Wage Inequality and the Contribution of Capital, Differential Labor Quality and Efficiency to Economic Growth in Korea, 1965-2007

Sung Yeung Kwack *

We show that skilled and unskilled labors are imperfect substitutes and that capital and skilled labor are complementary in production. The Korean economy has experienced skill-biased technical changes. The capital stock growth is found to be the main source of the economic growth. The contribution of the efficiency and labor input growth of skilled workers is the second most important source. The rate of contribution of TFP growth to GDP growth has increased from 27% in 1991-1996 to 36% in 2001-2007. This paper shows that Korea's policy of educating its workforce has boosted productivity and growth and it prevented a widening in wage inequality.

Keywords: Wage inequality, Labor efficiency, Skill-biased technological change, TFP, Korea

JEL Classification: E13, J31, N15, O30, O47, O53

* This is the last article the author submitted to this journal before his sudden death from a deadly fire at his home in April 2011. The editors felt deeply sorry for this news, and have decided to publish his article in appreciation of his life-long contribution to the study of the Korean economy. His last position was a Professor of Economics, Howard University, Washington, D.C., USA. He would like to thank John Bennett, Peter Clark, Satish Wadhawan, and Young Sun Lee for their helpful suggestions. He was also grateful to the Institute for Monetary & Economic Research, the Bank of Korea for the assistance services provided. A portion of this paper was completed while he was a visiting professor at the Institute. The views expressed are not necessarily those of the Institute and the Bank of Korea.
[**Seoul Journal of Economics** 2012, Vol. 25, No. 1]

I. Introduction

The ratio of the wages received by skilled workers relative to the wages of unskilled workers in the United States has increased markedly since the 1970s. This increase in relative wage inequality has received enormous attention on the source of the steady rise in the wage inequality.[1] A central hypothesis regarding wage inequality in the literature is that technological change has shifted labor demand toward skilled worker; skill-biased technological changes (SBTC).[2]

A similar increase has occurred in Korea. Before the early 1960s, Korea was largely a closed economy. The majority of employed persons were engaged in agriculture and in government service sectors or were employed by utilities and banks. The government of Korea initiated the First Five Year Economic Plan in 1961, at which time Korea exported low tech light manufactured goods.[3] By the 1990s, however, the Korean economy produced and exported knowledge-intensive goods and services. Figure 1 gives the trend of wage inequality during the 1965-2007 period.[4] It shows that the ratio of the wage rate of skilled workers to less skilled workers declined from 4.3 in 1960 to 3.4 in 1964, but then rose to a peak level of 6.3 in 1976.[5] Wage inequality then generally declined to the level of 3.3 in 2000 before showing a tendency to rise again at a slow rate from 2001 to 2007. The average ratio of 3.47 during the 2001-2007 period is only slightly higher than the average ratio of 3.4 during the period 1993-2000 and is below the average ratio in the 1960s. We note that a rise in wage inequality does not necessarily mean that unskilled workers become worse off, but it mean that unskilled workers become better off at a slower pace than the skilled workers.

The purposes of this paper are threefold. First, it examines which factors are main sources of wage inequality between skilled and unskilled

[1] The wage inequality is the wage earnings of skilled workers relative to the wage earnings of unskilled workers. The term is interchangeably used in the literature with earnings inequality, wage premium, and relative wage rate.

[2] See, for example, Katz and Murphy (1992), Autor (2008), and Autor, Katz, and Kearney (2008).

[3] For Korean development strategy and trade, see Kwack (1986), Cho (1994), Hong (1994), Kim (1994), Nam (1994), Yoo (2008), Kwack and Lee (2010b), and Lee (2010).

[4] For the data and descriptions, see Kwack and Lee (2010a, Chapter 4) and Kwack (2010).

[5] Skilled workers are those who graduated university or higher. This definition is discussed later in the paper.

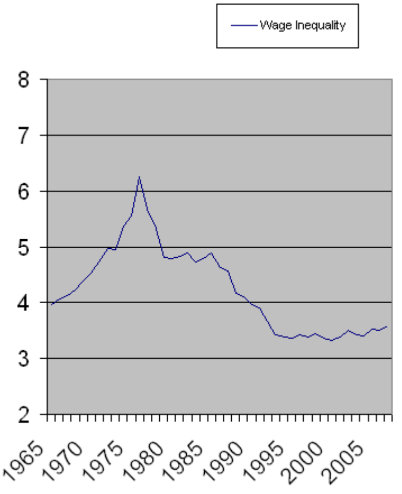

FIGURE 1
WAGE INEQUALITY, 1965-2007

workers in Korea. The Korean labor market evolved in line with changes in the economy's production structure and its openness to trade. Hence, wage inequality is expected to reflect the relative demand for skilled workers in an open economy which is affected by the capital stock and trade openness and the relative supply of skilled labor. We show that the two types of labor are imperfect substitutes and that capital and skilled labor are complementary in production. The paper computes the efficiencies of skilled and unskilled labor in Korea since 1965. The ratios in efficiency between skilled and unskilled workers showed that skill-biased technological changes have been occurring. Finally, using a growth accounting method, it analyzes the contribution of factors of production to economic growth and shows that total factor productivity growth captures the efficiencies and quality changes of workers. Our empirical findings provide evidence that Korea's educated labor force enabled Korea to attain its productivity and economic growth without greatly widening wage inequality and thus income inequality.

The rest of the paper is organized into four sections. Section II describes the production sector framework for the analysis of wage inequality. It presents the specification for empirically investigating wage inequality and discusses the empirical results. Section III computes and discusses skilled and unskilled labor efficiencies. Section IV analyzes the contribution of factors of production to economic growth and empirically shows that total factor productivity growth is related to the efficiencies and quality changes of workers. Section V provides a concluding summary.

II. Production Sector Framework

We consider a production function with three inputs — capital, skilled labor, and unskilled labor — and with different types of technologies.[6] In the literatures on wage inequality, one approach uses a CES production function while others use a translog production or a translog cost function.[7] For our purposes, the production function of a CES variety is sufficient.

Katz and Murphy (1992) emphasize the role of skill biased technological change (SBTC) in wage inequality between skilled and unskilled workers.[8] The CES production function of Katz and Murphy (1992) is

$$Y = [(q_U L_U)^{\rho} + (q_S L_S)^{\rho}]^{\frac{1}{\rho}} \qquad \rho = (1-\sigma)/\sigma \tag{1}$$

Y is output produced by skilled and unskilled labor inputs, L_S and L_U, respectively; q_S and q_U represent the levels of efficiency of skilled and unskilled labor inputs; and ρ is the substitution parameter with σ the elasticity of substitution between skilled and unskilled labor (less skilled labor) input.

The production function used by Caselli and Coleman (2006) meets our purposes for analyzing both wage inequality and labor efficiency. The production function is as follows:

[6] We follow our detailed discussions given in chapter 6 of Kwack and Lee (2010a).

[7] The translog approach to examine wage inequality usually takes a translog cost function. The first application to wage inequality was done by Berman, Bound, and Griliches (1994). Kwack and Lee (2010a, Chapter 6) presents and discusses the results obtained using a translog cost approach. In Chun (2003), capital stock K in the cost share equation is decomposed into IT capital and non-IT capital. Non-IT capital is divided into structure capital and non-IT equipment capital. Chun (2003) includes R&D intensity and the age of each capital stock.

[8] The CES approach is thoroughly discussed in Katz and Autor (1996). Autor, Katz, and Krueger (1998) and Autor, Katz, and Kearney (2008) extend the framework of Katz and Murphy (1992).

$$Y = K^{\alpha}[(q_U L_U)^{\rho} + (q_S L_S)^{\rho})]^{\frac{1-\alpha}{\rho}} \tag{2}$$

Factor markets are competitive and perfect. Each factor earns its marginal product. The first order conditions yield the cost-minimizing ratio of wages between skilled and unskilled labor as follows:

$$\frac{W_S}{W_U} = \left(\frac{L_S}{L_U}\right)^{-\frac{1}{\sigma}} \left(\frac{q_S}{q_U}\right)^{\frac{\sigma-1}{\sigma}} \tag{3}$$

The wage inequality relationship is the same as the relationship of Katz and Murphy (1992). From the above, the effect of a change in the relative supply and efficiency on the wage inequality is as follows:

$$\frac{\partial \ln(W_S / W_U)}{\partial \ln(L_S / L_U)} = -\frac{1}{\sigma} < 0, \quad \text{and} \quad \frac{\partial \ln(W_S / W_U)}{\partial \ln(q_S / q_U)} = \frac{\sigma - 1}{\sigma}$$

The wage inequality, or relative wage rate, W_S/W_U, is a decreasing function of relative supply of skills, L_S/L_U. An increase in the relative skilled labor efficiency, q_S/q_U, indicates skilled biased technological changes. The effect on the relative wage rate of a change in the relative labor efficiency depends on the elasticity of substitution σ. If $\sigma > 1$ a rise in the relative labor efficiency increases the wage inequality between skilled and unskilled labor. As $\sigma \rightarrow \infty$, the effect on the relative wage rate approaches to one.[9]

Griliches (1969) has identified a capital-skill labor complementary relationship in U.S. data. Recently, computer based automation has enhanced skilled labor time and effective skill hours, raising the marginal product of skilled relative to less skilled workers. This development implies that recent technological progress is skill-biased technological change (SBTC).[10] Recent growth in the relative supply of well-educated workers has induced innovations that have fostered complementarity between capital and skill.[11]

[9] The effect of a change in the elasticity of substitution on the relative wage rate is positive, $\partial \ln(W_S/W_U)/\partial \sigma > 0$ and $\partial^2 \ln(W_S/W_U)/\partial^2 \sigma < 0$.

[10] See Goldin and Katz (1998) and Murphy, Raiddell, and Romer (1998) for SBTC discussions.

[11] See Acemoglu (1998) for this argument.

Krusell *et al.* (2000) have explored how capital equipment is complementary to skilled labor. There are four factors of production — unskilled labor, skilled labor, structure capital, and equipment capital. It is assumed that the production function is a CES function as follows:

$$Y = AK_S{}^{\alpha}\left[\mu(q_U L_U)^{\sigma} + (1-\mu)(\lambda(q_E K_E)^{\rho} + (1-\lambda)(q_S L_S)^{\rho})^{\sigma/\rho}\right]^{(1-\alpha)/\sigma} \tag{4}$$

where A is total factor productivity or neutral technological progress. K_S and K_E are capital stock in structure and equipment, respectively. q_E is the efficiency or quality per equipment capital. α, μ, $\lambda \in (0, 1)$ and σ, $\rho \in (-\infty, 1)$. The CES parameter μ and λ govern income shares. The income share of structure is equal to the technological parameter α. The two substitution parameters are σ and ρ. The elasticity of substitution between equipment capital and unskilled labor and the elasticity of substitution between skilled labor and unskilled labor are both equal to $1/(1-\sigma)$. The elasticity of substitution between equipment capital and skilled labor is $1/(1-\rho)$. Complementary relationship between equipment capital and skilled labor requires $\sigma > \rho$. In the case of capital-skill complementarity, K_E/L_S, is positive on the relative wage of skilled labor when the capital input rises.

The expansion of international trade raises the relative demand for the factor intensively used in production and thus the relative prices of the intensively used factors (Stolper-Samuelson effects associated with increasing trade). When Korea exports more unskilled labor-intensive goods, trade expansion leads to a rise in the relative wages of unskilled workers in Korea. As Korea's trade openness promotes the development of skilled labor forces, Korea produces and exports more skilled labor-intensive goods. Firms are induced to use more advanced technology and technology-embodied imported goods and raise the absorptive capacity and R&D activities to understand new innovations.[12] New innovations induced through trade with developed industrial countries like German, France, Japan, United Kingdom, and U.S.A. are skill-complementary innovations. Hence, trade induces skill-biased technical changes.[13] The trade and adaptation of new technologies favors the skilled workers and raises the skill premium paid to the more skilled workers.[14] Feenstra

[12] Catch up and technology adaptation are described in Nelson and Pack (1999) and Lee and Lim (2001).

[13] Accemoglu (1998, 2002) and Wood (1998) discuss channels for it.

[14] Economists have found little empirical support for the trade explanation to

and Hanson (1999) attribute a substantial rise in U.S. wage inequality to international outsourcing activity and foreign direct investment (FDI) by U.S. multinational firms. The openness of Korea to trade and outsourcing are expected to raise the wage gap between skilled and unskilled workers.

A. Econometric Specification

The approach by Katz and Murphy (1992) has several applications to Korea. Kim (2005) shows the importance of changes in educational and age distributions of labor supply in the determination of wage inequality in Korea. The wage data utilized are from the "Wage Structure Survey" by the Ministry of Labor. The employment data and population data are from the "Annual Report on Economically Active Population Survey" and the "Population Projection" by the National Statistical Office. The period of estimation is from 1978 to 2002. The elasticity of substitution between skilled and less skilled labor is estimated be $1.7<\sigma<2.5$. The specification of Choi, Jeong, and Jung (2005) is a variety of the specification of Katz and Murphy (1992). Like Kim (2005), the wage data utilized are from the "Wage Structure Survey" by the Ministry of Labor, and the employment data are from the "Annual Report on Economically Active Population Survey." The unit of period is a five years, and the years of data are 1982, 1987, 1992, 1997, and 2000. The substitution elasticity estimates appear to be quite high, and the range of the estimates is $3.8<\sigma<4.2$.

We want to quantitatively find what are the important contributors to wage inequality in Korea. Based on the discussions above, changes in the wage inequality are expected to be captured in terms of four categories of factors that affect the relative demand for skilled workers — skill-biased technical changes (SBTC), trade openness, and labor market disturbances — and the relative supply of skilled labor. The factors which affect SBTC are grouped into the domestic efforts — (a) the ratio of capital stock to GDP and (b) R&D stock — and the foreign efforts — (c) the R&D stock of foreign G5 countries — France, Germany, Japan, United Kingdom, and United States.[15] The degree of the openness in trade of

generate large movements in relative wages of skilled workers in the North. The increase in wage inequality occurred in both the North and most of the Southern countries. See Feenstra and Hanson (2004) for an overview of the wage inequality literature.

[15] Development of endogenous growth economics has emphasized the importance of R&D efforts as an engine of growth. See Grossman and Helpman (1991, Chapters 3-5). In open economy models, both domestic and foreign R&D efforts

goods and services are represented by the ratio of export volume of goods and services to GDP and the ratio of the average of exports and import to GDP. Foreign direct investment in the form of its intensity or asset stock is not considered here because FDI transactions were not significant until 1990s.[16] The prices of foreign trade are not utilized because the information on the contents of trade is very limited, as Krugman (2008) states. In our earlier studies, we found that the occurrences of labor disputes-number of disputes and working days lost, and Korean R&D stock and foreign R&D stock were insignificant variables.[17] Hence, these variables are not included in the specification. The specification for wage inequality is as follows:

$$\ln \frac{W_S}{W_U} = \alpha_1 + \alpha_2 \ln(\frac{L_S}{L_U}) + \alpha_3 \ln(\frac{K_{-1}}{GDP}) + \alpha_4 OP \qquad (5)$$

GDP is aggregate output, and K is the capital stock at the end of year.[18] OP denotes the trade openness, and proxy measures of trade openness are represented by the ratio of exports of goods and services to GDP, OP_X, and the ratio of exports and imports to GDP, OP_{XM}.

are shown to affect TFP growth. See Coe and Helpman (1995), Kwack (1997), and Lee (2005). Choi and Jeong (2005) provides indirect evidence for the assumption that indicators of technological changes are ratio of scientists and engineers to total number of the employed, R&D expenditure as a percent of sales, total factor productivity, and ICT investment intensity.

[16] Baldwin (1994) discusses the importance of FDI.

[17] Our studies include Kwack and Lee (2010a, Chapter 6) and Kwack (2010). We constructed R&D capital stock using the perpetual inventory method with the initial benchmark figure and depreciation rate. We assume a depreciation rate of 12 percent per year for the R&D stock of Korea and G5 countries. The bench mark year is the end of 1964. Three methods are used for the construction of foreign R&D stock. (1) The first proxy variable for foreign total R&D stock is a geometrically weighted average of individual G5 country's total R&D stock. As Coe and Helpman (1995) used, the weights are based on the value share of bilateral imports. (2) The second foreign R&D stock is an average of individual G5 country's R&D stock, weighted by the value of bilateral imports to Korea's nominal GDP. (3) The third foreign R&D stock is an unweighted sum of individual G5 country's R&D stock.

[18] The capital stock is represented by the total capital stock and the capital stock excluding residential structure.

B. Empirical Results

(a) Data Description

The equation specification is tested using the economy-wide data.[19] The economy-wide data are described from Kwack and Lee (2010a, Chapters 2-4) that constructed time series annual data on a consistent basis by industry and different types of labor and capital service inputs by industry. The data sources are many and include the "National Accounts" and "Input-Output Tables" published by the Bank of Korea, "the Report on Wage Survey by Occupational Category" by Ministry of Labor, and "the Survey of Population and Housing" by National Statistical Offices, and "Korea Capital Input Data" by EU KLEMS (2008).[20]

Drawing upon the raw data in "The Report on Wage Survey by Occupational Category" by the Ministry of Labor, we constructed wage rate per hour and man-hours worked per worker and the number of workers by sex and education for individual occupation for 1970 and from 1973-2007. Then, we constructed cross-tabulation data on workers by occupation classification and educational attainment classification and found that the higher the educational attainment of workers, the higher would be their occupational ranking. After examining the data, the workers who graduated from jr. college and below are classified to be less-skilled workers or unskilled workers. The workers who graduated university and above are classified to be skilled workers or highly skilled-workers. As workers are not homogenous, the labor input includes both the quantity of labor conventionally measured by un-weighted sum of hours worked and the quality of labor reflecting the composition of workers. Changes in the composition of workers are captured by weighting the hours of different labor groups by their marginal products. The employment data cover all the persons engaged in production and include the self-employed. The labor input includes the flows of labor services of both employed and self-employed workers. It holds that $P_{L,t} L_t = W_{S,t} L_{S,t} + W_{U,t} L_{U,t}$, where L and P_L are aggregate labor input and its price.[21]

The capital stock of an asset in industry is constructed using the

[19] The data sources and descriptions are in the chapters 2-4 of Kwack and Lee (2010a) and empirical results are in part from Kwack and Lee (2010a, Chapter 6) and reported in Kwack (2010).

[20] EU KLEMS is a European Commission financed, industry level, growth, and productivity research project. EU KLEMS stands for EU level analysis of capital (K), labour (L), energy (E), materials (M), and service (S) inputs.

[21] For the discussions on labor input and the data construction, see Jorgenson and Stiroh (2002, Appendix C) and Kwack and Lee (2010a, Chapter 4).

perpetual inventory method with the initial benchmark figure and depreciation rate, using $K_{j,t}=I_{j,t}+(1-\delta_j)K_{j,t-1}$ where δ_j is the depreciation rate for asset of type j, K_j, and real investment expenditure is I_j.[22] Capital stock by industry consists of seven types of assets: (i) residential buildings, (ii) non-residential buildings and other construction, (iii) transport equipment, (iv) machinery and equipment other than both IT computing equipment and IT communication equipment, (v) IT computing equipment, (vi) IT communication equipment, and (vii) intangible fixed assets. (IT capital assets consist of IT computing equipment, IT communication equipment and intangible fixed assets). The depreciation rates are assumed to be 0.025 for residential buildings, 0.035 for non-residential buildings and other construction, 0.15 for transport equipment, 0.12 for machinery and equipment other than both IT computing equipment and IT communication equipment, 0.32 for IT computing equipment, 0.12 for IT communication equipment, and 0.32 for intangible fixed assets. The benchmark year is selected as 1960 and the initial benchmark figure is computed using $K_{j,0}=I_{j,0}/(g_j+\delta_j)$ where g_j is the growth rate of capital investment. The implicit depreciation rate per year for total capital stock changed from 0.046 in the early 1960s to 0.061 in the middle 2000s. Capital stock figures in industry are not adjusted for changes in asset compositions. Hence, total capital stock for the economy is the sum of the capital stock levels of individual industries. Consequently, the total capital stock differs from total capital input that comprise the capital stock and capital quality arising from changes in their compositions. The use of labor input, capital stock, and aggregate output is in accordance with the theoretical framework we assume, namely one good, one capital good, and workers of two different types.

(b) Regression Results

Our preliminary regression results found that the DW statistics are low. We tried to correct the serial correlation in the residuals, assuming that the residuals exhibit a first-order correlation, but regression results obtained the first-order serial correlation were not satisfactory.

Table 1 summarizes the empirical results.[23] Equation (1.1) of the table is the result we obtained when we applied the model of Katz and Murply (1992):

[22] See Christensen and Jorgenson (1969), Fraumeni and Jorgenson (1980), and Kwack and Lee (2010a, Chapters 3 and 4).

[23] The data used for the regressions are available upon request.

TABLE 1
WAGE INEQUALITY, $\ln(W_S/W_U)$

Equation No.	1.1	1.2	1.3
constant	-17.40	-0.141	-0.09
	(1.67)	(0.53)	(0.29)
t	0.09		
	(1.75)		
$\ln(Ls/Lu)$	-0.39	-0.49	-0.47
	(3.89)	(6.55)	(5.94)
$\ln(K(-1)/\text{GDP})$		0.17	0.15
		(3.05)	(2.73)
OPx		0.52	
		(2.18)	
OPxm			0.27
			(1.64)
adjusted R^2	0.63	0.73	0.69
SEE	0.11	0.10	0.10
DW	0.30	0.48	0.43

1. Figures in ( ) are *t*-statistics.

$$\ln(W_S / W_U) = \alpha_0 + \alpha_1 t + \alpha_2 \ln(L_S / L_U) \quad (6)$$

where t is a time trend variable. The relative supply of skilled workers, L_S/L_U, is highly significant and has a negative effect. The implied elasticity of substitution between skilled and less skilled workers is 2.54. This estimate is close to the estimate of Kim (2005) an is higher than the estimates around 1.67 by Katz and Murphy (1992), 1.8 in Autor *et al.* (2008), and 1.5 in Krusell *et al.* (2000) for the U.S. economy. The coefficient of the time trend variable indicates that the relative wage increases at annual rate of 0.09 percent.

Equations (1.2) and (1.3) provide the results of our specification as given in (5). Two variables that are hypothesized to determine technological changes — capital-to-GDP ratio and trade openness — and the relative supply of skilled workers are statistically significant and have expected signs.[24] In Equation (1.2), the trade openness is represented by the ratio of exports of goods and services to GDP, and in Equation

[24] We alternatively used the ratio of the capital stock excluding residential buildings. The regression results are very similar.

(1.3), it is represented by the ratio of export and imports to GDP. The coefficient estimates of the labor supply and capital-to-GDP variables are close in both equations. But, the coefficient estimate of the export-to-GDP ratio in (1.2) is more significant than the coefficient estimate of the export and import-to-GDP ratio. It appears that Equation (1.2) is preferable to Equation (1.3). Hence, our statistical inference is made on the basis of Equation (1.2). The elasticity of substitution between skilled and less skilled workers is 2.05. The elasticity of the wage inequality with respect to a change in the capital-to-GDP is positive and 0.17. This shows that skilled labor is complementary to capital stock.[25] The elasticity of the wage inequality with respect to a change in the openness on trade is 0.11 at the mean value. Other things being equal, a one percent rise in the trade openness leads to a 0.11 percent widening the wage inequality. The significance of the capital-to-GDP ratio and trade openness confirm the SBTC hypothesis in the case of Korea.

Using Equation (1.2) and the estimated elasticity of substitution, the actual changes in the relative wage rate are decomposed into changes in relative demand and relative supply. Table 2 summarizes the computation. Across the earlier sub-periods, 1965-1976 and 1977-1994, and the latest sub-period, 2000-2007, changes in relative supply were higher than changes in relative demand. For the sub-period, 1995-2000, relative demand outstrips relative supply. The unidentified missing factors promoted rising wage inequality in the sub-period, 1965-1976, and sub-period, 2000-2007. Relative demand growth for skilled workers *via* technological changes and trade liberalization has been rising at an annual rate 3 percent in the 2000-2007. The relative supply of skilled workers in the period has been increasing at the annual rate of 5.5 percent. The rise in the relative supply has greatly contributed narrowing the wage inequality.

The most important findings from our empirical results are three. First, skilled labor and capital stock has a complementary relationship in production. Second, the openness in trade has a significant positive effect on wage inequality. The trade openness and capital stock are the main sources of skill-biased technological progress (SBTC). Third, changes in the relative supply of skilled workers had a significant and substantial negative effect on the wage inequality.

[25] The complimentarily relationship between labor and plant and equipment capital is reported in Kwack and Lee (2005).

TABLE 2

CHANGES IN THE WAGE INEQUALITY AND THE RELATIVE SUPPLY AND DEMAND FOR SKILLED WORKERS, 1965-2007

	Actual Relative Wage (1)	Difference (2)=(1)−(3)	Predicted Relative Wage (3)=(4)−(5)	Relative Demand (4)	Capital to GDP Ratio	Openness in Exports	Relative Supply (5)
1965~1976	5.17	5.82	-0.65	3.63	1.31	0.45	4.99
1977~1994	-3.42	-1.34	-2.09	2.15	0.78	0.27	6.44
1995~2000	-0.03	-0.35	0.33	5.01	0.77	1.66	4.33
2000~2007	-1.41	0.10	-1.50	2.86	0.54	0.85	5.95
1965~2007	0.15	1.32	-1.17	3.09	0.78	0.72	5.50

Changes in variable z is annual rates of change in percent, $100 \times$ changes in log (z).
The elasticity of substitution estimate is 2.055.

III. Efficiency of Labor

This section is designed to compute the efficiency of skilled labor and the efficiency of unskilled labor. We utilize the method used by Caselli and Coleman (2006) and by Unel (2008). Equations (2) and (3) can be used to solve for q_S and q_U. The solutions are: for j=S, U

$$q_j = \beta_j^{\frac{\sigma}{\sigma-1}} \left(\frac{Y}{L_j}\right)\left(\frac{Y}{K}\right)^{\alpha/(1-\alpha)} \qquad \text{with} \qquad \beta_j = \frac{w_j L_j}{w_S L_S + w_U L_U} \tag{7}$$

The efficiency of each of skilled and unskilled labor can be computed with the data on output, capital stock, skilled and unskilled labor, prices of labor services, and α, the cost share of capital services in the value of output, and the estimate of σ, 2.055.

The annual values of β_j are defined as the two period average value shares of the earnings of j^{th} group in the total earnings. The annual values of α are defined as the two period average value shares of the compensation for the aggregate capital stock in the nominal value of

TABLE 3
AVERAGE ANNUAL GROWTH RATES OF EFFICIENCY, %

	q_S	q_U	q_S/q_U
1965~1980	-0.12	-8.52	8.41
1981~1990	3.95	3.34	0.61
1991~1996	3.40	-2.70	6.09
1997~1999	-4.93	-6.56	1.63
2000~2007	7.61	1.50	6.11

$\sigma=2.055$ is used.

GDP. The capital share is 1-the labor share, defined to be the ratio of employees' and self-employed workers' compensation to the nominal value of GDP, $P_{L,t}L_t/P_{y,t}Y_t$, where Y and P_y are real GDP and the GDP price deflator.[26]

We computed the efficiencies of skilled labor and unskilled labor.[27] The computed efficiencies are summarized in Table 3 and plotted in Figure 2. The efficiency of skilled labor rose at the annual negative rate of 0.12 percent in the period of 1965-1980, grew at 4 percent rate in the period of 1981-1990, rose at 3.4 percent rate in the period of 1991-1996 and has grown rapidly at the annual rate of 7.6 percent from 2000 onwards. The efficiency of unskilled labor rapidly declined at an annual rate of 8.5 percent during the period 1965-1980, it rose at 3.3 percent rate during the period of 1981-1990. It declined at 2.7 percent rate during the period of 1991-1996. From 2000 to 2007, the average annual growth rate was 1.5 percent.

The efficiency of skilled labor relative to the efficiency of unskilled labor represents the degree of skill-biased technological changes (SBTC). It rose at the annual rate of 8.4 percent during the period 1965-1980, 0.6 percent during the period 1981-1990, 6.1 percent during both the period 1991-1996 and 2000-2007. The SBTC rose positively but with a declining rate of change.[28] The Korean economy has experienced skill-biased technical changes and becoming relatively more efficient at utilizing skilled labor. A question that the time paths of the labor efficiencies may raise is: what caused the different paths after 1980. Detailed studies are

[26] For the discussions on measuring labor's share, see Krueger (1999).

[27] The data on capital share income, earnings share of skilled labor, and labor efficiencies are available upon request.

[28] The regression of a second degree Taylor approximation equation, $\ln(q_S/q_U) = \eta_0+\eta_1 t+\eta_2 t^2$, yields $\eta_1=2.2$ and $\eta_2=-0.0005$.

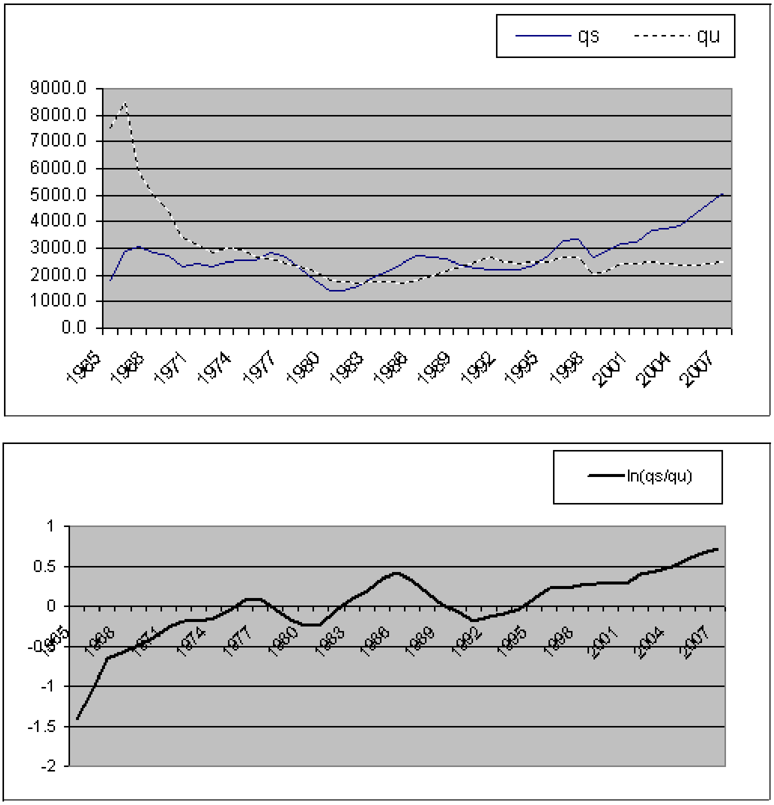

FIGURE 2
TIME PATH OF LABOR EFFICIENCIES

needed to give persuasive answers to this question in the case of Korea. Nevertheless, two sources will be a worldwide skill-biased technological development including IT revolution and shifts of Korea's industrial structure toward skill-biased technology industries.

IV. Contribution of Capital, and Skilled and Unskilled Labor to Economic Growth

We assume that the production function (1) is a CES function and both output and factor markets are perfectly competitive. Output growth can be decomposed into growth in three factor inputs:

TABLE 4
GDP GROWTH AND FACTOR INPUT CONTRIBUTIONS

		1965-1980	1981-1990	1991-1996	1997-2007
GDP	[1]	7.8	8.4	7.4	4.3
Contribution to GDP growth by					
K	[2]	8.7	5.0	5.1	2.6
q	[3]=[4]+[5]	-3.7	1.8	1.4	0.4
q_S	[4]	-0.1	0.5	0.9	0.7
q_U	[5]	-3.6	1.4	0.5	-0.3
L	[6]=[7]+[8]	2.6	2.1	1.5	0.6
L_S	[7]	0.4	0.7	1.4	0.7
L_U	[8]	2.1	1.4	0.0	-0.1
residuals	[1]-[2]-[3]-[6]	0.2	-0.6	-0.5	0.6
Contribution as percent of GDP growth					
K		111.3	59.8	68.7	60.9
q		-47.5	22.1	18.3	10.4
q_S		-1.8	5.9	12.2	16.5
q_U		-45.7	16.2	6.1	-6.1
L		33.1	24.7	19.9	14.9
L_S		5.7	8.5	19.4	16.5
L_U		27.4	16.2	0.5	-1.6
residuals		3.0	-6.6	-6.9	13.8

Notes: 1. Contribution to GDP growth is the ratio of the growth in input factor growth to GDP growth in percent.
2. 'residuals' are rounding errors in the computation, *i.e.*, differences between actual and computed figures of GDP growth.

$$\Delta \ln Y_t = \alpha_t \Delta \ln K_t + (1-\alpha_t)\frac{\sigma}{\sigma-1}[\beta_{S,t}\Delta(\ln q_{S,t} L_{S,t}) + (1-\beta_{S,t})\Delta(\ln q_{U,t} L_{U,t})] \tag{8}$$

Table 4 presents the results of decomposing their contributions to the growth in the economy's total output. Capital stock growth is the main source of the economic growth. The contribution by the capital stock to economic growth has been high, but at a declining rate: 111% in 1965-1980, 60% in 1981-1990, 69% in 1991-1996, and 61% in 1997-2007. The contribution of worker efficiency has declined -47% in 1965-1980, but then improved to 22% in 1981-1990, 18% in 1991-1996, and 10% in 1997-2007, although the contribution of the efficiency of skilled workers has increased from -2% in 1965-1980, to 6% in 1981-1990, 12% in 1991-1996, and 17% in 1997-2007. The contribution of labor hours has declined from the 1965-1980 period: 33% in 1965-1980, 25% in 1981-1990, 20% in 1991-1996, and 15% in 1997-2007. The contribution of labor hours worked by skilled labor has risen from 6% in 1965-1980, 9% in 1981-1990, 19% in 1991-1996, and 17% in 1997-2007.

It is interesting to compare the sources of economic growth presented above with those obtained using the following Cobb-Douglas aggregate production:

$$Y = AK^{\alpha}(L_U^{(1-\beta_S)} L_S^{\beta_S})^{(1-\alpha)} \tag{9}$$

From (9), the GDP growth can be decomposed into growth in capital, labor, and total factor productivity (TFP), denoted by A:

$$\Delta \ln Y_t = \Delta \ln A_t + \alpha_t \Delta \ln K_t + (1-\alpha_t)(\beta_{S,t} \Delta L_{S,t} + (1-\beta_{S,t})\Delta L_{U,t}) \tag{10}$$

Subtracting (8) from (10) yields

$$\begin{aligned} \Delta \ln A_t &= (1-\alpha_t)(\beta_{S,t} \Delta L_{S,t} + (1-\beta_{S,t})\Delta L_{U,t})(1-\frac{\sigma}{\sigma-1}) \\ &+ (1-\alpha_t)\frac{\sigma}{\sigma-1}[\beta_{S,t}\Delta(\ln q_{S,t}) + (1-\beta_{S,t})\Delta(\ln q_{U,t})] \end{aligned} \tag{11}$$

When $\sigma \to \infty$ (*i.e.*, perfect factor substitutes in the case of Cobb-Douglas production function), TFP growth is a linear function of a cost-share weighted average of changes in the improvement of skilled and unskilled labor-augmenting efficiency:

$$\Delta \ln A_t = (1-\alpha_t)[\beta_{S,t}\Delta(\ln q_{S,t}) + (1-\beta_{S,t})\Delta(\ln q_{U,t})]. \tag{12}$$

The contribution of TFP growth to GDP growth and the contributions of efficiency growth to TFP growth are presented in Table 5.[29] The rate of contribution of TFP growth to GDP growth has increased considerably in recent years: -32% in 1965-1980, 27% in 1981-1990, 27% in 1991-1996, and 36% in 1997-2007. The negative contribution of TFP growth

[29] TFP growth measured as a residual under neo-classical assumptions includes improvements in allocative and technical efficiency and the effects of measurement errors on output and input.

TABLE 5
TFP GROWTH AND FACTOR CONTRIBUTIONS

	1965-1980	1981-1990	1991-1996	1997-2007	2000-2007
TFP growth	-2.5	2.2	2.0	1.5	2.6
% of GDP growth	-32.0	26.6	26.6	36.1	50.8
Contribution to TFP growth					
q	-3.7	1.8	1.4	0.4	1.9
L-H	1.0	0.9	1.1	0.5	0.6
residuals	0.2	-0.6	-0.5	0.6	0.1
Contribution as percent of TFP growth					
q	148.4	83.0	69.0	28.8	74.1
L-H	-39.0	41.8	56.8	32.9	23.4
residuals	-9.4	-24.8	-25.8	38.3	2.5

Notes: 1. TFP growth is traditionally defined TFP growth, namely output growth-contributions of capital stock and hours-worked growth.
2. *H* is the hours worked, and *L-H* is labor quality resulting from changes in labor compositions.
3. Residuals are the differences between actual and computed figures of GDP growth.

in the period 1965-1980 indicates that the utilization of resources during the early development period under President Park Chung Hee was inefficient. TFP growth captures efficiency gains from innovations in the manner workers perform jobs and work smarter with existing technology. As a result, a substantial portion of the TFP growth consists of the contribution of skilled and unskilled labor efficiencies. It confirms the important contribution of Jorgenson and Griliches (1967) that points out TFP growth measures the net gains in output over and above factor inputs.

While the Korean TFP contribution rate to GDP growth rose in recent years, it seems lower than in other OECD industrial countries (see Table 6). During the 1985-2007 period, the average rate of Korea TFP contribution was 29%. The Canadian contribution rate, 17%, was lower than the Korean contribution rate during the same period. The TFP contribution rates of other counties are higher than the Korean contribution rate: 31% in Australia, 63 percent in France, 79% in Germany, 34% in Italy, 75% in Japan, 49% in Sweden, 40% in UK, and 37% in USA.

TABLE 6
TFP GROWTH OF MAJOR INDUSTRIAL ECONOMIES

		TFP Growth	Ratio of TFP Growth to GDP Growth
Korea	1985-2007	1.85	0.29
Australia	1985-2005	1.04	0.31
Canada	1985-2007	0.49	0.17
France	1985-2007	1.36	0.63
Germany	1991-2007	1.2	0.79
Italy	1985-2006	0.61	0.34
Japan	1985-2006	1.7	0.75
Sweden	1985-2006	1.13	0.49
UK	1985-2005	1.08	0.4
USA	1985-2007	1.06	0.36

The figure for Korea is calculated in this study.
Source: Table 2 of Mulugetta, Abraham, and Yugo Mulugetta (2009).

V. Conclusions

We have applied a well-established theory of wage inequality to explain the wage inequality in Korea during the period of 1965-2007. We have found that wage inequality is related negatively to the relative supply of skilled labor and positively to the capital-to-GDP ratio and trade openness, as represented by the ratio of exports of goods and services to GDP. The elasticity of substitution between skilled and unskilled labor is estimated to be 2.055. Capital and skilled labor are found to be complementary in production. The time paths of the efficiency of skilled labor relative to the efficiency of unskilled labor indicate that the Korean economy has experienced skill-biased technical changes and is becoming relatively more efficient at utilizing skilled labor.

The contribution by the capital stock growth to economic growth has been high, making capital stock growth the main source of the economic growth : 61 percent during the 1997-2007 period. The contribution of the efficiency and labor input growth of skilled workers is the second most important source: 33 percent during the period 1997-2007 period. The contribution of the efficiency and labor input growth of unskilled workers is found to be negative: -8 percent. The rate of contribution of TFP growth to GDP growth has increased considerably in recent years from 27% in 1991-1996 to 36% in 2001-2007. The TFP growth captures efficiency gains from innovations in the manner in which workers perform their jobs, and a substantial portion of the TFP growth is found to be the contribution of skilled and unskilled labor efficiencies.

Korea has followed a policy of educating its workforce.[30] Our empirical findings show that this policy has boosted economic growth and has prevented a widening in wage inequality and thus in income inequality.

(Received 23 April 2011; Revised 31 December 2011; Accepted 31 December 2011)

References

Acemoglu, Daron. "Technical Change, Inequality, and the Labor Market." *Journal of Economic Literature* 40 (No. 1 2002): 7-72.

________. "Why Do New Technologies Complement Skill? Direct Technological Change and Wage Inequality." *Quarterly Journal of Economics* 113 (No. 4 1998): 1055-189.

Autor, David H. "Structural Demand Shifts and Potential Labor Supply Responses in the New Century." In Katherine Bradbury, C. L. Forte, and Robert K. Triest (eds.), *Labor Supply in the New Century.* Boston: Federal Reserve Bank of Boston, pp. 161-208, 2008.

Autor, David H., Katz, Lawrence F., and Kearney, Medissa S. "Trends in U.S. Wage Inequality: Revising the Revision." *Review of Economics and Statistics* 90 (No. 2 2008): 300-23.

Autor, D. H., Katz, L. F., and Krueger, M. S. "Computing Inequality: Have Computers Changed the Labor Market?" *Quarterly Journal of Economics* 113 (November 1998): 1169-213.

Baldwin, Robert E. "The Effects of Trade and Foreign Direct Investment on Employment and Relative Wages." *OECD Economic Studies* 23 (Winter 1994): 7-54.

Bank of Korea. *National Accounts*. Various Years (1966-2009).

________. *The Input-Output Table*. Various Years (1966-2009).

Berman, Eli., Bound, J., and Griliches, Z. "Changes in the Demand for Skilled Labor within U.S. Manufacturing: Evidence from the

[30] As discussed in Kwack and Lee (2010a, Chapter 2), about 71 percent of the workers in 1966 attended primary school and did not attend schools, decreasing to 29 percent of workers in 1990 and 13 percent in 2007. 3 percent of the workers in 1966 graduated university and higher, rising to 8 percent in 1990 and 24 percent in 2007.

Annual Survey of Manufacturers." *Quarterly Journal of Economics* 109 (No. 2 1994): 367-97.

Caselli, Frtancesco, and Coleman II, W. John. "The World Technology Frontier." *American Economic Review* 96 (No. 3 2006): 499-522.

Cho, Soon. *The Dynamics of Korean Economic Development.* Washington, D.C.: Institute for International Economics, 1994.

Choi, Kang-Shik, and Jeong, Jinnook. "Technological Change and Wage Premium in a Small Open Economy: the Case of Korea." *Applied Economics* 37 (No. 1 2005): 119-31.

Choi, Kang-Shik, Jeong, Jin-Ho, and Jung, Jin Hwa. "The Rising Supply of College Graduates and Declining Returns for Young Cohort: the Case of Korea." *Global Economic Review* 34 (No. 2 2005): 167-80.

Christensen, Laurits R., and Jorgenson, Dale W. "The Measurement of U.S. Real Capital Input, 1929-1967." *Review of Income and Wealth* 15 (No. 4 1969): 293-320.

Chun, Hyunbae. "Information Technology and the Demand for Educated Workers: Disentangling the Impacts of Adoption versus Use." *Review of Economics and Statistics* 85 (No. 1 2003): 1-8.

Coe, D. T., and Helpman, E. "International R&D Spillovers." *European Economic Review* 39 (No. 5 1995): 859-87.

EU KLEMS. *Korea Capital Input Data.* March 2008.

Feenstra, Robert C., and Hanson, G. H. "The Impact of Outsourcing and High Technology Capital on Wage Estimates for the United States, 1979-1990." *Quarterly Journal of Economics* 114 (No. 3 1999): 907-40.

________. "Global Production Sharing and Rising Inequality: A Survey of Trade and Wages." In E. Kwan Choi and James Harrigan (eds.), *Handbook of International Trade.* Volume 2, Malden, M.A.: Blackwell, Chapter 6, 2004.

Fraumeni, Babara M., and Jorgenson, Dale W. "The Role of Capital in the U.S. Economic Growth, 1948-1976." In George M. Von Furstenberg (ed.), *Capital, Efficiency, and Growth.* Cambridge, MA: Ballinger Publishing Co., pp. 9-250, 1980.

Goldin, C., and Katz, L. "The Origin of Technology-Skill Complementarity." *Quarterly Journal of Economics* 113 (No. 3 1998): 693-732.

Griliches, Z. "Capital-Skill Complementarity." *Review of Economics and Statistics* 51 (No. 4 1969): 465-68.

Grossman, G. M., and Helpman, E. *Innovation and Growth in the Global Economy.* Cambridge, MA: MIT Press, 1991.

Hong, Wontack. *Trade and Growth - A Korean Perspective.* Seoul: Kudara International, 1994.

Jorgenson, Dale W., and Griliches, Z. "The Explanation of Productivity Change." *Review of Economics Studies* 34 (No. 3 1967): 249-83.

Jorgenson, Dale W., and Stiroh, Kevin J. "Raising the Speed Limit?: U.S. Economic Growth in the Information Age." In Dale W. Jorgenson (ed.), *Econometrics Volume 3 - Economic Growth in the Information Age.* Cambridge, MA: MIT Press, pp. 71-150, 2002.

Katz, L., and Autor, David H. "Changes in the Wage Structure and Earnings Inequality." In Orley C. Ashenfelter and David Card (eds.), *Handbook of Labor Economics.* Volume 3, Netherland: Elesevier Science B.V., Chapter 26, pp. 1464-555, 1996.

Katz, L., and Murphy, K. "Changes in Relative Wages, 1963-1987." *Quarterly Journal of Economics* 107 (No. 1 1992): 357-58.

Kim, Chung-yum. *Policymaking on the Front Lines-Memoirs of a Korean Practitioner, 1945-79.* Washington, D.C.: the World Bank, 1994.

Kim, Dae Il. "Growth in College Education and Wage Differentials in Korea." *Seoul Journal of Economics* 18 (No. 2 2005): 87-123.

Krueger, Alan B. "Measuring Labor's Share." *AEA Papers and Proceedings* 89 (No. 2 1999): 45-51.

Krugman, Paul R. "Trade and Wages, Reconsidered." *Brookings Papers on Economic Activity* 39 (No. 1 2008): 103-54.

Krusell, Per, Ohanian, L.E., Rio-Rull, J., and Violante, G. "Capital-Skill Complementarity and Inequality: A Macroeconomic Analysis." *Econometrica* 68 (No. 5 2000): 1029-53.

Kwack, Sung Y. "The Economic Development of the Republic of Korea, 1965-1981." In Lawrence R. Lau (ed.), *Models of Development: A Comparative Study of Economic Growth in South Korea and Taiwan.* San Francisco: ICS Press, pp. 65-134, 1986.

________. *A Study on Productivity Growth and Contribution to Economic Growth.* Seoul: Korea Institute for Industrial Economics & Trade, 1997 (in Korean).

________. "Wage Inequality and the Efficiency of Workers in Korea, 1965-2007." the Institute for Monetary & Economic Research, the Bank of Korea, Working Paper 437, October 2010.

Kwack, Sung Yeung, and Lee, Young Sun. "Economies of Scale, Technological Progress, and the Sources of Economic Growth: Case of Korea, 1969-2000." *Journal of Policy Modeling* 27 (No. 3 2005): 265-83.

________. *Korea's Production Database, 1960-2007: Highlighting the Role* *of Human Capital and Trade Liberalization in the Changes of Total Factor Productivity and Wage Inequality.* Seoul: Korea Institute for Industrial Economics & Trade, March 2010a.

________. "Historical Transformation and Prospects of the Korean Economy." *Korean Economic Forum* 3 (No. 2 2010b): 25-42.

Lee, Keun, and Lim, Chaisung. "Technological Regimes, Catching-Up and Leaffrongging: Findings from the Korean Industries." *Research Policy* 30 (No. 3 2001): 459-83.

Lee, Gwanghoon. "International R&D Spillovers Revisited." *Open Economies Review* 16 (No. 3 2005): 249-62.

Lee, Jaymin. "Understanding the Korean Economic 'Miracle'." *Korean Economy Forum* 3 (No. 2 2010): 5-24.

Ministry of Labor (Korea). "Labor, Capital Service, and Productivity Contributions to National Economic Growth: Focusing on the Japanese Case." The Report on Wage Survey by Occupational Category Mulugetta, Abraham, and Mulugetta, Yuko. *Global Economic Journal* 9 (No. 3 2009): 1-20.

Murphy, Kevin, Raiddell, C., and Romer, P. "Wages, Skills, and Technology in the United States and Canada." NBER Working Paper No. 6638, 1998.

Nam, Duck Woo. "Korea's Economic Takeoff in Retrospect." In Sung Yeung Kwack (ed.), *The Korean Economy at a Crossroad-Development Prospects, Liberalization, and South-North Economic Integration.* Westport: Praeger, pp. 3-19, 1994.

National Statistical Office (Korea). *The Annual Report on the Economically Active Population Survey*. Various Years.

________. *The Survey of Population and Housing*. Various Years.

________. *The Population Projection*. Various Years.

Nelson, R. R., and Pack, H. "The Asian Miracle and Modern Growth Theory." *Economic Journal* 109 (No. 457 1999): 416-36.

Unel, Bulent. "Analyzing Skilled and Unskilled Labor Efficiencies in the U.S." Department of Economics, Louisiana State University, Baton Rouge, LA, May 2008, Unpublished.

Wood, Adrian. "Globalization and the Rise in Labor Market Inequalities." *Economic Journal* 108 (No. 450 1998): 1463-82.

Yoo, Jungho. "How Korea's Rapid Export Expansion Began." Working Paper 8-18, Seoul: KDI School of Policy and Management, September 2008.