[working paper]

Skill-biased Technological Change in Small Open Economies: Accounting for Changing Wage and Employment Structures[*]

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Abstract: Recent decades have seen rising earnings inequality combined with changing employment structure, for which skill-biased technological change (SBTC) has been proposed as a driving force. We reexamine the effects of SBTC in a small innovative open economy context where both factor and output markets are integrated to world markets. We demonstrate that market openness further exacerbates the SBTC effects on both wage inequality and employment chances for unskilled workers, because openness essentially boosts the marginal productivity of skilled workers more and fosters incentives to conduct R&D investment, holding other things constant. Using micro data about a small open economy that experienced rising openness and R&D activities over the sample period of 1998-2008, we obtain evidence that the wages and employment of skilled labor have increased more over time in the high-tech and trade industries that are more likely to be affected by SBTC. Some implications are discussed.

Key Words: skill, technology, employment, small open economy, trade, capital mobility, immigration.
JEL classification: E25; J31; O33.

I. Introduction

The recent decades have witnessed changes in employment structure combined with rising earnings inequality. As for the phenomena, skill-biased technological change (SBTC) has been proposed as a driving force in the literature. This view has been popularly taken in the literature and has received broad empirical support, but to our knowledge, it has not been seriously considered in a small open economy context where (i) final good and input markets are integrated to the world markets and (ii) free trade provides greater chances to both adopt and create SBTC (e.g., Acemoglu, 2003). Perhaps this inattention seems because trade has not been taken as a theoretically and empirically important factor in the U.S. (e.g., Bound and Johnson, 1992). However, this view is slowly changing in the recent literature.[1]

In the context of small open economies, the capital market can be said more open than ever to the world market in recent decades. Part of the labor market can also be said to be linked to the world market because foreign workers, especially the unskilled labor, have access to the labor markets of small open economies for higher wages. Moreover, small open economies with high R&D activities have more opportunities for SBTC shocks, given that trade openness boosts incentives to conduct technology development in line with Acemoglu (2003).[2] In this paper, (i) we demonstrate that the factor market openness combined with trade openness further exacerbates the SBTC effects on wage inequality and fewer employment chances for low-skilled workers. (ii) Then, we show that our theoretical predictions are consistent with empirical evidence from the data of a small-open economy with vigorous R&D activities. Our analysis demonstrates that during the sample period where both openness and R&D activities get intensified over time, the wages and employment of skilled labor have increased relatively more over time in the high-tech and trade industries that are more intensively and frequently affected by SBTC.

Since the 1990s, the literature on the skill premium has been growing, and the trend of skill premium in the U.S. and other developed countries has been well documented. The literature

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[1] The inattention to trade is slowly changing in the recent literature as we see in Autor *et al*. (2013), and Autor *et al*. (2016). They note that the change in the real value of imports from China to the U.S. makes substantial loss to affected workers. In addition, the SBTC hypothesis has been modified to deal with the observation that workers at both ends of the task distribution experience a rising demand while workers at the middle face a falling demand due to automation replacing their routine tasks.

[2] Acemoglu (2003) provides an explanation that increased international trade induces skill-biased technical change. As a result, trade opening can cause a rise in inequality both in the U.S. and the less developed countries, and thanks to the induced SBTC, this can happen without a rise in the relative prices of skill-intensive goods in the U.S., which is the usual intervening mechanism in the standard trade models.

uses the ratio of college graduates' earnings relative to high school graduates' as a proxy for skill premium. In the case of the U.S., starting from 1940, the trend of the earnings ratio (so-called skill premium or college wage premium) exhibited a "W" shape: it decreased in the 1940s, then increased until around 1970, decreased again for a decade, and has increased dramatically since then (see Katz, 1999; Goldin and Katz, 1999; Krusell *et al*., 2000; Acemoglu, 2003). Meanwhile, the relative quantity of skilled labor, measured by the ratio between workers holding college degrees and high school diplomas, has risen over time.

Some popular explanations about the aforementioned trend of the skill premium include (i) investment-specific technological change through capital-skill complementarity[3] (see Krusell *et al*., 2000; henceforth, KORV), (ii) international trade-induced skill-biased technology change (Acemoglu, 2003), and (iii) skill-biased technological change associated with the computer revolution (Autor *et al*., 1998). Among them, KORV (2000) highlight the importance of SBTC in a macroeconomic context. They argue that with the capital-skill complementarity in a neoclassical aggregate production function, a greater investment in capital equipment will complementarily increase the marginal product of skilled labor and hence raise its relative demand. They also quantitatively assess how much this capital-skill complementarity has affected the skill premium and find that changes in observed factor inputs can account for most of the variation in the skill premium.

Meanwhile, compelling microeconomic evidence can be found in Katz and Murphy (1992) and Autor *et al*. (1998). Among others, Katz and Murphy (1992) demonstrate that a standard supply and demand framework can explain the trend of skill premium.[4] In the context of a typical small open economy that substantially depends on foreign capital, Kim (2004) considers international trade as an important element affecting the employment and wage structures of Korea. In his analysis of the Korean labor markets, Kim demonstrates that both demand and supply of labor are crucial. Using simple decomposition methods of Katz and Murphy (1992), he shows suggestive evidence that in the face of a rising supply of skilled workers, even faster increases in

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[3] Compelling evidence of capital-skill complementarity has been found in Griliches (1969) and is well accepted in the labor economics literature.

[4] A smooth secular increase in the relative demand for college graduates combined with the observed fluctuations in the rate of growth of relative supply could potentially explain the movements in the college wage premium from 1963 to 1987. Autor *et al*. (1998) also demonstrate that a steady growth of relative demand of skilled labor started from 1950, but the growth rate of relative supply of skilled labor fluctuated, implying that supply side also matters.

demand for skilled labor, especially the workers closely related to trade, led to a rising skill premium in Korea.

The existing literature has successfully demonstrated the nature of recent earnings inequality and employment issues from the demand side using SBTC, but they have not addressed how SBTC effects in small open economies differ from those in the usual economies with limited openness to the world markets. We reexamine the consequences of SBTC in small open economies with a main focus on the structures of wages and employment. Most importantly, using a simple general equilibrium model, we highlight that the existing findings about effects of a given SBTC amplify in small open economies with factor market openness because factor mobility essentially boosts the marginal product of skilled workers more favorably. Using the micro data about a small open economy (i.e., the Korean labor market) during 1998~2008 where both openness and R&D activities get intensified, we find evidence that the wages and employment of skilled labor have increased more over time in the high-tech and trade industries that are known to be more affected by SBTC.

What separates SBTC in the Korean labor market from that in the other economies lies in the following. (i) The Korean economy relies heavily on international trade, and its factor markets are highly open to the rest of the countries: the capital market has been perfectly open since the 1997 Asian financial crisis, and the labor market is largely open to low-skilled workers from nearby Asian countries. (ii) Aside from trade openness, R&D activities have rapidly grown with a rising trend of the ratio of R&D expenditures to GDP reaching the world highest level. To our knowledge, how these small open economy features interact with the effects of SBTC is an unexplored, interesting research topic. We address how SBTC combined with small open economy features affects the wage and employment structures.

The rest of the paper consists of the following sections. Section II presents our basic model describing markets in a small open economy setting, and shows the stationary general equilibrium in the model economy. Section III calibrates the benchmark model along with counterfactual models to derive useful implications. It explains how we parameterize this model economy and we provide calibration results. In Section IV, we show some empirical evidence supporting our model and calibration exercise. Section V discusses main results and acknowledges limitations of our study, and Section VI makes concluding remarks.

II. The model

1. Structure of the model

Consider an economy populated by agents of measure 1 who are identical except for a dichotomous ability difference: a certain fraction of workers are born with high ability a_h who end up being a skilled worker and others are born with low ability who eventually become an unskilled worker.[5] As in the conventional wage inequality literature, the fractions of two types of (domestic) workers are predetermined with a and $1-a$ without population growth. Given that the focus of our analysis lies in characterizing wage inequality over time in response to innovations at the production side, we abstract from intertemporal savings decision in individual problem and therefore, capital is treated as an exogenous variable throughout the model with mobility across countries.

Consumers

Individuals optimize on their consumption C and hours of labor supply H.

$$U(C_h, H_h; a_h) = f(C_h) - D_h \frac{H_h^{1+1/\eta}}{1+1/\eta}, \tag{1}$$

with $f'(C^h) > 0, f''(C^h) < 0$, and $\eta > 0$

where η is the intertemporal labor supply elasticity; superscript h refers to high-ability individuals; and D_h is the scale parameter for the disutility of work of high-ability individuals. The budget constraint for high-ability individuals is given by:

$$C_h = (1 - \tau_h) w_h H_h + nl_h \tag{2}$$

where *nl* is the non-labor income, τ_h = the tax rate for college graduates/high-ability individuals' income. The aggregation of individual labor supply becomes the employment of skill labor S:

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[5] Since we focus on the drastic labor market changes within a relatively short period of time, we do not address endogenous skill (human capital) investment decisions. Obviously, endogenous skill investment decisions affect the wage and employment structures in a general equilibrium covering a long time horizon. For this issue, refer to He (2006) where the interaction between skill premium and skill investment activities is considered.

$S = \int_0^a H_h dx = aH_h$. From this individual problem, we obtain the two usual first-order conditions:

$$f'(C_h) = v \quad \text{and} \tag{3}$$

$$D_h H_h^{\eta} = -v \cdot w_h . \tag{4}$$

where v is the Lagrangean multiplier. Combining the two FOCs with the budget constraint (2), we can determine consumption and labor supply at a point in time, ignoring savings for the sake of simplicity. Similarly, we can define the comparable problem for a low-ability individual:

$$\max U(C_l, H_l; a_l) = f(C_l) - D_l \frac{H_l^{1+1/\eta}}{1+1/\eta} . \tag{5}$$

$$\text{s.t.} \quad C_l = (1-\tau_l)w_l H_l + nl_l , \tag{6}$$

where superscript l refers to high-ability individuals, τ_l = the tax rate for high-school graduates/low-ability individuals' income, and D_l is the scale parameter for the disutility of work of low-ability individuals with the natural assumption of $D_h \le D_l$. Similarly, the aggregation of individual labor supply becomes the unskilled labor employment: $U = \int_a^1 H_l dx = (1-a)H_l$. For each of individuals with different skill levels, he optimizes consumption and labor supply to maximize utility, given the market wages and non-labor incomes.

Producers

Following the vast literature on labor demand and supply and the resulting wage inequality, we posit the production function with three factors of production, i.e., capital, skilled labor and unskilled labor:

$$Y = AF(K,S,U)$$
$$= A \cdot \left[\mu U^{\theta} + (1-\mu)\left(\lambda (BK)^{\rho} + (1-\lambda)S^{\rho} \right)^{\theta/\rho} \right]^{1/\theta} \tag{7}$$

where $\rho < 1$ and $\theta < 1$ should hold as regularity conditions for profit-maximizing firms; μ and λ are the relative scale parameters for unskilled labor and capital, respectively.

Note that in this type of production function, the elasticity of substitution between capital

and skilled labor is given by $1/(1-\rho)$ and similarly, the elasticity of substitution between unskilled labor and the "composite skilled input" $\left(\lambda(B \cdot K)^{\rho} + (1-\lambda)S^{\rho}\right)^{1/\rho}$ is given by $1/(1-\theta)$. The specific form of this production function is based on the study by Krusell *et al*. (KORV) (2000) where the capital-skill complementarity is reflected by the inequality $\theta > \rho$.[6] The difference between our production function and KORV's (2000) is that we do not distinguish between structure and equipment, so capital K in our model is the usual total capital stock.

Two types of SBTC

　　　　Here, we model the skill-biased technological progress using the variable B first. A permanent increase in B may reflect an investment-specific technological progress.[7] The scale parameter B is defined in contrast to the total factor productivity (A) growth. An increase in B represents the case where capital becomes more efficient in production, and therefore skilled labor becomes a more valuable input, given the high complementarity between capital and skilled labor. Meanwhile, we also consider the impact of an improvement in TFP A. While A takes a form that is neutral to all factors $U, S,$ and K, in the presence of complementarity between capital and skilled labor, such a neutral TFP shock can essentially function as SBTC. We will explore these two types of SBTC in our calibration model to quantitatively assess the effects of SBTC on wages and employment. In response to advancement of SBTC, we will compare the steady-state employment and wage structures.

Prices

Then, the firm owned by the household maximizes its expected discounted profit with respect to the capital stock k as

$$\text{Max}_{\{S,U,K\}} \quad Y - w_h S - w_l U - (r+\delta)K \tag{8}$$

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[6] This is because the inequality $1/(1-\rho) < 1/(1-\theta)$ is empirically supported in the literature.

[7] Our definition of the investment-specific technological progress may not be precisely identical to that in KORV where capital accumulation is fully considered unlike our model. We rather focus on characterizing differences in steady-state equilibrium across different model economies with different sets of policies regarding capital and labor markets.

where r represents the domestic interest rate. Maximizing the discounted profit with respect to factors, K, S, and U yields:

$$r = \lambda(1-\mu)AB^{\rho}G\big(\lambda(BK)^{\rho} + (1-\lambda)S^{\rho}\big)^{\theta/\rho-1}K^{\rho-1} - \delta \tag{9}$$

$$w_h = (1-\lambda)(1-\mu)AG\big(\lambda(BK)^{\rho} + (1-\lambda)S^{\rho}\big)^{\theta/\rho-1}S^{\rho-1} \tag{10}$$

$$w_l = \mu AGU^{\theta-1} \tag{11}$$

where $G = \big[\mu U^{\theta} + (1-\mu)\big(\lambda(BK)^{\rho} + (1-\lambda)S^{\rho}\big)^{\theta/\rho}\big]^{1/\theta-1}$, δ is the depreciation rate for capital. In our small-open economy model, the interest rate is fixed at the world level r^*, such that capital inflow and outflow occur perfectly freely. Therefore the price variables to determine in the benchmark model are the wages of skilled and unskilled workers only.

Equilibrium

The equilibrium of the model is given by the capital and labor market equilibrium. Given that the capital market is open, capital supply is perfectly elastic, implying that the equilibrium capital stock is set such the marginal productivity of capital equals the world interest rate plus the rate of depreciation: $r = r^* = MP_K - \delta$.

The labor market equilibrium is characterized by the condition that the marginal productivity of each type of labor equals the marginal disutility of its labor such that labor demand equals labor supply for each type of labor: $S_t = aH_h$ and $U_t = (1-a)H_l$, where labor supply by low-ability and high-ability individuals is the solution to the individual maximization problem illustrated in (1) through (4). We can therefore determine the set of equilibrium quantity and prices: $\{K, S, U, r, w^h, w^l\}$.

2. Implications of the model

Skill premium

Using the two equations (10) and (11) for wages, we can define a measure of wage

inequality or the skill premium as follows:

$$\frac{w_h}{w_l} = \frac{(1-\lambda)(1-\mu)}{\mu}\left[\lambda\left(\frac{BK}{S}\right)^\rho + (1-\lambda)\right]^{\theta/\rho-1}\left(\frac{U}{S}\right)^{1-\theta}. \tag{12}$$

Log-linearizing the above equation around the steady-state equilibrium, we can derive the rate of change in skill premium, $\widetilde{\left(\frac{w_h}{w_l}\right)}$:

$$\widetilde{\left(\frac{w_h}{w_l}\right)} \cong \frac{\lambda(\theta-\rho)\left(\frac{BK}{S}\right)^\rho}{\left[\lambda\left(\frac{BK}{S}\right)^\rho + (1-\lambda)\right]}\left(\tilde{B}+\tilde{K}-\tilde{S}\right) + (1-\theta)\left(\tilde{U}-\tilde{S}\right)$$

$$\approx \underbrace{\lambda(\theta-\rho)\left(\frac{BK}{S}\right)^\rho\left(\tilde{B}+\tilde{K}-\tilde{S}\right)}_{1st\ term} + \underbrace{(1-\theta)\left(\tilde{U}-\tilde{S}\right)}_{2nd\ term} \tag{13}[8]$$

This equation is essentially identical to KORV (2000) except the investment-specific shock term B, implying that new technology (SBTC) enhances the productivity of capital that is complementary with skilled labor. It says that the growth rate of skill premium is determined by the following elements. (i) The first is the capital-skill complementarity effect, represented by $\lambda(\theta-\rho)\left(\frac{BK}{S}\right)^\rho\left(\tilde{B}+\tilde{K}-\tilde{S}\right)$ with $\theta>\rho$. Note that a greater positive gap $\theta-\rho>0$ means that with a greater complementarity between capital and skilled labor,[9] an occurrence of SBTC ($\tilde{B}$) leads to a greater wage inequality, holding other things constant. (ii) The second is the well-known quantity effect. If the growth rate of the relative supply of unskilled labor is high: $(1-\theta)\left(\tilde{U}-\tilde{S}\right)>0$, then the relative quantity effect exacerbates the wage gap. For instance, an influx of foreign unskilled labor ($\tilde{U}$) would exacerbate the wage gap. Similarly, if capital grows faster than skilled labor as denoted by $\tilde{K}$, the skill premium rises in the presence of capital-skill complementarity $\theta>\rho$. With a partial factor market openness for foreign unskilled labor, we can

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[8] This is based on an approximation that at a low value of ρ the denominator $\left[\lambda\left(\frac{BK}{S}\right)^\rho + (1-\lambda)\right]$ gets closer to unity.
[9] This statement holds when the elasticity of substitution between capital and skilled labor is smaller than the elasticity of substitution between composite skill input and unskilled labor.

therefore expect a lower wage for unskilled labor. (iii) And third, in the context of a small open economy, capital inflow responds more sensitively to a productivity innovation (i.e., an additional $\tilde{K}$ is induced by $\tilde{B}$), because the resulting high marginal product of capital is likely to attract more foreign capital [see the first term in (13)].[10]

Industries adopting advanced modern technologies are naturally subject to innovations arising from B as well as A, so it seems warranted to examine the wage gap in those high-tech industries. Combined with the capital-skill complementarity, a productivity improvement in either A or B essentially functions as a skill-biased technological change, and as a result, the wage gap (or skill premium) grows further – this is because of the *positive* correlation between productivity improvement (in either A or B) and K in a small open economy where the capital market adjusts until the interest rate gets back to the original world rate despite a rising demand for capital. We will study this issue more in detail later using a calibration analysis.

Small open economy implications

One of the salient features of a small open economy is that capital is mobile. We will assess the implied structure of employment and wages that arises from distinctive features of a small open economy. To provide a counterfactual economic circumstance in a comparable, closed economy, we consider the case where capital supply is fixed as opposed to a small open economy where capital is perfectly elastic due to free mobility.

[Closed economy]

$$r = \lambda(1-\mu)AB^{\rho}G\left(\lambda(B\overline{K})^{\rho} + (1-\lambda)S^{\rho}\right)^{\theta/\rho-1}\overline{K}^{\rho-1} - \delta \qquad (9')$$

$$w_h = (1-\lambda)(1-\mu)AG\left(\lambda(B\overline{K})^{\rho} + (1-\lambda)S^{\rho}\right)^{\theta/\rho-1}S^{\rho-1} \qquad (10')$$

$$w_l = \mu AGU^{\theta-1} \qquad (11')$$

where r = the domestic, closed-economy interest rate;

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[10] While the TFP parameter A does not appear in equation (13), quantity variables there are indirectly affected by A, causing changes in the wage gap.

w_i = the net wage rate given to individuals with skill type i;

$$G = \left[\mu U^\theta + (1-\mu)\left(\lambda(B\overline{K})^\rho + (1-\lambda)S^\rho\right)^{\theta/\rho}\right]^{1/\theta-1};$$

other supply-side first-order conditions are not shown for brevity.

In such a counterfactual (closed) economy with fixed $\overline{K}$, we think that SBTC shows the following features compared to the benchmark case: the wage gap narrows and employment of low-skilled workers rises and the overall employment gap goes down. We will examine whether these features really arise in a carefully calibrated model. And also we investigate the magnitudes of the wage and employment gaps in the counterfactual economy.

Next, a more realistic simulation experiment would be that both capital and low-skilled workers can have access to the local markets with perfect mobility. In such a case, we need to set not only the interest rate but the wage rate of the low-skilled workers as fixed at certain low levels – e.g., a developing country's level. The modified set of equations is:

[Economy with mobile capital and mobile unskilled labor]

$$r^* = \lambda(1-\mu)AB^\rho G\left(\lambda(BK)^\rho + (1-\lambda)S^\rho\right)^{\theta/\rho-1}K^{\rho-1} - \delta \tag{9''}$$

$$w_h = (1-\lambda)(1-\mu)AG\left(\lambda(BK)^\rho + (1-\lambda)S^\rho\right)^{\theta/\rho-1}S^{\rho-1} \tag{10''}$$

$$w_l^* = \mu AGU^{\theta-1} \tag{11''}$$

where r^* and w_l^* are fixed at certain low world market levels; other supply side first-order conditions are not shown for brevity.

In this more realistic case, the supply of low-skilled workers comes from not only domestic markets but also foreign labor markets, putting downward pressure on low-skilled workers wages. One would expect that the low wage for low skilled workers leads to low employment of low-skilled workers and the overall earnings gap rises along with the employment gap between two different skill groups. This result partially depends on the substitution between skilled and unskilled labor in production, so the exact impact is an empirical question.

Finally, we will discuss some missing aspect of discussion in our model -- trade. First, since a more open economy has to compete more intensively with the rest of the world, adoption and creation of new (skill-biased) technology will be more active if they afford to conduct R&D activities.[11] The impact of SBTC will therefore be stronger. For this reason, looking at the wage gap in the trade industries seems necessary. Second, the changes in the trade pattern induced by frequent SBTCs of small open economies may drastically affect the wage premium. Korea's trade pattern is changing toward exporting high value-added products. In this case, invoking the Stolper-Samuelson theorem applies,[12] workers in the sectors producing those high value-added trade goods will be paid higher. With these features, it would be safe to say that a large earnings gap arises between skilled and unskilled workers. Overall, trade also exacerbates the wage gap and thus the employment gap, and we will quantitatively assess how much the gaps rise below.

Employment effects of SBTC

In response to SBTC, employment structure also changes. SBTC raises the demand for skilled labor while lowering the demand for unskilled labor. The wage premium changes neutralize the demand-side implications on employment to some extent, but the employment issue cannot be addressed in a closed form manner at this point due to the convoluted general equilibrium nature of the model including labor supply incentives. In what follows, we discuss this topic with focus using a calibration exercise and regression analysis later.

III. Calibration results

1. Calibration of the model

For our calibration, we first determine two essential elasticity parameters in the production function. Following Griliches (1969) and Fernandez-Villaverde (2001), we set the coefficient for

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[11] As Acemoglu (2003) argues, technology is endogenous. If skilled labor is available, technology creation can happen with trade opening.

[12] The Stolper–Samuelson theorem is at the heart of the Heckscher–Ohlin type trade theories. It describes a relation between the relative prices of output goods and relative factor rewards, specifically, real wages and real returns to capital. The theorem states that—under some economic assumptions (constant returns, perfect competition, equality of the number of factors to the number of products)—a rise in the relative price of a good will lead to a rise in the return to that factor which is used most intensively in the production of the good, and conversely, to a fall in the return to the other factor.

substitution between capital and skilled labor $\rho=-0.67$, which amounts to the exact elasticity of substitution between them is 0.6, and the coefficient for substitution between unskilled labor and capital-skilled labor combination $\theta = 0.33$, which amounts to the exact elasticity of substitution between unskilled labor and skilled input is 1.5. Through this formulation, we reflect the well-known empirical regularity in the form of the restriction: $\rho < \theta$. The intertemporal elasticity of labor supply, η, is set at 0.5, following Lee (2001).

The benchmark TFP level A is normalized at unity. We set the depreciation rate of capital $\delta = 0.069$ by following Imrohoroglu *et al.* (1999), where they calculate this parameter from annual US data since 1954. The interest rate r is set equal to 0.05 to describe the recent Korean economy. The population of skilled labor is posited as the same as that of unskilled labor, in accordance with the data: $a = 0.5$. The KLIPS data shows that college graduates and high school graduates are roughly identical in the total labor force as of year 2010.

The tax rate for capital income is set at 0.22, i.e., the level of the corporate income tax rate. The tax rate for skilled labor is set at 0.25 to reflect the average national tax burden combined with social security burden, while that for unskilled labor is set at 0.16. Meanwhile, we assume that the government transfer to unskilled labor, essentially non-labor income, is a set at $nl^l = 0.05$ to account for the labor supply behavior of low-skilled labor relative to skilled labor.

Other parameters are set as follows. To replicate the share of labor income relative to GDP, about 0.6 in the recent Korean economy,[13] we choose scale parameters B (the scale parameter for K), J (the scale parameter for the composite skill input[14]) and λ (the relative share between BK and S in composite skill input) at 0.33, 3, and 0.709. We use the King-Plosser-Rebelo type utility function that is popularly used in macro studies: $U(C_i, H_i; a_i) = \ln(C_i) - D_i \dfrac{H_i^{1+1/\eta}}{1+1/\eta}$. Scale parameters for the disutility of work, D_i with $i=h, l$, are chosen to match the average employment of skilled and unskilled workers in recent years. Table 1 reports the parameter values adopted in calibration.

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[13] This is often assumed in equivalent to the labor income to GDP ratio

[14] The composite skill input enters the production function in the form of $J(\lambda(BK)^\rho + (1-\lambda)S^\rho)^{1/\rho}$ with the scale parameter J set at 3.

2. Results at the base case

      Table 2 describes the base case equilibrium for each of model scenarios. Scenario 1 describes the typical small open economy discussed earlier. Scenario 2 refers to the closed economy. Scenario 3 is the economy that allows perfect mobility for unskilled labor in the small open economy of Scenario 1.

      Under the base case equilibrium of Scenario 1, the wage gap between skilled and unskilled labor κ is found to be 1.6, while the capital share of GDP α is 0.39. These values match the Korean economy reasonably well. The employment of skilled and unskilled labor in the labor force is calibrated in our model using their respective labor supply. Given that we use the King-Plosser-Rebelo type utility function as in most macro studies, labor supply and employment in a competitive market would not change with respect to changes in work incentives over time. However, we introduced non-labor income nl^I for low-income individuals, i.e., the government transfers to low-skilled labor, and therefore, low-skilled workers' labor supply and employment can change in response to market incentives. Overall, the wage gap between skilled and unskilled arises largely from the difference in marginal productivity, the wage rate, and partially from a difference in labor supply.

      In Scenario 2, we calibrate an economy with fixed capital supply (i.e., closed economy). Unless other shocks arrive, this economy is identical to the benchmark, perfect capital mobility economy. In Scenario 3, we further allow labor mobility of unskilled labor from the international labor market. The wage for the unskilled labor is exogenously set at the international labor market at an arbitrarily low level of $w_2 = 0.6$. In this case, the reduction in labor cost by the inflow of foreign unskilled labor leads to a better production environment for firms, and therefore the demand for unskilled labor rises. In the steady state equilibrium, more capital input is used in production. However, domestic unskilled labor faces a deteriorating work environment and therefore labor supply and hence employment of domestic workers goes down, while the increase in unskilled workers from abroad more than compensates the fall in domestic supply of unskilled workers, and the overall employment goes up. A surprising finding here is that the wage gap κ rises substantially to 2.4. Overall, the opening of the labor market to the unskilled labor is found to be quite negative to unskilled labor, but total production expands. In the current calculation, we do not consider the shortage of international unskilled labor, and they can flow into Korea perfectly

elastically at a fixed wage. In reality, most countries adopt a certain quota for foreign workers, in which case a general equilibrium increase in demand for unskilled labor leads to a higher wage. The negative effect on domestic unskilled workers may dampen in this case.

3. The role of SBTC: effects of a TFP innovation and an investment-specific innovation

TFP shocks

       In this subsection, we conduct a set of calibration exercises using the two types of SBTC: a TFP innovation A and an investment-specific innovation B (see Tables 3, 4, 5, and 6). First, in comparison between Scenarios 1 and 2 (see Table 3), we see that a TFP innovation has favorable effects on skilled labor under both scenarios, but this tendency stands out more clearly in the typical small open economy setting, compared to the closed economy setting. Greater marginal product of capital due to a TFP innovation gives rise to a large capital inflow, which further raises the demand for skilled labor in the presence of a complementary between capital and skilled labor. This exercise highlights the importance of openness of the capital market, which amplifies the gaps.

       Second, in comparison between Scenarios 1 and 3 (see Table 4), the wage gap becomes highest in the small open economy with mobile capital and labor. This is because the effect of a greater supply of low skilled labor is added to the capital inflow effect discussed earlier. This exercise highlights the importance of openness of the labor market for unskilled labor, which also amplifies the gaps. Overall, the results imply that given the structure of our production function, a general TFP change can essentially function as SBTC raising the demand for skilled labor.

An investment-specific innovation

       When an investment specific improvement occurs, it raises the marginal product of capital instantaneously due to an increase in B. The subsequent economic responses are basically identical to those reported in the analysis of a TFP innovation (see Table 5). First, in comparison between Scenarios 1 and 2 in Table 3, the same increase in B under Scenario 1 leads to a greater inequality in wages. Employment of unskilled labor rises only slightly, and overall employment remains roughly the same. However, capital mobility is limited in Scenario 2, and thus both wage gap and

employment gap go down.[15]

Second, in comparison between Scenarios 1 and 3 (see Table 6), the same increase in *B* in Scenario 3 leads to a greater inequality in both wages and employment (see the values for κ and *u*). With respect to an increase in *B* (SBTC), employment of unskilled labor rises slightly in Scenario 1 but in Scenario 3 employment of domestic unskilled labor (numbers in parentheses) rather goes down due to low work incentives. The wage gap grows more rapidly in the face of SBTC.

IV. Some evidence from the KLIPS data

1. Data and sample

We use the KLIPS (Korea Labor Institute Panel Study) database for our empirical analysis. It follows up about 5,000 households from year 1998 to year 2008. For our purpose of study, we need information about dependent variables, wages and employment at particular industries, along with control variables, such as human capital investment of an individual, industry at which an individual is employed, the exposure to international trade of their jobs, and other individual and demographic characteristics. We limit our samples to working individuals with proper information about individual and firm characteristics.

The sample period covers the period after the 1997 financial crisis, which is the year that the financial market is liberalized to the rest of the world and the foreign capital begins to flow into Korea since then in accordance with the recovery from the crisis. Further, as the sample period goes on, the world financial market gets more integrated and the inflow of low-skilled workers rises, which reflects greater factor mobility over time. Therefore, the data covering this sample period provides a very useful chance to identify the effects of SBTC in a small-open economy. In particular, we test whether some industries that are more likely to be affected by SBTC have really paid greater wages to skilled workers and also have employed skilled workers more over time, as our theoretical analysis implies.

For identification of high tech industries, we have consulted the OECD directorate for science, technology and industry information prepared by Economic Analysis and Statistics

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[15] Since employment responds very little, the employment gap reduction is marginal.

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Division, where high-technology industries include those related to aircraft and spacecraft; pharmaceuticals; office, accounting and computing machinery; radio, TV and communications equipment; medical, precision and optical instruments.[16] Similarly, the trade-related industries are determined based on the information about the share of export plus import values in the total industry output, based on the data from the Bank of Korea at the three digit industry level. We treat the industries with the trade volume share above 50% as the trade industry using the trade dummy variable. Applying the sample requirements discussed above, we obtain a sample of about 10,000.

2. Empirical specifications

First, following the identification ideas mentioned above, we posit the wage equation as follows:

$$\log w_i = \alpha_0 + \alpha_1 s_i + \alpha_2 DSBTC\_IND_i + \alpha_3 s_i \cdot DSBTC\_IND_i + DYear_t \cdot \alpha_4$$
$$+ DSBTC\_IND_i \cdot DYear_t \cdot \alpha_5 + \alpha_6 Z_i + \varepsilon_i \qquad (14)$$

where $w_i =$ hourly (real) wage rate;

$s_i =$ skill level proxied by years of schooling;

$DSBTC\_IND_i =$ dummy variable for the industries that are affected by SBTC;

$s_i \cdot DSBTC\_IND_i =$ interaction between skill level and the dummy for the industries that are affected by SBTC;

$DYear_t =$ vector of year dummy variables for the sample years 1998-2008;[17]

$DSBTC\_IND_i \cdot DYear_t =$ interaction between the dummy for the industries that are affected by SBTC and year dummies;

$Z_i =$ vector of control variables including dummy variables for gender, part time work, white collar worker, large firm employment, residence.

In this empirical specification, we test whether or not skilled workers are paid more when they are in the industries that are more likely to be affected by SBTC, and whether or not the SBTC industries that will be shown later to employ skilled workers more have actually paid greater wages over time during the sample period because the factor market has been more increasingly open to

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[16] Other industries are classified as medium-high-technology industries, medium-low-technology industries, and low-technology industries.
[17] Specifically, we use Dyear01=1 for the year 1998, and 0 for other years; similarly Dyear11=1 for the year 2008, the last sample year.

the world. In our empirical analysis, we will use the dummy variable $DSBTC\_IND_i$ to proxy high-tech or trade industries which are conventionally viewed as the sector where SBTC has played an important role. The coefficient α_1 captures whether skilled workers receive higher earnings; α_3 measures whether labor with the same skill faces higher wages in the industries affected by SBTC; and α_5 captures whether skilled workers receive increasingly higher earnings in the industries affected by SBTC over time. For instance, more market-oriented government policy changes may imply that the full effects of SBTC arise with some time lag.[18]

Second, the equation for employment at high-tech or trade industries, $Demp\_SBTC_i$, is posited as follows:

$$Demp\_SBTC_i = \beta_0 + \beta_1 s_i + DYear_t \cdot \beta_2 + s_i \cdot DYear_t \cdot \beta_3 + \beta_4 Z_i + \varepsilon_i \qquad (15)$$

where $Demp\_SBTC_i$ is the dummy variable indicating whether employed in the SBTC industries. While highly simplistic, the empirical specification in (15) can test whether or not the labor demand for skilled workers is high, and whether or not the labor demand for skilled workers gets higher over time. The coefficient β_1 captures whether skilled workers face higher chances of employment at high-tech or trade industries; β_2 captures whether there is any time trend for employment in the industries affected by SBTC; and β_3 captures whether there is any time trend for the employment of skilled workers in the industries affected by SBTC.

Note that in order to test the SBTC effects, we need to look at both wages and employment of skilled labor at the industries affected by SBTC. Therefore, we will examine coefficients of the two empirical specifications at the same time.

The actual variables used in estimation are defined as follows:

Definitions of the variables used

dhtchin2= high-tech industry dummy;

dtrdin2=trade industry dummy;

schlyr = years of schooling;

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[18] Before the 1997 financial crisis, wages and employment at the labor market were heavily influenced by government interventions, but those interventions have weakened over time since then. In that case, the effects of SBTC may have arisen in the data over time.

poexpyr = potential experience;

poexpyr2= potential experience squared;

dmale= male dummy;

djtprm2=regular worker dummy;

dprwkr=production worker dummy;

dlgent=large enterprise dummy;

darea=Seoul city dummy;

dear01-dyear11=year dummy variables for 1998 to 2008.

3. Empirical Results

Wage effects

We look at how SBTC affects wages and employment using the KLIPS database. Given that SBTC can be interpreted as changing production process that accompanies a higher demand for skilled labor, we examine the implications of SBTC: whether wages and employment have risen in favor of skilled labor relative to unskilled labor in the industries that are more likely to be affected by SBTC.

More directly, we can select the industries that are more closely associated with SBTC and examine whether these industries exhibit the properties of higher wages and employment in accordance with the theory. For instance, high-techs, such as information technology, are the recently developed technology, such that they are more likely to reflect SBTC. In addition, firms that are more closely related to international trade may have to compete with firms abroad which are known to experience SBTC also[19] – in this context, firms in the industries that are more widely exposed to international trade are more likely to adopt technologies with the features of SBTC. We will examine whether high-tech firms or trade firms have paid skilled workers more and this tendency has strengthened over time with a rising demand for skilled labor. This can be a more direct attempt to check how wages and employment respond to the advancement of SBTC.

Table 9 presents that skilled labor receives higher wages, as already well documented in the returns to education literature. High-tech industries also pay higher wages as skill premium

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[19] The SBTC hypothesis has been proven to be a substantial element in the wage and employment pattern of developed countries.

that is uncontrolled for by the education level. What is not obvious is that the same skills measured in terms of years of education are paid greater in high tech industries, because high tech industries adopt recently-developed technologies that are more influenced by SBTC (see the estimated coefficient of *dht2_scyr* column 2).[20] This effect is found to be statistically significant at any conventional level. Among the seemingly identical skilled workers, high tech firms and/or industries demand more the skills that may not be observable to econometricians, and this feature may have been captured in regression. What is clear is that if SBTC is an important factor, individuals working in a firm that is heavily influenced by SBTC, will face a greater wage. More important, column 3 shows that the wage growth at high tech firms gets higher over time (see the time trend coefficients for *dy*02_*dht2* through *dy*11_*dht2*). The time trend estimation shows about a 12% increase in wages over 10 years, with a fairly high statistical significance (see the F statistic). This pattern still arises in estimates even after controlling for the interaction term for skill and high tech industry, *dht*2_*scyr* with a bit lower statistical significance. Of course, the supply of high-skilled workers may have risen during the sample period, but our empirical evidence highlights that demand-side forces dominate the effect arising from supply-side increases. Given the industrial shift from traditional to high-tech industries in recent decades combined with a greater employment of skilled labor in the high-tech sector – an empirical fact to be discussed later, the wage gap between skilled and unskilled labor can be said to rise over time due to SBTC.

In Table 10, we conduct estimation of wage effects of trade. The trade sector has been expanding over time, focusing on IT products, cars, ship building and other high value-added products – these industries are particularly based on recent technologies. These products are largely produced by some innovative developed countries. According to the Heckscher-Ohlin model, workers in these industries are likely to receive the factor price that is close to the level of developed countries. The estimated coefficient for *dtr*2_*scyr* is 0.014 with a high statistical significance in column 2. We also examine whether these trade industry employees have experienced a rapid wage increase due to an expansion of trade volume over time. In fact, we do see some mildly increasing trend for the wages of trade-related jobs (see the coefficients for *dy*02_*dtrd2* through *dy*11_*dtrd2*). Although the estimated time trend is not statistically very

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[20] Of course, industry movers may compound the true SBTC effects because those movers are likely to be more able. However, given that industry changes are not common due to the loss of industry-specific human capital, we do not examine the industry mover effects with focus in this paper.

significant, the trade sector seems to have paid greater wages over time. Given the rising international trade over the sample period combined with a greater employment of skilled labor in the trade sector – an empirical fact to be discussed later, the wage gap between skilled and unskilled labor can be said to rise over time.

In Table 11, we allow for both high tech industry and trade industry to interact with the year dummy. This is to examine which one of the two determines the time trend more directly. As columns 3 and 4 show, the interaction of high tech dummy with year dummy variables has a more salient increasing time trend compared to that of trade with the time dummy. We interpret that although both factors lead to greater wages for skilled labor, skill demand by high tech industries has more explanatory power than trade in accounting for the rising wage gap.

Meanwhile, the estimated coefficients of other variables, such as gender dummy, regular worker dummy, production worker dummy, residence dummy, exhibit reasonable magnitudes that are reported in other studies. For brevity, we skip discussion of these issues.

SBTC and Employment

Now, we discuss the employment effects of skills. A higher skill level in terms of years of education raises the probability of employment in high-tech and trade industries – more than two percentage points per a year of education, as seen from all columns of Table 12 (see the estimated coefficient of the *schlyr* variable). In the table, columns 1 and 2 are based on the use of employment at high-tech industries as a dependent variable and columns 3 and 4 are based on the use of employment at trade industries as another dependent variable. In all regressions, using the cubic terms of potential experience (*poexpyr*), we have fully controlled for life-cycle effects that arise naturally from aging of sampled individuals over time, along with other typical demographic effects.

In column 1, we see that skilled workers have faced a greater chance of employment in high tech industries over the sample period as the estimated coefficient of *schlyr* shows. Moreover, the estimated coefficients of *dy*02-11 tend to get larger over time. This increasing trend of employment at high-tech industries reflects expansion of high-tech industries with a very high statistical significance (see the *F*-statistic). Employment shift from traditional to high-tech and trade industries are strongly supported by the data.

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However, employment of skilled labor has been favored in these industries over the sample period but such bias seems to stay constant over the sample period as seen from the estimated coefficients of *scyr_dy*02-11 in column 2. That is, skilled workers are demanded more in high tech industries, but their employment relative to unskilled workers has remained constantly high as seen in column 2. In column 4 based on the use of employment at trade industries as another dependent variable, we see slightly different evidence: employment of skilled labor has been favored more in trade industries, as the coefficients of *scyr_dy*02-11 in column 4 exhibit a mildly rising time trend with a little statistical significance.

Overall, it seems safe to say that SBTC favors skilled workers, so their wages grow rapidly over time, and employment in the industries that are affected by SBTC has expanded over time, giving greater employment chances to skilled labor. The estimated employment patterns seem largely consistent with our calibration results. Given that both wages and employment in the industries that have been affected by SBTC have risen in favor of skilled labor, we can say that SBTC has led to the increase in demand for skilled labor more disproportionately.

Using firm level data can more clearly show how individual firms have changed their wages and employment patterns at the firm level, which leaves a further avenue to this line of research. Linking R&D investment with labor demand at the firm level seems also interesting research.

V. Summary and conclusions

The recent decades have witnessed changing employment structure combined with rising earnings inequality around the world. Skill-biased technological change (SBTC) has been proposed as a crucial factor in the literature, while it is uncertain whether this hypothesis holds regardless of the openness of an economy and the stages of economic development. We examine the effects of SBTC in a small, innovative open economy where openness and R&D activities are high.

With this motivation in mind, we first construct a simple general equilibrium model of a small open economy with mobile capital, and then generalize the simple model to accommodate the features such as partial labor market openness. To understand the wage and employment structure under SBTC, we have set up a small open economy model with heterogeneous skills at

the individual level. Using our calibrated model, we have examined the roles of (i) capital mobility and (ii) mobility of foreign unskilled workers. We also derived implications drawn from the change in trade pattern toward exporting high value-added goods, invoking the Stolper-Samuelson theorem within the framework of our model. We provided some evidence that intrinsically, the small open economy nature leads to a rise in earnings inequality and the resulting employment gap between skilled and unskilled workers. An open economy with high R&D investment experience more frequent SBTC, amplifying the wage and employment gaps across skill groups. Opening the market for unskilled workers is found to worsen low-skilled workers' wellbeing and employment.

Our natural research agenda is to examine why the skill premium starts to decline in the later period, 2009~2019. We believe that SBTC continues to affect the economy, but the growing inequality has already become a grave political issue. Social pressure builds up against firms and industries benefiting from SBTC, which would lead to proliferation of regulations and taxes including more union activities in profitable firms. In response to these policy changes, firms may more actively engage in outsourcing and conducting FDI abroad. This is essentially equivalent to exporting SBTC effects to foreign countries, leaving domestic labor markets less affected by SBTC with generally low labor demand causing shortages in decent jobs.

In addition, it seems important to design fiscal and labor policies that deal with the problems arising from SBTC. The nature of inequality is so structural that it would be hard to reduce inequality through direct market interventions. For instance, raising progressivity of labor income taxes seems inevitable from the equity perspective. Taxing capital income may also be warranted because modern innovations generate profits from uses of capital and skilled labor more than ever, although a precise optimal taxation analysis may have different solutions. Uses of increased tax revenues seem important because the usual transfers may weaken labor supply incentives of unskilled labor who experiences falling labor demand. We may want to rethink EITC and training subsidies in the era of rising gaps.

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Table 1. The Base Case Parameters

Parameter	Definition	Value
Parameters for Technology		
$(1-\rho)^{-1}$	Elasticity of Substitution between Capital and Skilled Labor	0.60
$(1-\theta)^{-1}$	Elasticity of Substitution between Composite Skilled Input and Unskilled Labor	1.50
η	Intertemporal Labor Supply Elasticity	0.50
δ	Capital Depreciation Rate	0.069
r	Marginal Return to Capital	0.05
A	Aggregate Production Efficiency (TFP)	1.00
B	Efficiency Parameter for Capital	0.33
J	Efficiency Parameter for Skilled Input	3.00
λ	Relative Share of Capital to Skilled Labor in Production	0.709
μ	Share of Unskilled Labor in Production	0.355
Preference Parameters		
D_h	Disutility of Skilled Labor Supply	0.50
D_l	Disutility of Unskilled Labor Supply	0.50
nl_h	Non-labor Income for Skilled Workers	0.0
nl_l	Non-labor Income for Unskilled Workers	0.05
Policy Parameters		
τ_r	Capital Income Tax Rate	0.22
τ_h	Labor Income Tax Rate for Skilled Workers	0.25
τ_l	Labor Income Tax Rate for Unskilled Workers	0.16

Notes: (i) TFP is normalized at unity. (ii) Different labor supply arises from different non-labor income.

Table 2. The benchmark model: equilibrium under various scenarios

Variables	[1] Scenario 1: perfect capital mobility	[2] Scenario 2: fixed capital	[3] Scenario 3: perfect labor mobility for unskilled labor
capital (K)	14.530	14.530	15.926
skilled labor (S)	1.260	1.260	1.260
unskilled labor (U)	1.239	1.239	2.104
domestic unskilled labor (U_d)	--	--	1.233
foreign unskilled labor (U_f)	--	--	0.871
total labor ($L \equiv S + U$)	2.499	2.499	3.364
capital intensity ($k \equiv K / L$)	5.815	5.815	4.734
skilled vs. unskilled labor in ratio ($u \equiv S / U$)	1.018	1.018	0.599
interest rate (r)	0.05	0.05	0.05
wage of the skilled labor (w_1)	1.205	1.205	1.383
wage of the unskilled labor (w_2)	0.768	0.768	0.60
the output share of capital $\alpha \equiv MPK \times K / Y$	0.386	0.386	0.360
the ratio of capital to labor income $\gamma \equiv rK /(w_1 S + w_2 U)$	0.294	0.294	0.265
the ratio of skilled to unskilled labor income $\kappa \equiv w_1 S /(w_2 U)$	1.596	1.596	2.355

Footnotes: 1. Scenario 1: the benchmark model = small open economy with perfect capital mobility; Scenario 2: the closed economy with constant capital level; Scenario 3: the benchmark model + perfect labor mobility for unskilled labor;

2. In Scenario 1, the interest rate is set at r=0.05; In Scenario 3, the wage for the unskilled labor is exogenously set at w_2=0.60.

Table 3. The effects of changes in A : Scenarios 1 vs. 2

Variables	Scenario 1			Scenario 2		
	$A = 1$ Base Case	$A = 1.5$	$A = 2$	$A = 1$ Base Case	$A = 1.5$	$A = 2$
capital (K)	14.530	22.148	29.147	14.530	14.530	14.530
skilled labor (S)	1.260	1.260	1.260	1.260	1.260	1.260
unskilled labor (U)	1.239	1.247	1.251	1.239	1.246	1.249
total labor ($L \equiv S + U$)	2.499	2.507	2.511	2.499	2.506	2.510
capital intensity ($k \equiv K / L$)	5.815	8.835	11.610	5.815	5.799	5.791
skilled vs. unskilled labor in ratio ($u \equiv S / U$)	1.018	1.010	1.007	1.018	1.012	1.009
interest rate (r)	0.05	0.05	0.05	0.05	0.103	0.157
wage of the skilled labor (w_1)	1.205	2.437	3.855	1.205	1.781	2.376

wage of the unskilled labor (w_2)	0.768	1.271	1.795	0.768	1.149	1.529
the output share of capital $\alpha \equiv MPK \times K / Y$	0.386	0.337	0.304	0.386	0.386	0.386
the ratio of capital to labor income $\gamma \equiv rK /(w_1 S + w_2 U)$	0.294	0.238	0.205	0.294	0.409	0.465
the ratio of skilled to unskilled labor income $\kappa \equiv w_1 S /(w_2 U)$	1.596	1.937	2.163	1.596	1.568	1.567
$\Delta K / K \times 100$	--	52.43	100.60	--	0.00	0.00
$\Delta L / L \times 100$	--	0.32	0.48	--	0.28	0.44
$\Delta u / u \times 100$	--	-0.79	-1.08	--	-0.59	-0.88
$\Delta w_2 / w_2 \times 100$	--	65.49	133.72	--	49.61	99.09
$\Delta \gamma / \gamma \times 100$	--	-19.05	-30.27	--	39.12	58.16
$\Delta \kappa / \kappa \times 100$	--	21.37	35.53	--	-1.75	-1.82

Table 4. The effects of changes in A : Scenarios 1 vs. 3

Variables	Scenario 1			Scenario 3		
	$A = 1$ Base Case	$A = 1.5$	$A = 2$	$A = 1$ Base Case	$A = 1.5$	$A = 2$
capital (K)	14.530	22.148	29.147	15.926	28.953	43.232
skilled labor (S)	1.260	1.260	1.260	1.260	1.260	1.260
unskilled labor (U)	1.239	1.247	1.251	2.104 (1.233)	7.598 (1.233)	13.928 (1.233)
total labor ($L \equiv S + U$)	2.499	2.507	2.511	3.364	6.338	15.188
capital intensity ($k \equiv K / L$)	5.815	8.835	11.610	4.734	3.810	2.847
skilled vs. unskilled labor in ratio ($u \equiv S / U$)	1.018	1.010	1.007	0.599	0.199	0.090
interest rate (r)	0.05	0.05	0.05	0.05	0.05	0.05
wage of the skilled labor (w_1)	1.205	2.437	3.855	1.383	3.752	7.328
wage of the unskilled labor (w_2)	0.768	1.271	1.795	0.60	0.60	0.60
the output share of capital $\alpha \equiv MPK \times K / Y$	0.386	0.337	0.304	0.360	0.265	0.208
the ratio of capital to labor income $\gamma \equiv rK /(w_1 S + w_2 U)$	0.294	0.238	0.205	0.265	0.170	0.123
the ratio of skilled to unskilled labor income	1.596	1.937	2.163	2.355	6.391	12.483

$\kappa \equiv w_1 S /(w_2 U)$						
$\Delta K / K \times 100$	--	52.43	100.60	--	81.80	171.46
$\Delta L / L \times 100$	--	0.32	0.48	--	88.41	351.49
$\Delta u / u \times 100$	--	-0.79	-1.08	--	-66.78	-84.97
$\Delta w_2 / w_2 \times 100$	--	65.49	133.72	--	0.00	0.00
$\Delta \gamma / \gamma \times 100$	--	-19.05	-30.27	--	-35.85	-53.58
$\Delta \kappa / \kappa \times 100$	--	21.37	35.53	--	171.38	430.06

Table 5. The effects of changes in B : Scenarios 1 vs. 2

Variables	Scenario 1			Scenario 2		
	$B = 0.3$ Base Case	$B = 0.5$	$B = 0.8$	$B = 0.3$ Base Case	$B = 0.5$	$B = 0.8$
capital (K)	14.530	14.713	14.145	14.530	14.530	14.530
skilled labor (S)	1.260	1.260	1.260	1.260	1.260	1.260

unskilled labor (U)	1.239	1.241	1.243	1.239	1.241	1.243
total labor ($L \equiv S + U$)	2.499	2.501	2.502	2.499	2.501	2.503
capital intensity ($k \equiv K / L$)	5.815	5.883	5.653	5.815	5.810	5.806
skilled vs. unskilled labor in ratio ($u \equiv S / U$)	1.018	1.015	1.014	1.018	1.015	1.014
interest rate (r)	0.05	0.05	0.05	0.05	0.0514	0.047
wage of the skilled labor (w_1)	1.205	1.733	2.224	1.205	1.692	2.220
wage of the unskilled labor (w_2)	0.768	0.869	0.947	0.768	0.867	0.951
the output share of capital $\alpha \equiv MPK \times K / Y$	0.386	0.325	0.274	0.386	0.326	0.271
the ratio of capital to labor income $\gamma \equiv rK /(w_1 S + w_2 U)$	0.294	0.226	0.178	0.294	0.233	0.171
the ratio of skilled to unskilled labor income $\kappa \equiv w_1 S /(w_2 U)$	1.596	2.024	2.381	1.596	1.982	2.365
$\Delta K / K \times 100$	--	1.26	-2.65	--	0.00	0.00
$\Delta L / L \times 100$	--	0.08	0.12	--	0.08	0.16
$\Delta u / u \times 100$	--	-0.29	-0.39	--	-0.29	-0.39
$\Delta w_2 / w_2 \times 100$	--	13.15	23.31	--	12.89	23.83
$\Delta \gamma / \gamma \times 100$	--	-23.13	-39.46	--	-20.75	-41.84

$\Delta \kappa / \kappa \times 100$	--	26.82	49.19	--	24.19	48.18

Table 6. The effects of changes in B : Scenarios 1 vs. 3

Variables	Scenario 1			Scenario 3		
	$B = 0.3$ Base Case	$B = 0.5$	$B = 0.8$	$B = 0.3$ Base Case	$B = 0.5$	$B = 0.8$
capital (K)	14.530	14.713	14.145	15.926	16.472	15.976
skilled labor (S)	1.260	1.260	1.260	1.260	1.260	1.260
unskilled labor (U)	1.239	1.241	1.243	2.104 (1.233)	2.671 (1.233)	3.129 (1.233)
total labor ($L \equiv S + U$)	2.499	2.501	2.502	3.364	3.931	4.388
capital intensity ($k \equiv K / L$)	5.815	5.883	5.653	4.734	4.190	3.640
skilled vs. unskilled labor in ratio ($u \equiv S / U$)	1.018	1.015	1.014	0.599	0.472	0.403
interest rate (r)	0.05	0.05	0.05	0.05	0.05	0.05
wage of the skilled labor (w_1)	1.205	1.733	2.224	1.383	2.060	2.682

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wage of the unskilled labor (w_2)	0.768	0.869	0.947	0.60	0.60	0.60
the output share of capital $\alpha \equiv MPK \times K / Y$	0.386	0.325	0.274	0.360	0.293	0.243
the ratio of capital to labor income $\gamma \equiv rK /(w_1 S + w_2 U)$	0.294	0.226	0.178	0.265	0.196	0.152
the ratio of skilled to unskilled labor income $\kappa \equiv w_1 S /(w_2 U)$	1.596	2.024	2.381	2.355	3.509	4.568
$\Delta K / K \times 100$	--	1.26	-2.65	--	3.43	0.31
$\Delta L / L \times 100$	--	0.08	0.12	--	16.85	30.44
$\Delta u / u \times 100$	--	-0.29	-0.39	--	-21.20	-32.72
$\Delta w_2 / w_2 \times 100$	--	13.15	23.31	--	0.00	0.00
$\Delta \gamma / \gamma \times 100$	--	-23.13	-39.46	--	-26.04	-42.64
$\Delta \kappa / \kappa \times 100$	--	26.82	49.19	--	49.00	93.97

Footnotes: See the notes in earlier tables for notations.

Table 9. Wage effects of technological change over time

VARIABLES	(1) lnw	(2) lnw	(3) lnw	(4) lnw
dhtchin2	0.0311***	-0.101***	-0.0392	-0.156***
	(0.00907)	(0.0356)	(0.0349)	(0.0488)
schlyr	0.0412***	0.0374***	0.0415***	0.0380***
	(0.00214)	(0.00236)	(0.00214)	(0.00237)
dht2_scyr		0.0110***		0.00989***
		(0.00286)		(0.00288)
dy02_dht2			0.00902	0.0105
			(0.0442)	(0.0442)
dy03_dht2			0.0230	0.0257
			(0.0496)	(0.0495)
dy04_dht2			0.0570	0.0594
			(0.0446)	(0.0446)
dy05_dht2			0.0600	0.0614
			(0.0445)	(0.0445)
dy06_dht2			0.0615	0.0607
			(0.0446)	(0.0445)
dy07_dht2			0.0761*	0.0734*
			(0.0444)	(0.0444)
dy08_dht2			0.112**	0.107**
			(0.0442)	(0.0442)
dy09_dht2			0.0920**	0.0866**
			(0.0438)	(0.0438)
dy10_dht2			0.112**	0.106**
			(0.0439)	(0.0439)
dy11_dht2			0.122***	0.116***
			(0.0442)	(0.0442)
poexpyr	0.0294***	0.0297***	0.0295***	0.0298***
	(0.00122)	(0.00122)	(0.00122)	(0.00123)
poexpyr2	-0.000442***	-0.000448***	-0.000442***	-0.000448***
	(2.51e-05)	(2.51e-05)	(2.51e-05)	(2.51e-05)
dmale	0.429***	0.430***	0.430***	0.430***
	(0.00986)	(0.00985)	(0.00986)	(0.00985)
djtprm2	0.248***	0.249***	0.248***	0.249***
	(0.0128)	(0.0128)	(0.0128)	(0.0128)
dprwkr	-0.221***	-0.219***	-0.222***	-0.220***
	(0.0105)	(0.0105)	(0.0105)	(0.0105)
dlgent	0.335***	0.334***	0.335***	0.334***
	(0.00993)	(0.00993)	(0.00993)	(0.00993)
darea	0.0986***	0.0989***	0.0997***	0.0999***
	(0.0115)	(0.0115)	(0.0115)	(0.0115)
dyear02	-0.0687***	-0.0692***	-0.0682**	-0.0694***
	(0.0213)	(0.0213)	(0.0267)	(0.0267)
dyear03	-0.00734	-0.00740	-0.0119	-0.0132
	(0.0241)	(0.0240)	(0.0305)	(0.0305)
dyear04	0.0323	0.0324	0.0137	0.0127
	(0.0216)	(0.0215)	(0.0271)	(0.0271)
dyear05	0.105***	0.105***	0.0851***	0.0842***
	(0.0215)	(0.0215)	(0.0272)	(0.0272)

dyear06	0.183***	0.183***	0.163***	0.163***
	(0.0216)	(0.0216)	(0.0276)	(0.0276)
dyear07	0.268***	0.268***	0.241***	0.242***
	(0.0216)	(0.0216)	(0.0281)	(0.0281)
dyear08	0.363***	0.362***	0.318***	0.319***
	(0.0216)	(0.0216)	(0.0280)	(0.0280)
dyear09	0.441***	0.441***	0.406***	0.408***
	(0.0214)	(0.0214)	(0.0280)	(0.0280)
dyear10	0.480***	0.480***	0.434***	0.437***
	(0.0214)	(0.0214)	(0.0281)	(0.0281)
dyear11	0.539***	0.539***	0.488***	0.490***
	(0.0217)	(0.0217)	(0.0284)	(0.0284)
Constant	-2.099***	-2.060***	-2.080***	-2.045***
	(0.0370)	(0.0384)	(0.0387)	(0.0400)
Observations	10,250	10,250	10,250	10,250
R-squared	0.549	0.550	0.550	0.550
Test of time trend			1.78	0.06
F-statistic			(0.067)	(0.811)

Standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Dyear01 (or Dy01) =1 for the year 1998;

Dyear02 (or Dy02) =1 for the year 1999;

Dyear11 (or Dy11) =1 for the year 2008.

Table 10. Wage effects of trade over time

VARIABLES	(1) lnw	(2) lnw	(3) lnw	(4) lnw
dtrdin2	0.0149*	-0.148***	-0.0442	-0.197***
	(0.00883)	(0.0341)	(0.0351)	(0.0474)
schlyr	0.0409***	0.0348***	0.0409***	0.0349***
	(0.00219)	(0.00251)	(0.00219)	(0.00252)
dtr2_scyr		0.0138***		0.0134***
		(0.00278)		(0.00281)
dy02_dtrd2			0.0333	0.0334
			(0.0446)	(0.0445)
dy03_dtrd2			0.0712	0.0715
			(0.0500)	(0.0500)
dy04_dtrd2			0.0606	0.0608
			(0.0451)	(0.0450)
dy05_dtrd2			0.0280	0.0274
			(0.0450)	(0.0450)
dy06_dtrd2			0.0869*	0.0819*
			(0.0451)	(0.0451)
dy07_dtrd2			0.0522	0.0437
			(0.0450)	(0.0450)
dy08_dtrd2			0.101**	0.0911**
			(0.0448)	(0.0448)
dy09_dtrd2			0.0591	0.0463
			(0.0443)	(0.0443)
dy10_dtrd2			0.0816*	0.0680
			(0.0443)	(0.0443)
dy11_dtrd2			0.0595	0.0449
			(0.0447)	(0.0447)
poexpyr	0.0298***	0.0299***	0.0298***	0.0299***
	(0.00124)	(0.00124)	(0.00125)	(0.00125)
poexpyr2	-0.000450***	-0.000454***	-0.000449***	-0.000453***
	(2.55e-05)	(2.54e-05)	(2.55e-05)	(2.55e-05)
dmale	0.437***	0.438***	0.437***	0.439***
	(0.0101)	(0.0101)	(0.0101)	(0.0101)
djtprm2	0.247***	0.247***	0.248***	0.248***
	(0.0131)	(0.0131)	(0.0131)	(0.0131)
dprwkr	-0.221***	-0.222***	-0.220***	-0.222***
	(0.0108)	(0.0108)	(0.0108)	(0.0108)
dlgent	0.344***	0.345***	0.344***	0.345***
	(0.0101)	(0.0101)	(0.0101)	(0.0101)
darea	0.0841***	0.0851***	0.0842***	0.0853***
	(0.0119)	(0.0119)	(0.0119)	(0.0119)
dyear02	-0.0703***	-0.0704***	-0.0857***	-0.0857***
	(0.0221)	(0.0221)	(0.0293)	(0.0293)
dyear03	-0.00326	-0.00375	-0.0347	-0.0352
	(0.0249)	(0.0248)	(0.0331)	(0.0330)
dyear04	0.0328	0.0323	0.00594	0.00542
	(0.0224)	(0.0224)	(0.0300)	(0.0300)
dyear05	0.104***	0.104***	0.0919***	0.0919***
	(0.0224)	(0.0224)	(0.0301)	(0.0301)

dyear06	0.185***	0.184***	0.146***	0.147***
	(0.0225)	(0.0225)	(0.0304)	(0.0303)
dyear07	0.266***	0.265***	0.243***	0.246***
	(0.0225)	(0.0225)	(0.0305)	(0.0304)
dyear08	0.366***	0.365***	0.321***	0.324***
	(0.0224)	(0.0224)	(0.0303)	(0.0302)
dyear09	0.444***	0.442***	0.418***	0.422***
	(0.0222)	(0.0222)	(0.0301)	(0.0301)
dyear10	0.481***	0.479***	0.444***	0.448***
	(0.0222)	(0.0222)	(0.0301)	(0.0301)
dyear11	0.542***	0.540***	0.516***	0.520***
	(0.0225)	(0.0224)	(0.0304)	(0.0304)
Constant	-2.098***	-2.028***	-2.073***	-2.007***
	(0.0382)	(0.0407)	(0.0411)	(0.0433)
Observations	9,685	9,685	9,685	9,685
R-squared	0.555	0.556	0.555	0.556
Test of time trend			0.67	0.56
F-statistic			(0.741)	(0.833)

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Dyear01 (or Dy01) =1 for the year 1998;

Dyear02 (or Dy02) =1 for the year 1999;

Dyear03 (or Dy03) =1 for the year 2000;

Dyear11 (or Dy11) =1 for the year 2008.

Table 11. Wage effects of both technological change and trade over time

VARIABLES	(1) lnw	(2) lnw	(3) lnw	(4) lnw
dhtchin2	0.0325***	-0.0909**	-0.0342	-0.142***
	(0.00996)	(0.0372)	(0.0378)	(0.0518)
dtrdin2	0.00355	-0.118***	-0.0329	-0.149***
	(0.00948)	(0.0352)	(0.0368)	(0.0495)
schlyr	0.0402***	0.0320***	0.0405***	0.0326***
	(0.00220)	(0.00263)	(0.00220)	(0.00264)
dht2_scyr		0.0101***		0.00897***
		(0.00305)		(0.00307)
dtr2_scyr		0.0102***		0.0103***
		(0.00292)		(0.00295)
dy02_dht2			0.00943	0.0104
			(0.0473)	(0.0472)
dy03_dht2			-0.00374	-0.00237
			(0.0534)	(0.0533)
dy04_dht2			0.0498	0.0507
			(0.0481)	(0.0481)
dy05_dht2			0.0715	0.0716
			(0.0485)	(0.0484)
dy06_dht2			0.0402	0.0386
			(0.0484)	(0.0483)
dy07_dht2			0.0875*	0.0849*
			(0.0486)	(0.0486)
dy08_dht2			0.0937*	0.0901*
			(0.0485)	(0.0484)
dy09_dht2			0.0954**	0.0909*
			(0.0485)	(0.0484)
dy10_dht2			0.114**	0.109**
			(0.0486)	(0.0486)
dy11_dht2			0.133***	0.127***
			(0.0489)	(0.0488)
dy02_dtrd2			0.0301	0.0289
			(0.0467)	(0.0466)
dy03_dtrd2			0.0744	0.0729
			(0.0529)	(0.0528)
dy04_dtrd2			0.0457	0.0441
			(0.0475)	(0.0474)
dy05_dtrd2			0.00365	0.00184
			(0.0479)	(0.0478)
dy06_dtrd2			0.0746	0.0693
			(0.0478)	(0.0478)
dy07_dtrd2			0.0206	0.0127
			(0.0481)	(0.0480)
dy08_dtrd2			0.0670	0.0579
			(0.0479)	(0.0479)
dy09_dtrd2			0.0210	0.0101
			(0.0478)	(0.0478)
dy10_dtrd2			0.0344	0.0224
			(0.0479)	(0.0479)

dy11_dtrd2			0.00492	-0.00799
			(0.0482)	(0.0482)
poexpyr	0.0300***	0.0304***	0.0302***	0.0305***
	(0.00125)	(0.00125)	(0.00125)	(0.00125)
poexpyr2	-0.000454***	-0.000463***	-0.000454***	-0.000462***
	(2.55e-05)	(2.55e-05)	(2.55e-05)	(2.55e-05)
dmale	0.437***	0.438***	0.438***	0.439***
	(0.0101)	(0.0101)	(0.0101)	(0.0101)
djtprm2	0.245***	0.246***	0.245***	0.245***
	(0.0131)	(0.0131)	(0.0132)	(0.0131)
dprwkr	-0.219***	-0.218***	-0.221***	-0.219***
	(0.0108)	(0.0108)	(0.0108)	(0.0108)
dlgent	0.340***	0.340***	0.340***	0.340***
	(0.0102)	(0.0102)	(0.0102)	(0.0102)
darea	0.0890***	0.0885***	0.0902***	0.0899***
	(0.0120)	(0.0120)	(0.0120)	(0.0120)
dyear02	-0.0720***	-0.0721***	-0.0874***	-0.0872***
	(0.0221)	(0.0221)	(0.0319)	(0.0319)
dyear03	-0.00507	-0.00495	-0.0328	-0.0326
	(0.0249)	(0.0248)	(0.0360)	(0.0360)
dyear04	0.0308	0.0311	-0.00771	-0.00729
	(0.0224)	(0.0224)	(0.0326)	(0.0325)
dyear05	0.102***	0.102***	0.0727**	0.0733**
	(0.0224)	(0.0224)	(0.0326)	(0.0326)
dyear06	0.183***	0.183***	0.136***	0.138***
	(0.0225)	(0.0225)	(0.0331)	(0.0330)
dyear07	0.263***	0.263***	0.217***	0.222***
	(0.0225)	(0.0225)	(0.0334)	(0.0334)
dyear08	0.363***	0.362***	0.292***	0.297***
	(0.0225)	(0.0224)	(0.0332)	(0.0332)
dyear09	0.440***	0.440***	0.390***	0.397***
	(0.0222)	(0.0222)	(0.0330)	(0.0329)
dyear10	0.477***	0.476***	0.411***	0.418***
	(0.0222)	(0.0222)	(0.0329)	(0.0329)
dyear11	0.538***	0.537***	0.476***	0.484***
	(0.0225)	(0.0224)	(0.0333)	(0.0333)
Constant	-2.099***	-2.010***	-2.063***	-1.980***
	(0.0382)	(0.0413)	(0.0420)	(0.0447)
Observations	9,685	9,685	9,685	9,685
R-squared	0.555	0.557	0.557	0.558

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 12. Employment effects of technological changes

VARIABLES	(1)	(2)	(3)	(4)
	Employment in high-tech industries		Employment in trade industries	
schlyr	0.0204***	0.0147***	0.0124***	0.00377
	(0.00232)	(0.00535)	(0.00251)	(0.00593)
scyr_dy02		0.00851		0.000969
		(0.00678)		(0.00741)
scyr_dy03		0.00854		0.00479
		(0.00792)		(0.00865)
scyr_dy04		0.00593		0.00620
		(0.00686)		(0.00755)
scyr_dy05		0.00776		0.00589
		(0.00691)		(0.00760)
scyr_dy06		0.00780		0.0103
		(0.00692)		(0.00761)
scyr_dy07		0.00540		0.0101
		(0.00698)		(0.00770)
scyr_dy08		0.00868		0.0135*
		(0.00707)		(0.00775)
scyr_dy09		0.00438		0.0155**
		(0.00702)		(0.00770)
scyr_dy10		0.00156		0.0162**
		(0.00702)		(0.00768)
scyr_dy11		0.00303		0.0165**
		(0.00714)		(0.00779)
poexpyr	-0.00149	-0.00151	-0.00880*	-0.00903*
	(0.00490)	(0.00491)	(0.00527)	(0.00528)
poexpyr2	-0.000457	-0.000453	0.000358	0.000359
	(0.000314)	(0.000315)	(0.000337)	(0.000337)
poexpyr3	1.50e-05*	1.48e-05*	-8.09e-06	-7.64e-06
	(7.64e-06)	(7.65e-06)	(8.17e-06)	(8.18e-06)
poexpyr4	-1.20e-07*	-1.18e-07*	7.10e-08	6.44e-08
	(6.19e-08)	(6.20e-08)	(6.59e-08)	(6.60e-08)
dmale	0.0129	0.0125	-0.0230*	-0.0226*
	(0.0109)	(0.0109)	(0.0118)	(0.0118)
djtprm2	0.0743***	0.0748***	-0.00228	-0.00520
	(0.0139)	(0.0139)	(0.0150)	(0.0151)
dprwkr	0.00750	0.00701	0.0682***	0.0703***
	(0.0114)	(0.0114)	(0.0123)	(0.0124)
dlgent	0.166***	0.166***	0.102***	0.101***
	(0.0106)	(0.0106)	(0.0115)	(0.0115)
darea	-0.211***	-0.211***	-0.131***	-0.131***
	(0.0123)	(0.0123)	(0.0136)	(0.0136)
dyear01	0.114***	0.180**	0.348***	0.447***
	(0.0441)	(0.0709)	(0.0478)	(0.0777)
dyear02	0.182***	0.150**	0.320***	0.408***
	(0.0433)	(0.0639)	(0.0466)	(0.0682)
dyear03	0.184***	0.152*	0.328***	0.373***
	(0.0456)	(0.0803)	(0.0492)	(0.0863)
dyear04	0.196***	0.193***	0.353***	0.382***
	(0.0439)	(0.0661)	(0.0473)	(0.0712)

dyear05	0.202***	0.178***	0.358***	0.391***
	(0.0441)	(0.0674)	(0.0476)	(0.0725)
dyear06	0.203***	0.179***	0.358***	0.341***
	(0.0443)	(0.0690)	(0.0478)	(0.0745)
dyear07	0.239***	0.243***	0.367***	0.352***
	(0.0445)	(0.0709)	(0.0480)	(0.0769)
dyear08	0.250***	0.214***	0.364***	0.307***
	(0.0446)	(0.0720)	(0.0480)	(0.0772)
dyear09	0.264***	0.280***	0.379***	0.296***
	(0.0445)	(0.0718)	(0.0479)	(0.0772)
dyear10	0.267***	0.318***	0.371***	0.280***
	(0.0447)	(0.0726)	(0.0481)	(0.0776)
dyear11	0.268***	0.301***	0.379***	0.284***
	(0.0453)	(0.0750)	(0.0488)	(0.0801)
Observations	10,371	10,371	9,798	9,798
R-squared	0.520	0.520	0.479	0.480
Test of time trend	8.27	0.95	1.29	0.71
F-statistic	(0.000)	(0.485)	(0.229)	(0.718)

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1