that further research investigating economic growth should explicitly measure human capital in the labor input variable to indicate the improvement of labor quality. Moreover, it lends support to those endogenous growth models that consider some form of production linearity in reproducible factors such as Romer (1986, 1990a, b), Lucas (1988), Barro (1990), Jones and Manuelli (1990), and Rebelo (1991). Furthermore, we obtain some evidence that human capital accumulation is related to the better learning environment captured by the development of financial markets and the openness of the economy; this is consistent with the endogenous learning models of Romer (1986), Stokey (1988), and Young (1991). One potential extension will be to link up the evolution and development of human capital in Taiwan to the possible increase in the composition of exports comprised of higher value-added products as suggested by Lucas (1993). Further related research along these lines will investigate the existence of increasing returns in aggregate production by developing an empirical method that can identify learning spillovers (external effects from the stock of human capital) separately from formal education.

Appendix: Description of the data

YD = per capita real gross domestic product (GDP),
GC = per capita real government consumption,
XR = export to import ratio,
K = per capita real gross private and public enterprise capital stock,
GK = per capita real gross government capital stock,
EM = employment to population ratio (employment per capita),
$M1B$ = per capita money supply,
N = population at and over the age of 6,
BR = crude birth rate,
PRIMARY, SECONDARY, HIGHER = number of individuals over the age of six that have completed the given level of education – we form the indices from these measures and N.

Units

(1) YD, GC, K, and GK: in thousands of new Taiwan dollars (NT$) per person at 1981 constant prices.

(2) N, Primary, Secondary, and Higher: in thousand persons.

(3) EM, XR, BR, and Literacy Rate: percentages.

(4) $M1B$: in thousands of NT$ per person at current prices.

Sources

(1) YD, GC, and XR: computed from the *National Income* (NI) of the Republic of China (ROC), 1991, Directorate-Generate of Budget, Accounting, and Statistics (DGBAS).

(2) EM: computed from the *Yearbook of Labor Statistics*, ROC, 1991, DGBAS, and computed from *Taiwan Statistics Data Book* (TSDB), 1992, Council for Economic Planning and Development (CEPD).

(3) K, GK: computed from NI, 1991, DGBAS, and *Input–Output Survey*, 1979, CEPD.

(4) $M1B$: from TSDB, original source Central Bank of China (CBC).

(5) Education Level Data, Literacy rate, and BR_t: computed from the TSDB, 1992, CEPD.

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