# Discussion Papers In Economics And Business

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**Abstract**

This study presents a simple two-country model in which firms in the manufacturing sector can choose a technology level (high or low). We show how trade costs and productivity levels affect technology choices by the firms in each country, where the fixed cost of adopting high technology differs. This depends on the productivity level of the high technology. In particular, if productivity is medium and trade costs are not too low, then a technology gap between the countries arises. In this case, improving the productivity of the high-technology country reduces the welfare level of consumers in the country in which low technology is adopted. To compensate for the welfare loss of the country from the technological improvement, trade costs should be reduced.

JEL Classification: F10; F12
Key words: Specialization, Technology Choice, Technology Gap

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# 1 Introduction

Production technologies have evolved significantly over a long period of time. Consequently, industries are able to choose various technologies to produce goods. Highly productive technologies have been developed in some industrialized countries and may be available in other countries. At the same time, technology gaps exist between countries through the technology choices of each firm, especially where technology is highly developed. It is sometimes said that one of the main reasons for the existence of such technology gaps is that production circumstances differ among countries. When a country whose productivity is not developed attempts to adopt a new technology, the country tends to incur more adoption costs than a country whose productivity is developed. To adopt the new technology, the following are required: absorption of costs, development of laws, and developed infrastructure, including financial systems and major railways; moreover, additional costs differ among developing countries. In addition to such technology issues, we must consider the effect of trade costs, which are a key determinant of international trade. In the context of the new trade theory of Krugman(1980), trade costs determine whether full agglomeration or partial agglomeration arises; in addition, such costs affect welfare levels. Hence, we must analyze the effects of technology advances on economic performance by considering trade costs. Such an analysis enables discussion of the manner of technology improvement in an economy with international trade.

In this study, we incorporate technology choice by firms in a two-country model. In each country, there are two sectors: the manufacturing sector, whose firms compete via monopolistic competition, and the agricultural sector, which is perfectly competitive. Labor is the only production factor. We assume that firms can choose a production technology to produce manufacturing goods from two types of technology: high or low. By adopting high technology, firms can produce manufacturing goods at a lower marginal cost and however, need a higher fixed cost than firms that adopt low technology. A theoretical feature of our model is that such a fixed-cost level depends on the location in which the firm adopts high technology. We can analyze how the trade costs and productivity levels of technology determine firms' agglomeration patterns and technology choices by examining firms in equilibrium. In addition, we can analyze how exogenous changes of trade costs and productivity levels affect welfare levels of consumers in each country and obtain the implications of the reduction in trade costs for each country in the case of a technology gap. In equilibrium, the model shows that a technology gap arises when the trade cost is not too low and the productivity level of high technology is medium. In addition, we find that an increase in the productivity level of the high technology always decreases the welfare level in a country in which low technology us adopted, while it increases the welfare level of a country in which high technology is adopted. These results indicate that technology needs to improve with decreasing trade costs in order not to decrease the welfare level of the low-technology country.

Our model is based mainly on Martin and Rogers (1991), although they assume that all firms face an identical technology. We incorporate technology choice into their model. There are many theoretical studies that focus on differences in production technology in trade theory.[1] There is far less research on technology choice in the new trade theory. Yeaple (2005) and Bustos (2011) incorporate technology choice into their trade models in a similar way to ours. However, both of the previous studies focus on the technology gap within a country, which is generated from the heterogeneity of labor skills or a firm's ex ante productivity.[2] In our model, we analyze the effect of the technology gap between countries, while the previous studies are unable to discuss. Furthermore, we can discuss the effects of technological improvement on welfare levels, while mentioning the policy implications of trade liberalization.

The key to generate the technology gap between countries is that we represent the difference in productivity circumstances of adopting high technology on the fixed costs of increasing-return technology. Although fixed costs are identical in previous studies, in our model, there is a difference in the ease of entry because each country varies in terms of entry regulations, financial support, or the absorption costs of adopting new technology. By assuming such differences, we can focus on the relationship between adopted technology and the productivity environment represented by the degree of fixed-cost levels and we can obtain additional implications about the effects on economic performance.

The remainder of the paper is organized into four sections as follows. In Section 2, we present the model. In Section 3, we characterize equilibrium. In Section 4, we analyze the effects of a reduction in international trade costs and an increase in productivity on the welfare level of consumers, and derive the implications for technology innovation and trade liberalization. Section 5 concludes.

# 2 The model

There are two countries, called country 1 and 2. Variables referring to country 1 have the subscript 1, and those referring to country 2 have the subscript 2. Each country is endowed with a fixed amount of labor, $L_1$ and $L_2$, respectively.

We assume that agents in both countries obtain their utility from consumption of homogeneous agricultural goods and differentiated manufactured goods. Labor can be used to produce agricultural goods and differentiated manufactured goods. While labor can be mobile between sectors in the same country, it cannot be mobile between the two countries.

[1] Melitz's (2003) model, in which each firm faces uncertain productivity determined by its distribution, provides rationale for the widely observed phenomenon that only high-productivity firms export to foreign markets. Since then, many subsequent studies have accumulated: Baldwin and Okubo (2006), Bernard et al. (2003, 2007), and Melitz and Ottaviano (2008).They assume that the technology gap between firms is given by the distribution function.

[2] In Yeaple's (2005) model, firms choose both their individual production technologies and types of workers, which are explained as giving rise to the difference between exporters and non-exporters. Hence, the technology choices of firms change by the distribution of labor skills in equilibrium. Bustos (2013) incorporates technology choice into the trade model with heterogeneity of firms to test consistency empirically. The model explains that the technology gap within a country arises from firm heterogeneity.

## 2.1 Demand

The utility function of agents in country $i$ $(i = 1, 2)$ is given by

$$U_i = A_i + \mu \ln M_i, \tag{1}$$

where

$$M_i = \left[ \int_0^{n_i} m_{ii}(j)^{\frac{\sigma-1}{\sigma}} dj + \int_0^{n_{i'}} m_{i'i}(j')^{\frac{\sigma-1}{\sigma}} dj' \right]^{\frac{\sigma}{\sigma-1}}, \sigma > 1, \quad i, i' \in \{1, 2\}, \ i \neq i'. \tag{2}$$

Here, $A_i$ is consumption of the agricultural goods in country $i$, $M_i$ is consumption of a composite of the manufactured goods in country $i$, and $\mu$ is a weight on the utility from consumption of the manufactured goods. $m_{ii'}(j)$ denotes consumption of a variety $j$ of the manufactured good in country $i'$ produced in country $i$. $n_i$ is the number of varieties produced by a firm in country $i$. $\sigma$ represents the elasticity of substitution among differentiated goods.

The budget constraint of the agent in country $i$ becomes

$$y_i \geq \sum_{i'=1}^{2} \int_0^{n_{i'}} p_{i'i}(j) m_{i'i}(j) dj + A_i, \tag{3}$$

where $p_{ii'}(j)$ denotes the price of a variety $j$ of the manufactured goods in country $i'$ produced in country $i$ and $y_i$ denotes the income level in country $i$. We take homogeneous agricultural goods as the numeraire. Then, we can obtain the following demand functions

$$m_{i'i} = \frac{p_{i'i}(j)^{-\sigma}}{P_i^{1-\sigma}} \mu, \tag{4}$$

$$A_i = y_i - \mu, \tag{5}$$

$$P_i = \left[ \sum_{i=1}^{2} \int_0^{n_i} p_{i'i}(j)^{1-\sigma} dj \right]^{\frac{1}{1-\sigma}}, \tag{6}$$

where $P_i$ stands for the "price index" in country $i$.

## 2.2 Production

Each good is produced by using only labor and each worker has one unit of labor. We describe the production structure of the agricultural sector. The agricultural goods market is perfectly competitive and taken as a numeraire. We assume that in both countries, one unit of agricultural goods is produced with one unit of labor and that the international trade of homogeneous goods incurs no trade costs. Therefore, the equilibrium wages in the two countries are $w_1 = w_2 = 1$. Because we assume free entry into the manufacturing sector, profits in the sector become zero, and therefore, income is equal to the wage, that is, $y_i = w_i = 1$.

### 2.2.1 Manufacturing sector and technology choice

In the manufacturing sector, monopolistic competition prevails and each firm produces a differentiated good. There are two types of technologies for producing each variety of manufacturing goods. The amount of goods a worker can produce is given by $a_z$, $z \in \{H, L\}$. z is an index to indicate the adopted technology for production. $z = H$ refers to high technology for producing manufacturing goods, and $z = L$ refers to low technology for producing the same goods. High technology is more productive than low technology, that is, $a_H > a_L = 1$.

To produce with technology $z \in \{H, L\}$ in country $i$, a firm in country $i$ is required to pay a fixed cost $f_i^z$. Since we consider low technology to be old or well known, the fixed cost of adopting it is assumed to be

$$f_1^L = f_2^L \equiv f_L. \tag{7}$$

That is, the firms in both countries incur the same level of fixed cost if they adopt the technology $L$. On the other hand, for high technology, we assume that the level of such a fixed cost depends on which technology the firm employs and which country it locates in, as follows

$$f^L < f_1^H < f_2^H. \tag{8}$$

The first inequality means that high technology is more costly. The firms bear a large cost to adopt the high technology because it incurs large equipment investment, payment of license fees, and so on. The second inequality represents differences in productivity circumstances for high technology between the countries because of differences in support systems by governments, such as subsidies to adopt high technology, infrastructure development, and absorption of costs in a skill-abundant country versus one with scarce skills. In other words, we assume that country 1 has an advantage in introducing technology $H$ over country 2. This assumption represents a differing degree-of-entry barrier between one country and another and is key for generating a technology gap between the countries.

Potential firms can enter production activities freely as long as their profits are positive and they can choose to employ a more profitable technology. Each manufacturing firm faces the demand function, (4) and thus sets the following constant markup price

$$p_{11}^z = p_{22}^z = \frac{\sigma}{(\sigma - 1)a_z}, \tag{9}$$

where $p_{ii}^z$ denotes the price of the manufactured good in country $i$ produced in country $i$ by technology $z$. The international trade of manufactured goods incurs "iceberg"-type trade costs. If a firm in one country sends one unit of its good to the other country, it must dispatch $\tau$ units of the good. $\tau - 1 > 0$ represents the trade costs. Thus, the price of imported manufactured goods in country $i$ becomes $\tau p_{ii'}$ and $i \neq i'$. Thus, the price index in country $i$ can be written as

$$P_i = \frac{\sigma}{\sigma - 1} \left[\alpha n_i^H + n_i^L + \varphi(\alpha n_{i'}^H + n_{i'}^L)\right]^{\frac{1}{1-\sigma}}, \; i, i' \in \{1, 2\}, \; i \neq i', \tag{10}$$

where $\varphi \equiv \tau^{1-\sigma}$ and $\alpha \equiv a_H^{\sigma-1}$. $\varphi$ represents the freeness of trade. $\varphi = 0$ corresponds to the case of autarky, whereas $\varphi = 1$ implies free trade. In other words, increasing $\varphi$ means trade liberalization. $\alpha$ corresponds to the gap of productivity between technologies and $\alpha \geq 1$. From Eqs. (4) to (9), profits of a firm in countries 1 and 2 can be expressed as follows

$$\pi_i^H = \frac{\mu\sigma^{-\sigma}\alpha}{(\sigma-1)^{1-\sigma}} \left( L_i P_i^{\sigma-1} + \varphi L_{i'} P_{i'}^{\sigma-1} \right) - f_i^H \tag{11}$$

$$\pi_i^L = \frac{\mu\sigma^{-\sigma}}{(\sigma-1)^{1-\sigma}} \left( L_i P_i^{\sigma-1} + \varphi L_{i'} P_{i'}^{\sigma-1} \right) - f^L. \tag{12}$$

# 3 Equilibrium

In equilibrium, agglomeration patterns and technology choices are determined by the two parameters, $\alpha$ and $\varphi$. In this section, we analyze how firms choose the technologies and derive the equilibrium number of firms, with close attention to the existing conditions of firms in both countries.

Although in practice firms in the same country can choose either technology for production, in our model, each firm in a country chooses the same technology in equilibrium because of the homogeneity of firms. Which technology it chooses mainly depends on the productivity level of the high technology relative to the fixed costs of the high technology adopted in the country. Specifically, technology choice by firms in country $i$ depends on whether the productivity level $\alpha$ is greater than the relative fixed costs of the technologies, $\frac{f_i^H}{f^L}$. We can summarize this as the following lemma

**Lemma 1**

1. *If $\alpha < \frac{f_1^H}{f^L}$, then all firms in countries 1 and 2 choose technology $L$.*
2. *If $\frac{f_1^H}{f^L} < \alpha < \frac{f_2^H}{f^L}$, firms in country 1 adopt technology $H$ whereas firms in country 2 adopt technology $L$.*
3. *If $\frac{f_2^H}{f^L} < \alpha$, then all firms choose technology $H$.*

**Proof.** See Appendix A.

We can categorize specialization of technology into three cases according to $\alpha$ from Lemma 1. When $\alpha$ is sufficiently low($\frac{f_1^H}{f^L} > \alpha$), all firms choose technology $L$ (low technology case). This case is consistent with the results of Helpman and Krugman (1985). On the other hand, when $\alpha$ takes moderate value, firms in country 1 adopt technology $H$ whereas firms in country 2 adopt technology $L$. In this case, a technology gap exists between the countries (technology gap case). When $\alpha$ is sufficiently high, all firms in both countries choose technology $H$ since adopting technology $H$ is profitable in both countries (high technology case).

In what follows, we derive the equilibrium number of manufactured goods (firms) when $\frac{f_1^H}{f^L} < \alpha < \frac{f_2^H}{f^L}$.[3] To focus on a clear and interesting case, we consider $L_1 > L_2$.[4]

As in the previous literature, the freeness of trade determines whether partial agglomeration equilibrium or full agglomeration occurs. Partial agglomeration arises when the following holds

$$\pi_1^H = \pi_2^L = 0. \tag{13}$$

The price index in this case becomes

$$P_1 = \frac{\sigma}{\sigma - 1}(\alpha n_1^H + \varphi n_2^L)^{\frac{1}{1-\sigma}}$$

$$P_2 = \frac{\sigma}{\sigma - 1}(n_2^L + \varphi \alpha n_1^H)^{\frac{1}{1-\sigma}}.$$

Thus, free-entry condition (13) can be rewritten as

$$\frac{\mu\alpha}{\sigma}(\frac{L_1}{\alpha n_1^H + \varphi n_2^L} + \frac{\varphi L_2}{n_2^L + \varphi \alpha n_1^H}) = f_1^H \tag{14}$$

$$\frac{\mu}{\sigma}(\frac{L_2}{n_2^L + \varphi \alpha n_1^H} + \frac{\varphi L_2}{\alpha n_1^H + \varphi n_2^L}) = f^L. \tag{15}$$

Dividing (14) by (15), we obtain the relationship between $n_1^H$ and $n_2^L$ as follows

$$n_1^H = \frac{\mu[\varphi(L_1 + L_2)f_1^H - (L_1 + \varphi^2 L_2)f^L \alpha]}{\alpha[\varphi(L_1 + L_2)f^L \alpha - (\varphi^2 L_1 + L_2)f_1^H)]} n_2^L. \tag{16}$$

The numerator of Eq. (16) is always negative but the sign of the denominator depends on $\varphi$. Therefore, the denominator must be negative in equilibrium; that is, the following inequality must hold[5]

$$\varphi(L_1 + L_2)f^L \alpha < (\varphi^2 L_1 + L_2)f_1^H. \tag{17}$$

We define $\varphi(\alpha)$ as follows,

$$\varphi(\alpha)(L_1 + L_2)f^L \alpha = (\varphi^2 L_1 + L_2)f_1^H. \tag{18}$$

$\varphi(\alpha)$ defines a relationship between $\alpha$ and $\varphi$ that is satisfied when (17) holds as an equality. If $\varphi < \varphi(\alpha)$, Eq. (17) can hold and the manufacturing firms locate in both countries in equilibrium.[6] From Eq. (16) and the free-entry condition $\pi_1 = 0$, we can obtain the number of manufacturing firms locating in country 2 as follows

$$n_2^L = \frac{\mu\alpha[\varphi(L_1 + L_2)F^L \alpha - (\varphi^2 L_1 + L_2)f_1^H]}{\sigma(f^L \alpha - f_1^H \varphi)(f^L \alpha \varphi - f_1^H)}. \tag{19}$$

[3]Similarly, we can derive other cases. See Appendix B.

[4]Similarly, we can discuss the other cases, in which $L_1 \leq L_2$.

[5]If Eq. (17) does not hold, that is $\pi_1^H > \pi_2^L$, then the firms agglomerate to country 1 in equilibrium. In other words, when $\varphi$ is too high, the full agglomeration arises.

[6]When $\varphi \leq \varphi(\alpha)$, all manufacturing firms locate in country 1.

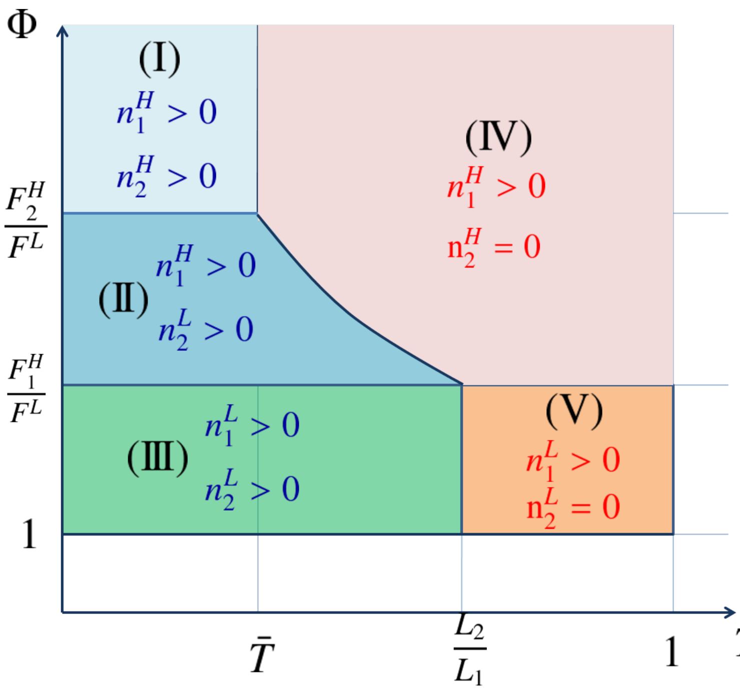


Figure 1: The patterns of location and technology choice

Hence, we obtain the Eq. (20) of manufacturing firms locating in country 1 as follows,

$$n_1^H = \frac{\mu[\varphi(L_1 + L_2)f_1^H - (L_1 + \varphi^2 L_2)f^L\alpha]}{\sigma(f^L\alpha - f_1^H\varphi)(f^L\alpha\varphi - f_1^H)}. \tag{20}$$

We can summarize the preceding arguments as follows

**Proposition 1** *A technology gap exists between countries if the following inequalities are satisfied*

$$\frac{f_1^H}{f^L} < \alpha < \frac{f_2^H}{f^L}$$

$$\varphi < \varphi(\alpha)$$

*In this case, partial agglomeration equilibrium arises and firms locating in country 1 employ technology H and firms in country 2 employ technology L.*

This proposition indicates that when the productivity of high technology is not sufficiently high and it is costly to trade goods, a technology gap exists.

As mentioned before, the type of technology that firms in each country adopt and whether full agglomeration arises depend on the relationship between $\varphi$ and $\alpha$. Hence, this can be summarized as shown in Figure 1. The vertical axis represents the productivity level $\alpha$ of technology H ($\alpha > 1$). The horizontal axis represents the freeness of trade, $\varphi$ ($0 < \varphi < 1$). Figure 1 shows how these parameters affect equilibrium and how the technology choice and agglomeration of firms depend on $\alpha$

and $\varphi$. From Proposition 1, the technology gap case arises when the combination of $\alpha$ and $\varphi$ is in the domain (Ⅱ).

As $\varphi$ becomes larger, full agglomeration tends to arise. Two factors affect the agglomeration pattern: the difference in market size and the fixed costs of adopting high technology in each country. In the low productivity case, only the difference in market size generates agglomeration power since firms face the same level of fixed costs. However, we start from the point at which both $\alpha$ and $\varphi$ are low enough to be in (Ⅲ). Increasing the productivity level $\alpha$ from the starting point to a medium level, only firms in country 1 change to the high-technology type. When $\alpha$ reaches a high level in (I), firms in country 2 catch up with the high-technology type.

Next, we analyze the effects of a change in the productivity level of high technology on the number of manufacturing firms. Differentiating $n_1^H$ and $n_2^L$ with respect to $\alpha$, we can obtain the following derivatives

$$\frac{\partial \ln n_1^H}{\partial \alpha} = f^L \varphi \left[ \frac{(\varphi^2-1)L_2 f_1^H}{[\varphi(L_1+L_2)f_1^H - (L_1+\varphi^2 L_2)f^L\alpha][f^L\alpha - f_1^H\varphi]} - \frac{\varphi}{f^L a_H^{\sigma-1}\varphi - f_1^H} \right] > 0$$

,

$$\frac{\partial \ln n_2^L}{\partial \alpha} = \frac{\varphi(L_1+L_2)f^L}{\varphi(L_1+L_2)f^L\alpha - (\varphi^2 L_1 + L_2)f_1^H} + \frac{\varphi(f^L\alpha + f_1^H)(f^L\alpha - f_1^H)}{\alpha(f_1^H - f^L\alpha\varphi)(f^L\alpha - f_1^H\varphi)} < 0.$$

Therefore, the following proposition can be obtained

**Proposition 2** *Productivity improvement of technology H increases the number of manufacturing firms locating in country* 1 *that adopt high technology but decreases the number of manufacturing firms in country* 2 *that adopt low technology.*

We provide an intuition as follows. Technology improvement increases the profit of firms locating in country 1 because improvement can reduce the marginal cost of adopting high technology; then, more manufacturing firms enter country 1.

# 4 Welfare Analysis

In this section, we examine the welfare effects of trade liberalization and technology improvement, which correspond to increases in $\varphi$ and $\alpha$. In addition, we analyze the comparative statics of these parameters. We focus on the case in which the technology adopted differs between countries.

First, substituting Eq. (4) into Eq. (1), we obtain the following indirect utility functions in the countries

$$V_1 = 1-\mu+\mu[\ln\frac{\mu(\sigma-1)}{\sigma}] + \frac{1}{\sigma-1}\ln\frac{\mu\alpha(1-\varphi^2)L_1}{\sigma(f_1^H - f^L\alpha\varphi)} \tag{21}$$

$$V_2 = 1-\mu+\mu[\ln\frac{\mu(\sigma-1)}{\sigma}] + \frac{1}{\sigma-1}\ln\frac{\mu\alpha(1-\varphi^2)L_2}{\sigma(f^L\alpha - f_1^H\varphi)}. \tag{22}$$

We can conduct the welfare analysis based on these indirect utility functions.

## 4.1 The effect of trade liberalization

Trade liberalization signals falling trade costs $\tau$(increasing $\varphi$). By differentiating Eq. (21) and (22) with respect to $\varphi$, we can obtain the following equations

$$\frac{\partial V_1}{\partial \varphi} = \frac{\mu[(\varphi^2+1)f^L\alpha - 2\varphi f_1^H]}{(\sigma-1)(1-\varphi^2)(f_1^H - f^L\alpha\varphi)} > 0$$

$$\frac{\partial V_2}{\partial \varphi} = \frac{\mu[(\varphi^2+1)f_1^H - 2\varphi f^L\alpha]}{(\sigma-1)(1-\varphi^2)(f^L\alpha - f_1^H\varphi)} > 0.$$

The second equation is satisfied because the following inequality must be satisfied in the equilibrium,

$$\alpha < \frac{(\varphi^2+1)f_1^H}{2\varphi f^L}.$$

In addition, we analyze the effect on the welfare gap between countries. By taking the difference between Eqs. (21) and (22) and differentiating it with respect to $\varphi$, we obtain

$$\frac{\partial(V_1^H - V_2^L)}{\partial \varphi} = \frac{(f^L\alpha)^2 - (f_1^H)^2}{(f^L\alpha - f_1^H\varphi)(f_1^H - f^L\alpha\varphi)} > 0.$$

Therefore, the result can be summarized as follows.

**Proposition 3** *Falling trade costs increase the welfare levels in both countries and widen the welfare gap between the countries*

This is because falling trade costs decrease the prices of all imported manufacturing goods, which increases their consumption. Hence, this increases the welfare level of all consumers.

## 4.2 The effect of technology improvement

Next, we analyze the effects of technology improvement in the case of a technology gap. We assume that technology improvement increases the productivity of the high-technology type, which corresponds to increasing $\alpha$. Differentiating Eqs. (21) and (22) with respect to $\alpha$, we obtain the following

$$\frac{\partial V_1}{\partial \alpha} = \frac{\mu}{\sigma-1}[\alpha^{-1} + \frac{f^L\varphi}{f_1^H - f^L\alpha\varphi}] > 0 \tag{23}$$

$$\frac{\partial V_2}{\partial \alpha} = \frac{-\mu f_1^H\varphi}{\alpha(f^L\alpha - f_1^H\varphi)} < 0 \tag{24}$$

because $\frac{f_1^H}{f^L} < \alpha < \frac{f_2^H}{f^L}$ and (17) hold.

**Proposition 4** *In the technology-gap case, by increasing the productivity of the high-technology type, the welfare of a consumer in country* 1 *increases and that of a consumer in country* 2 *decreases.*

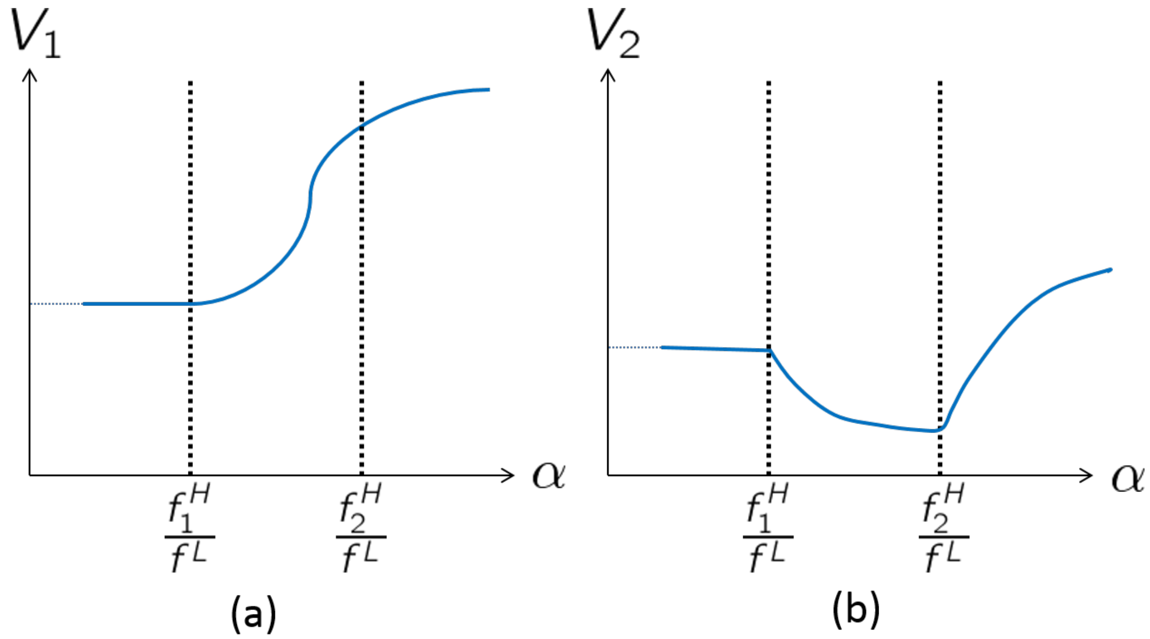


Figure 2: relationship between welfare and productivity

As well as the technology-gap case, we derive the welfare effect of the other cases in the Appendix. Hence, we present the relationship between productivity and the indirect utility for any $\alpha$ as shown in Figure 2.

Figure 2(a) shows that improving the productivity of technology $H$ always increases the welfare level of consumers in country 1. On the other hand, Figure 2(b) shows that the welfare level of consumers in country 2 decreases when the productivity level of technology $H$ is at medium levels. In this case, the welfare of country 2 is always lower than the case when productivity is low. Why does this occur? The reason is because increasing $\alpha$ has positive and negative effects on the consumption level of goods produced in each country. The positive effect arises from an increase of total demand of manufacturing goods produced in country 1. The negative effect rises from a decrease of total demand of manufacturing goods produced in country 2. Whether technology improvement increases welfare depends on which effect is larger for consumers in each country. For consumers in country 2, an increase of $\alpha$ decreases the total demand of domestic goods, which are consumed without incurring trade costs, and increases the total demand of imported goods, which do incur trade costs. Hence, the former (negative) effect is larger than the latter (positive) one. Conversely, country 1 has more benefits from an increase of domestic goods than a decrease of imported goods. Comparing the welfare level in country 2 between specialization patterns, Figure 2(b) also shows that the welfare level of the technology-gap case is always lower than that of the low-technology case ($\alpha < \frac{f_1^H}{f^L}$). Even if productivity becomes so high that firms in country 2 can employ technology $H$(high technology case), there exists an area in which the welfare level in country 2 is still lower than that of the low-technology case($\alpha$ is slightly larger than $\frac{f_2^H}{f^L}$). This implies that technology innovation works better for consumers in a high-technology country, but if the technology level is medium, then, a small improvement of the high-technology type makes those in low-technology country poorer by the presence of trade cost. From Proposition 1 and 2, we show that increasing $\alpha$ has a negative effect on welfare in country 2, which is opposite to decreasing trade costs. Therefore, decreasing trade costs can avoid the formation of U-shaped indirect utility in country 2. By total differentiation of (22), we obtain the following proposition.

**Proposition 5** *To compensate for the welfare loss in country 2 from technology improvement, trade costs have to be reduced by the following amount*

$$\frac{d\varphi}{d\alpha} = \frac{\varphi(1-\varphi^2)}{\alpha[\alpha(1+\varphi^2)f^L - 2\varphi f_1^H)]}(< 0).$$

This proposition implies the importance of trade liberalization to keep the welfare level in country 2 high. In particular, trade costs need to be reduced more if $\alpha$ is slightly larger than $\frac{f_1^H}{f^L}$, which is the threshold at which firms in country 1 change the technology into a high type, since the above equation decreases with $\alpha$. In addition, this result indicates that the low-technology country has a stronger incentive to promote trade liberalization in order to keep the welfare level when its technology is less developed. From Proposition 3, trade liberalization always works better for the welfare of both the countries. Thus, with regard to the policy impacts on social welfare, we should consider not only technology innovation but also trade liberalization.

# 5 Concluding remarks

In this study, we explain the relationship between the productivity level of technology and technology choice when fixed costs differ between countries. In addition, we examine how technology innovation affects the technology choice of firms and the welfare levels of consumers. Furthermore, we consider the effects of trade liberalization on location choice and welfare levels. We develop a simple two-country trade model with technology choice. Firms can choose a technology from two types (high or low) and the number of firms is determined through free entry. The productivity of the high-technology type is higher than that of the low-technology type, and high technology is more costly than low technology. Moreover, we assume that there is a large country and a small country, and that high technology employed in the large country is made available at a lower cost than the same technology type in the small country. The latter assumption means that a large country has an advantage in adopting high technology.

We find that in the equilibrium, firms locating in the developed country employ higher technology and firms locating in the developing country employ lower technology. In addition, we find that improving the productivity of higher technology does not always improve consumer welfare in both counties. In particular, when the productivity level of the high-technology type is medium, the welfare of a consumer in the small country decreases with a small technological improvement.

Finally, we comment on directions for future work. In this study, we analyze a static trade model. In the future, we will extend this model to a dynamic model in which the productivity of technology varies through time. In this paper, the effect of investment on R&D is not considered, but such an extension should be investigated.

# Appendix

# A Proof of Lemma 1

Assume a case in which firms in country 1 employ technology $H$. Then, $\pi_1^H = 0$ must be satisfied, that is, Eq. (11) is rewritten as follows

$$\frac{\mu\sigma^{\sigma-1}}{\sigma-1}(L_1P_1^{\sigma-1}+\varphi L_2P_2^{\sigma-1})\alpha = f_1^H. \tag{25}$$

Substituting (25) into (12), we can rewrite Eq. (12) as follows

$$\pi_1^L = \frac{f_1^H}{\alpha} - f^L. \tag{26}$$

If $\alpha \leq \frac{f_1^H}{f^L}$, the right-hand side of (26) is always positive, which induces firms to employ technology L. Hence, this contradicts the case in which all firms employ technology H. Therefore, $\frac{f_1^H}{f^L} < \alpha$ must be satisfied. Next, assuming that $\pi_1^L = 0$, the following equation is satisfied

$$\frac{\mu\sigma^{\sigma-1}}{\sigma-1}(L_1P_1^{\sigma-1}+\varphi L_2P_2^{\sigma-1}) = f^L. \tag{27}$$

Substituting (27), we can rewrite Eq. (11) as follows

$$\pi_1^H = f^L\alpha - f_1^H. \tag{28}$$

Employing the same argument above, we can show that $\alpha < \frac{f_1^H}{f^L}$ must be satisfied. Similarly, the same fact for country 2 can be shown in the same way.

# B Cases other than $\frac{f_1^H}{f^L} < \alpha < \frac{f_2^H}{f^L}$

When $\alpha < \frac{f_1^H}{f^L}$ holds, any firm employs technology L because the productivity of technology is not high enough to recover the fixed cost of technology H. Therefore, this case is consistent with Helpman and Krugman (1985). When $\frac{f_2^H}{f^L} < \alpha$ holds, any firm employs technology H because the productivity of technology H is high enough to recover its fixed cost. If $\pi_1^H > \pi_2^H$, $n_1^H > 0$ and $n_2^H = 0$ are in equilibrium. From Eq. (11),

$$n_1^H = \frac{\mu}{\sigma f_1^H}(L_1+L_2)$$

holds. Substituting it into Eq. (12), T must satisfy the following equation

$$\pi_2^H = \frac{(\varphi^2 L_1 + L_2) f_1^H - \varphi(L_1 + L_2) f_2^H}{\varphi(L_1 + L_2)} < 0. \tag{29}$$

Let $\bar{\varphi}$ satisfy the left-hand side of Eq. (29) is equal to zero. When $\varphi > \bar{\varphi}$, $n_1^H > 0$ and $n_2^H = 0$ is the equilibrium. Hence, we assume that $\varphi < \bar{\varphi}$. From free-entry conditions, we consider the following equations

$$\pi_1^H = \pi_2^H = 0.$$

The relationship between $n_1^H$ and $n_2^H$ is given by

$$n_1^H = \frac{\varphi(L_1 + L_2) f_1^H - (L_1 + \varphi^2 L_2) f_2^H}{\varphi(L_1 + L_2) f_2^H - (\varphi^2 L_1 + L_2) f_1^H} n_2^H. \tag{30}$$

Then, substituting (30) into the free-entry condition $\pi_1^H = 0$, we can obtain the number of manufacturing firms locating in country 1 and country 2 by

$$n_1^H = \frac{\mu\varphi(L_1 + L_2) f_1^H - (L_1 + \varphi^2 L_2) f_2^H}{\sigma(f_2^H - f_1^H \varphi)(f_2^H \varphi - f_1^H)} \tag{31}$$

,

$$n_2^H = \frac{\mu\varphi(L_1 + L_2) f_2^H - (\varphi^2 L_1 + L_2) f_1^H}{\sigma(f_2^H - f_1^H \varphi)(f_2^H \varphi - f_1^H)}. \tag{32}$$

In this case, the number of firms is independent from $a$.

# C Derivation of Figure 2

When $\alpha < \frac{f_1^H}{f^L}$ holds, all firms employ L technology. Then, indirect utility is obtained as follows

$$V_1 = 1 - \mu + \mu[\ln \frac{\mu(\sigma - 1)}{\sigma} + \frac{1}{\sigma - 1} \ln \frac{\mu(1 + \varphi) L_1}{\sigma f^L}], \tag{33}$$

$$V_2 = 1 - \mu + \mu[\ln \frac{\mu(\sigma - 1)}{\sigma} + \frac{1}{\sigma - 1} \ln \frac{\mu(1 + \varphi) L_2}{\sigma f^L}]. \tag{34}$$

This implies that the welfare level is independent from $\alpha$ because no firm employs H technology. When $\frac{f_1^H}{f^L} < \alpha < \frac{f_2^H}{f^L}$, firms locating in country 1 employ H technology and firms locating in country 2 employ L technology. Then, indirect utility is obtained as follows

$$V_1 = 1 - \mu + \mu[\ln \frac{\mu(\sigma - 1)}{\sigma} + \frac{1}{\sigma - 1} \ln \frac{\mu(1 - \varphi^2) L_1 \alpha}{\sigma(f_1^H - f_2^H \varphi)}], \tag{35}$$

$$V_2 = 1 - \mu + \mu[\ln \frac{\mu(\sigma - 1)}{\sigma} + \frac{1}{\sigma - 1} \ln \frac{\mu(1 - \varphi^2) L_2 \alpha}{\sigma(f_2^H - f_1^H \varphi)}]. \tag{36}$$

Considering the effect of an increase in $\alpha$, we derive the following equations

$$\frac{\partial V_1}{\partial \alpha} = \frac{\partial V_2}{\partial \alpha} = \mu\alpha^{-1} > 0, \tag{37}$$

$$\frac{\partial^2 V_1}{\partial \alpha^2} = \frac{\partial^2 V_2}{\partial \alpha^2} = -\mu\alpha^{-2} < 0. \tag{38}$$

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