

Did Technical Progress Play a Primary Role in Taiwan's Economic Growth in the Last Decade of the Twentieth Century?

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Abstract

In this research, we sought to answer a question that has endured over the last thirty years—what was the primary source of economic growth in Taiwan in the 1990s? We tested the hypothesis that Taiwan's economic growth in the last decade of the twentieth century could be traced primarily to exogenous factors, such as technical progress (i.e., technology shocks). We compared regressions for the earlier period (1965-1990) with those from an overlapping but later period (1975-2000) to distinguish the relative contributions made by sources to Taiwan's economic growth during these two periods. We then observed the differences in the statistical results to draw certain inferences regarding the 1990s. We concluded that technical progress played a primary role in the economic growth of Taiwan during the 1990s. That is, the primary source of economic growth in Taiwan in the last decade of the twentieth century was mainly exogenous.

Keywords

Education, Economic Growth, Technical Progress, Complementarity Test, Technology Shocks

1. Introduction

Economists continue to seek the primary source of Taiwan's economic growth during the 1990s. Past studies, such as those from Hsieh and Hsing (2002) and Lin (2003, 2004), have investigated the essential contributions made by several factors to Taiwan's economic growth during the last four decades of the twentieth century. Findings have shown that human capital (i.e., education) played an essential role in Taiwan's economic growth during this period. However, these and related

studies did not find that technical progress also played an important role (Lin, 2003; Barro, 2001; Park & Lee, 2001).

On the other hand, statistical evidence from the *Taiwan Statistical Data Book* shows that the electronics and information sectors expanded rapidly to become the main industries in Taiwan in the last decade of the twentieth century. More importantly, the production value shares for the electrical and electronics sectors in the manufacturing industry significantly increased from 13.3% in 1989 to 30.1% in 1999. In fact, 30.4% of Taiwan's exports in 1999 were from electronic, information, and telecommunication products. Furthermore, Taiwan's manufacturing industry had become increasingly knowledge-based in the last decade of the twentieth century. As a result, professional information, telecommunications, and networking services expanded most rapidly, while electronic commerce became a service trend. Moreover, the information technology revolution during the 1990s had the greatest effect not only on the United States and other developed countries, but also on developing areas, such as Taiwan. These findings lead to the question: Did technical progress play a primary role in Taiwan's economic growth in the last decade of the twentieth century?

To investigate this issue, we compared regressions for the earlier period (1965-1990) with those for overlapping but later period (1975-2000) to distinguish specific sources' relative contributions to growth in these two periods. In other words, we opted to use two sample periods—one excluding the 1990s and the other including the 1990s. We then observed the differences in the statistical results to draw certain inferences regarding the 1990s. This led to a research hypothesis for this study: the primary source of Taiwan's economic growth in the 1990s could be mostly exogenous (i.e., technical progress/technology shocks).

2. Methodology

2.1. The Econometric Model

Here, the production function is displayed as the Cobb-Douglas form, which is shown in Lin (2006). The output is modeled as a function of labor, physical capital, and human capital (i.e., education stock), such that:

$$Y_t = (A_0 e^{\xi t}) K_t^\alpha (L_t H_t)^\beta, \quad (1)$$

where Y stands for real output, K stands for physical capital, L stands for raw labor input, H stands for the quality of human capital, $(L \cdot H)$ is defined as effective labor, $(A_0 e^{\xi t})$ is regarded as an exogenous knowledge and technological factor, α and β are the physical capital and effective labor shares, respectively, and t is time trend.

We assumed that an individual's income relies on his/her human capital, which is a function of schooling. Hence, the individual's income is expressed as:

$$I(h(E_t)) = \varpi \cdot h(E_t), \quad (2)$$

where I stands for the individual's income, ϖ stands for the wage per unit of

human capital, and $h(\cdot)$ is the quality of human capital as a function of schooling, which is denoted by E . Thus, the estimated general form of the structural earning function is displayed as follows:

$$\ln I = \Omega + g(E), \quad (3)$$

where Ω is a constant term.

According to Equations (2) and (3), human capital may be given by:

$$H(E_t) = e^{g(E_t)}, \quad (4)$$

while Ω corresponds to $\ln(\varpi)$. The standard assumptions about the $g(E)$ are that $g' > 0$ and $g'' \leq 0$ (Willis, 1986). To simplify the model, we assumed that $g(E_t) = \gamma E_t$, where γ is a constant parameter, and then substituted Equation (4) into Equation (1). Therefore, the production function can be rewritten as follows:

$$Y_t = (A_0 e^{\xi t}) K_t^\alpha (L_t e^{\gamma E_t})^\beta. \quad (5)$$

We next took natural logarithms for both sides of Equation (5); hence, the production function became linear, such as:

$$\ln Y_t = \ln A_0 + \xi t + \alpha \ln K_t + \beta \ln L_t + \gamma \beta E_t. \quad (6)$$

According to Equation (6), we can construct the econometric model as:

$$\ln Y_t - \ln Y_{t-1} = C_0 + a_K (\ln K_t - \ln K_{t-1}) + a_L (\ln L_t - \ln L_{t-1}) + a_E (E_t - E_{t-1}) + \varepsilon_t, \quad (7)$$

where ε_t is stochastic disturbance terms, assuming a mean 0 and a variance σ^2 . In Equation (7), Y stands for real output, K stands for physical capital, L stands for raw labor, and E stands for education stock.

2.2. Data Measurement

We defined economic output (Y) as GDP (gross domestic product). This variable is measured in millions of New Taiwan dollars (NT\$) at 1996 constant prices. We defined physical capital (K) as real capital stock, which includes gross fixed capital formation and increases in stocks (e.g., buildings, equipment, and other construction) in the domestic economy, and is also measured in millions of New Taiwan dollars at 1996 constant prices. We defined labor (L) as the number of people in the economically active population of those who are employed. This variable is reported in thousands of employed people. Moreover, we defined human capital (E) as the average number of years of formal education per person among employed people [i.e., the average number of years of formal education per person = (primary stock \times 6 + junior stock \times 9 + senior stock \times 12 + college stock \times 16)/total employed people]. **Figure 1** shows the average years of education per person among employed people in Taiwan during 1964-2000.

The sources of the Taiwan data for 1964-2000 used in this study consist of annual measures of economic output, physical capital input, labor input, and educational stock compiled mainly from the *Taiwan Statistical Data Book, Statistical*

Abstract of National Income in the Taiwan Area, Monthly Bulletin of Manpower Statistics in the Taiwan Area, Education Statistics of Taiwan, and Quarterly National Economic Trends in the Taiwan Area.

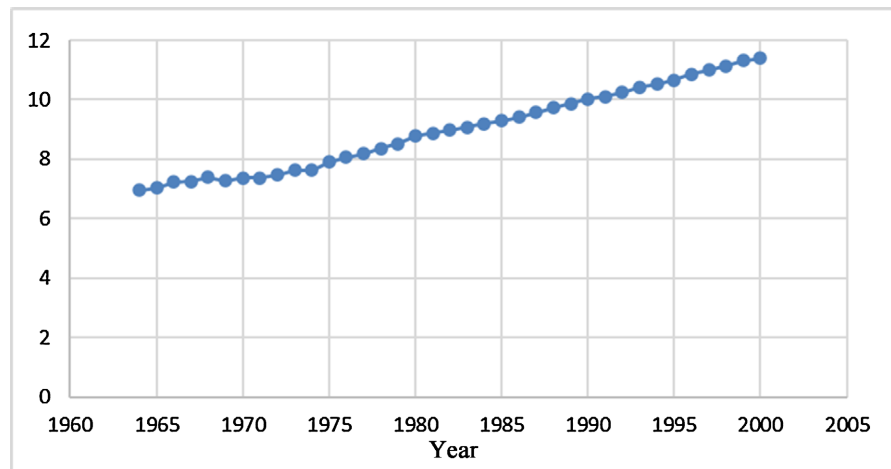


Figure 1. Average years of education per person among employed people in Taiwan (1964-2000).

3. Results

Reported in Column (1) of **Table 1** are estimated results for the period 1965-1990. The estimate of the average share of education on the effect of output growth is 0.18131. Besides, the estimated effect of education is positive and statistically significant at the 5 percent level, indicating potent effects of education on growth. Both physical capital and labor shares are estimated to be 0.14458 and 0.6417, and the effects on output growth are statistically significant at the 5 percent level. Nevertheless, the coefficient of technical progress is estimated at 2.517 percent. It is not even statistically significant at the 1, 5, or 10 percent level. The R-square is about 37.6 percent. The Durbin-Watson and LM tests indicate that autocorrelation does not exist. In addition, it should be noted that the period of 1963-1980 was the most rapid growth in Taiwan's economic development history. Taiwan maintained an annual growth rate of 10 percent over these 18 years.

Moreover, the estimated results for the period 1975-2000 are presented in Column (2) of **Table 1**. Surprisingly, the estimated effect of average education is shown to be negative, but it is not statistically significant at the 1, 5 or 10 percent level, indicating no relationship between education and real output growth. However, the effect of technical progress, as shown in the constant, is markedly significant at the 1 percent level, and the coefficient of the constant, estimated at 4.902 percent, is extremely higher than the estimate for 1965-1990. Additionally, the R-square of over 60 percent is remarkably larger than the coefficient in 1965-1990. Finally, both the Durbin-Watson and LM tests show that autocorrelation does not exist. In addition, it should be noted that during the period of 1981-1999, Taiwan's annual growth rate dropped to 7.15% from the near 10% average over the period of 1963-1980. The reasons for the mild slowdown could be a consequence of

Table 1. Estimates of $\ln Y_t - \ln Y_{t-1}$.

Explanatory Variables	Explained variable: $\ln Y_t - \ln Y_{t-1}$	
	1965-1990 (1)	1975-2000 (2)
Constant	0.02517 (1.22)	0.04902*** (4.12)
$\ln K_t - \ln K_{t-1}$	0.14458** (2.76)	0.16806*** (4.09)
$\ln L_t - \ln L_{t-1}$	0.6417** (2.44)	0.8520*** (3.64)
$E_t - E_{t-1}$	0.18131** (2.09)	-0.03521 (-0.49)
R^2	0.376	0.603
\bar{R}^2	0.291	0.549
F-Statistic	4.42**	11.13***
Durbin-Watson	1.40	1.85
Autocorrelation (LM Test)	No	No
Observations	26	26

Note: Number in parentheses is t -value; *** $p < 0.01$; ** $p < 0.05$.

structural changes in the industrial sector. However, political and social transformations could also be part of the reasons. During that period, the agricultural sector had the lowest performance, but the service sector experienced the highest growth rate.

In short, dramatic differences in the role of education as revealed in the analysis, which divided the sample period between “1965-1990” and “1975-2000”, can be attributed to the development of the 1990s. Thus, two questions remain: Why couldn't the growth in Taiwan in the latter period 1975-2000, especially in the 1990s, be explained by formal education? In addition, according to the result, the effect of technical progress on growth, represented by the constant term, in the latter period is remarkably significant. Was economic growth primarily driven by technology shocks in Taiwan in the 1990s? To answer these questions, we need further discussion and exploration.

4. Further Exploration and Discussion

In this study, annual data were employed. Their use of annual data means that the effects of annual fluctuations, which are driven more by unspecified demand-side factors, probably dominate the determination of the size and significance of the coefficients, but to an unknown extent. These short-run fluctuations probably swamp the longer slow but steady growth-related side effects from human and physical capital formation. For example, [Figure 3](#) and [Figure 5](#) show dramatic

annual fluctuations in the annual growth of physical capital from 1975 through 2000, especially in the earlier part of this later period, and relatively little annual fluctuation in the annual change in education levels in Taiwan.

One would expect that the human capital coefficient would be almost zero and not significant in explaining these sharp fluctuations in annual growth of real GDP in this period. In fact, this is the case. The graphs and empirical results have a lot to say about the sensitivity of physical capital investment to the wild cyclical swings in interest rates in the 1980s and given that investment demand is an additive component of GDP, about the swings in real GDP, but relatively little to say about longer-run growth effects on production from the supply side. Long-term interest rates in the United States went to 13.9 percent in 1981 and stayed above 10.6 percent through 1985; real rates of interest were 9.1 percent in 1982, which with the globalization of financial markets surely affected Taiwan and investment in physical capital there as well. Average educational attainments are far less affected by this since the base human capital stock is so large and since most education is not financed by borrowing which is sensitive to real interest rate conditions in the financial markets. The fact that GDP growth fell in the 1980s thus may have a lot more to do with Reaganomics than with the lessening significance of human capital to Taiwan's long-run growth and welfare.

Moreover, looking at the trends alone, there does appear to be a slowdown in the annual growth rate of real GDP for the entire period (shown in **Figure 2** as a percentage annual change), a slowdown in the annual growth rate of physical capital (shown in **Figure 3**), and a slowdown in the growth rate of raw labor inputs (shown in **Figure 4**). At the same time, there is slightly higher average growth in education levels. For this reason, it is possible to assume that human capital is being substituted for raw labor, and it is also possible that there is some substitution of human capital for physical capital. Thus, a complementarity test is provided to investigate whether there is a relationship (i.e., complements or substitutes) between human capital and physical capital as well as raw labor.

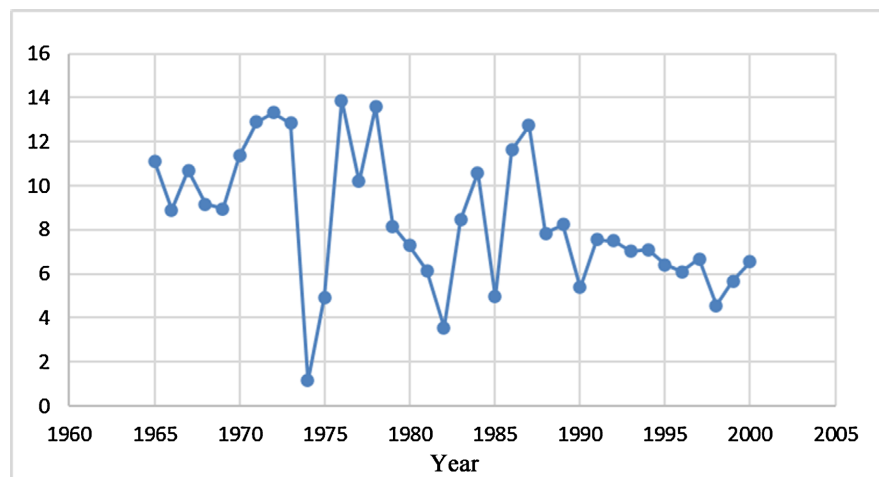


Figure 2. Annual growth rate of real GDP in Taiwan (1965-2000) %.

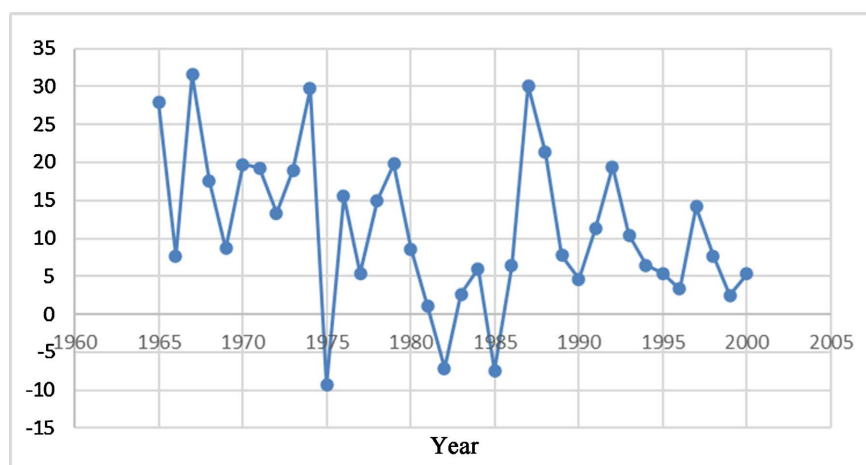


Figure 3. Annual growth rate of capital in Taiwan (1965-2000) %.

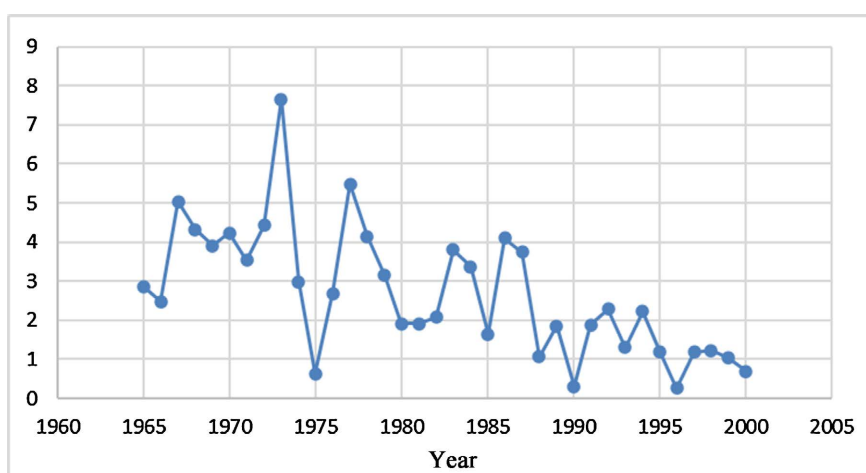


Figure 4. Annual growth rate of labor in Taiwan (1965-2000) %.

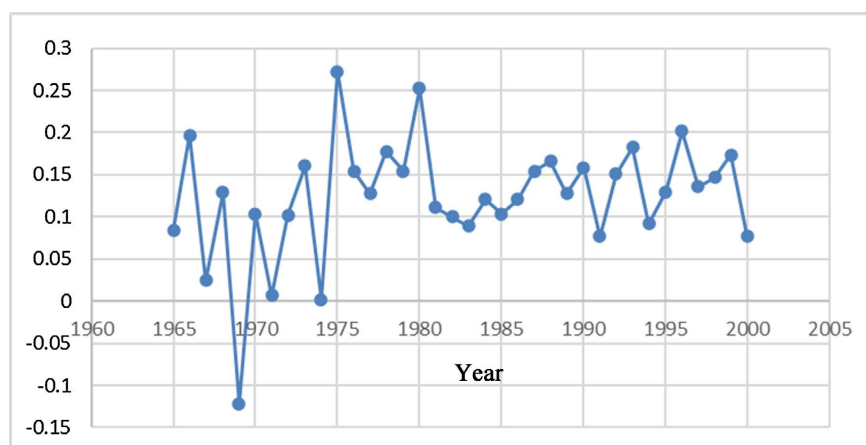


Figure 5. Annual change for average education in Taiwan (Year).

The complementarity formation may be modeled using a generalization of the Cobb-Douglas model, the transcendental logarithmic production function, which is:

$$\begin{aligned}
\ln Y_t - \ln Y_{t-1} = & C_0 + a_K [\ln K_t - \ln K_{t-1}] + a_L [\ln L_t - \ln L_{t-1}] + a_E [E_t - E_{t-1}] \\
& + b_{KK} [(\ln K_t)^2 - (\ln K_{t-1})^2] / 2 + b_{LL} [(\ln L_t)^2 - (\ln L_{t-1})^2] / 2 \\
& + b_{EE} [E_t^2 - E_{t-1}^2] / 2 + b_{KL} [\ln K_t \ln L_t - \ln K_{t-1} \ln L_{t-1}] \quad (8) \\
& + b_{KE} [\ln K_t \cdot E_t - \ln K_{t-1} \cdot E_{t-1}] + b_{LE} [\ln L_t \cdot E_t - \ln L_{t-1} \cdot E_{t-1}] \\
& + b_{D1} D1_t + b_{D2} D2_t + \varepsilon_t,
\end{aligned}$$

where $D1$ and $D2$ are dummy variables to capture the effects of the two oil crises of 1973-1975 and 1979-1982 (indicated as $D1$) and the Asian financial crisis of 1997-1998 (indicated as $D2$). If human capital and physical capital as well as raw labor are substitutes, it should be able to estimate $b_{KE} < 0$ and $b_{LE} < 0$. According to the results shown in **Table 2**, unfortunately, no remarkable relationship is found between human capital and raw labor; but the finding shows that human capital and physical capital are complements because the effect is positive and statistically significant at the 10 percent level.

In addition, could it be possible that human capital is being substituted for technical progress in the later period? If so, a complementarity test may be necessary for human capital and technical progress. A simple model for human capital and technical progress complementarity can be constructed as follows:

$$\begin{aligned}
\ln Y_t - \ln Y_{t-1} = & C_0 + a_K [\ln K_t - \ln K_{t-1}] + a_L [\ln L_t - \ln L_{t-1}] + a_E [E_t - E_{t-1}] \quad (9) \\
& + a_{Et} [E_t \cdot t - E_{t-1} \cdot (t-1)] + a_{D1} D1_t + a_{D2} D2_t + \varepsilon_t.
\end{aligned}$$

If technical progress and human capital are substitutes, an estimate of $a_{Et} < 0$ should be feasible. Based upon the results shown in **Table 2**, fortunately, the substitution of technical progress for human capital is occurring at the statistically significant level of 1 percent. Therefore, it is possible that human capital was being substituted for technical progress in the later period.

In summary of this point, the insignificance of human capital formation in the later period, and the relatively high significance of physical capital in all periods, may largely reflect annual fluctuations. The substitution of technical progress for human capital may also be occurring in this instance. Additionally, prior to the 1960s, Taiwan's economy was primarily geared toward agricultural and non-technical production (Liang & Liang, 1988; Kim & Lau, 1994). But during the 1960s, Taiwan transformed itself into a newly industrializing country, and the policy priorities of the Taiwan government were industrial production and the education of the population. Investment in education in the following decades provided positive and significant effects on growth. In the 1990s, however, the world saw the New Economy develop as a result of rapidly advancing information technology. Higher productivity led to dramatic increases in total real output in the 1990s. The information technology revolution (Jorgenson, 2001) and quantum rise in productivity affected not only developed countries, but also many developing countries, including Taiwan. Technological advances in Taiwan and their impact on its economic productivity must be examined from a new perspective. For example, Internet innovation was not invented in Taiwan, but it was

Table 2. Results of the complementarity test (1975-2000).

Explanatory variables	Explained variable: $\ln Y_t - \ln Y_{t-1}$	
	(1)	(2)
Constant	0.07682*** (6.14)	0.12062*** (4.06)
$\ln K_t - \ln K_{t-1}$	39.35* (1.85)	0.14651*** (4.43)
$\ln L_t - \ln L_{t-1}$	-57.92 (-0.97)	0.4076 (1.40)
$E_t - E_{t-1}$	-7.86 (-0.47)	0.12448* (1.96)
$\frac{(\ln K_t)^2 - (\ln K_{t-1})^2}{2}$	-0.7669** (-2.23)	
$\frac{(\ln L_t)^2 - (\ln L_{t-1})^2}{2}$	6.385 (1.14)	
$\frac{(E_t)^2 - (E_{t-1})^2}{2}$	-0.3481 (-1.28)	
$\ln K_t \cdot \ln L_t - \ln K_{t-1} \cdot \ln L_{t-1}$	-1.494 (-1.31)	
$\ln K_t \cdot E_t - \ln K_{t-1} \cdot E_{t-1}$	0.6015* (1.72)	
$\ln L_t \cdot E_t - \ln L_{t-1} \cdot E_{t-1}$	-0.3364 (-0.38)	
$E_t \cdot t - E_{t-1} \cdot (t-1)$		-0.005858*** (-2.73)
$D1_t$	-0.03221*** (-4.48)	-0.034334*** (-4.30)
$D2_t$	-0.00927 (-0.74)	-0.009935 (-1.01)
R^2	0.897	0.823
\bar{R}^2	0.816	0.767
F-Statistic	11.08***	14.69***
Durbin-Watson	2.45	2.19
Autocorrelation (LM Test)	No	No
Observations	26	26

Note: Number in parentheses is t -value; *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

carried to Taiwan and led to many Internet-related industries and new jobs, thereby further improving worker productivity. Such innovation in Taiwan obviously exerts an exogenous impact on technology. Therefore, according to the

results of this study and analysis, we conclude that exogenous technology stocks could explain much of the real output growth in Taiwan in the 1990s.

5. Conclusion

The previous empirical work has shown that human capital investment through educational achievement was a central source of Taiwan growth during the last four decades of the twentieth century, but this paper offers several more observations in the data set and engages in minor alterations of the empirical model. The econometric evidence supports the consensus view that human capital growth is important for explaining Taiwan's growth over the period 1965-1990, and most of the attention in the paper, though, examines the finding that the human capital measure no longer has explanatory power for Taiwan's economic growth over the sample period 1975-2000.

In addition, according to the results, the coefficient of technical progress is remarkably larger and more significant for the later period (1975-2000) than for the earlier period (1965-1990), implying the larger role of technical progress in the growth that occurred during the 1990s. Therefore, we emphasize the contrasting empirical results and draw the inference that the sources of economic growth in Taiwan in the 1990s could be mostly exogenous.

Finally, the AI (artificial intelligence) era is coming to the world now. Will AI play the primary role in the economic growth of Taiwan in the 2020s? We will leave this topic for our investigation in the future research.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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