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4 Old and New Development Models: The Taiwanese Experience

Ji Chou

The neoclassical growth model, pioneered by Robert Solow (1956), has as its basic features a closed economy with competitive markets and a production technology exhibiting diminishing returns to capital and labor separately and constant returns to all inputs jointly. In this model, population growth and the propensity to save, which affect the per capita level of income, are only affected by exogenous factors. Exogenously determined technology is the only force accounting for growth in per capita income. Therefore the model assigns a comparatively small role to other factors.

There have been calls for modification of these restrictive assumptions since the model's introduction.[1] The recent "new" growth theory includes the role of increasing returns to scale (Romer 1986), the learning-by-doing effects of human capital (Lucas 1988), and the dynamic spillover effects of export expansion (Grossman and Helpman 1991). It emphasizes that, when investment takes place under increasing returns to scale, the marginal product of capital need not decline over time. Hence the incentive to accumulate capital may persist for successive periods, sustaining a steady state of growth.

Recently, Mankiw, Romer, and Weil (1992, henceforth MRW) tested the neoclassical model and found that including human capital accumulation lowers the estimated effects of savings and population growth to roughly the value predicted by the Solow model. Moreover, the differences in savings, education, and population growth can explain about 80 percent of cross-country differences in income per capita. Two points are raised about their study. First, the study tests the neoclassical growth model by estimating the determination of a steady state level of income per capita rather than directly estimating the pro-

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1. For instance, Solow (1959) himself introduced a model that allowed for the embodiment effect between investment and technical progress. Arrow (1962) suggested the potential of learning by doing as a way of accounting for economic growth.

duction function as conventional approaches do. Second, the study, maintaining the old-fashioned assumptions of the neoclassical model, treats the determinants as exogenous and leaves technological change unexplained. Nevertheless, MRW's study stimulates us in this paper to ask the following questions:

1. Can a country's specific data be applied to MRW's model? Paul Romer (1987) argued that a production function regression using data such as postwar annual time series for a single country yields estimates that are ambiguous, since they cannot be justified in the context of a model for business cycles. Most recent empirical studies employ cross-country data to test growth theory. However, MRW's approach does not test the production function directly and might avoid the problem that Romer raised.

2. Is the exogenous assumption for savings ratio, population growth, and human capital accumulation valid? As MRW demonstrate in their paper, higher savings and lower population growth lead to a higher level of income and thus a higher level of human capital. Following from this consequence, the higher level of human capital accumulation will also lead to a higher level of income and thus a higher savings ratio or a slower growth of population. This implies that there is a contemporaneous feedback from income to the income determinants. Therefore, the exogenous assumption might not be valid. From an empirical viewpoint, both the least squares estimation method and the instrumental variable method should be employed and the estimation results compared to check the validity of the exogenous assumption.

3. What is the possible explanation for technological change? The beauty of the MRW approach is that the parameters of the production function are implied in the income determination function. The determinants of income, i.e., savings ratio and population growth, find their correspondent variables in the production function. The relaxation of the exogenous assumption in income determinants is equivalent to the relaxation of exogeneity of factor inputs in the production function.

The endogeneity of factor inputs might give more of a rationale to the embodiment hypothesis which Solow (1988) suggested; that is, a strong positive association exists between the growth rate of total factor productivity (which Solow called the rate of technical progress in the broad sense) and investment speed in intermediate-run transactions, even if the steady state of growth is not affected. If the interaction between total factor productivity and factor inputs can be applied to physical capital, the interaction between total factor productivity and other factor inputs, i.e., labor force and human capital, should also be taken into consideration.

4. What is the role of exports in growth in the above context? It has been found that there is a strong positive correlation between economic growth and export growth. There are numerous factors which explain this correlation, but how they can be linked within this context is the question. As Solow reminds us, "rapid technical progress and high investment could both be the result of some third factor, like the presence of conditions that encourage entrepreneurial activity. High investment and fast technical progress will then go together" (Solow 1988, 315).

Export expansion, which stimulates the derived demand of factor inputs and enlarges the scale of operations, could serve as the third factor encouraging entrepreneurial activity to enhance the interaction effect which we discussed in the context of question 3.

5. What additional economic implications can be obtained by including human capital accumulation as the third factor input in the production function? In this study, we examine whether including human capital accumulation corrects the overestimated impact of savings on income. Furthermore, we also test Lucas's assertion that human capital accumulation has both internal and external effects. The internal effect is the private marginal product paid to the person endowing the human capital. The external effect is that people interact with others who are more educated in the production process and thereby learn by doing. This has a social value which the private individual may not realize at all.

In order to tackle the problems raised, this paper is divided into two parts. First, we examine the MRW empiric on time-series data for Taiwan for the period 1953–92. The level of income per capita is determined by savings ratio, population growth, and human capital accumulation. The weighted enrollment rate of high schools and universities is compiled as the proxy for human capital accumulation. The aggregate physical capital stock is also compiled for measurement of the depreciation rate and to account for the impact of physical capital on growth of output.

Second, we examine the growth of technological change from the interaction effect between total factor productivity and factor inputs. The parameters of production, which are the implied parameters from the income determinant, are used for the calculation of total factor productivity. The simple interaction effect is rejected. We then propose a modified interaction effect in which the interaction effects of factor inputs coexist with the scale effect generated by export expansion. The implied parameters for the production function show a constant return to scale, and the externality of factor input cannot be separated from scale effect. In this regard, we conclude that the old, neoclassical development model is valid in the sense that the input factor owners are paid by their own marginal productivity. However, the new development model provides an explanation for technological change, in which external effects, factor inputs, and export expansion interact each other.

4.1 Taiwan's Growth Experience: 1953–92

Over the past 40 years, Taiwan's economy has achieved spectacularly rapid growth. Although only a small island of 13,900 square miles with few natural resources and a very high population density,[2] Taiwan realized a 10-fold increase in real GDP per capita with an average annual growth rate of 6.27 percent between 1953 and 1992. As shown in table 4.1, real GDP per capita increased from NT$19,942 in 1953 to NT$213,910 in 1992.[3] During the same period, the population growth rate dropped from 3.81 percent to 0.95 percent and the savings ratio increased from 14.45 percent to 28.42 percent. Therefore, Taiwan's growth has followed the prediction of established growth theory, i.e., high savings and lower population growth lead to a higher level of income.

Before World War II, Taiwan was occupied by the Japanese, and the colonial government regarded Taiwan as a source of agricultural products for their own country. In order to raise output, the Japanese invested in such infrastructure as irrigation and elementary education. After World War II, there was a severe scarcity of materials and foreign exchange due to acute inflation and the withdrawal of the Nationalist forces from mainland China to Taiwan. Faced with these conditions, the government imposed stringent import restrictions and encouraged import substitution industries to invest. However, since Taiwan is a small island, the domestic market reached its saturation point around the mid-1950s, and enterprises had to compete fiercely for the limited domestic market. Real GDP per capita grew only 3.68 percent over 1953–62. The import share was 16.8 percent of GDP, while the export share was only 10.43 percent. This was the only decade during the 1953–92 period that Taiwan's economy suffered a trade deficit and had domestic investment higher than domestic savings. To make up the current account deficit, U.S. aid filled the gap.

When the emphasis of trade policy shifted gradually from import restriction to export promotion following the Nineteen-Point Economic and Financial Reform of 1958,[4] the average growth rate for exports increased from 9.23 percent to 25.42 percent in the 10 years before and after 1963. Consequently, the high growth in exports brought about high growth in investment and imports during the 1963–72 period. The average annual growth rate of real GDP per capita also reached its highest level—7.89 percent—over the past 40 years with declining population growth.

In the period 1973–82, in spite of two oil crises in 1974 and 1979, the export growth rate remained at 9.23 percent, quite high for a period during which most developed countries suffered from stagflation. Meanwhile, mass public investment projects were implemented to raise the investment ratio to 30.73

2. The population density was 568 persons per square kilometer for Taiwan in 1991. This density is higher than in Japan (333 persons) and South Korea (439 persons). Although Hong Kong (5,550 persons) and Singapore (4,750 persons) are highest among the East Asian countries, they are city-states. The most notable high-density country among the industrialized economies is the Netherlands with 369 persons per square kilometer in 1991.

3. In current U.S. dollars, the GNP per capita was $169 in 1953 and $10,215 in 1992.

4. For a description of the background and implementation of export-led policy, see Lee and Liang (1982).

Table 4.1 Economic Growth Indicators in Taiwan, 1953–92

Indicator	1953	1953–62	1963–72	1973–82	1983–92	1992
GDP per capita (NT$ at 1986 prices)	19,942	24,973	43,542	87,794	165,281	213,907
Annual growth rate (%)		3.68	7.89	5.56	6.23	5.59
Population growth rate	3.81	3.51	2.82	1.91	1.11	0.95
Gross domestic saving/ GDP (%)	14.45	15.15	23.78	31.81	33.45	28.42
Gross domestic investment/GDP (%)	14.04	16.86	23.25	30.73	21.80	23.91
Current account/GDP (%)	0.40	−1.71	0.54	1.08	11.65	4.51
Export/GDP (%)	8.64	10.43	26.05	48.75	52.47	44.24
Import/GDP (%)	13.81	16.87	26.06	47.26	42.21	41.90
Export growth rate (%)		9.23	25.42	9.36	10.59	6.39
Import growth rate (%)		6.59	21.44	7.95	12.92	10.89
Literacy rate (%)[a]	56.01[b]	62.88	76.84	87.84	91.92	93.59
Secondary school enrollment rate (%)[a]	17.73[c]	29.28[c]	54.79[c,d]	66.52	81.33	85.20
Higher education enrollment rate (%)[a]	1.35[c]	2.73[c]	14.86[c,d]	17.85	25.27	38.62

Sources: Directorate-General of Budget, Accounting and Statistics (DGBAS), *National Income Account* (Taipei, 1993); DGBAS, *Social Indicators of the Republic of China* (Taipei, 1992).

[a]Figures for 1956, 1966, 1976, and 1986 are given for the decades 1953–62, 1963–72, 1973–82, and 1983–92; respectively.

[b]This figure is for 1950.

[c]Military servicemen are not included in the age cohort.

[d]Age cohorts are 15–19 and 20–24 rather than 12–17 and 18–22, since population data for single ages are not available for 1965.

percent. Shares of both exports and imports increased to around 48 percent of GDP, which slightly favored the current account. Real GDP per capita grew at 5.56 percent during this period.

During the period 1983–92, real GDP per capita growth rose to 6.23 percent due to the dramatic depreciation of the U.S. dollar in 1986 accompanied by the relatively slow appreciation of the local currency. Both exports and imports grew quickly during this period; however, that the export share of GDP was 10 percent greater than the import share implied that a great portion of available resources could not be absorbed for domestic use. Although the savings ratio increased to 33.45 percent, the investment ratio dropped to 21.80 percent due to the sluggish growth of public investment and the decline of labor-intensive industries because of the rise in wage rates and appreciation. In order to solve the problem of excess savings, the government implemented the so-called Six-Year National Development Plan in 1991 to boost public infrastructure construction. Furthermore, tremendous effort has been made by the government to encourage private investment.

There is a puzzle as to the growth in the period 1983–92. While the conventional factor inputs such as capital stock and employment grew relatively slowly, they still supported the fast growth of output. This implies that some factors beyond those studied in traditional growth theory should be considered. However, capital is only one factor which has been suggested to make a significant contribution to economic growth. Advances in knowledge and the diffusion of new ideas and objectives are necessary to remove economic backwardness and instill human abilities and motivations that are favorable to economic achievement. Secondary school enrollment was 17.73 percent in 1953 and 85.23 percent in 1991. Compulsory education was extended from six years to nine years in 1968, raising the secondary school enrollment rate from 29.28 percent in 1960 to 54.79 percent in 1970. The increase in income has also increased the demand for higher education. The enrollment ratio of higher education was only 1.35 percent in 1953, but jumped to 33.49 percent in 1991. This factor was very important when Taiwan began to emphasize labor-intensive industries and needed large numbers of skilled laborers in the 1960s to 1980s. And later, this helped Taiwan develop technology-intensive industries in the 1980s.

Compared with other middle-income developing countries, the human capital level in Taiwan is relatively high. In terms of adult literacy, the primary school enrollment ratio, and the secondary school enrollment rate, all of Taiwan's figures are higher than those for countries in the same income group, as shown in table 4.2. In fact, Taiwan's GNP per capita was even lower than the average for middle-income economies in 1970. However Taiwan's GNP per capita increased to twice the average for middle-income economies in 1989. A further observation should be made: the export growth rate is also high and this could enhance the international knowledge spillover effect and hasten economic growth, as outlined in Grossman and Helpman's (1990) paper.

4.2 The MRW Empirics of Growth Model

In this section we use Taiwanese data to test the MRW argument that (1) Solow's growth model predicts that increasing the rate of savings and decreasing population growth will raise the steady state level of per capita income, (2) the influence of the rate of savings is biased in the standard Solow model, (3) the inclusion of human capital in the production function could correct this bias, and (4) the exogenous assumption of income determinants is valid. We begin by reviewing the MRW Solow growth model with implications for a country's specific data.

Table 4.2 **Education Level, Per Capita GNP, and Export Growth Rate: An International Compensation**

Countries	Adult Literacy Rate 1961	Adult Literacy Rate 1981	Primary School Enrollment Rate 1961	Primary School Enrollment Rate 1981	Secondary School Enrollment Rate 1961	Secondary School Enrollment Rate 1981	Per Capita GNP (U.S. $) 1970	Per Capita GNP (U.S. $) 1989	Average Export Growth Rate 1961–89
Taiwan	74.1	90.1	96.0	99.8	33.1	82.6	392	7,201	16.2
Middle-income economies	48.1	65.2	75.2	100.0	14.1	38.9	490	3,190	4.8
High-income economies	98.0	98.9	113.9[a]	101.5[a]	63.9	89.2	2,050	19,240	5.4

Sources: For Taiwan, education data is from DGBAS, *Social Indicators of the Republic of China* (Taipei, 1992); export growth rate is from DGBAS, *National Income Account* (Taipei, 1992). For middle-income and high-income economics, education data is from World Bank *World Table. Volume II, Social Data* (Washington, D.C., 1983); export growth rate is calculated from World Bank, *World Table* (Washington, D.C., 1991).

Note: GNP per capita for Taiwan is calculated according to the World Bank Atlas method of converting data in national currency to U.S. dollars.

[a]The primary school enrollment rate is the enrollment of all ages in primary schools as a percentage of the population of primary school age, which normally covers all children from ages 6–11. The enrollment rate may exceed 100 percent because some pupils are below or above the official school age.

4.2.1 Models

MRW present two growth models. One is the standard Solow growth model with two inputs, capital and labor, which are paid their marginal products. The other adds human capital accumulation to the Solow model.

In the first model, it is assumed that a Cobb-Douglas production function at time t is given by[5]

$$(1) \qquad Y(t) = A(t)K(t)^{\alpha}L(t)^{1-\alpha}, \quad 0 < \alpha < 1,$$

where Y is output, K capital, L labor, and A the level of technology.

The model assumes that L grows exogenously at rate n and that a constant fraction of output s is invested. Through derivation of the evaluation of capital per capita, the standard Solow model indicates that the steady state income per capita is[6]

$$(2) \qquad \ln\left(\frac{Y(t)}{L(t)}\right) = \ln A(t) + \frac{\alpha}{1-\alpha}\ln(s(t)) - \frac{\alpha}{1-\alpha}\ln(n(t) + \delta(t)),$$

where δ is the rate of depreciation.

5. MRW assume the production function is labor augmented. In contrast, we do not assume this initially, but discuss the possibility of labor augmentation in the next section.

6. We specify $\ln A(t)$ rather than $\ln A(0) + gt$ as shown in MRW's eq. (6) because we apply the model for time-series analysis rather than cross-sectional analysis.

Equation (2) states that the steady state income per capita is related positively to the rate of saving and negatively to the rate of population growth. Because the model assumes that factors are paid their marginal products, it predicts not only the signs but also the magnitudes of the coefficients on savings and population growth. However the magnitudes of the coefficients on savings and population growth will be biased if the important input factor is omitted in equation (2). Therefore, the second model is introduced.

The second model expands the Solow model to include human capital. With the production function adding the stock of human capital, H, as the third production input, we can go through a similar derivation. Assuming that human capital depreciates at the same rate as physical capital, combining the determination equation with the level of human capital yields an equation for income as a function of the rate of investment in physical capital, the rate of population growth, and the level of human capital:

$$(3)\qquad \ln\left(\frac{Y(t)}{L(t)}\right) = \ln A(t) + \frac{\alpha}{1-\alpha}\ln(s(t)) - \frac{\alpha}{1-\alpha}\ln(n(t)+\delta(t)) + \frac{\beta}{1-\alpha}\ln(H(t)).$$

Equation (3) and equation (2) are different because of the additional variable H, which is omitted in equation (2). The omitted human capital term biases the coefficient on savings and population in equation (2).

4.2.2 Specification

Although equations (2) and (3) claim that the higher savings rates and human capital, the higher the level of income per capita, and that the higher the population growth, the lower the income per capita, there is another factor which could influence income level in both equations, i.e., $A(t)$, the technological level. Since the $A(t)$ term reflects not just technology but international and domestic shocks, as well as cyclical fluctuation, it may therefore be determined by

$$\ln A(t) = a + \varepsilon(t),$$

where a is a constant and ε is a random variable which is independent of the savings rate, human capital, and population growth rate.

Therefore equations (2) and (3) can take the stochastic forms:

$$(4)\qquad \ln\left(\frac{Y(t)}{L(t)}\right) = a + \frac{\alpha}{1-\alpha}\ln(s(t)) - \frac{\alpha}{1-\alpha}\ln(n(t)+\delta(t)) + \varepsilon(t),$$

$$(5)\qquad \ln\left(\frac{Y(t)}{L(t)}\right) = a + \frac{\alpha}{1-\alpha}\ln(s(t)) - \frac{\alpha}{1-\alpha}\ln(n(t)+\delta(t)) + \frac{\beta}{1-\alpha}\ln(H(t)) + \varepsilon(t).$$

Equations (4) and (5) are the empirical specification of MRW's version when applied to the time-series data.

In reality, however, the income level could affect savings and population growth (e.g., see Tsiang 1964). Furthermore, higher savings and lower population growth lead to a higher level of income and hence a higher level of human capital. This implies that s, n, and H are endogenous. Using ordinary least squares would lead to a potentially inconsistent estimation result.

In order to deal with this problem, we utilize both the ordinary least squares estimation method and the instrumental variable method.

4.2.3 Data Source and Compilation

The empirical study is conducted using annual data for Taiwan from 1953 to 1992 subject to the availability of data. We measure n as the annual growth rate of the working population aged 15–64. We measure s as the share of real investment in real GDP,[7] and Y/L as real GDP at 1986 constant prices divided by the working-age population in that year. To measure the depreciation rate, we measure the aggregate capital stock for Taiwan, then take the depreciation allowance over the capital stock. The measurement of capital stock is described in the appendix.

In measuring human capital to implement the model, we restrict our focus to formal education and, as MRW did, (1) ignore investment in health and on-the-job training, (2) ignore the forgone labor earnings which measured GDP fails to include, and (3) ignore primary education and the input of teachers. However, we include higher education in human capital.

The Harbison-Myers index, which is derived from the secondary school enrollment rate plus five times the university enrollment rate in the respective age cohorts, is used as the proxy of human capital accumulation (see Harbison, Maruhnic, and Resnick 1970). However, data for the single age cohorts for the periods 1963–68 and 1972–73 in Taiwan are not available. We are forced to use the population aged 15–19 and aged 20–24 as the denominator to derive the student population in secondary schools and higher education. Although this variable is not perfect since the age ranges in the two sets of data are not exactly the same, the variable might reflect the concept of stock which lagged the enrollment rate by several years to distinguish the stock of human capital from the flow of human capital.

4.2.4 Time-Series Data Considerations

The difficulties of using annual macrodata to analyze economic growth has been raised by Romer (1987, 186) in at least three respects. They are serially

7. Using the share of investment in GDP rather than the savings share in GDP has special significance for Taiwan. In the 1980s, Taiwan experienced excess savings of over 20 percent of GDP, which could have been used to invest to raise the income level, but which were not absorbed domestically.

correlated disturbances, cyclical fluctuation, and contemporaneous feedback. Since we will estimate the model using both the ordinary least squares method and the instrumental variable method, the third problem has been taken into account. The first two difficulties are discussed here with respect to the stationarity of time-series data with serially correlated disturbance and the addition of a cyclical variable to the equations.

Stationarity

Since the macroeconomic data are generally nonstationary, we have tested the hypothesis of unit roots for the variables studied in this paper to find stationarity. To test for a unit root, we ran both DF and ADF regression at the level and at the first-order difference of the variables.[8]

Table 4.3 shows that all variables except population growth n accept the unit root hypothesis at the level; all variables other than human capital and physical capital reject the unit root hypothesis at the first-order difference. Although the cointegregation approach is one way to deal with the unit root problem in the model, variables in equations (4) and (5) are not integrated to the same order and the length of sample is not long enough. This approach is not appropriate for this study. We tried the first-order difference form to estimate equations (4) and (5), but the results do not make any economic sense. We used the Plosser-Schwert-White (1982) differencing test and found the difference regression, indeed, leads to different results.

The low power test for the unit root hypothesis leads us to scrutinize the time property of per capita income $\ln(Y/L)$. The F-test for the hypothesis $\beta_1 = 0$, $\beta_2 = 1$ for the model

$$\ln\left(\frac{Y(t)}{L(t)}\right) = \beta_0 + \beta_1 t + \beta_2 \ln\left(\frac{Y(t-1)}{L(t-1)}\right) + \beta_3\left[\ln\left(\frac{Y(t-1)}{L(t-1)}\right) - \ln\left(\frac{Y(t-2)}{L(t-2)}\right)\right] + e_t$$

is 6.12, which is rejected at the 10 percent significance level.[9]

8. For a discussion of stationarity and the DF and ADF regression for unit test, see Maddala (1992, 258–63, 578–602).

9. The ordinary least squares estimates of the model are

$$\ln\left(\frac{Y(t)}{L(t)}\right) - \ln\left(\frac{Y(t-1)}{L(t-1)}\right) = \underset{(0.18)}{0.64} + \underset{(0.005)}{0.02t} - \underset{(0.07)}{0.23} \ln\left(\frac{Y(t-1)}{L(t-1)}\right) + \underset{(0.15)}{0.29}\left[\ln\left(\frac{Y(t-1)}{L(t-1)}\right) - \ln\left(\frac{Y(t-1)}{L(t-1)}\right)\right],$$

$$\text{RSS} = 0.021228,$$

$$\ln\left(\frac{Y(t)}{L(t)}\right) - \ln\left(\frac{Y(t-1)}{L(t-1)}\right) = \underset{(0.01)}{0.04} + \underset{(0.16)}{0.31}\left[\ln\left(\frac{Y(t-1)}{L(t-1)}\right) - \ln\left(\frac{Y(t-2)}{L(t-2)}\right)\right],$$

$$\text{RSS} = 0.028876,$$

where RSS denotes the residual sum of squares and the numbers in parentheses are standard errors. The F-test for the hypothesis $\beta_1 = 0$, $\beta_2 = 1$ is 6.12, while the 90 percent point of the distribution is given in table VI of Dickey and Fuller (1981) as 5.47.

Table 4.3 **Tests of Unit Roots**

Variable	Level		First-Order Difference	
	DF	ADF	DF	ADF
$\ln(Y/L)$	−3.12	−3.36	−4.45	−4.16
$\ln(I/Y)$	−1.28	−1.58	−4.38	−3.50
$\ln(n+\delta)$	−4.59	−3.88	−8.12	−6.64
lnH	−2.45	−1.88	−2.75	−2.53
$\ln(I/Y) - \ln(n+\delta)$	−3.05	−2.35	−7.98	−6.41
$\ln H - \ln(n+\delta)$	−2.98	−2.36	−7.99	−6.27
lnK	−0.40	−3.26	−1.50	−1.80

Notes: For variable X_t, DF and ADF are the t-statistics for b in the regressions $\Delta X_t = a + bX_{t-1} + ct + U_t$ and $\delta X_t = a + bX_{t-1} + c\Delta X_{t-1} + dt + U_t$, respectively.
At the 5 percent significance level with sample sizes 25 and 50, the critical values are −3.60 and −3.50, respectively, for both DF and ADF.

Therefore, we are forced to use the conventional approach and tolerate the low Durbin-Watson (DW) statistic. The occurrence of a low DW value might be due to the fact that omitted variables other than human capital should be considered.[10]

Cyclical Fluctuation

To account for cyclical fluctuation, we added the manufacturing capacity utilization rate, commonly considered the best candidate for cyclical variation, to equations (4) and (5). Only data since 1976 are available. We ran the regression with the additional capacity utilization rate for the period 1976–92 and found the additional variable is not significant. Although this might be caused by the short sample observation, another reason is that the model deals with income per capita at the steady state level rather than the product output of the conventional production model. Therefore, the model is not sensible with respect to cyclical fluctuation.

4.2.5 Results

Table 4.4 shows the estimation result of the Solow model with and without human capital in the case of Taiwan. Both the ordinary least squares estimation method (OLS) and the instrumental variable method (INST) are reported. The sample period is from 1953 to 1992. Equations are estimated with and without imposing the constraint that the coefficient of $\ln(n + \delta)$ is equal to $\ln s$ in the case without human capital, and the constraints that the coefficient of $\ln(n + \delta)$ is equal to $\ln s$ and is equal to $\ln H$ in the case with human capital.

Equation (a) is the neoclassical growth model without human capital estimated by OLS. The result supports the model in two respects. First, the coeffi-

10. The omitted variable might be the export variable, which will be discussed in the next section.

Table 4.4 **Estimation of the Solow Model with and without Human Capital in Two Estimation Methods, Annual Data 1953–92 (NOB=40) (Dependent Variable: log real GDP per working-age person)**

	OLS		INST	
Variable	(a)	(b)	(c)	(d)
CNST	3.43	0.87	2.17	0.29
	(4.58)	(1.79)	(2.33)	(−0.45)
ln(*I*/*Y*)	1.22	−0.10	1.19	−0.22
	(9.81)	(−0.66)	(8.66)	(−1.09)
ln(n+δ)	−1.38	−1.38	−1.87	−1.76
	(−5.31)	(−9.79)	(−5.74)	(−9.85)
ln*H*		0.81		0.84
		(9.49)		(7.84)
$\bar{R}^2$	0.82	0.95	0.82	0.94
DW	0.44	1.01	0.81	1.30
SSR	2.82	0.81	3.10	0.97
	Restricted Regression			
CNST	3.80	2.59	3.75	2.68
	(49.48)	(15.47)	(47.01)	(14.49)
ln(*I*/*Y*) − ln(n+δ)	1.26	0.20	1.34	0.36
	(13.48)	(1.35)	(13.64)	(2.00)
ln*H* − ln(n+δ)		0.71		0.64
		(7.59)		(5.98)
$\bar{R}^2$	0.82	0.93	0.82	0.93
SSR	2.84	1.11	2.90	1.14
F	0.25	6.81	−2.41	3.18
Implied α	0.56	0.17	0.57	0.26
β		0.42		0.39

Note: Numbers in parentheses are *t*-statistics.

cients for savings and population growth have predicted signs and are highly significant. Second, the restriction that the coefficients on ln s and ln(n + δ) are equal in magnitude and opposite in sign is not rejected. The estimated impacts of savings and labor force growth (0.56) are similar to the MRW results and imply the estimate is much higher than the model prediction that $\alpha = 1/3$.

Equation (b) presents regressions of the log of income per capita on the log of the investment rate, the log of n + δ, and the log of human capital. The human capital measure enters significantly and improves the fit of the regression compared with equation (a). The DW statistic rises from 0.44 to 1.01, indicating that human capital is the important factor dominating income per capita—which is itself autocorrelated—and has been omitted from equation (a), the standard neoclassical growth model. Although the unrestricted form of equation (b) exhibits the multicollinearity problem, which makes the coefficient of ln(*I*/*Y*) insignificant and of the wrong sign, the implied value of α in the restricted regression has been reduced from 0.56 to 0.17. The other implied parameter β shows that the impact of human capital on income per capita, 0.42, is still higher than the model prediction. Nevertheless, the F-statistic, 6.81, rejects at the 5 percent level the equal impact of physical capital and human capital.

Equations (c) and (d) take into account the endogeneity of the income determinants by employing two-stage least squares estimation procedures, using lagged values of all variables shown in table 4.4 as instruments.[11] For the case without human capital, the results of equation (c) are similar to those of equation (a) for the biased value of α, but with an improvement in the DW statistic.

When human capital is included in the consideration of endogeneity, as shown in equation (d), the autocorrelation problem is almost solved since the DW statistic, 1.30, is close to the lower limit for significance. Furthermore, the implied values of α and β are closer to 1/3, as MRW proposed. We conclude that the MRW proposal of the income per capita model, i.e., adding human capital to the Solow model, can be tested in country-specific time-series data with consideration of endogeneity. The relaxation of the exogeneity assumption on the determinants leads us to move from the old development model to the new development model.

4.3 Interaction between Factor Inputs and Productivity Growth

We have examined a Solow model which includes accumulation of human as well as physical capital using country-specific data. The results are derived from a Cobb-Douglas production function implying that factor inputs are paid by their own marginal productivities. Although the results explain the determinants of the long-term level of output per worker, they do not explain the fast productivity growth and the strong positive association between trade and growth. For the study of productivity growth, Jorgenson (1990) carefully distinguishes the contribution of capital and labor quality from the contribution of capital stock and hours worked based on the strict neoclassical assumption of constant returns to scale. Boskin and Lau (1992) employ the meta–production function to identify separately the degree of returns to scale, the rate of technical progress, and the bias of technical progress. While the time-series and cross-sectional analyses of growth by Jorgenson, as well as Lau and his coauthors, have the flavor of a well-specified theory, they do not take into account the externality factor of input and trade.

Economists including Solow argued that a factor input could generate externalities and contribute to economic growth in excess of what the factor itself earns. We examine this possibility through the interaction effect between total factor productivity (TFP) and factor inputs first, then show the importance of

11. The alternative set of instruments, which includes government consumption, public investment, exports, and imports, as well as the lagged values of these four variables plus the constant term, gives a similar result.

trade and the importance of the trade and factor externalities in the consequent context.

4.3.1 The Simple Interaction Effect

There are three potential interaction effects. First, the embodiment effect suggests that substantial capital accumulation is necessary to put new inventions into practice and to affect widespread employment (Solow 1988; Nelson 1964; Wolff 1991). Second, the improvement in labor quality, due to both the changing age-sex composition of the work force and the decline of work hours,[12] could affect TFP[13] (Nelson 1964; Denison 1979). Third, there is an interaction between human capital and TFP. Lucas (1988) argued that human capital accumulation is a social activity: the more educated workers interact with other educated people, the more new ideas come about which improve productive efficiency. Therefore human capital exerts two effects on the production process: one is the internal effect of an individual's human capital on his own productivity; the other is the external effect that no individual human capital accumulation decision can take into account.

The TFP level is defined as the ratio of total output (Y) to a geometrically weighted average of physical capital input (K), human capital input (H), and labor input (L):

(6) $$\text{TFP} = Y / (K^{\alpha} L^{1-\alpha-\beta} H^{\beta}).$$

Total factor productivity growth can then be defined as

(7) $$\widehat{\text{TFP}} = \hat{Y} - \alpha\hat{K} - (1 - \alpha - \beta)\hat{L} - \beta\hat{H},$$

where the "hat" (^) indicates the relative rate of change.

In general, a production function associated with the interaction effect in the paper could be expressed as

(8) $$Y = AK^{\alpha} L^{1-\alpha-\beta} H^{\beta} X^{\gamma}, \quad \gamma > 0,$$

where X could be either physical capital, labor input, or human capital. The rate of growth of TFP is then defined as

(9) $$\widehat{\text{TFP}} = \hat{A} + \gamma\hat{X}.$$

Equation (9) is used as the specification for testing the interaction hypothesis by positing a positive association between the rate of growth of TFP and

12. The conventional argument for labor improvement includes improvement in educational attainment in the production function of two inputs (i.e., capital and labor). Since we add human capital as another factor input, an improvement in educational attainment will contribute directly to human capital.

13. The common practice with regard to labor improvement in growth analysis is the labor augmentation approach which treats labor input exogenously and uses another exogenous variable (e.g., production efficiency) as a proxy for labor improvement. If labor input is endogenous, there is no difference between the labor augmentation and the labor interaction effects.

the rate of growth of factor inputs. In this simple version of the interaction effect, there is no other effect involved.

The results of the estimation are shown in table 4.5. All three equations reject the hypothesis. In the case of human capital, the sign of the estimated interaction coefficient is opposite at a significant level. Both physical capital and labor input show statistically insignificant results, while the sign for the capital growth coefficient is also opposite. The results are similar to Dollar's (1991) study on the convergence of South Korean productivity to West German levels, where the hypothesis of the interaction effect between TFP and capital accumulation was also rejected.

4.3.2 The Role of Exports

The rejection of the simple interaction effect is a result of ignoring the export expansion which has played an important role in the economic growth of a small economy like Taiwan's. Exports can be substituted for import goods which either are scarce in nature or for which Taiwan has no advantage in domestic production. Furthermore, it has been found that there is a statistically significant correlation between export expansion and output growth as shown in equation (d) of table 4.5. The relation between export performance and economic growth has been a subject of considerable interest to development economists for various reasons, including economies of scale, efficiency of resource allocation, and international knowledge spillover.[14]

However, Chen and Tang found that "export expansion leads to scale enlargement, thereby contributing to productive growth. But aside from its indirect contribution to the scale of output, export expansion has a rather ambiguous and weak linkage to productivity growth in Taiwan" (1990, 583). Apparently, the scale effect of export expansion can enlarge other external effects which are generated by factor inputs. We attempt to make up for Chen and Tang's gap, and postulate the hypothesis that export expansion will generate economies of scale which coexist with and enhance the externalities of factor inputs in productivity growth.

4.3.3 The Modified Interaction Effect

Our modified version of the interaction effect is derived from a production function

(10) $$Y = AK^{\alpha} L^{1-\alpha-\beta} H^{\beta} X^{f(\hat{E})},$$

where the interaction effect of factor input X will be enhanced by the scale

14. The proponents of externalities from trade include Bhagwati (1978) who considers scale economies the largest benefit of the export promotion trade strategy, Feder (1984) who argues for the reallocation of existing resources from the less efficient nonexport sector to the higher productivity export sector, and Grossman and Helpman (1991) who see the international knowledge spillover generated by trade coexisting with the externality of domestic innovation.

Table 4.5 **Interaction Effect, 1953–92 (Dependent Variable: $\hat{TFP}$)**

Variable	(a)	(b)	(c)	(d)
CNST	0.03	0.02	0.05	0.00
	(0.97)	(0.87)	(5.46)	(0.42)
$\hat{K}$	−0.6			
	(−0.25)			
$\hat{L}$		0.21		
		(0.40)		
$\hat{H}$			−0.35	
			(−4.01)	
$\hat{E}$				0.11
				(3.39)
$\bar{R}^2$	−0.02	−0.02	0.28	0.22
DW	1.87	1.86	1.86	1.94
SSR	0.04	0.04	0.03	0.32
ρ	0.46	0.46	0.21	0.49

Notes: Numbers in parentheses are t-statistics. All equations are corrected for serial correlation.

effect of export expansion $f(\hat{E})$. For simplicity, we assume the scale effect is proportional to export growth, $f(\hat{E}) = \gamma\hat{E}$. Thus, the specification for the hypothesis test of the modified version of the interaction effect will be

(11) $$\hat{TFP} = \hat{A} + \gamma\hat{E}\hat{X}.$$

The modified interaction effect shows that the factor interaction effect "interacts" with the scale effect generated by export expansion. This can be seen from the derivative of $\hat{TFP}$ with respect to $\hat{X}$:

(12) $$\frac{d\hat{TFP}}{d\hat{X}} = \gamma\hat{E}.$$

Therefore, the impact of factor growth on productivity is not independent of export growth.

The results of the regression of the modified interaction effects are shown in equations (a)–(c) of table 4.6. The rates of growth of the physical capital and labor inputs now show significant positive effects on the rate of growth of total factor productivity, while human capital still shows an insignificant negative effect without any explanatory power for TFP.

We check the human capital series and find there is a structural break in 1968 (see fig. 4.1.). In that year, the length of compulsory education in Taiwan was extended from six years to nine years. However, the effect of the extension of the length of compulsory education in the human capital series was offset by including servicemen in the population statistics beginning in 1969. Because most servicemen are in the 20–24 age cohort, the exclusion of servicemen leads to a calculation of the higher education portion of the human capital index which is more heavily weighted prior to 1969. Therefore, the data structures for the human capital index before and after 1969 are different.

Table 4.6 **Modified Version of Interaction Effect in Two Different Periods (Dependent Variable: $\hat{TFP}$)**

	1953–92			1970–92		
Variable	(a)	(b)	(c)	(d)	(e)	(f)
CNST	0.00	0.00	0.02	0.00	−0.10	0.02
	(0.15)	(0.72)	(2.69)	(0.16)	(−0.08)	(2.30)
$\hat{E}\hat{K}$	1.14			1.96		
	(4.06)			(7.50)		
$\hat{E}\hat{L}$		2.75			9.48	
		(2.79)			(8.22)	
$\hat{E}\hat{H}$			−0.31			3.95
			(−0.99)			(2.05)
$\bar{R}^2$	0.28	0.15	−0.00	0.72	0.76	0.13
DW	1.95	1.90	1.87	1.87	1.91	1.98
SSR	0.03	0.03	0.04	0.009	0.008	0.023
ρ	0.53	0.52	0.39	0.64	0.70	0.15
F				14.26	24.38	6.42

Notes: Numbers in parentheses are *t*-statistics. All equations are corrected for serial correlation. $F_{1,40}$ at the 5 percent significance level = 4.08.

Table 4.7 **Alternative Version of Interaction Effect in Two Different Periods (Dependent Variable: $\hat{TFP}$)**

	1953–92			1970–92		
Variable	(a)	(b)	(c)	(d)	(e)	(f)
CNST	0.00	0.00	−0.00	−0.00	−0.00	−0.00
	(0.17)	(0.42)	(−0.23)	(−0.54)	(−0.59)	(−0.25)
$\hat{E}\hat{K}$	1.52			−1.02		
	(1.99)			(−1.82)		
$\hat{E}\hat{L}$		−0.46			−5.19	
		(−0.23)			(−1.84)	
$\hat{E}\hat{H}$			−1.90			−1.14
			(−7.89)			(−1.32)
$\hat{E}$	−0.05	0.13	0.28	0.41	0.43	0.30
	(−0.54)	(1.82)	(9.47)	(5.11)	(4.87)	(9.91)
$\bar{R}^2$	0.27	0.19	0.70	0.82	0.82	0.84
DW	1.94	1.93	1.87	1.93	1.94	1.80
SSR	0.03	0.03	0.01	0.01	0.01	0.01
ρ	0.54	0.48	0.47	0.28	0.29	0.56
F				16.93	26.68	4.03

Notes: Numbers in parentheses are *t*-statistics. All equations are corrected for serial correlation. $F_{2,40}$ at the 5 percent significance level = 3.23.

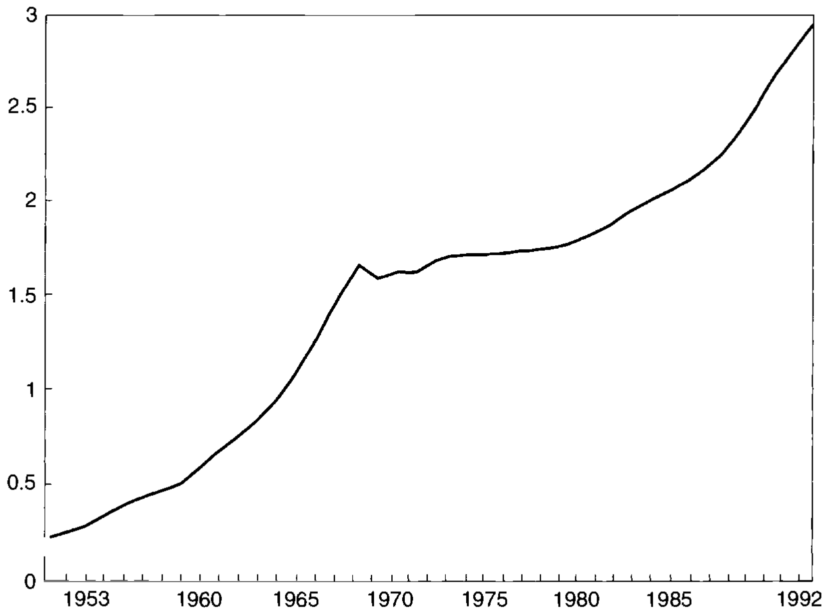

Fig. 4.1 Human capital index

Equations are rerun for the period 1970–92 and are shown in equations (d)–(f) of table 4.6. Chow's *F*-tests, which are statistically significant at the 5 percent level in all three equations, imply the existence of structural change. All three factor inputs' interaction effects, coexisting with the scale effect, are significantly positively correlated with TFP in the period 1970–92. The explanatory powers of the regressions in the new period have increased from 0.28, 0.15, and 0.0 to 0.72, 0.76, and 0.13 for physical capital, labor input, and human capital, respectively.[15,16]

15. Capacity utilization is another important explanatory variable used to catch the cyclical fluctuation in TFP analysis. However, annual data for Taiwan are available only for 17 years, i.e., 1976–92. Running the regression for that period, we found that the value of adjusted R^2 is raised and the coefficient of the utilization rate is significantly positive. The inclusion of the utilization rate does not alter the importance of export growth on productivity growth, which might imply that export growth generates a scale effect rather than cyclical effects. Since the results do not alter our prediction much, we do not list them here.

16. We tried regression with interactive terms along with the export growth variable, as shown in table 4.7. For the whole period (1953–90), only the interactive term for physical capital is significantly positive, while the additional export growth variable is insignificant. The interactive terms for both labor and human capital are negative with significantly positive export growth. For the period 1970–92, all interactive terms turn negative, while the export growth variable is significantly positive. Five out of six cases show the positive association of export growth with productivity; however, the negative impact of the interactive term on productivity contradicts predicted theory. We are forced to drop the additional export growth variable in table 4.6.

4.4 Conclusion

We find that the neoclassical growth model can be applied to the Taiwanese experience when human capital accumulation is added to physical capital and labor input in the neoclassic production function and when the exogeneity of factor inputs is relaxed. In a perfectly competitive market with constant returns to scale, factors are paid their internal marginal productivity. In other words, the estimated equations in section 4.2 show that, except for population growth and the rate of investment, human capital could change the long-run level of output per worker. This finding essentially supports established growth theory with human capital as the third factor influencing production and with a relaxation of the exogeneity of factor inputs.

However, this finding is not sufficient to explain the rapid growth of the Taiwanese economy in the past 40 years unless we tackle the technological change issue. We examine the interaction effect between technological change and factor inputs and find that in a small open economy like Taiwan's, the interaction effect coexists with the scale effect generated by export expansion. Therefore, our empirical results in section 4.3 show that growth and trade have risen by leaps and bounds as Romer (1986) and Lucas (1988) have suggested.

Our findings stress the importance of trade and human capital accumulation, both of which have been pursued by new growth theory. Because of the coherence of the scale effect from trade for a small open economy and international knowledge spillover from the external effect of human capital and international trade, our empirical findings have empirical and policy implications, i.e., a small country can grow as fast as a large one by introducing international trade and human capital. Therefore, this paper supports the hypothesis that an orientation toward foreign trade is at the heart of the spectacular growth performance of the East Asian economies.

Appendix

Measurement of Aggregate Capital Stock for Taiwan

Although series for capital stock in Taiwan are published by the government statistics agency, the Directorate-General of Budget, Accounting and Statistics (DGBAS), the series start from 1961 and do not yet include aggregate capital stock. We measure the capital stock series in the form

$$K(t) = K(t-1) + I(t) - D(t), \tag{A1}$$

where $K(t)$ is the real capital stock at period t, $I(t)$ is the real gross fixed investment, and $D(t)$ is the real capital depreciation allowance. The benchmark year is 1951. We calculate the initial stock[17] by

17. The approach of calculating initial capital stock is suggested by William W. F. Chao and Lawrence Lau.

(A2) $$K(1) = \frac{I(0)e^{\theta}}{\theta},$$

where $I(0)$ and θ are the estimated coefficients of the constant term and TIME in the following form, by ordinary least squares estimation:

(A3) $$\ln I(t) = C + \theta\text{TIME}.$$

The estimation is that (1) the capital stock in the first period is the sum of all past investments:

(A4) $$K(1) = \int_{t=-\infty}^{1} I(t)dt;$$

and (2) the investment series may be approximated by an exponential time trend:

(A5) $$I(t) = I(0)e^{\theta t}.$$

Inserting equation (A5) into equation (A4) yields equation (A2). Taking natural logarithms of equation (A5), we obtain equation (A3) where the constant term c is ln $I(0)$.

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Comment Chia Siow Yue

This paper is a useful contribution to the growing literature on the empirical testing of growth and development models and provides additional insights into Taiwan's miraculous economic performance. Some empirical studies support Solow's neoclassical growth model, and others support the new endogenous growth models. Researchers have found significant relationships between some variables and economic growth, but few results are robust and many could be altered by addition of other explanatory variables. There is no clear distinction between the Solow and endogenous growth models empirically, in part because the two theories complement each other and in part because the

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existing statistical tests are not powerful enough. The Solow model does not assign any distinctive productive role to human capital or to government policy; growth is due to exogenous technological change. The endogenous growth models complement Solow in explaining technological change and are capable of dealing with issues such as increasing returns to scale, learning-by-doing effects of human capital, and dynamic spillover effects of export growth.

Chou's paper has two parts. The first part uses time-series data on Taiwan to test an extended Solow growth model incorporating human capital accumulation. The second part examines technological change by testing for the interaction effects between total factor productivity and factor inputs. Studies such as this, based on country-specific time series, complement existing studies based on cross-country data and provide more robust relationships. Time-series regressions are more appropriate for studying long-run growth paths. Cross-country studies face the problems of different initial conditions, data of uneven quality and consistency, and comparable quantification of policy variables. However, time-series data face the problems of serially correlated disturbances, cyclical fluctuations, and contemporaneous feedback. Chou used the instrumental variable method in addition to ordinary least squares to take care of contemporaneous feedback, and the manufacturing capacity utilization rate as a proxy for cyclical fluctuations. The problem of serially correlated disturbances remained.

Economists have long stressed the importance of human capital in economic growth, but the role of human capital came into greater prominence with the endogenous growth models. Human capital enhances productivity of both labor and physical capital inputs. Chou's paper explored the effect of adding human capital accumulation to the Solow model. He found human capital to be an important factor in Taiwan's economic growth, and its inclusion in the growth regression improves the fit significantly and corrected for the upward bias in the estimated effects of the savings ratio and population growth. Chou used secondary and tertiary school enrollment as a proxy measure for human capital accumulation. However, enrollment ratios ignore the important role of training and learning by doing and the productivity effect of the educational curriculum. Additionally, labor efficiency depends not only on education and training, but also on labor-management relations and work ethics. In East Asia, Taiwan is noted for its high priority on broad-based education as well as its emphasis on technical and science-based education and training and its absence of industrial strife. Lucas has argued that human capital affects economic growth in two ways, via the internal effect of an individual's human capital on his own productivity and an external effect. For the latter, when educated workers interact, more new ideas emerge to improve productive efficiency. Chou tested the interaction between human capital and total factor productivity in Taiwan but found that the coefficient had an opposite sign which is statistically significant. The implication is that human capital in Taiwan serves the role of accumulating capital, complementing physical capital and labor rather than providing economy-wide externality.

Economists studying East Asia, particularly the Asian newly industrialized economies (NIEs), have stressed the importance of outward orientation in explaining the region's exceptional economic dynamism. However, outward orientation has generally been measured in terms of trade orientation or, more particularly, export orientation. The role of imports, including foreign technology, and the role of foreign investments have been given much less attention. Gains from trade arise from both the static effects of improved resource allocation according to comparative advantage and improved capacity utilization, as well as from positive externalities arising from the exploitation of scale economies and international knowledge spillovers generated by trade coexisting with domestic innovation activity and more efficient management in response to international competition. Evidence of positive level effects does not necessarily imply that trade will lead to faster rates of economic growth. A number of cross-country studies have shown little correlation between economic growth and export-GDP ratios once the growth regressions included other important variables. Chou's study found a statistically significant correlation between export growth and economic growth in Taiwan. Export growth led to productivity growth mainly through the scale effect, which has particularly significant implications for small countries, as represented by the four Asian NIEs. Export growth enhances the externalities of factor inputs in productivity growth. The international spillover effect of exports is unclear.

Chou's paper has demonstrated the importance of human capital and exports in explaining Taiwan's economic growth. However, policy measures affecting human capital formation and exports in Taiwan remain unclear. What are the incentives for education, training, and learning by doing at the individual, household, and firm levels? Is Confucian ethics important in the emphasis on education by individuals and households? Or can the emphasis on education be explained by the reward system, in terms of both earnings and social prestige of the more educated vis-à-vis the less educated? Also, what explains Taiwan's export growth? In particular, given the dominance of small and medium-sized enterprises in the industrial structure, how do these firms achieve export success, and what incentives and assistance are provided by government? Further, in view of the considerable foreign direct investment in Taiwan, what is its role in both human capital accumulation and export performance?