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INTERNATIONAL TRADE, PRODUCTIVITY GROWTH, EDUCATION AND THE WAGE DIFFERENTIAL: A CASE STUDY OF TAIWAN

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The cause of changes in the wage differential between skilled and unskilled labor has been an important subject of debate for several decades. International trade and productivity growth are two main causes that have been suggested from large country studies. Recent research proposes that education is another influence. All three causes have been significantly associated with Taiwan's economic development. This paper attempts to contribute to the literature by investigating the wage differential in Taiwan, a small open economy. A Dynamic Intertemporal General Equilibrium (DIGE) model is used to perform theoretical simulation. An Error Correction Model (ECM) incorporating both short- and long-run effects is employed to accomplish the empirical examination. That education and international trade are important causes of changes in the wage differential is substantiated by Taiwanese data. Productivity growth has a significant influence on the wage differential in the short run but not in the long run.

JEL classification codes: C12, C15, C51, F10, F41, H52, J31
Key words: wage differential, dynamic intertemporal general equilibrium model, error correction model

I. Introduction

The cause of changes in the wage differential between skilled and unskilled labor has been an important issue of debate for several decades. There is a

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large amount of research that attempts to settle this issue. Essentially, the argument has been about whether international trade (reflected in trade volume, prices, measures of protection and globalization) or technological change (which induces de-industrialization and productivity growth) is the main cause. The debate is ongoing. Both labor economists (such as Katz and Autor, 1999; Wood, 1994) and trade theorists (such as Bhagwati and Dehejia, 1993; Leamer, 1994) contribute to the literature, theoretically and empirically, by proposing compelling arguments from various angles and by elaborating different methodologies. However, the more investigation one does the less conclusive the debate becomes.

Katz and Autor (1999) have developed a supply-demand-institutions (SDI) framework to assess the role of market forces (supply and demand shifts) and institutional factors in changes in the wage structure. In their discussion of market forces they analyze skill-biased technological change, globalization and de-industrialization in the determination of the wage differential. Deardorff and Hakura (1994) conducted a selective survey of the empirical literature on trade and wages, and categorized the discussion into trade volumes, prices, and measures of protection. A role for technological innovation (sometimes also referred to loosely as productivity growth) was introduced when research, for example Bound and Johnson (1992), and Lawrence and Slaughter (1993), failed to find that trade has a significant impact on wages. The majority of existing research focuses on developed or large countries and is based either theoretically on a Heckscher-Ohlin-Samuelson framework or empirically on econometric models. The econometric approaches use either reduced forms from relatively simple theoretical models or somewhat ad hoc forms, neither of which is sufficiently comprehensive.

This paper attempts to contribute to the literature by investigating the wage differential in Taiwan, a small open economy. The existing literature on the issue of trade and wages in Taiwan is quite limited. The recent work of Chen and Hsu (2001) ends with a different conclusion from both that of the studies of the U.S. and the simulation results in Chang (2000).[1] Another study, by Chan et al (1998), concludes that Taiwan's technological change is skill-biased

[1] Chen and Hsu (2001) conclude that "Taiwan's exports to less-developed countries benefit unskilled workers and thus make the income distribution more equal…".

and that progress in technology increases the wage differential. They further conclude that an increase in Taiwan's net exports increases the wage differential. In addition to providing different models compared to these existing researches, the present paper includes education investment, which is seldom discussed in the literature, as a factor underlying the wage differential.[2] An Error Correction Model (ECM) incorporating both short- and long-run effects is employed to accomplish the examination. The relevance of trade, productivity growth and education in the model as explanatory variables is substantiated by a more comprehensive theoretical model, using Dynamic Intertemporal General Equilibrium (DIGE) methodology, developed in Chang (2000). All three proposed factors have played important roles in Taiwan's economic development. This makes Taiwan an interesting case study. The results not only suggest some policy implications for the Taiwanese government but also contribute to the literature by providing comparisons with the large country cases.

This paper concludes that the results of the empirical test of the roles of trade, productivity growth and education are fairly consistent with the theoretical simulation results. That is, first, an increase in international trade increases the wage differential in both the short and the long run, with the increase being larger in the short run; second, productivity growth reduces the wage differential in the short run; and, third, an increase in government education investment decreases the wage differential in both the short and the long run, with the decrease being larger in the long run. In addition the conclusion implies that the adjustment cost of skill formation of Taiwan has been low enough to enable unskilled labor to upgrade to skilled labor and that Taiwan's productivity growth is not skill-biased.[3] It also indicates the importance of examining the cost of skill adjustment in future researches on the wage differential.

Section II illustrates a profile of the wage differential in Taiwan. Section

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[2] Chan et al (1998) only use education as a criterion to separate labor into skilled and unskilled groups. In their regression, there is no explicit variable for education.

[3] This finding is opposite to the finding of Chan et al (1998).

III briefly sets out the theoretical model, Section IV demonstrates the empirical test and Section V summarises the conclusions.

II. The Wage Differential in Taiwan

This section describes the wage differential between different skill groups in Taiwan from 1978 to 1999. The monthly average wage data by education attainment are from the Manpower Utilization Survey. The real wage is the nominal wage deflated by the GDP deflator measured on the base of the price level in 1996. Conventionally, education attainment is the principal determinant of skilled and unskilled labor. Practically, the education level used to split labor into skilled and unskilled groups might affect the consequences. This section presents two versions of the split.[4] First, individuals with a degree from college or above are designated as skilled labor while the remainder are designated as unskilled labor. Second, individuals with a degree from junior college or above are designated as skilled labor while the remainder are designated as unskilled labor. To manipulate the raw data, which include several categories in the group of unskilled labor, the weighted average monthly wage is used, with the weights being the population proportion of each category in the group.[5]

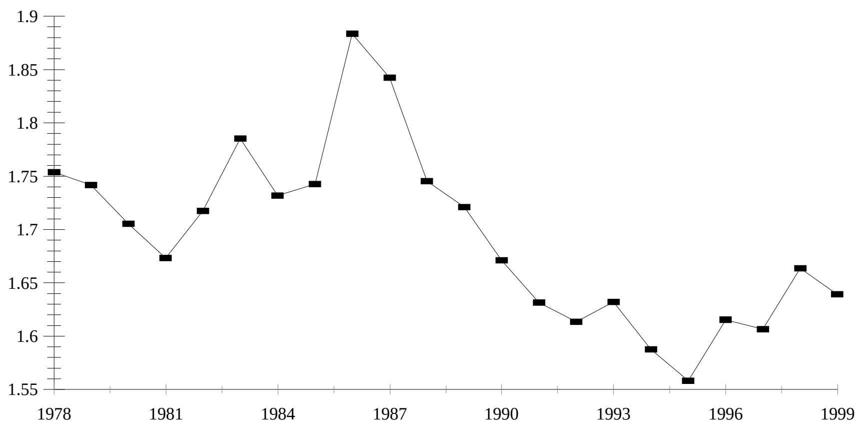
A. Degree from College or Above Designated to Skilled Labor

Figure 1 illustrates the variations in the ratio of the wage of skilled labor to the wage of unskilled labor from 1978 to 1999. From 1981 to 1986, the wage ratio shows fluctuations around an upward trend. From 1987 to 1995, the ratio follows a straight downward trend (except for 1993). This indicates that the unskilled wage grew more than the skilled wage and reflects a continuing

[4] The reason being, in Taiwan, there is a category called “junior college.” Students spend two, three, or five years to get a degree which is of a lower rank than a four-year college degree. The subjects offered in junior colleges are similar to those offered in colleges. Hence, it is considered reasonable to take a look at the case where this category is included in skilled labor. Katz and Murphy (1992) created a measurement of college and high school equivalents, which might not be a good alternative given the limited time series data.

[5] The categories are: illiterate, self-educated, primary school, junior high (including junior vocational) school, senior high school, vocational school, and/or junior college.

Figure 1. Wage Ratio: Skilled to Unskilled Labor, College or Above as Skilled Labor



shortage of unskilled labor in Taiwan. During this period, government policy on importing foreign labor becomes important.[6] After 1995, the wage ratio shows a tendency to increase.

B. Degree from Junior College or Above Designated to Skilled Labor

In this case both the growth rate and the wage ratio are similar to those in Section II.A except that the wage ratio is smaller than when junior college is not designated to skilled labor. Figure 2 illustrates the wage ratio when junior college is designated as skilled labor. Obviously the smaller wage ratio is the result of the use of a weighted average method and the fact that the wage rate resulting from junior college education is less than that resulting from college education.

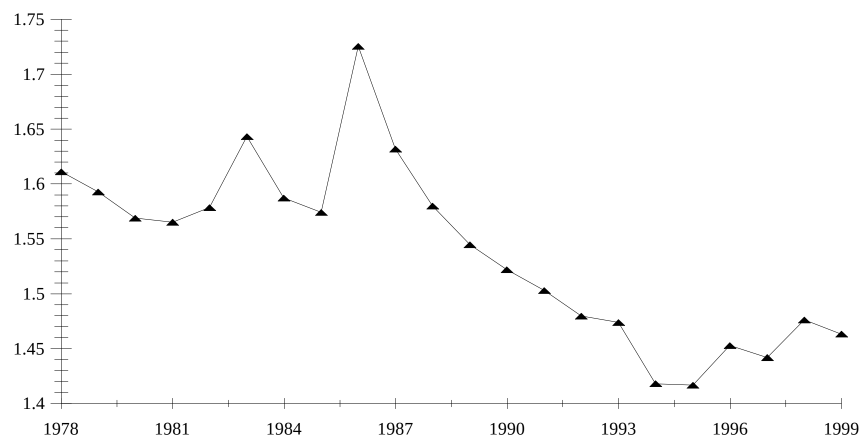
In summary, both versions show that there is no convincing evidence of a growing wage differential in Taiwan over the past two decades.

III. Theoretical Model

The conventional Heckscher-Ohlin-Samuelson model is usually used to

[6] Refer to Tsay (1995) for a detailed discussion.

Figure 2. Wage Ratio: Skilled to Unskilled Labor, Junior College or Above as Skilled Labor



investigate issues involving international trade. Among the limitations of the Heckscher-Ohlin-Samuelson model are that the quantities of factors of production are assumed fixed and that predictions of the variations in the wage differential are limited to the long-run variations. Under its simplified framework, due to the fixed quantities of production factors, it predicts that an increase in international trade decreases a country's unskilled wage and increases its skilled wage if the country exports skilled-labor intensive goods and imports unskilled-labor intensive goods. Technological progress, if it is biased toward the demand for skilled labor, leads to an increase in the wage differential. The converse also applies. The assumption of fixed endowments precludes consideration of the important role of changes in factor supplies. Failure to consider changes in factor supplies may result in wrong conclusions concerning the effect of an increased demand for skilled labor on the wage ratio if the supply of skilled labor has increased relative to the supply of unskilled labor.

In contrast to the Heckscher-Ohlin-Samuelson model, the dynamic intertemporal general equilibrium model in this paper examines a small open economy with three types of goods: exports, imports, and non-traded goods; three agents: firms, households and government; and two kinds of labor: skilled labor and unskilled labor. The production factor endowments, i.e. physical capital, skilled labor and unskilled labor, are allowed to vary over time in line with the optimising choices of the three agents. The model goes a step further than CGE models in that it shows not only the long-run transitions but also the short-run transitions of the endogenous variables. It shows that what happens in the long run may not be a good guide to what happens in the short run. A modelling framework is summarized as follows.[7]

A. Firms

Firms employ physical capital, skilled labor and unskilled labor to produce three types of goods. The firms sell these goods to households for consumption, to government for education capital investment, and to themselves for physical capital investment. There are three representative firms in the economy; they represent, respectively, the export sector, the import sector and the non-traded sector. Exports are a function of foreign income and the inverse of terms of trade. The capital accumulation in each sector depends on the rate of fixed capital formation and the rate of depreciation.

To initialize the model, it is assumed that sector 1 is relatively skilled-labor intensive, sector 2 is relatively unskilled-labor intensive and sector 3 is relatively capital intensive. It is also assumed that exports consist of good 1, imports consist of good 2 and that good 3 is non-traded. It follows from these assumptions that exports are relatively skilled-labor intensive and imports are relatively unskilled-labor intensive. Table 1 illustrates these characteristics.

Table 1. Sector Characteristic

Sector	Factor intensive	Trade
1	Skilled labor	Export
2	Unskilled labor	Import
3	Capital	Non-traded

[7] Refer to Chang (2000) for a detailed discussion of this model.

B. Households

Households supply unskilled labor to firms and skilled labor to both firms and government in return for wages. They also own the physical capital and earn financial dividends. Their income is used to finance goods consumption from firms and purchases of education from government. The opportunity cost of leisure is the forgone opportunity of working. To maximize their utility households distribute consumption optimally on both goods and leisure under their budget constraints.

The optimal net skill formation chosen by households is the fixed skill formation minus skill depreciation. Households' education spending depends on fixed skill formation and an adjustment cost function. The adjustment cost reflects the forgone production and relies on the ratio of fixed skill formation to skilled labor. If skilled labor is increasing, the adjustment cost is decreasing. This is plausible due to the spill over effect within the labor force. The elasticity of the skilled labor supply, with respect to the wage of skilled labor, is greater than zero since the supply of skilled labor is not fixed. It is less than infinity in the short run, because the transformation from unskilled to skilled labor is not free. Some skills are specific or patented, and training facilities are not always available. Hence, the supply of skilled labor is also not perfectly elastic in the long run. Technically, because of the endogenous wages and the leisure variable in households' utility function, the labor supply of both types has an endogenous ceiling in this framework.

C. Government

The government buys goods from firms and transforms them into education capital. The government hires skilled labor and uses this in conjunction with the education capital to produce education. By its collection of labor income tax and by selling education to households the government exactly finances its spending on education capital investment and skilled labor. That is, the budget is balanced. The role of government as an education supplier is essential. This model captures the reality of government supplying education in consideration of the beneficial externalities resulting from education. Total government investment on education capital is assumed to be exogenously controlled by the government. The accumulation of education capital is given by the total investment by government minus the depreciation.

To ensure the model is consistent in achieving general equilibrium, the rule of demand equal to supply is applied to both the goods and the factor markets. The full model in the steady state is shown in Appendix.

D. The Wage Differential in the Steady State

Due to the complexity of the above model, there is no reduced form that can be derived to present the wage differential. An expression, possibly the simplest, of the wage differential in the steady state is as follows,

$$W_s = W_u + [\, P_E / (1 - \tau)]\, [\theta + \theta\ \Phi\ \delta_s + \delta_s + (1/2)\ \Phi\ \delta_s^2\,] \qquad (1)$$

where W_s is the skilled wage, W_u is the unskilled wage, P_E is the price of education, τ is the tax rate, θ is the rate of time preference, Φ is the skill adjustment cost parameter and δ_s is the rate at which skill depreciates.

The expression of equation (1) is independent of the functional form of both the utility and the production function.[8] The equation provides a rigorous theoretical result for the wage differential. The relationship between the skilled and the unskilled wage depends on parameters, namely, the rate of time preference (θ), the depreciation rate of skill (δ_s) and the skill adjustment cost parameter (Φ); and on endogenous variables, namely, the tax rate (τ) and the price of education (P_E). A higher skill adjustment cost and a higher skill depreciation rate tend to boost the cost of skill formation, therefore leading to a higher skilled wage. The rate of time preference counts because an investment in skill formation takes time to repay. A larger time preference involves a larger adjustment cost for skill formation, therefore a patient household will expect a higher skilled wage. The education price and the tax rate are endogenous in this model. Theoretically, each endogenous variable in (1) can be solved and substituted by the exogenous variables and parameters, so implicitly the wage differential is a function:

[8] A detailed proof is available from the author.

$$\frac{W_s}{W_u} = f(A_{Q_i}, I_E^G, Y^* \mid parameters) \tag{2}$$

where A_{Qi} is the technology variable for each sector, I_E^G is the education investment controlled by the government and Y^* is the foreign income which directly affects domestic exports.

The wage differential equation (1) illustrates both the importance and the transmission channel of education in the determination of the wage differential. This substantiates the inclusion of education in the debate on the wage differential, in addition to the traditional arguments of trade and productivity growth. The government, as an education supplier and tax collector, has the ability to control the wage differential to a certain extent. What matters in a general equilibrium outcome is the interactive effect of the education price and the tax rate. Simulation becomes necessary to explore the short- and long-run transitions of each endogenous variable and so establish the policy implications.

E. Simulation Results

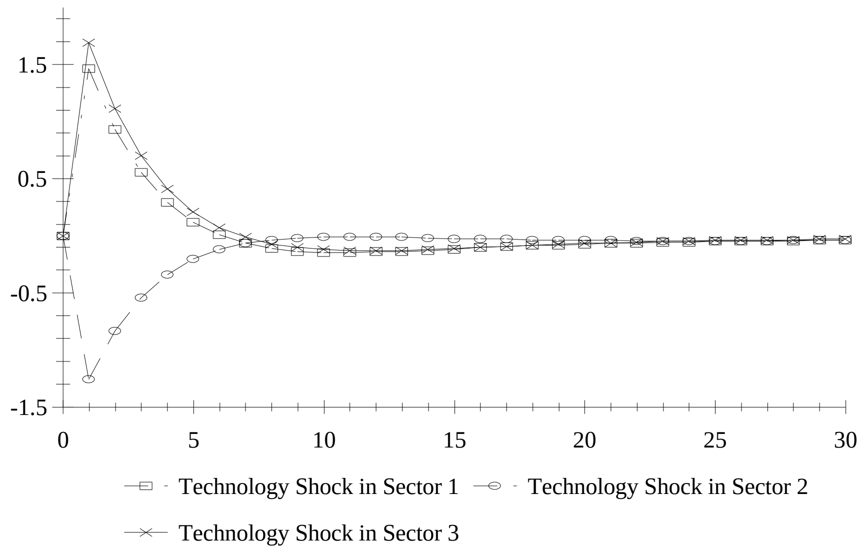
The main results from this model are that, in the long run, productivity growth and an increase in government education investment lessen the wage differential.[9] Generally speaking, increased education investment also lessens the wage differential in the short run, albeit with a fluctuation in the early stage. (The fluctuation occurs because the adjustment process of skill formation takes time and households make optimal choices between working and leisure.) Productivity growth, at most, raises the wage differential only in the short run: it may reduce the wage differential in the short run if productivity growth is biased towards unskilled labor. An increase in international trade increases the wage differential to a larger extent in the short run than in the long run.[10] These simulation paths are presented in Figure 3.

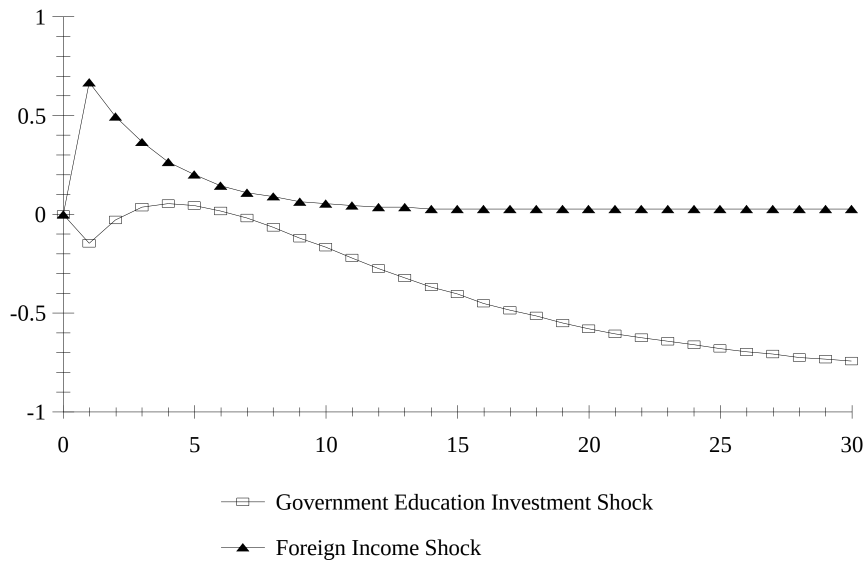
Intuitively, an increased demand for skilled labor resulting from a growth

[9] Productivity growth lessens the wage differential to a small but non-zero extent.

[10] In the long run, the wage differential is enlarged to a small but non-zero extent.

Figure 3. Simulation Results: Wage Ratio





in productivity or exports can eventually be filled in the long run as skill supply plays an important role in the wage determination.[11] In the short run, the created demand cannot be filled immediately due to the time required for skill formation. By using equation (1), the transitions are as follows. Productivity growth pushes down goods prices. This reduces the costs of government purchases and motivates the government to cut the tax rate, which, in turn, decreases the wage differential. If the government increases education investment, thereby decreasing the education price, it can cause diminution of the wage differential. While the international trade factor is not explicitly shown in equation (1), its effect is transmitted from production to wages through the education price. An increase in skill-intensive exports boosts the price of exports and the demand for skilled labor. This increases the demand for education and, hence, the price of education. Therefore, the wage differential rises.

From a theoretical perspective it is unconvincing that productivity growth raises the wage differential in the long run since skill formation eventually catches up with the progress of technology as long as the adjustment cost is affordable for the unskilled labor.

F. Sensitivity Test

Since there are three sectors with a different intensity of each factor, and five different shocks -technological progress in sectors 1, 2 and 3, government education investment and foreign income-, there are a total of thirty cases within this framework. Sector 1 is designated the export sector, sector 2 the import sector, and sector 3 the non-traded sector.

The key variable investigated is the change of the wage ratio in the steady state. The results, set out in Table 2, show that this model is fairly robust. In Table 2, the first column gives the combination of three sectors with different

[11] In the simulation, an aggregation of three sectors leads to a case of factor-biased productivity growth, a reason emphasized by Krugman and Laurence (1994) for enlarged the wage differential. However, the present model allows the skill demand and supply to determine the skilled wage whereas in their paper it is asserted that increased demand results in an increased wage.

intensities of inputs. Numbers stand for sectors and letters stands for inputs, for example 1U2S3K represents sector 1 as unskilled-labor intensive, sector 2 as skilled-labor intensive and sector 3 as capital intensive. The second to sixth columns respectively stand for an improvement in technology in sectors 1, 2 and 3, an increase in government education investment and an increase in foreign income. A minus sign (-) means a decreased wage differential and a plus sign (+) means an increased wage differential.

Table 2. Sensitivity Test: The Effect of Shocks on the Wage Differential

	Tech 1	Tech 2	Tech 3	Government *EDUN*	Foreign income
1S2U3K	-	-	-	-	+
1S2K3U	-	-	-	-	+
1U2S3K	-*	-*	-	-	-
1U2K3S	-	-	-	-	-
1K2S3U	-	-	-	-	-
1K2U3S	-	-	-	-	+

Note: * When the share of education capital in education production is equal to or greater than 0.5, the sign becomes +.

To summarize, on the one hand, the effect on the wage differential of an improvement in technology in any of the sectors or of increased government investment in education is insensitive to different combinations of sectors, that is, in each case the wage differential decreases in the long run, whereas, on the other hand, the effect on the wage differential of a foreign income shock that raises exports is sensitive to different combinations of sectors.

IV. Empirical Testing

This section demonstrates empirical tests for the theoretical results based on equation (2). The data set tested in this section is from several data sources. The monthly average wage data by education attainment comes from the

Manpower Utilization Survey, which is published by the Directorate-General of Budget, Accounting, and Statistics (DGBAS) of the Republic of China. As mentioned in Section II, the raw wage data have been manipulated to be a weighted average level. Government investment in education is proxied by the share of government expenditure on education, science and culture in GDP (*EDUN*). This measure, which reflects a broad definition of education investment, is from the CEIC Database, which is maintained by EconData Pty. Ltd.. The use of *EDUN* as a proxy is justified for the following reasons. During the past two decades, first, the Taiwanese government did not overwhelmingly target any specific education level: education expenditure per student at all levels increased to a similar extent.[12] Second, university and college levels took a rapidly growing share of total spending on education owing to more high school graduates entering the university level.[13] These two reasons make the following proposition plausible, for a case study of Taiwan, that more government education investment forms more skilled labor and thereby decreases the wage differential.

The proxies for productivity growth and international trade are, respectively, the annual growth rate of total factor productivity (*TFP*) and the share of net exports in GDP (*NETX*). These proxies are drawn from various issues of the Taiwan Statistical Data Book, published by the Council for Economic Planning and Development of the Republic of China.[14] Since the wage data are drawn from the whole economy, the *TFP* calculated from the combined industry (manufacturing, construction, and electricity, gas and water), agriculture and service sectors is an appropriate explanatory variable to use in testing the effect of productivity growth on the wage differential. Net exports, which are driven by foreign income (the shock tested in the theoretical model), measure an approximate net effect of international trade on the wage differential.

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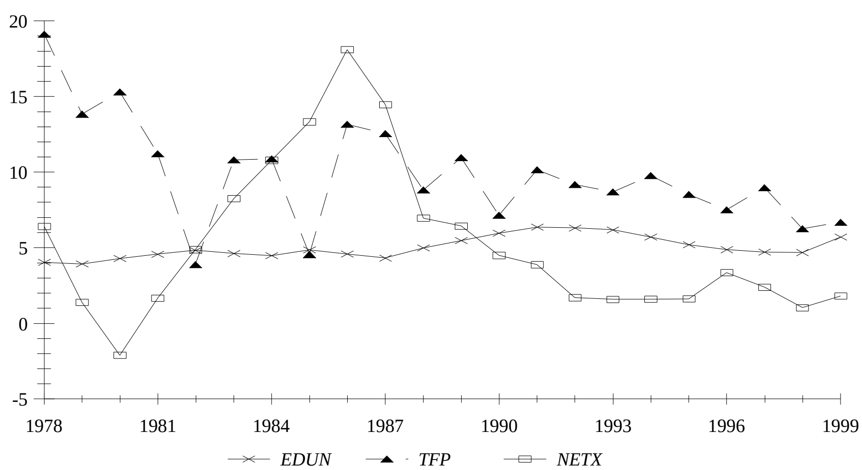
[12] Table 14-10 in Taiwan Statistical Data Book 2000.

[13] The rapidly growing share results from the policy of removing the government-imposed limit on the number of tertiary education institutes in Taiwan. Discussion of this issue is beyond the scope of this paper.

[14] Total factor productivity is the weighted average, by using the shares in GDP as the weights, of the annual growth rates of the industry, service and agriculture sectors.

The time series covers the period from 1978 to 1999. Figure 4 presents a graphical description of the variables *TFP*, *EDUN* and *NETX*. Due to it being a small sample, a Bootstrapping estimation is constructed for the robustness test. The wage differential is measured by W_s/W_u, that is, by the ratio of the average monthly wage with a college or above degree (skilled labor) to that with a degree from junior college or below (unskilled labor).[15] Based on the theoretical framework in the previous section, a long-run model and an Error Correction Model are established to demonstrate both the long run and the short-run effects of *TFP*, *EDUN* and *NETX* on the wage differential.

Figure 4. *EDUN*, *TFP* and *NETX* (Unit:%)



A. Unit Root Tests

Table 3 illustrates the results of Dickey-Fuller unit root tests.[16] Although the Dickey-Fuller test is known to have low power in testing for unit roots, especially when dealing with a small sample, it still provides suggestive results for the stationarity of time series. The Dickey-Fuller test for unit roots shows that *TFP* is I(0) and the other three variables, W_s/W_u, *EDUN*, *NETX*, are I(1).

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[15] To focus on the conventional definition of college or above as skilled labor is plausible due to the systematic shift downwards of the wage ratio if junior college is included.

[16] Phillips-Perron unit root tests end with the same results.

Table 3. Unit Root Tests

	W_s / W_u	*TFP*	*EDUN*	*NETX*	C.V. 5%[1]
constant, no trend [2]					
A(1) = 0 t-test	-1.5	-3.4	-1.5	-1.3	-2.9
A(0) = A(1) = 0	1.2	6.0	1.5	0.9	4.6
constant, trend					
A(1) = 0 t-test	-1.9	-4.7	-1.6	-1.4	-3.4
A(0) = A(1) = A(2) = 0	1.3	7.6	1.1	0.7	4.7
A(1) = A(2) = 0	1.8	11.2	1.3	1.0	6.3
Conclusion	I(1)	I(0)	I(1)	I(1)	

Notes: [1] C.V. 5% means critical value at 5% significance level. [2] The Augmented Dickey-Fuller (ADF) regression equations in Shazam use the first-difference regressant with and without a time trend, where A(0) is the "drift" coefficient, A(1) is the coefficient of the tested variable with one lag, and A(2) is the time trend coefficient. The null hypothesis for the existence of unit roots is A(1) = 0.

B. Long-Run Model

Since the sample size is small, the power of the Dickey-Fuller unit root test is low and both I(0) and I(1) may be included as explanatory variables for this case. Hence, whether or not *TFP* should be included in the model is examined. The result shows that *TFP* is an insignificant long-run factor in the determination of the wage differential.[17] Therefore, the following long-run model is proposed and estimated to examine the long-run relationship.[18] Table 4 shows the estimation results.

[17] The theoretical model suggests that in the long run, *TFP* and international trade respectively have a small negative and a small positive effect on the wage differential. The empirical data can further determine their significance (or lack thereof) in the empirical model.

[18] This linear specification performs a better statistical significance in terms of a range of diagnostic testing than the non-linear specification with which the square terms of *EDUN* or/and *NETX* are embedded.

$$W_s / W_u = \beta_0 + \beta_1 EDUN + \beta_2 NETX + \varepsilon \qquad \varepsilon \sim \text{i.i.d. } N(0, \sigma_\varepsilon^2) \qquad (3)$$

Table 4. The Long-Run Model

Variable	Estimated coefficient	Standard error	t-ratio 16 d.f.	p-value	Elasticity at means
EDUN	-3.9574	1.7694	-2.2365	0.0375	-0.1178
NETX	1.0415	0.2536	4.1067	0.0006	0.0319
constant	184.1	9.4496	19.472	0.0000	1.0863
Durbin-Watson = 1.7985					
R-square adjusted = 0.8027					
Log of the likelihood function = -58.3249					

In the long run, trade and education have a significant effect on the wage differential. If government education investment increases by 1 per cent of GDP, the wage ratio drops by about 0.04 (2.34 per cent of the average wage differential over the period). If net exports increase by 1 per cent of GDP, the wage ratio rises by around 0.01 (0.61 per cent of the average wage differential over the period). This shows that, in the long run, government education investment has a larger effect on the wage differential than do net exports. Following from the theoretical simulation, this positive effect of net exports on the wage differential implies that Taiwan's exports are relatively skilled-labor intensive compared with imports. This result for the effect of net exports on the wage differential is consistent with the findings of Chan et al (1998) and is stronger than the findings of Chen and Hsu (2001).[19]

C. An Error Correction Model

The following ECM provides a case of *TFP* only affecting the wage differential in the short run. *EDUN* and *NETX* are included in both the short

[19] Using a full model regarding the Taiwanese economy as a whole, they find that net exports have a positive but insignificant effect on the wage differential.

and the long run. In equation (4), if the terms in the brackets are used this may not satisfy the regularity condition in the sense that these terms are I(1) while the left-hand side is I(0). Also, to avoid losing degrees of freedom, the bracketed terms are replaced by the residual from the long-run model. Table 5 illustrates the results of the estimation of equation (4) after correcting for both heteroskedasticity and autocorrelation using the Shazam program.

$$\Delta(W_s / W_u) = \beta_0 + \beta_1 \, TFP_t + \beta_2 \, \Delta EDUN_t + \beta_3 \, \Delta NETX_t + \quad (4)$$

$$+ \gamma [(W_s / W_u)_{t-1} - \delta_2 \, EDUN_{t-1} - \delta_3 \, NETX_{t-1}] +$$

$$+ \omega_t \qquad \omega_t \sim i.i.d. \; N(0, \sigma^2_\omega)$$

Table 5. An ECM without Long-Run Effect of TFP and Bootstrapping Estimation

Variable	Estimated coefficient	Standard error	t-ratio 16 d.f.	p-value	Bootstrapping means
TFP	-0.2472	0.0620	-3.9877	0.0011	-0.2471
Δ*EDUN*	-3.9247	0.6333	-6.1973	0.0000	-3.9298
Δ*NETX*	1.1644	0.0715	16.279	0.0000	1.1671
RESIDUAL	1.2249	0.0404	30.295	0.0000	1.2253
constant	2.3200	0.8151	2.8462	0.0117	2.2856
Durbin-Watson = 2.0293					
R-square adjusted = 0.9653					
Log of the likelihood function = -28.2702					

This ECM estimation results in a fairly good match to the simulation results in Section III. In the short run, if the total factor productivity growth increases by 1 percentage point (e.g. from 6 per cent to 7 per cent), the wage ratio drops by about 0.0025 (0.15 per cent of the average wage differential over the period). Corresponding to the theoretical simulation, the effect of total factor productivity in decreasing the wage differential implies that Taiwan's productivity growth in terms of the whole economy is unskilled-biased. If government education investment increases by 1 per cent of GDP, the wage ratio drops by about 0.039 (2.32 per cent of the average wage differential over the period). If net exports increase by 1 per cent of GDP, the wage ratio rises by around 0.012 (0.69 per cent of the average wage differential over the period). Taiwan's exports have shifted from having a high degree of labor intensity to having a medium or high degree of technology intensity. In line with the upgrade of technology, greater skilled labor intensity is also embedded in exports. Its imports have shifted from having a low degree of labor intensity to having a high degree of labor intensity. Incorporating these two facts, the empirical result of international trade raising the wage differential is consistent with the large country cases. Comparing these results with those in the long run, government education investment has a relatively smaller effect in decreasing, and net exports have a relatively larger effect in increasing, the wage differential in the short run. These results are consistent with the theoretical results, which substantiate that skill formation takes time, and they add a new dimension to the results of the existing research.

Since these empirical data involve a small sample size, a Bootstrapping procedure (Efron, 1979) with a 2000 random re-sampling replication is used to test the robustness of the estimation. The Bootstrapping estimation is shown in the last column of Table 5. The mean of each variable is fairly close to its estimated coefficient in the above ECM model. This supports the validity of the estimation.

V. Conclusion

This paper portrays the profile of Taiwan's wage differential and employs an error correction model, which can perform tests in both the short and long run, to examine the effects of international trade, productivity growth and education investment on Taiwan's wage differential. Whether or not junior college graduates are designated to skilled or unskilled labor, there is no convincing evidence of a growing wage differential in Taiwan over the past two decades.

That education could be an important determinant of the wage differential is substantiated by both the theoretical model and the empirical data. Education investment takes time to have its full effect, therefore the empirical data show smaller decreases in the wage differential in the short run than in the long run. In the long run, if government education investment increases by 1 per cent of GDP, the wage ratio drops by about 2.34 per cent due to more skilled labor being available in the economy. International trade is also a significant determinant of the wage differential. If net exports increase by 1 per cent of GDP, the wage ratio rises by around 0.69 per cent in the short run and by around 0.61 per cent in the long run. Productivity growth has a significant influence on the wage differential in the short run, but may have only a minor effect in the long run. If total factor productivity growth increases by 1 percentage point, the wage ratio drops by about 0.15 per cent in the short run. This study thus points out that the short-run effects are different from the long-run effects, adding a new dimension to the existing research.

An inference that the skill adjustment cost in Taiwan is low enough to allow unskilled labor to be transformed into skilled labor (when skilled labor is required) can be made for the Taiwanese economy. By pointing out the importance of the skill adjustment cost in the determination of the wage differential, this paper proposes a new angle for future researches. Different countries face different affordable skill adjustment costs. Even within a country, the skill adjustment cost may vary over time as a result of other changes in the economy.

Appendix

Table A.1. The Theoretical Model in the Steady State

Equations		
Q_i	=	$A_{Qi} K_i^{\alpha i} L_{s,i}^{F \beta i} L_{u,i}^{1-\alpha i-\beta i}$
$J_{t,i}$	=	$\delta_i K_{t,i}$
I_i	=	$J_i (1 + \phi_i \delta_i /2)$
$Q_{i,Ls}$	=	W_s / P_i

Table A.1. (Continued) The Theoretical Model in the Steady State

Equations		
$Q_{i,Lu}$	=	W_u/P_i
λ_i	=	$1+\phi_i\delta_i$
Q_{Ki}	=	$(r+\delta_i)\lambda_i - \phi_i\delta_i^2/2$
$P_{2,t}\,M_t$	=	$P_{1,t}X_t$
X	=	$(P_2/P_1)^\rho\, Y^*$
0	=	$r_t F_t + (1\text{-}\tau_t)\,[(W_s/P_2)\,L_{s,t} + (W_u/P_2)\,L_{u,t}] - [(P_1/P_2)\,C_{1,t} + C_{2,t} +$
		$+\,(P_3/P_2)\,C_{3,t} + (P_{E,t}/P_2)\,S_{E,t}\,]$
$J_{s,t}$	=	$\delta_s L_{s,t}$
F_t	=	$(P_1/P_2)\,\lambda_{1,t}K_{1,t} + \lambda_{2,t}K_{2,t} + (P_3/P_2)\,\lambda_{3,t}K_{3,t}$
$S_{E,t}$	=	$J_{s,t}\,(1+\Phi\,\delta_s/2)$
l_t	=	$T - L_{s,t} - L_{u,t}$
U_{Ci}	=	$(P_i/P_2)\,\mu_1$
$U_{Lu,t}$	=	$-\mu_1\,(1-\tau)\,W_u/P_2$
μ_2	=	$\mu_1\,P_E\,(1+\Phi\,\delta_s)/P_2$
r_t	=	θ
U_{Ls}	=	$(\theta+\delta_s)\,\mu_2 - \mu_1\,[(1-\tau)\,W_s + P_E(\Phi\,\delta_s^2)/2]/P_2$

Table A.1. (Continued) The Theoretical Model in the Steady State

Equations		
S_E	=	$K_E^{\xi}\ L_s^{G^{1-\xi}}$
I_E^G	=	$\delta_E\ K_E$
$I_{E,t}^G$	=	$(P_1\ I_{E,1}^G + P_2\ I_{E,2}^G + P_3\ I_{E,3}^G)\,/\,P_E^G$
$P_E^G\ I_E^G + W_s\ L_s^G$	=	$\tau\ (W_s\ L_s + W_u\ L_u) + P_E\ S_E$
$Q_{1,t} - X_t$	=	$C_1 + I_{E,1}^G + I_1$
$Q_{2,t} + M_t$	=	$C_2 + I_{E,2}^G + I_2$
$Q_{3,t}$	=	$C_3 + I_{E,3}^G + I_3$

Note: Notation: (subscript i = 1, 2, 3 stands for Sector 1, 2, and 3). Q: Production; A: Technology; K: Capital; L_s^F: Skilled labor hired by firms; L_s^G: Skilled labor hired by government; L_s: Total skilled labor; L_u: Unskilled labor; J: Fixed capital formation; I: Capital investment; W_s: Skilled wage; W_u: Unskilled wage; P: Price; M: Imports; X: Exports; Y^*: Foreign Income; F: Financial asset; C: Consumption; S_E: Amount of education buying; J_s: Fixed skill formation; I_E: Household's education investment; l: Leisure; T: Time constraint; U_Z: Marginal utility of Z; P_E: Price of education; r: Interest rate; K_E: Education capital; I_E^G: Government education investment; P_E^G: Weighted price index; τ: Tax rate; α, β: Input shares in goods production function; δ: Depreciation rate of capital; ϕ: Adjustment cost parameter of capital investment; λ: Shadow price of capital; ρ: Parameter; δ_s: Depreciation rate of skill; Φ: Skill adjustment cost parameter; μ_1: shadow price of financial asset; μ_2: shadow price of skill; θ: Rate of time preference; ξ: Input share in education production function; ε: Weight of pooled price index; δ_E: Depreciation rate of education capital.

References

Bhagwati, J. and V.H. Dehejia (1994), "Freer Trade and Wages of the Unskilled- Is Marx Striking Again?," in J. Bhagwati and M.H. Kosters, eds., *Trade and Wages: Leveling Wages Down?*, Washington, D.C., AEI Press.

Bound, J. and Johnson, G. (1992), "Changes in the Structure of Wages in the 1980s: An Evaluation of Alternative Explanations," *American Economic Review* **82**: 371-392.

Chan, V.L., Chen, L.T. and S.C. Hu (1998), "Implications of Technology and Education for Wage Dispersion: Evidence from Taiwan," in G. Ranis, S.C. Hu and Y.P. Chu, eds., *The Political Economy of Taiwan's Development into the 21st Century*, Cheltenham, Edward Elgar.

Chang, H.C. (2000), "Wage Differential, Trade, Productivity Growth and Education," Working Papers in Trade and Development 2000/1, The Australian National University.

Chen, B.L. and M. Hsu (2001), "Time-Series Wage Differential in Taiwan: The Role of International Trade," *Review of Development Economics* **5**: 336-354.

Council for Economic Planning and Development, Various Years, *Taiwan Statistical Data Book*, Taipei, Republic of China.

Deardorff, A.V. and D.S. Hakura (1994), "Trade and Wages -What Are the Questions?," in J. Bhagwati and M.H. Kosters, eds., *Trade and Wages: Leveling Wages Down?*, Washington, D.C., AEI Press.

Directorate-General of Budget, Accounting, and Statistics (DGBAS), Various Years, *Manpower Utilization Survey*, Taipei, Republic of China.

Efron, B. (1979), "Bootstrap Methods: Another Look at the Jackknife," *Annals of Statistics* **7**: 1-26.

Katz, L.F. and D.H. Autor (1999), "Changes in the Wage Structure and Earnings Inequality," in O. Ashenfelter and D. Card, eds., *Handbook of Labor Economics 3*: 1463-1555, New York and Oxford, Elsevier Science, North-Holland.

Katz, L.F. and K.M. Murphy (1992), "Changes in Relative Wages, 1963-1987: Supply and Demand Factors," *Quarterly Journal of Economics* **107**: 35-78.

Lawrence, R.Z. and M.J. Slaughter (1993), "Trade and U.S. Wages: Giant Sucking Sound or Small Hiccup?," *Brookings Papers on Economic Activity,* Microeconomics: 161-210.

Leamer, E.E. (1994), "Testing Trade Theory," in D. Greenaway and L.A. Winters, eds., *Surveys in International Trade*, Oxford, Blackwell Publishers.

Tsay, C.L. (1995), “Labor Migration in Asia: Taiwan,” *ASEAN Economic Bulletin* **12**: 175-190.

Wood, A. (1994), *North-South Trade, Employment and Inequality, Changing Fortunes in a Skill-Driven World*, Oxford, Clarendon Press.