Cost-Reducing R&D Investment, Occupational Choice, and Trade *

Tadashi Morita †
Graduate School of Economics, Osaka University

August 12, 2010

Abstract

In this paper, I construct a two-country general equilibrium model in which oligopolistic firms export goods and undertake cost-reducing R&D investment. Each country imposes tariffs. When the cost of education is sufficiently high, an increase in the tariff rate decreases the level of R&D investment. However, when the cost of education is sufficiently small, an increase in the tariff rate increases the level of R&D investment.

Keywords: R&D, Occupational Choice, Trade, Oligopoly
JEL classification: F12, F13

*I am very grateful to Koichi Futagami for his valuable help. I would also like to thank Masahisa Fujita, Takeo Hori, Toshihiro Matsumura, Tomoya Mori, Se-il Mun, Takayuki Ogawa, Rhoji Ohdoi, Ryosuke Okamoto, Makoto Okamura, Yoshiyasu Ono, Tsuyoshi Toshimitsu, and seminar participants at Chuo University, Kwansei Gakuin University, Kyoto University, Osaka University, and Osaka City University, Osaka Prefecture University, at the 23rd Annual Meeting of the Applied Regional Science Conference at Yamagata University, the 4th Conference of Macroeconomics for Young Professionals, the 2010 Japanese Economic Association Spring Meeting at Chiba University, and Asia Pacific Trade Seminar (2010). I acknowledge financial support from the Research Fellowships for Young Scientists of the Japan Society for the Promotion of Science.

†Graduate School of Economics, Osaka University, 1.7 Machikaneyama, Toyonaka, Osaka 560-0043, JAPAN e-mail: gge013mt@mail2.econ.osaka-u.ac.jp

1 Introduction

Trade liberalization has been occurring in recent decades. Wacziarg and Welch (2008) showed that the number of countries having open trade policy increased from 22% of all countries in 1960 to 46% in 2000. [1] However, over the last two decades, R&D investment has increased sharply and the wage gap between skilled and unskilled workers has widened sharply. Using data for the US, according to Braun (2008), the ratio of industrial R&D expenditures to GDP increased from about 1% in 1979 to 1.43% in 1990 and 1.7% in 2004. Moreover, the wage gap between skilled and unskilled workers has increased in many countries recently. Acemoglu (2002) pointed out that percentage of US workers with a college education increased sharply from 6% in 1939 to 28% in 1996. He also pointed out that in the US, the college premium increased from about 0.4 in 1980 to about 0.6 in 1995.

On the basis of the above data, this paper has three objectives. First, this paper investigates the relationship between the level of cost-reducing R&D investment and trade liberalization. When trade liberalization occurs, do firms increase the level of R&D investment? Few papers investigate the relationship between R&D investment and trade liberalization empirically. Funk (2003) concluded that US manufacturing firms that sell their product to the US market decrease their R&D investment when trade liberalization occurs. However, US manufacturing firms with foreign sales increase their R&D investment. Scherer and Huh (1992) showed that average US high-tech firms reduce their R&D investment in the short run when trade liberalization occurs.

The second and third objectives of this paper are to consider whether the number of skilled workers and the wage gap between skilled and unskilled workers increases or not when trade liberalization occurs. Many researchers have investigated the relationship between the wage gap and trade liberalization. Wood (1994), Leamer (1996) and Kurokawa (2010) argued that there is positive relationship between the wage gap and trade liberalization. However, when trade liberalization occurs, does the wage gap between skilled and unskilled workers widen and does the number of skilled workers increase?

In this paper, I construct a two-country general equilibrium model in which oligopolistic firms export goods and undertake cost-reducing R&D investment. The governments of the countries impose tariffs on imported goods. The ability of individuals is heterogeneous. Individuals choose to become skilled workers by paying the cost of education or remain unskilled workers, which involves no cost. In Braun (2008) and Morita (2009), there are two types of workers: skilled workers and unskilled workers. However, the numbers of skilled and unskilled workers are exogenously given. In this paper, the number of skilled workers is determined endogenously through the individual's choice.

[1] A definition of open trade policy is provided by Sachs and Warner (1995).

In this paper, I obtain two results regarding the relationship between the tariff rate and the level of R&D investment. One is that a decrease in the tariff rate reduces the level of R&D investment when the cost of education is sufficiently high. However, a decrease in the tariff rate raises the level of R&D investment when the cost of education is sufficiently low. This paper also shows that a decrease in the tariff rate increases the wage gap between skilled and unskilled workers when the cost of education is sufficiently high. When the cost of education is sufficiently low, the effect of decreasing the tariff rate on the wage gap is ambiguous. Furthermore, this paper shows that a decrease in the tariff rate increases the number of skilled workers when the cost of education is sufficiently high. When the cost of education is sufficiently low, the relationship between trade liberalization and the number of skilled workers is ambiguous.

Many papers have investigated the relationship between trade liberalization and cost-reducing R&D investment. Braun (2008) and Haaland and Kind (2008) constructed a simple model of international oligopoly. In their papers, consumers are homogeneous agents. They do not consider the labor market for simplification. The result of these papers illustrates that trade liberalization increases R&D investment. In contrast with these papers, Morita (2009) constructed a general equilibrium model by incorporating the labor market into the model of Braun (2008) and Haaland and Kind (2008). I show that trade liberalization decreases R&D investment. In this paper, the cost of education determines the effects of trade liberalization on the level of R&D investment. Then, this paper summarizes the results of these papers.

The remainder of this paper is organized into four sections. The next section presents the basic structure of the model. Section 3 obtains the equilibrium condition of this model. I conclude in Section 4.

2 The model

There are two countries, Home and Foreign, indexed by $l \in \{H, F\}$ and these countries are symmetric. The population size in each country is equal to L. There are two types of workers; skilled and unskilled. Individuals choose to become either a skilled or an unskilled worker. This determines the number of skilled and unskilled workers. There are two types of goods, X and Y. Good X is chosen to be the numeraire. Good X and good Y can be produced in both countries. The firm producing good Y in the Home country is named Firm H. The firm producing good Y in the Foreign country is named Firm F. I assume that Firm H and Firm F compete strategically by using their product quantities, that is, they engage in Cournot competition. The governments of both countries levy tariffs on their imports of good Y and the tariff rate is denoted by τ.

2.1 Individual

The utility function of individual i in each country is given by

$$U^{i,l}(q_{i,l}, x_{i,l}) = x_{i,l} + aq_{i,l} - \frac{b}{2}q_{i,l}^2, l \in \{H, F\}, i \in \{0, 1\}, \tag{1}$$

where $x_{i,l}$ is consumption of good X in country l by individual i, $q_{i,l}$ is consumption of good Y, and a and b are positive parameters. The budget constraint of consumer i in country l is as follows:

$$x_{i,l} + p_l q_{i,l} = E_{i,l}, l \in \{H, F\}, \tag{2}$$

where p_l is the price of good Y, and $E_{i,l}$ is expenditure in country l by consumer i. From the first-order condition of the individual, I obtain the following inverse demand function:

$$\begin{aligned} p_l &= a - bq_{i,l} \\ &= a - bq_l, \end{aligned} \tag{3}$$

where q_l denotes the average consumption level of good Y in country l. Therefore, the inverse demand function in country l is as follows:

$$p_l = a - b\frac{Q_l}{L}, \tag{4}$$

where Q_l denotes the aggregate consumption level of good Y in country l.

2.2 Occupational choice

I assume that individuals can choose their occupation; skilled or unskilled worker. i_l denotes the ability of individual i_l in country l and $i_l \in [0, 1]$. Ability is distributed uniformly over the unit interval. When individual $i_l \in [0, \gamma]$ becomes a skilled worker, he or she does not have to pay good X. When individual $i_l \in [\gamma, 1]$ decides to become a skilled worker, he or she has to pay $D(i_l - \gamma)$ unit of good X. However, when individual i_l wants to become an unskilled worker, he or she pays nothing. Each individual has one unit of labor and supplies one unit of labor inelasticity. When individual $i_l > \gamma$ becomes a skilled worker, his or her income becomes $w_l - D(i_l - \gamma)$, where w_l denotes the wage rate of a skilled worker in country l. However, when individual $i_l > \gamma$ becomes an unskilled worker, his or her income is the wage rate of an unskilled worker in country l, $w_{U,l}$. I assume that an individual $\hat{i}_l$ is indifferent between becoming a skilled worker and an unskilled worker. Then, the threshold of ability $\hat{i}_l$ becomes:

$$w_l - D(\hat{i}_l - \gamma) = w_{U,l}, l \in \{H, F\}. \tag{5}$$

Thus, $\hat{i}_l L$ individuals become skilled workers and $(1-\hat{i}_l)L$ individuals become unskilled workers. When the cost of education D is zero, the economy is similar to those of Braun (2008) and Haaland and Kind (2008). On the contrary, when the cost of education D is infinity, the proportion of skilled workers is γ. Then, this economy is the same as those of Morita (2009).

2.3 Production

2.3.1 Good X sector

Production of one unit of good X requires one unit of unskilled workers in both countries. I assume that perfect competition prevails in the good X market and good X can be traded freely. Thus, the wage rate for unskilled workers in both countries equals to unity, that is, $w_{U,H} = w_{U,F} = 1$.

2.3.2 Good Y sector

Each firm produces good Y and conducts cost-reducing R&D investment to decrease their marginal cost of production. Production of good Y requires both skilled and unskilled workers. Production of one unit of good Y requires θ units of skilled workers and $\alpha(k_l) \in [0, \bar{\alpha}]$ units of unskilled workers in country l. k_l denotes the number of skilled workers that is allocated to cost-reducing R&D investment in country l. I assume that $\partial\alpha(k_l)/\partial k_l < 0$ and $\partial^2\alpha(k_l)/\partial k_l^2 \geq 0$. The profit of Firm H is then given by

$$\pi_H = p_H y_{HH} + (p_F - \tau)y_{HF} - (y_{HH} + y_{HF})(\alpha(k_H) + \theta w_H) - w_H k_H, \tag{6}$$

where $y_{t,s}$ denotes the output of firm t that is sold in country s. Hence, the good Y market clearing conditions in both countries is as follows:

$$y_{HH} + y_{FH} = Q_H, \tag{7}$$

$$y_{HF} + y_{FF} = Q_F. \tag{8}$$

The left hand side of these equations represents the supply of good Y and the right-hand side of these equations represents the demand for good Y. Substituting the inverse demand function, (4), (7), and (8) into the profit function (6), I rewrite the profit function of Firm H as follows:

$$\pi_H = \left(a - b\frac{y_{HH} + y_{FH}}{L}\right) y_{HH} + \left(a - b\frac{y_{HF} + y_{FF}}{L} - \tau\right) y_{HF} - (y_{HH} + y_{HF})(\theta w_H + \alpha(k_H)) - w_H k_H. \tag{9}$$

Firms maximize their profits by simultaneously choosing the quantity of good Y in the two markets and the level of cost-reducing R&D investment. Then, the profit maximization of the firms leads to the following levels of output and R&D investment:

$$y_{HH} = \frac{L}{2b}\left[a - \theta w_H - \alpha(k_H)\right] - \frac{y_{FH}}{2}, \tag{10}$$

$$y_{HF} = \frac{L}{2b}\left[a - \tau - \theta w_H - \alpha(k_H)\right] - \frac{y_{FF}}{2}, \tag{11}$$

$$w_H = -(y_{HH} + y_{HF})\alpha'(k_H). \tag{12}$$

I assume that the firms take the wage rate of skilled workers and the wage rate of unskilled workers as being constant. In the same way, the output levels of Firm F are as follows:

$$y_{FF} = \frac{L}{2b}\left[a - \theta w_F - \alpha(k_F)\right] - \frac{y_{HF}}{2}, \tag{13}$$

$$y_{FH} = \frac{L}{2b}\left[a - \tau - \theta w_F - \alpha(k_F)\right] - \frac{y_{HH}}{2}. \tag{14}$$

Because I assume that Home and Foreign countries are symmetric and that both firms have the same unit cost function, Firms H and F produce the same output level. Thus, the level of R&D investment, the wage rate for skilled workers, and the proportion of skilled workers are the same in both countries: $k_1 = k_2 \equiv k$, $w_H = w_S \equiv w$, and $\hat{\imath}_H = \hat{\imath}_F = \hat{\imath}$. From (10), (11), (13), and (14), the output levels of Firm H and Firm F are given by

$$y_{HH} = y_{FF} = \frac{L}{3b}\left[a + \tau - \theta w - \alpha(k)\right], \tag{15}$$

$$y_{HF} = y_{FH} = \frac{L}{3b}\left[a - 2\tau - \theta w - \alpha(k)\right]. \tag{16}$$

I assume that the parameter a is sufficiently large in order that the output levels of the firms have positive values. Because the purpose of this paper is to investigate the effects of tariffs, I focus on the case in which positive amounts of good Y are traded between the countries.

2.4 Labor market equilibrium conditions

The demand for skilled workers is derived from R&D investment and production of good Y. The demand for unskilled workers comes from production of good X and good Y. Because the supply of skilled workers is $\hat{\imath}L$ and that of unskilled workers is $(1 - \hat{\imath})L$, the labor market equilibrium conditions in country H are given by:

$$\hat{i}L = k_H + \theta(y_{HH} + y_{HF}), \tag{17}$$

$$(1 - \hat{i})L = x_H^P + \alpha(k_H)(y_{HH} + y_{HF}), \tag{18}$$

where x_H^P denotes the labor demand for the good X sector in country H.

3 Equilibrium

From (12), (15), and (16), I can obtain the wage rate for skilled workers as follows:

$$w = \frac{-\alpha^{'}(k)L\left[2a - \tau - 2\alpha(k)\right]}{3b - 2\theta\alpha^{'}(k)L}. \tag{19}$$

From (19), I obtain the output level of Firm H as follows:

$$y_{HH} + y_{HF} = \frac{LA(k,\tau)}{B(k)}, \tag{20}$$

where $A(k,\tau) \equiv 2a - \tau - 2\alpha(k) > 0$ and $B(k) \equiv 3b - 2\theta\alpha^{'}(k)L > 0$.

From (5) and (19), I can obtain the threshold of ability $\hat{i}$ as follows:

$$\hat{i} = \frac{-\alpha^{'}(k)LA(k,\tau)}{B(k)D} + \gamma - \frac{1}{D}. \tag{21}$$

Inserting (19), (20) and (21) into the skilled worker equilibrium condition (17), I can obtain the excess labor demand function as follows:

$$\begin{aligned} H(k,\tau) &= k + \frac{\theta L(2a - \tau - 2\theta w - 2\alpha(k))}{3b} - \hat{i}L \\ &= k + \frac{LA(k,\tau)(\theta D + \alpha^{'}(k)L)}{B(k)D} - L(\frac{D\gamma - 1}{D}). \end{aligned} \tag{22}$$

When $H(k,\tau) = 0$, I can obtain the optimal level of R&D investment. Hereafter, I assume that $\alpha(k) = \bar{\alpha}e^{-k}$ and $\gamma = \frac{\theta}{\bar{\alpha}L}$ for simplicity. At $k = 0$, there is positive excess labor demand when the cost of skilled labor is relatively high, that is $D > \frac{\bar{\alpha}L}{\theta}$, and $\tau < \tau_1$ where

$$\tau_1 = 2(a - \bar{\alpha}) - \frac{3b + 2\theta\bar{\alpha}L}{\bar{\alpha}L}. \tag{23}$$

However, at $k = 0$, there is negative excess labor demand when the cost of skilled labor is relatively low, that is $D < \frac{\bar{\alpha}L}{\theta}$, and $\tau < \tau_1$. In addition, the slope of the excess labor demand function at $k = 0$ has a negative slope when $\tau > \tau_2$ where:

$$\tau_2 = 2(a - \bar{\alpha}) + \frac{(3b + 2\theta\bar{\alpha}L)\left[D(3b + 2\theta\bar{\alpha}L) + 2\bar{\alpha}L(\theta D - \bar{\alpha}L)\right]}{\bar{\alpha}L^2(3b + 2\theta^2 D)}. \tag{24}$$

The stability condition of this equilibrium is $\tau < \bar{\tau}$ where

$$\bar{\tau} = 2(a - \bar{\alpha}) - \frac{2\bar{\alpha}(3b + 2\theta\bar{\alpha}L)}{3b}. \tag{25}$$

Comparing τ_1 with τ_2 and $\bar{\tau}$, I can obtain $\tau_1 < \bar{\tau} < \tau_2$ when $3b > 2\bar{\alpha}^2 L$ holds.[2] Hereafter, I focus on $\tau < \bar{\tau}$. Then, I can obtain the following proposition (see Appendix for the proof).

PROPOSITION 1. *Suppose that $3b > 2\bar{\alpha}^2 L$. Then, there exists an unique and a positive level of R&D investment when $D > \frac{\bar{\alpha}L}{\theta}$ and $\tau_1 < \tau < \bar{\tau}$ and when $D < \frac{\bar{\alpha}L}{\theta}$ and $\tau < \tau_1 < \bar{\tau}$.*

The excess labor demand function of $H(k, \tau)$ can be depicted in Figures 1(a) and 1(b) when $D > \frac{\bar{\alpha}L}{\theta}$. When $D > \frac{\bar{\alpha}L}{\theta}$ and $\tau < \tau_1$ in Figure 1(a), the intercept of $H(k, \tau)$ has a positive value. However, when $D > \frac{\bar{\alpha}L}{\theta}$ and $\tau_1 < \tau < \bar{\tau}$ in Figure 1(b), the intercept of $H(k, \tau)$ has a negative value. When $D > \frac{\bar{\alpha}L}{\theta}$ and $\tau < \bar{\tau} < \tau_2$ in Figures 1(a) and 1(b), the slope of $H(k, \tau)$ at $k = 0$ has a positive value. Therefore, when $D > \frac{\bar{\alpha}L}{\theta}$ and $\tau_1 < \tau < \bar{\tau}$, there exists a unique and positive level of R&D investment in Figure 1(b).

(a) $\tau < \tau_1$

(b) $\tau_1 < \tau < \bar{\tau}$

Figure 1: When $D > \frac{\bar{\alpha}L}{\theta}$

When the cost of education, D, is sufficiently small, the excess labor demand function of $H(k, \tau)$ can be depicted in Figures 2(a) and 2(b). When $D < \frac{\bar{\alpha}L}{\theta}$ and $\tau < \tau_1$ in Figure 2(a), the intercept of $H(k, \tau)$ has a negative value. However, when $D < \frac{\bar{\alpha}L}{\theta}$ and $\tau_1 < \tau < \bar{\tau}$ in Figure 2(b), the intercept of $H(k, \tau)$ has a positive value. When $D < \frac{\bar{\alpha}L}{\theta}$ and $\tau < \bar{\tau} < \tau_2$ in Figures 2(a) and 2(b), the slope of $H(k, \tau)$ at $k = 0$ has a positive value. Therefore,

[2] When this inequality holds, $\tau_1 < \bar{\tau} < \tau_2$. When this inequality does not hold, $\bar{\tau} < \tau_1 < \tau_2$. I can obtain the same result whether this inequality holds or not.

when $D < \frac{\bar{\alpha}L}{\theta}$ and $\tau < \tau_1$, there exists a unique and positive level of R&D investment in Figure 2(a).

(a) $\tau < \tau_1$ (b) $\tau_1 < \tau < \bar{\tau}$

Figure 2: $D < \frac{\bar{\alpha}L}{\theta}$

The relationship between the tariff rate and the level of R&D investment is given by following proposition (see Appendix for the proof).

PROPOSITION 2. *When $D > \frac{\bar{\alpha}L}{\theta}$ and $\tau > \tau_1$, a decrease in the tariff rate decreases R&D investment. When $D < \frac{\bar{\alpha}L}{\theta}$ and $\tau < \tau_1$, a decrease in the tariff rate increases R&D investment.*

Figure 3 describes the case when the cost of education is sufficiently high, that is, $D > \frac{\bar{\alpha}L}{\theta}$. Then, a decrease in the tariff rate roatates the excess labor demand function of $H(k,\tau)$ around $k = \ln \frac{\bar{\alpha}L}{\theta D} < 0$ in a counterclockwise direction. Therefore, a decrease in the tariff rate decreases the level of R&D investment. However, Figure 4 describes the case when the cost of education is sufficiently low. Then, a decrease in the tariff rate roatates the excess labor demand function of $H(k,\tau)$ around $k = \ln \frac{\bar{\alpha}L}{\theta D} > 0$ in a counterclockwise direction. Therefore, a decrease in the tariff rate increases the level of R&D investment.

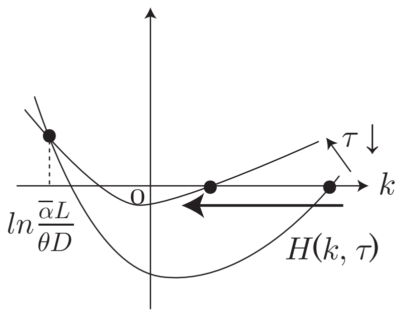

Figure 3: $D > \frac{\bar{\alpha}L}{\theta}$

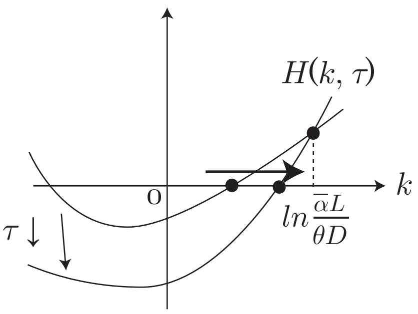

Figure 4: $D < \frac{\bar{\alpha}L}{\theta}$

The effects of the tariff rate can be divided into three effects: *trade effect*, *wage effect*, and *occupational choice effect*. Firstly, the *trade effect* is where a decrease in the tariff rate increases cost-reducing R&D investment. When the tariff rate decreases, both firms increase their output levels and the marginal benefit of R&D investment increases. Therefore, both firms increase their level of R&D investment and the labor demand for skilled workers increases. Secondly, the *wage effect* is where a decrease in the tariff rate reduces cost-reducing R&D investment. When the tariff rate decreases, both firms increase their output. Then, the demand for skilled workers increases and the wage rate of skilled workers increases. An increase in the wage rate of skilled workers raises the cost of R&D and decreases the level of R&D investment. Finally, the *occupational choice effect* is where a decrease in the tariff rate increases cost-reducing R&D investment. When the tariff rate decreases, both firms increase their output levels. Then, the demand for skilled workers increases and the wage rate of skilled workers increases. Consequently, the income of skilled workers increases and the number of skilled workers increases. Then, the number of skilled workers hired in R&D activities increases and the demand for skilled labor increases.

Intuitively, when the cost of education is sufficiently high, individuals are less likely to become skilled workers. Then, the number of skilled workers is scarce and the *wage effect* is sufficiently high. The *wage effect* overcomes the sum of the *trade effect* and the *occupational effect*. Therefore, when the cost of education is sufficiently high, a decrease in the tariff rate decreases the level of R&D investment. When the cost of education is sufficiently low, individuals easily becomes skilled workers and the supply of skilled workers is abundant. Then, the *wage effect* is sufficiently small. Therefore, the *wage effect* is smaller than the sum of the *trade effect* and the *occupational effect*. Hence, when the cost of education is sufficiently small, a decrease in the tariff rate increases the level of R&D investment.

The next proposition shows the relationship between the tariff rate and the output level of good Y (see Appendix for the proof).

PROPOSITION 3. *When $D < \frac{\bar{\alpha}L}{\theta}$, a decrease in the tariff rate increases the output level.*

When the tariff rate decreases, there is a direct effect and an indirect effect. The direct effect is that when the tariff rate decreases, the cost of exports decreases and the firms increase their exports and output levels. The indirect effect is that when the tariff rate decreases, the level of R&D investment changes. An increase in the level of R&D investment raises productivity and the output level. A decrease in the level of R&D investment reduces productivity and the output level. Therefore, when the cost of education is sufficiently low, a decrease in the tariff rate increases the level of R&D investment as shown in Proposition 2 and increases the output level. However, when the cost of education is sufficiently high, a decrease in the tariff rate decreases the level of R&D investment. Then, the direct effect is opposite to the indirect effect. The relationship between the tariff rate and the output level is ambiguous.

When the tariff rate decreases, does the wage rate of skilled workers increase and the number of skilled workers increase? As for the relationship between the tariff rate and the number of skilled workers, I can obtain the following proposition.

PROPOSITION 4. *When $D > \frac{\bar{\alpha}L}{\theta}$, a decrease in the tariff rate increases the wage gap between skilled and unskilled workers and increases the number of skilled workers.*

Proof. The effect of the tariff rate on the wage rate of skilled workers can be divided into two parts: direct effect and indirect effect. Differentiating (19) with respect to τ, I obtain the following equation:

$$\frac{\partial w}{\partial \tau} = \frac{\partial w}{\partial \tau} + \frac{\partial w}{\partial k}\frac{\partial k}{\partial \tau} = -\frac{\bar{\alpha}e^{-k}L}{B(k)} + \frac{\partial w}{\partial k}\frac{\partial k}{\partial \tau}. \tag{26}$$

The first term of (26) has a negative value. From the stability condition, $\frac{\partial w}{\partial k} < 0$. When $D > \frac{\bar{\alpha}L}{\theta}$ holds, $\frac{\partial k}{\partial \tau} > 0$ as shown in Proposition 2. Then, the second term of (26) has a negative value and $\frac{\partial w}{\partial \tau} < 0$. Therefore, when the cost of education is sufficiently high, a decrease in the tariff rate increases the wage rate of skilled workers. When $D < \frac{\bar{\alpha}L}{\theta}$ holds, $\frac{\partial k}{\partial \tau} < 0$ as shown in Proposition 2. Then, the second term of (26) has a positive value and the sign of $\frac{\partial w}{\partial \tau}$ is ambiguous. Therefore, when the cost of education is sufficiently low, the relationship between the tariff rate and the wage rate of skilled workers is ambiguous. □

I explain the above proposition intuitively. There is a direct effect and an indirect effect. The first term of (26) represents the direct effect and the second term represents the indirect effect. The direct effect is when the tariff rate decreases given the level of R&D investment, the cost of exports decreases, and both firms increase their volume of exports and increase their output level. Then, the demand for skilled workers increases. Hence, the direct effect has a positive effect on the wage rate of skilled workers. However, the indirect effect is that the level of R&D investment affects the price of good Y. When the cost of education is sufficiently high, a decrease in the tariff rate decreases the level of R&D investment. Then, the cost of good Y increases and the relative price of good Y increases. Then, the demand for skilled workers increases relatively. Then, when the cost of education is sufficiently high, the indirect effect also has a positive effect. Therefore, when the cost of education is sufficiently high, a decrease in the tariff rate increases the wage rate of skilled workers. However, when the cost of education is sufficiently small, a decrease in the tariff rate increases the level of R&D investment and decreases the cost of good Y. Then, the relative price of good Y decreases, the demand for unskilled workers increases, and the wage rate of skilled workers decreases relatively. Therefore, when the cost of education is sufficiently small, the indirect effect has a negative effect. Then, the

	$D>\bar{\alpha}L/\theta$		$D<\bar{\alpha}L/\theta$	
	$\tau<\tau_1$	$\tau_1<\tau<\bar{\tau}$	$\tau<\tau_1$	$\tau_1<\tau<\bar{\tau}$
$\partial k/\partial\tau$	0	+	-	0
$\partial(output)/\partial\tau$	+	?	+	+
$\partial w/\partial\tau$	-	-	?	-

Figure 5: The results of proposition 2, 3, and 4.

relationship between the tariff rate and the wage rate of skilled workers is ambiguous when the cost of education is sufficiently small.

4 Conclusion

In this paper, I constructed a two-country general equilibrium model in which the ability of individuals is heterogeneous and oligopolistic firms produce goods and undertake cost-reducing R&D investment. There are two main results. The first result is the relationship between trade liberalization and the wage gap. Trade liberalization increases the wage gap between skilled workers and unskilled workers when the cost of education is sufficiently high. When the cost of education is sufficiently low, the relationship between trade liberalization and the wage rate of skilled workers is ambiguous.

The second result is the relationship between trade liberalization and the level of R&D investment. This paper investigated the effects of trade liberalization on R&D investment. There are three effects: *trade effect*, *wage effect*, and *occupational choice effect*. First, the *trade effect* is that a decrease in the tariff rate increases R&D investment. This effect is focused on by Braun (2008) and Haaland and Kind (2008). They concluded that a decrease in the tariff rate increases R&D investment. Second, the *wage effect* is that a decrease in the tariff rate decreases R&D investment. When the tariff rate decreases, both firms increase their output level. Morita (2009) considered these two effects: *trade effect* and *wage effect*. He constructed a general equilibrium model by incorporating the labor market into the model of Braun (2008) and Haaland and Kind (2008). He concluded that the *wage effect* dominates the *trade effect* for any tariff rate.

The result of this paper is separated into two cases. First, when the cost of education is sufficiently low, the *trade effect* plus the *occupational choice effect* dominate the *wage effect* and a decrease in the tariff rate increases cost-reducing R&D investment. This case is similar to Braun (2008) and Haaland and Kind (2008). Second, when the cost of education is sufficiently high, the *wage effect* dominate the *trade effect* plus the *occupational choice effect* and a decrease in the tariff rate decreases cost-reducing R&D investment. This case is similar to Morita (2009). Therefore, the cost of education determines the effects of trade liberalization on the level of R&D investment.

Comparing this paper and Morita (2009), this paper provided a long-term analysis and Morita (2009) provided a short-term analysis. In the short term, it is difficult for workers to acquire skills. Therefore, in the short term, the ratio of skilled workers to unskilled workers is constant. However, the ratio of skilled workers to unskilled workers is endogenous. This paper and Morita (2009) concluded that trade liberalization decreases the level of R&D investment in the short term and increases the level of R&D investment in the long term.

A Appendix

A.1 Proof of Proposition 1

This proof can be solved in four steps. In the first step, I analyze the value of $H(k,\tau)$ at $k=0$. The Second step investigates the value of $H(k,\tau)$ when k approaches to infinity. The third step examines the gradient of $H(k,\tau)$ at $k=0$. Finaly, the fourth step shows that the equilibrium is stable when $\tau \leq \tau_3$. In addition, I show that $\tau_1 < \bar{\tau} < \tau_2$.

First step: Investigating the value of $H(0,\tau)$, I obtain the following lemma.

LEMMA 1. *If $\tau > \tau_1$ and $D > \frac{\bar{\alpha}L}{\theta}$, there is excess labor supply when $k=0$. However, if $\tau > \tau_1$ and $D < \frac{\bar{\alpha}L}{\theta}$, there is excess labor demand when $k=0$.*

Proof. Remember that I assumed that $\alpha(k) = \bar{\alpha}e^{-k}$ and $\gamma = \frac{\theta}{\bar{\alpha}L}$. The intercept of $H(k,\tau)$ is given by:

$$H(0,\tau) = \frac{\theta D - \bar{\alpha}L}{\bar{\alpha}D(3b + 2\theta\bar{\alpha}L)} \left[\bar{\alpha}L(2a - \tau - 2\bar{\alpha}) - 3b - 2\theta\bar{\alpha}L\right]. \tag{A.1}$$

When $\tau > \tau_1$ and $D > \frac{\bar{\alpha}L}{\theta}$, I obtain:

$$H(0,\tau) < \frac{\theta D - \bar{\alpha}L}{\bar{\alpha}D(3b + 2\theta\bar{\alpha}L)} \left[\bar{\alpha}L(2a - \tau_1 - 2\bar{\alpha}) - 3b - 2\theta\bar{\alpha}L\right] = 0. \tag{A.2}$$

However, when $\tau > \tau_1$ and $D < \frac{\bar{\alpha}L}{\theta}$, the intercept of $H(0,\tau)$ has a positive value. □

Second step: The second step investigates the value of $H(k,\tau)$ when k approaches infinity. When k approaches infinity, the limiting value of $H(k,\tau)$ is as follows:

$$\lim_{k\to\infty} H(k,\tau) = \lim_{k\to\infty}\left(k + \frac{LA(k,\tau)(\theta D + \alpha'(k)L)}{B(k)D} - L(\frac{D\gamma - 1}{D})\right)$$
$$= \lim_{k\to\infty} k + \left[\frac{L(2a-\tau)\theta D}{3bD} - L(\frac{D\gamma-1}{D})\right] = \infty.$$

Therefore, when R&D investment of k approaches infinity, the excess labor demand increases without bound.

Third step: In the third step, I examine the shape of the excess demand function, $H(k,\tau)$. Then, I obtain the following lemma.

LEMMA 2. *When $\tau > \tau_2$, the slope of $H(k,\tau)$ at $k = 0$ is negative.*

Proof. Differentiating $H(k,\tau)$ with respect to k, I can obtain the following:

$$\frac{\partial H(k,\tau)}{\partial k} = 1 + \frac{\bar{\alpha}e^{-k}Lg(k,\tau)}{DB(k)^2}, \tag{A.3}$$

where

$$g(k,\tau) \equiv 2(\theta D - \bar{\alpha}e^{-k}L)B(k) + LA(k,\tau)(3b + 2\theta^2 D). \tag{A.4}$$

Differentiating $g(k,\tau)$ with respect to k, I can obtain the following:

$$\frac{\partial g(k,\tau)}{\partial k} = 2\bar{\alpha}e^{-k}LB(k) - 4(\theta D - \bar{\alpha}e^{-k}L)\theta\bar{\alpha}e^{-k}L + 2L(3b+2\theta^2 D)\bar{\alpha}e^{-k} \tag{A.5}$$
$$= 4\bar{\alpha}e^{-k}L(3b + 2\theta\bar{\alpha}e^{-k}L) > 0. \tag{A.6}$$

Therefore, $g(k,\tau)$ is increasing function of k. Then, when k is sufficiently small, the sign of (A.3) is negative. However, when k is sufficiently large, the sign of (A.3) is positive. Then, the sign of (A.3) changes once.

When $k = 0$ and $\tau > \tau_2$, the slope of the excess demand function is given by

$$\frac{\partial H(k,\tau)}{\partial k}|_{k=0} = \frac{[DB(0)^2 + \bar{\alpha}L\{2(\theta D - \bar{\alpha}L)B(0) + L(2a - \tau - 2\bar{\alpha})(3b + 2\theta^2 D)\}]}{DB(0)^2}$$
$$< \frac{[DB(0)^2 + \bar{\alpha}L\{2(\theta D - \bar{\alpha}L)B(0) + L(2a - \tau_2 - 2\bar{\alpha})(3b + 2\theta^2 D)\}]}{DB(0)^2} = 0. \tag{A.7}$$

Thus, when $\tau > \tau_2$, the value of $\frac{\partial H(k,\tau)}{\partial k}|_{k=0}$ has a negative value.

□

Fourth step: In this step, I show that the equilibrium is stable when $\tau \leq \bar{\tau}$ and $\tau_1 < \bar{\tau} < \tau_2$. To analyze the stability condition, I differentiate the wage rate with respect to the level of R&D investment.

$$\frac{\partial w}{\partial k} = \frac{1}{B(k)^2}\left[\left\{-\bar{\alpha}e^{-k}LA(k,\tau)+2\bar{\alpha}e^{-k}L\bar{\alpha}e^{-k}\right\}B(k)-\bar{\alpha}e^{-k}LA(k,\tau)(-2\theta\bar{\alpha}e^{-k}L)\right]$$
$$= -\frac{\bar{\alpha}e^{-k}L}{B(k)^2}C(k,\tau), \tag{A.8}$$

where

$$C(k,\tau) \equiv 3bA(k,\tau) - 2\bar{\alpha}e^{-k}B(k). \tag{A.9}$$

When the equilibrium is stable, the excess labor demand curve is downward sloping against the wage rate of skilled workers. Then, because the excess labor demand function is an increasing function, the stability condition is $\frac{\partial w}{\partial k} < 0$, that is $C(k,\tau) > 0$. When the stability condition is satisfied and there exists excess labor demand (supply), the wage rate of skilled labor increases (decreases). Then, the level of R&D investment decreases (increases). Investigating the sign of $C(k,\tau)$, I obtain the following lemma.

LEMMA 3. *When $\tau \leq \bar{\tau}$, the equilibrium is stable.*

Proof. The stability condition is $\frac{\partial w}{\partial k} < 0$, that is $C(k,\tau) > 0$. Then,

$$\begin{aligned} C(k,\tau) &= 3b(2a - \tau 2\bar{\alpha}e^{-k}) - 2\bar{\alpha}e^{-k}(3b + 2\theta\bar{\alpha}e^{-k}L) \\ &\geq 3b(2a - \tau - 2\bar{\alpha}) - 2\bar{\alpha}(3b + 2\theta\bar{\alpha}L) \\ &\geq 3b(2a - \bar{\tau} - 2\bar{\alpha}) - 2\bar{\alpha}(3b + 2\theta\bar{\alpha}L) = 0. \end{aligned} \tag{A.10}$$

Then, when $\tau < \bar{\tau}$, $C(k,\tau)$ has a positive value. □

Therefore, when $\tau < \bar{\tau}$, $\frac{\partial w}{\partial k}$ has a negative value and the equilibrium is stable. Next, I compare $\bar{\tau}$ to τ_1 and to τ_2.

$$\begin{aligned} \bar{\tau} - \tau_1 &= 2(a-\bar{\alpha}) - \frac{2\bar{\alpha}(3b + 2\theta\bar{\alpha}L)}{3b} - 2(a-\bar{\alpha}) + \frac{3b + 2\theta\bar{\alpha}L}{\bar{\alpha}L} \\ &= \frac{3b + 2\theta\bar{\alpha}L}{3b\bar{\alpha}L}\left[3b - 2\bar{\alpha}^2L\right] > 0, \end{aligned} \tag{A.11}$$

because $3b > 2\bar{\alpha}^2L$. Then, $\bar{\tau}$ is larger than τ_1.

$$\begin{aligned} \tau_2 - \bar{\tau} &= 2(a-\bar{\alpha}) + \frac{(3b + 2\theta\bar{\alpha}L)\left[D(3b + 2\theta\bar{\alpha}L) + 2\bar{\alpha}L(\theta D - \bar{\alpha}L)\right]}{\bar{\alpha}L^2(3b + 2\theta^2 D)} - 2(a-\bar{\alpha}) + \frac{3b + 2\theta\bar{\alpha}L}{\bar{\alpha}L} \\ &= \frac{3b + 2\theta\bar{\alpha}L}{3b\bar{\alpha}L^2(3b + 2\theta^2D)}\left[3bD(3b + 2\theta\bar{\alpha}L) + 6b\bar{\alpha}L\theta D + 4\theta\bar{\alpha}^3L^3\right] > 0. \end{aligned} \tag{A.12}$$

Then, τ_2 is larger than $\bar{\tau}$. Therefore, I can obtain $\tau_1 < \bar{\tau} < \tau_2$.

Summarizing the above four steps, there exists a unique and positive level of R&D investment when $D > \frac{\bar{\alpha}L}{\theta}$ and $\tau_1 < \tau < \bar{\tau}$, and when $D < \frac{\bar{\alpha}L}{\theta}$ and $\tau < \tau_1 < \bar{\tau}$.

A.2 Proof of Proposition 2

Differentiating $H(k,\tau)$ with respect to τ, I can obtain

$$\frac{\partial H(k,\tau)}{\partial \tau} = \frac{L(\theta D - \bar{\alpha} e^{-k} L)}{B(k)D} \frac{\partial A(k,\tau)}{\partial \tau} = -\frac{L(\theta D - \bar{\alpha} e^{-k} L)}{B(k)D}. \tag{A.13}$$

Then, when $k > \log(\frac{\bar{\alpha}L}{\theta D})$, $\frac{\partial H(k,\tau)}{\partial \tau}$ has a negative value. However, when $k < \log(\frac{\bar{\alpha}L}{\theta D})$, $\frac{\partial H(k,\tau)}{\partial \tau}$ has a positive value. Therefore, when $D > \frac{\bar{\alpha}L}{\theta}$, a decrease in the tariff rate rotates the excess labor demand function around $k = \ln \frac{\bar{\alpha}L}{\theta D} < 0$ in a counterclockwise direction. However, when $D < \frac{\bar{\alpha}L}{\theta}$, a decrease in the tariff rate rotates the excess labor demand function around $k = \ln \frac{\bar{\alpha}L}{\theta D} > 0$ in a counterclockwise direction.

A.3 Proof of Proposition 3

Differentiating (20) with respect to τ, I can obtain:

$$\frac{\partial (y_{HH} + y_{HF})}{\partial \tau} = \frac{2\bar{\alpha} e^{-k} L}{B(k)^2} \left[B(k) + \theta L A(k,\tau) \right] \frac{\partial k}{\partial \tau} - \frac{L}{B(k)}. \tag{A.14}$$

The second term represents the direct effect and the first term represents the indirect effect when the tariff rate changes. The second term of this derivative has a negative value for all values of education cost, D. The value of the first term in parentheses has a positive value because $A(k,\tau) > 0$ and $B(k) > 0$. When $D < \frac{\bar{\alpha}L}{\theta}$, $\frac{\partial k}{\partial \tau}$ is negative as shown in Proposition 2. Therefore, the sign of $\frac{\partial (y_{HH}+y_{HF})}{\partial \tau}$ has a negative value. Hence, a decrease in the tariff rate increases the output level when the cost of education is sufficiently low. However, when $D > \frac{\bar{\alpha}L}{\theta}$, $\frac{\partial k}{\partial \tau}$ is positive from Proposition 2. Then, the first term has a positive value. Therefore, the sign of $\frac{\partial (y_{HH}+y_{HF})}{\partial \tau}$ is ambiguous. Hence, when the cost of education is sufficiently high, the relationship between the tariff rate and the output level is ambiguous.

References

Acemoglu, Daron (2002) 'Technical Change, Inequality, and the Labor Market.' *Journal of Economic Literature*, 40:1, 7-72

Braun, Sebastian (2008) 'Economic Integration, Process and Product Innovation, and Relative Skill Demand.' *Review of International Economics*, 16:5, 864-873.

Funk, Mark (2003) 'The Effects of Trade on Research and Development.' *Open Economies Review* 14:1, 29-42.

Haaland, Jan I, and Hans Jarle Kind (2008) 'R&D policies, trade and process innovation.' *Journal of International Economics*, 74:1, 170-187.

Kurokawa, Yoshinori (2010) 'Variety-Skill Complementarity: a simple resolution of the trade-wage inequality anomaly.' *Economic Theory*, forthcoming.

Leamer, Edward E. (1996) 'In Search of Stolper-Samuelson Effects on U.S. Wages,' NBER working paper No.5427.

Morita, Tadashi (2009) 'Cost-reducing R&D investment, Labor Market, and Trade.' GCOE discussion paper series, Osaka University, No.83.

Sachs, Jeffrey D., and Andrew Warner (1995) 'Economic Reform and the Process of Global Integration.' *Brookings Papers on Economic Activity*, 1:1-95.

Scherer, F, M and Huh Keun (1992) 'R&D Reactions to High-Technology Import Competition.' *Review of Economics and Statistics*, 74:2, 202-212.

Wacziarg, Romain, and Karen Horn Welch (2008) 'Trade Liberalization and Growth: New Evidence.' *The World Bank Economic Review*, 22:2, 187-231.

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