# Regional agglomeration and transfer of pollution reduction technology under the presence of transboundary pollution*

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**Abstract**

This paper presents analyses of effects of technology transfer to reduce pollution caused by regional agglomeration with transboundary pollution. Analyses use a model extended by introducing an inter-regional pollution-reduction technology gap and transboundary pollution into the model of Ottaviano, Tabuchi, and Thisse (2002). It is insufficient to analyze transboundary pollution problems such as that of acid rain within one region to determine prescriptions for it. Such a problem must be considered within the economic system because most pollution is produced through various economic activities. Recently, various factors in addition to pollution have become mobile between regions because of the disappearance of economic borders. Therefore, we consider those environmental problems using a core-periphery model, which is solvable analytically as the effect of pollution reduction technology transfer on regional agglomeration. Results of analysis using this model are that, first it is possible to relax agglomeration by pollution-reduction technology transfer when the transportation cost of manufactured goods is high. Second, technology transfer of pollution reduction does not affect regional agglomeration when the rate of transitory pollution between regions is large. Thirdly, such technological transfer can promote agglomeration when both the transportation cost and the rate of transboundary pollution between regions are low.

**Key words: agglomeration, transboundary pollution, technology transfer**

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# 1 Introduction

This paper presents analyses of effects of technology transfer to reduce pollution caused by regional agglomeration with transboundary pollution. The analyses use a model extended by introducing an inter-regional pollution-reduction technology gap and transboundary pollution into the model presented by Ottaviano, Tabuchi, and Thisse (2002). Many countries have expressed interest in environmental problems such as global warming and have argued for environmental policy, but single countries cannot find effective solutions because environmental policy involves and affects not only the environmental characteristics and processes in one region; it affects and involves various sectors aside from the environment. Although "The Kyoto Protocol" was adopted at the third session of the Conference of the Parties (COP3) to the United Nations Framework Convention on Climate Change (UNFCCC) held in Kyoto, Japan, in December 1997, numerous countries have taken a long time to ratify and adopt obligations for reduction of greenhouse gas emissions. Eventually, the treaty came into effect in February 2005. For example, Japan, a developed country, has committed to reducing its emissions by 6% from base-year emissions, but such a reduction obligation is not imposed on developing countries. In many cases, because of the pollution's inherent properties, environmental problems cannot be solved through environmental policies intended and undertaken only for particular regions where the pollution is emitted. Pollution and acid rain are transboundary types of pollution for which the party of origin differs from the affected party. Air pollution and acid rain are types of transboundary pollution. Therefore, they affect not only the region of origin, but also regions aside from the region of origin. Consequently, the environmental policy for the region of origin is not often effective for all regions. Acid rain, which rose to prominence as an environmental issue in the 1950s in the EU, is exemplary. Many countries regard support for environmental problems in other regions as important. Moreover, it is difficult for some developed countries whose pollution reduction technologies are well-developed to reduce pollution further. In such cases, those countries' support for transfer of reduction technologies to developing countries and attempts to account for the reduced pollution there as reduced pollution in their own countries (CDM mechanism). Figure 1 portrays the total Japanese ODA and the ratio of environmental policy to the total sum. As presented in Fig. 1, support for the environment occupies 30% of all Japanese ODA.

As Fig. 1 shows, the environment is regarded as important among efforts for support of developing countries using Japanese ODA. Consequently, the presentation of theoretical grounds is necessary to demonstrate the validity of support by ODA. Because most environmental problems result from various economic activities, it is insufficient to argue merely for environmental policy goals without consideration of other factors: trade, factor mobility, and so on. A policy must be drafted for a world environment where economic boundaries between countries have disappeared and the mobility of goods and production factors have become simplified.

Many models incorporating spatial mobility of goods or production factors have been constructed in a new economic geography (NEG) mode. Particularly,

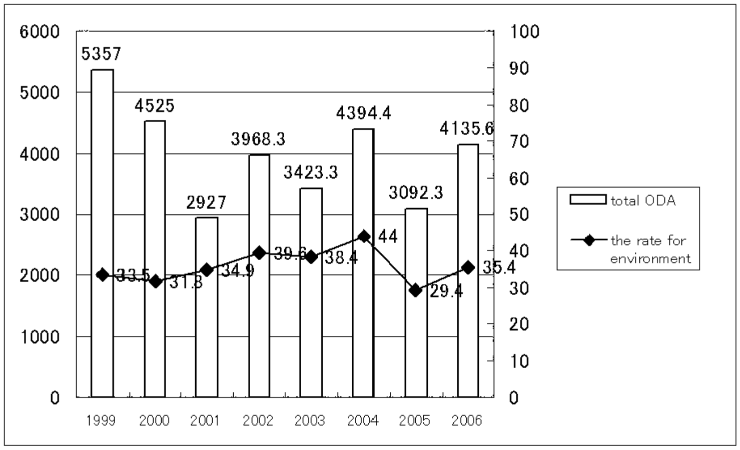


Figure 1: Total ODA and rate of environmental policy in Japan:
(**Source**) Homepage of the Ministry of Foreign Affairs in Japan

after formulating monopolistic competition by Dixit and Stiglitz (1978), many models introducing monopolistic competition have been constructed in urban economics or spatial economics. Krugman (1991) explained regional agglomeration theoretically with a simple model introducing monopolistic competition and describing increasing returns to scale. Krugman (1991), and Fujita, Krugman, and Venables (1999) have contributed to the new economic geography and constructed their models incorporating nonlinear general equilibrium systems. They derived the equilibrium through numerical analyses using computers. Moreover, a limit exists by which the mark up rate is constant in the model, although their formulation with a Dixit–Stiglitz type based on CES utility function includes income effects. Those models derive the equilibrium using computer calculations, whereas some studies have been undertaken to construct model that is solved analytically without changing the basic framework. Ottaviano, Tabuchi, and Thisse (2002) constructed a model that uses not the CES utility function, but rather a quasi-linear utility function to derive the equilibrium analytically. The Ottaviano, Tabuchi, and Thisse model (hereinafter OTT model) posits each firm's profit maximizing price as a decreasing function with respect to varieties and can solve the model analytically, although no income effect exists in their model. Consequently, it is possible to compare the equilibrium with the optimum using the OTT model.

Some studies extend the core–periphery model formulated by Krugman (1991), Fujita, Krugman, and Venables (1999) by introducing various factors into their models. For example, Tabuchi (1998) introduced a core–periphery model into a land market. In the core–periphery model, centripetal force is explained by preference of variety and centrifugal force is modeled as a transportation cost or competition among firms. A decrease of transportation costs attributable to improvement of transportation technology engenders weakened centrifugal force and agglomeration of population and firms in one region. However, it is also important to consider centrifugal forces aside from these forces and agglomeration diseconomies such as pollution and congestion. Some studies have been undertaken specifically to examine those diseconomies of agglomeration. Tabuchi (1998) considers competition as centrifugal force, and Naito (1999) characterizes transportation congestion similarly. Although it is important to consider these factors as diseconomies of agglomeration, it is also necessary to consider environmental factors. Hosoe and Naito (2006) combined Copeland and Taylor (1999) with a core-periphery model to analyze effects of polluting externalities on regional agglomeration.

Some researchers have introduced environmental factors into models in international economics and analyzed the effects of those factors on models. For example, Copeland and Taylor (1999) consider a two-sector model in which pollution caused by one sector affects the productivity of another sector. They analyze production in each country along with social welfare. Unteroberdoerster (2001) extended Copeland and Taylor (1999) to model transboundary pollution. Moreover, Hosoe and Naito (2006) consider the effect of transboundary pollution in a core–periphery model on regional agglomeration or effectiveness of environmental policy and show that the stability of the population distribution depends not only on the transportation cost but also on the amount of transboundary pollution between regions. However, Hosoe and Naito (2006) assume that reduction technologies of pollution in both regions are symmetric and consider not direct regulation but regulation via tariffs as environmental policy. Ikazaki and Naito (2008) introduced damage caused by pollution into Yamamoto (2005), which analyzed the relation between agglomeration and technological conversion in intermediate goods sector and explained the Environmental Kuznets Curve under optimal taxation and the Environmental Kuznets Curve, which is shown by many empirical studies to have an inverted U-shape with respect to economic growth, results from technological conversion in a theoretical model. Moreover, many papers describe technology transfer between regions. For instance, Ito and Tawada (2003) and Takarada (2005) consider technology transfer of pollution reduction in the framework of Copeland and Taylor (1999). Our model follows those settings in relation to pollution reduction technology transfer.

We follow not a core–periphery model using the CES utility function, such as that of Hosoe and Naito (2006) or Ikazaki and Naito (2008), but one using a quasi-linear utility function, such as the OTT model, which takes account of transboundary pollution and asymmetrical reduction technology of pollution, and analyzes the effect of technology transfer of pollution reduction on regional agglomeration. Consequent to our analysis, we show that technology transfer does not always affect regional agglomeration.

This paper is organized along the following lines. First, we present a basic model of a two-sector-one region economy and describe the respective behaviors of the sectors. In section 3, we derive the short-run equilibrium, where labor is immobile between regions. Section 4 analyzes the long-run equilibrium, where laborers are mobile between regions, and the effect of technology transfer on regional agglomeration. Finally, we conclude this paper and present some points that are not discussed in the text and suggest some that remain as future subjects for examination.

## 2 The model

We consider a model with two sectors and two regions. The economy comprises agricultural goods, manufactured goods, and two regions (region $H$ and region $F$). The agricultural good, labeled as $A$, is produced with constant returns to scale for a perfectly competitive market. Here we assume that this agricultural good is numeraire. The workers, who are the only production factor and who are always immobile between regions, are distributed equally in each region. In fact, $A/2$ workers reside in each region because they assume the total number of workers as $A$. Manufactured goods are discriminated and face a monopolistic competitive market. The number of total laborers in the economy is $L$ and the quantities of labor in region $H$ and region $F$ are, respectively, $\lambda L$ and $(1-\lambda)L$. Although laborers in each region are immobile between regions in the short run, they are mobile between regions in the long run. In the long run, laborers can move to the region in which they achieve higher utility. Regarding transportation costs, agricultural goods can be shipped without transportation cost, but the transportation of manufactured goods between regions requires $\tau$ units agricultural goods.

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### 2.1 Household

Presuming that households are homogeneous, all households have the same utility function. Here we set up the household's utility function in region $l(=H,F)$ as follows:[1]

$$U_l = \alpha \int_0^N q(i)di - \frac{\beta-\gamma}{2}\int_0^N [q(i)]^2 di - \frac{\gamma}{2}\left[\int_0^N q(i)di\right]^2 + q_0 - \delta_3 D_l^2, \quad (1)$$

where $q(i)$ and $q_0$ respectively represent the consumption of variety $i(i \in (0,N))$ and the endowment of agricultural goods. Parameters in (1) are satisfied with $\alpha > 0$, $\beta > \gamma > 0$. In addition, $\alpha$, $\beta > \gamma$, and $N$ represent the degree of preference for discriminated manufactured goods based on the number of varieties. Moreover, as for environmental damage, $D_l$ means the total pollution which households in region $l$ suffer and $\delta_3$ is the parameter of disutility caused by pollution, which depends on the reduction technology in each region. Households deal with this pollution level as given and cannot control its level by themselves. Households have a unit of labor and $\bar{q}_0$ units of agricultural goods as endowments. Letting $p(i)$ represent the price of manufactured goods variety $i$, the budget constraint is given as

$$\int_0^N p(i)q(i)di + q_0 = y + \bar{q}_0. \quad (2)$$

[1] In our model, the utility function follows the OTT model

Substituting (2) into (1) and solving the maximization for utility with respect to $q(i)$, the first order condition is given as

$$\alpha - (\beta - \gamma)q(i) - \gamma \int_0^N q(j)dj = p(i), \quad for \quad i \in [0, N]. \tag{3}$$

Therefore, we can derive the demand function of variety $i \in (0, N)$ from (3) as

$$q(i) = a - bp(i) + c \int_0^N [p(j) - p(i)]dj, \quad for \quad i \in [0, N], \tag{4}$$

where $a \equiv \alpha/[\beta + (N-1)\gamma]$, $b \equiv 1/[\beta + (N-1)\gamma]$ and $c \equiv \gamma/(\beta - \gamma])[\beta + (N-1)\gamma]$ are satisfied. [2] Moreover, we derive the indirect utility function as shown below.

$$\begin{aligned} V_l &= \frac{a^2 N}{2b} - a \int_0^N p(i)di + \frac{b + cN}{2} \int_0^N [p(i)]^2 di - \frac{c}{2} \left[ \int_0^N p(i)di \right]^2 \\ &+ y + \bar{q}_0 - \delta_3 D_l^2 \end{aligned} \tag{5}$$

## 2.2 Production

### 2.2.1 Agricultural goods sector

The agricultural goods sector requires labor as the only input factor to produce its goods with constant returns to scale and the agricultural goods is numeraire. Presuming that the workers are distributed throughout both regions equally and immobile between regions. Let $w_H^A$ and $w_F^A$ respectively signify the wages of workers in region $H$ and region $F$. Presuming that one unit of labor is required to produce one unit of agricultural goods without losing generality, the wages of workers in region $H$ and region $F$ are one. [3]

### 2.2.2 Manufactured goods sector

The agricultural goods market is perfectly competitive, whereas the manufactured goods market is monopolistic. Moreover, we assume that the manufactured goods sector emits environmental pollution as a by-product in production processes. Regarding the formulization of the manufactured goods sector, we follow the monopolistic competition of the OTT model, in which any production of each variety requires $\phi$ units of labor.[4] Here, let $n_H$ and $n_f$ respectively represent the number of varieties in region $H$ and $F$. The total number of laborers in both regions is $L$ and labor is also the only input factor of manufactured goods. Therefore, we derive the following quantities of variety in region $H$ and $F$ because of the market clearing condition of the labor market.

$$n_H = \lambda L/\phi \tag{6}$$

[2]See Ottaviano, Tabuchi, and Thisse (2000) for the meanings of each parameter

[3]We assume that the transportation cost of agricultural goods between regions is costless and that the agricultural goods market is perfectly competitive.

[4]Formulation of monopolistic competition in OTT model differs from that of Krugman (1991) and does not consider marginal labor input. Consequently, $\phi$ also shows the degree of increasing returns to scale.

$$n_F = (1-\lambda)L/\phi \tag{7}$$

As understood from (6) or (7), $n_H$ and $n_f$ are decreasing functions with respect to $\phi$, which is the fixed labor input of variety, and the increasing function with respect to $L$, which is the total labor of manufactured goods sector in both regions. The profit of each variety as well as Dixit and Stiglitz (1978) is zero in equilibrium. Considering that labor is the only input factor of manufactured goods, the revenue of the manufactured goods sector reverts to labor income in both regions. We assume that the producer of each variety can discriminate the price for each region to maximize profit and that the technology of each variety is symmetric. We describe $q_{HH}, q_{HF}$ as the demand of variety $i$ produced in $H$ and consumed in region $l(=H,F)$. The following $q_{HH}$ and $q_{HF}$ are derived as (4):

$$q_{HH}(i) = a - (b+cN)p_{HH}(i) + cP_H \tag{8}$$

$$q_{HF}(i) = a - (b+cN)p_{HF}(i) + cP_F, \tag{9}$$

where $P_l(l=H,F)$ signifies the price index of manufactured goods in region $l(=H,F)$, i.e.,

$$P_H \equiv \int_0^{n_H} p_{HH}(i)di + \int_0^{n_F} p_{FH}(i)di \tag{10}$$

$$P_F \equiv \int_0^{n_H} p_{HF}(i)di + \int_0^{n_F} p_{FF}(i)di. \tag{11}$$

Let $w_H$ represent the wage rate of manufactured goods sector in region $H$; the profit function is $\Pi_H$ for variety $i$.

$$\Pi_H = p_{HH}q_{HH}(p_{HH})(A/2+\lambda L) + (p_{HF}-\tau)\{A/2+(1-\lambda)L\} - \phi w_H, \tag{12}$$

## 2.3 Environment

We assume that the manufactured goods sector emits environmental pollution as a by-product in the production process. This pollution engenders household disutility as pollution damage in (1). Here we define $d_l,(l=H,F)$ as the pollution caused in region $l(=H,F)$ as

$$d_H = \xi\left[\int_0^{n_H}\{q_{HH}(i)+q_{HF}(i)\}di\right] \tag{13}$$

and

$$d_F = \theta\xi\left[\int_0^{n_F}\{q_{FH}(i)+q_{FF}(i)\}di\right], \tag{14}$$

where $\xi(\in(0,1))$ and $\theta(\geq 1)$ respectively denote the parameter of pollution reduction technology and the technological difference between regions. The smaller the value of $\xi$ is, the higher the pollution reduction is. Moreover, we assume that $\theta$ is more than one. Therefore, the pollution reduction function in region $H$ is superior to that in region $F$. Pollution reduction technologies in both regions are equivalent when $\theta$ is one. Although Ikazaki and Naito (2007) hold that the pollution remains within the region of origin and that no effect of pollution exists on household utility in other regions, we consider transboundary pollution as do

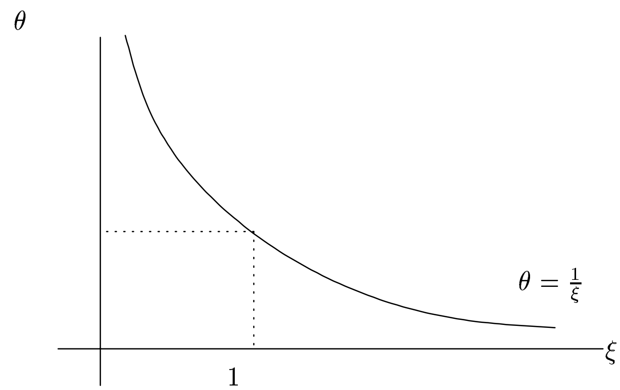


Figure 2: Difference between regions of pollution reduction technologies

Ito and Tawada (2003) and Takarada (2005). Let $D_l(l = H, F)$ and $t \in [0, 1]$ respectively represent total pollution including transboundary pollution in region $l(= H, F)$ and the amount of transboundary pollution. Consequently, $D_l$ is given as [5]

$$D_H = (d_H + td_F) \tag{15}$$

$$D_F = (d_F + td_H) \tag{16}$$

Presuming that $t$ is equal to zero, no transboundary pollution exists; the pollution remains within the region of origin. On the other hand, the pollution occurring in one region transfers to the other region perfectly when $t$ is one. In the former case, we can deal with soil pollution in the model; the latter case signifies an environmental problem such as global warming. Here we consider $t$, which exists within (0,1).

# 3 Short-run equilibrium

Having set up the basic model of this paper in the previous section, we next derive the short-run equilibrium, in which laborers and workers are immobile between regions. Therefore, we derive it by dealing with $\lambda$ as given. Each variety sets up a discriminatory price for each region. Now, let $p^*_{HH}, p^*_{HF}$ represent $p_{HH}, p_{HF}$ to maximize the profit function (12). Then, $p^*_{HH}, p^*_{HF}$ is given as the function of the price index of manufactured goods in each region $P_H, P_F$. Consequently, $P_H, P_F$ are given as

$$P_H = n_H p^*_{HH}(P_H) + n_F p^*_{FH}(P_F) \tag{17}$$

and

$$P_F = n_H p^*_{FH}(P_H) + n_F p^*_{FF}(P_F).. \tag{18}$$

[5]The actual amount of transboundary pollution in each region is not necessarily the same value because of natural conditions. However, we assume that $t$ has a common value irrespective of the region for simplification.

We accept $\lambda$ as given. Therefore, the number of varieties $n_H, n_F$ is constant. Each variety has prices set to maximize profit in region $H$ and in region $F$. When we describe $p^*_{lm}$ as the price of manufactured goods produced in region $l(=H,F)$ and sold in region $m(=H,F)$, we can derive $p^*_{lm}$ in equilibrium as follows.

$$p^*_{HH} = \frac{1}{2}\frac{2a+\tau c(1-\lambda)N}{2b+cN} \tag{19}$$

$$p^*_{FF} = \frac{1}{2}\frac{2a+\tau c\lambda N}{2b+cN} \tag{20}$$

$$p^*_{HF} = p^*_{FF} + \frac{\tau}{2} \tag{21}$$

$$p^*_{FH} = p^*_{HH} + \frac{\tau}{2} \tag{22}$$

Here we make an interpretation of the derived equilibrium price. We know that $p^*_{HH}$ is a decreasing function with respect to $\lambda$, which is the distribution of labor in region $H$ because (19). On the other hand, $p^*_{FF}$ is a decreasing function with respect to $\lambda$ because (20). Although the increase of transportation cost between regions $\tau$ engenders increased $p^*_{HH}$, $p^*_{FF}$, $p^*_{HF}$, and $p^*_{FH}$, the effect of increasing $\tau$ on prices depends on $\lambda$. Consequently, the price set in one region differs from others because $n_H$ and $n_F$ depend on $\lambda$. Let $\Pi^*_{HH}$ and $\Pi^*_{HF}$ respectively denote the profit by selling the variety produced at region $H$ in region $H$ and $F$. We can derive the following $\Pi^*_{HH}$ and $\Pi^*_{HF}$ because (19) and (21).

$$\Pi^*_{HH} = (b+cN)(p^*_{HH})^2\left(\frac{A}{2}+\lambda L\right) \tag{23}$$

and

$$\Pi^*_{HF} = (b+cN)(p^*_{HF}-\tau)^2\left(\frac{A}{2}+(1-\lambda)L\right) \tag{24}$$

Moreover, the surplus of households in region $H$ from consumption estimated in (19) and (22) is the following. Taking account of symmetry, we can derive $S_F(\lambda)$ as well as $S_H(\lambda)$.

$$\begin{aligned} S_H(\lambda) \equiv\ & \frac{a^2L}{2b\phi} - \frac{aL}{\phi}\left[\lambda p^*_{HH} + (1-\lambda)p^*_{FH}\right] \\ +\ & \frac{(b\phi+cL)L}{2\phi^2}\left[\lambda(p^*_{HH})^2 + (1-\lambda)(p^*_{FH})^2\right] \\ -\ & \frac{cL^2}{2\phi^2}\left[\lambda p^*_{HH} + (1-\lambda)p^*_{FH}\right]^2 \end{aligned} \tag{25}$$

$$\begin{aligned} S_F(\lambda) \equiv\ & \frac{a^2L}{2b\phi} - \frac{aL}{\phi}\left[(1-\lambda)p^*_{HF} + \lambda p^*_{FF}\right] \\ +\ & \frac{(b\phi+cL)L}{2\phi^2}\left[(1-\lambda)(p^*_{HF})^2 + \lambda(p^*_{FF})^2\right] \\ -\ & \frac{cL^2}{2\phi^2}\left[(1-\lambda)p^*_{HF} + \lambda p^*_{FF}\right]^2 \end{aligned} \tag{26}$$

Presuming that production of variety is symmetric, we define total manufactured goods produced in region $H$, $Q_H$, as shown below.

$$\begin{aligned} Q_H &\equiv n_H\,(q_{HH}+q_{HF}) \\ &= \frac{\lambda L}{\phi}(b+cN)\left(\frac{2a-b\tau}{2b+cN}\right) \end{aligned} \tag{27}$$

Similarly, we can derive $Q_F$ as follows.

$$\begin{aligned} Q_F &\equiv n_F(q_{FF}+q_{FH}) \\ &= \frac{(1-\lambda)L}{\phi}(b+cN)\left(\frac{2a-b\tau}{2b+cN}\right) \end{aligned} \tag{28}$$

Next we determine the wage rate of labor in equilibrium. The manufactured goods sector is a monopolistic competition market. Therefore, the zero profit condition is satisfied in equilibrium. Moreover, we can derive the wage rate in both regions because the labor is the only input in the manufactured goods sector. When the wage of laborers in region $H$, $w_H^*$, is given as

$$\begin{aligned} w_H^*(\lambda) &= \frac{b\phi+cL}{4(2b\phi+cL)^2\phi^2}, then\Bigg\{[2a\phi+\tau cL(1-\lambda)]^2\left(\frac{A}{2}+\lambda L\right) \\ &+ [2a\phi-2\tau b\phi-\tau cL(1-\lambda)]^2\left[\frac{A}{2}+(1-\lambda)L\right]\Bigg\}. \end{aligned} \tag{29}$$

Similarly, we can derive $w_F^*$ as follows.

$$\begin{aligned} w_F^*(\lambda) &= \frac{b\phi+cL}{4(2b\phi+cL)^2\phi^2}\Big\{[2a\phi+\tau cL\lambda]^2\left(\frac{A}{2}+(1-\lambda)L\right) \\ &+ [2a\phi-2\tau b\phi-\tau cL\lambda]^2\left(\frac{A}{2}+\lambda L\right)\Big\} \end{aligned} \tag{30}$$

We assume that the pollution is produced during the production process of manufactured goods and that total pollution is given as (15) or (16). Therefore, we can derive the total pollution in region $H$ as presented below.

$$D_H = \frac{\xi L}{\phi}\left[\left(\frac{2a-b\tau}{2b+cN}\right)(b+cN)(t\theta+(1-t\theta)\lambda)\right] \tag{31}$$

Similarly we can derive the following $D_F$ because the total pollution in region $F$ is given as (16).

$$D_F = \frac{\xi L}{\phi}\left[\left(\frac{2a-b\tau}{2b+cN}\right)(b+cN)(\theta+(t-\theta)\lambda)\right] \tag{32}$$

Although it is desirable that pollution of some kind be considered as stock, we deal with the environmental damage as follows within particular terms. Presuming that no technological difference of pollution reduction exists between regions and that $\lambda$ is 0.5, the households' utility in one region level is equal to that in the other. Actually, $\lambda = 0.5$ is not established in equilibrium because of the asymmetric technology of pollution reduction.

# 4 Long-run equilibrium

## 4.1 Equilibrium and pollution damage

We determine short-run endogenous variables when we address labor distribution between regions as given in the previous section. We consider the long-run equilibrium in which a laborer in one region can compare his utility level with that in the other region and move the region to obtain higher utility. Letting $V_H(\lambda)$ represent the indirect utility function in the short run, we consider the labor distribution between regions as given and describe $V_H(\lambda)$ as follows.

$$V_H(\lambda) = S_H(\lambda) + w_H^*(\lambda) - \delta_3(D_H)^2 + \bar{q}_0 \tag{33}$$

¿From (1) and (31), we infer that the damage caused by pollution to utility is given as

$$\begin{aligned} \delta_3(D_H)^2 &= \delta_3\left[\left(\frac{\xi L}{\phi}(b+cN)\left(\frac{2a-b\tau}{2b+cN}\right)\right)(t\theta+(1-t\theta)\lambda)\right]^2 \\ &= C_2[t\theta+(1-t\theta)\lambda]^2. \end{aligned} \tag{34}$$

Similarly, the following damage caused by pollution in region $F$ for utility is the following.

$$\begin{aligned} \delta_3(D_F)^2 &= \delta_3\left[\left(\frac{\xi L}{\phi}(b+cN)\left(\frac{2a-b\tau}{2b+cN}\right)\right)(\theta+(t-t\theta)\lambda)\right]^2 \\ &= C_2[\theta+(t-\theta)\lambda]^2 \end{aligned} \tag{35}$$

Here we define $C_2$ in (34) and (35) as follows.

$$C_2 \equiv \delta_3\left[\left(\frac{\xi L}{\phi}(b+cN)\left(\frac{2a-b\tau}{2b+cN}\right)\right)\right]^2 \tag{36}$$

$$V_H(\lambda) = S_H(\lambda) + w_H^*(\lambda) - C_2[t\theta+(1-t\theta)\lambda]^2 + \bar{q}_0 \tag{37}$$

Moreover, the indirect utility function in region $F$ is

$$V_F(\lambda) = S_F(\lambda) + w_F^*(\lambda) - C_2[\theta+(t-\theta)\lambda]^2 + \bar{q}_0. \tag{38}$$

Next we consider the labor distribution in the long-run equilibrium. Labor is immobile between regions in the long run. Therefore, every laborer enjoys the same long-run utility level and has no incentive to move to the other region. Consequently, the long-run labor distribution is $\lambda \in (0,1)$ to satisfy the following condition:

$$\Delta V(\lambda) \equiv V_H(\lambda) - V_F(\lambda) = 0. \tag{39}$$

Presuming that $\Delta V(\lambda)$ is larger than zero within $\lambda \in (0,1)$, then all laborers agglomerate in region $H$. The labor distribution in the long-run equilibrium is $\lambda$ to satisfy $\Delta V(\lambda) = 0$ if the $\lambda$ to satisfy $\Delta V(\lambda) = 0$ within $\lambda \in (0,1)$. [6]

[6]Now we do not refer to the specific $\lambda$ to satisfy $\Delta V(\lambda) = 0$

Consequently, compiling the above-described argument, the labor distribution in the long-run equilibrium is $\lambda$ to satisfy the following condition.

$$\Delta V(\lambda) \equiv V_H(\lambda) - V_F(\lambda) = 0 \tag{40}$$

Substituting (33) and (34) into (40), the following $\Delta V(\lambda)$ is given as

$$\begin{aligned}\Delta V(\lambda) &= S_H(\lambda) - S_F(\lambda) + w_H^*(\lambda) - w_F^*(\lambda) \\ &- C_2[t\theta + (1-t\theta)\lambda]^2 + C_2[\theta + (t-\theta)\lambda]^2 \\ &= C\tau(\tau^* - \tau)\left(\lambda - \frac{1}{2}\right) \\ &- C_2(1-t^2)\left[(1-\theta^2)\lambda^2 + 2\theta^2\lambda - \theta^2\right]. \end{aligned}\tag{41}$$

We define $C$ and $\tau^*$ respectively as follows.

$$C \equiv \left[2b\phi(3b\phi + 3cL + cA) + c^2L(A+L)\right]\frac{L(b\phi + cL)}{2\phi^2(2b\phi + cL)^2} > 0 \tag{42}$$

$$\tau^* \equiv \frac{4a\phi(3b\phi + 2cL)}{2b\phi(3b\phi + 3cL + cA) + c^2L(A+L)} > 0 \tag{43}$$

Here we define the first term and second term in the right hand of (41), respectively, and can rearrange (41) as follows.

$$\Delta V(\lambda) = g(\lambda) - f(\lambda) \tag{44}$$

Consequently, $g(\lambda)$ and $f(\lambda)$ are as follows.

$$g(\lambda) \equiv C\tau(\tau^* - \tau)\left(\lambda - \frac{1}{2}\right) \tag{45}$$

$$f(\lambda) \equiv C_2(1-t^2)\left[(1-\theta^2)\lambda^2 + 2\theta^2\lambda - \theta^2\right] \tag{46}$$

We understand that the shape of $f(\lambda)$ depends on the technological difference of pollution reduction in both regions and the parameter $t$ describing the amount of transboundary pollution attributable to (46). The damage occurring in both regions is similar to the international public goods if $t$ is equal to one. No effect of this damage exists on determining labor's residence in this case. Therefore, we can obtain the same result as Ottaviano, Tabuchi, and Thisse (2002). Consequently, we assume that the pollution in one region does not transfer to the other region perfectly. That is, $t$ exists within $(0, 1)$.

## 4.2 Effect of technology transfer on regional agglomeration

### 4.2.1 Case of high transportation costs

First, we consider the shape of function $g(\lambda)$. The shape of $g(\lambda)$ under any transportation cost depends on whether $g(\lambda)$ is an increasing function with respect to $\lambda$ or not. When the transportation cost is high ($\tau > \tau^*$), the function

$g(\lambda)$ is a decreasing function with respect to $\lambda$ and is satisfied with $g(1/2) = 0$. Next we consider the function $f(\lambda)$. Arranging function $f(\lambda)$, we describe it as follows.

$$f(\lambda) = C_2(1-t^2)\left[(1-\theta^2)\left(\lambda - \frac{\theta^2}{\theta^2-1}\right)^2 + \frac{\theta^2}{\theta^2-1}\right] \tag{47}$$

Presuming that $\theta$ is larger than one, it is certain that (47) is an inverted-U shaped function with respect to $\lambda$ and that it is satisfied with $f(1/2) < 0$ and $f(1) > 0$. The $\lambda$ to maximize the function $f(\lambda)$ is larger than one. Therefore, $\lambda$ to satisfy $f(\lambda) = 0$ exists from $\frac{1}{2}$ to 1. Describing $f(\lambda)$ and $g(\lambda)$, we can derive the equilibrium labor distribution in Fig. 3. Figure 3 portrays the long-run labor

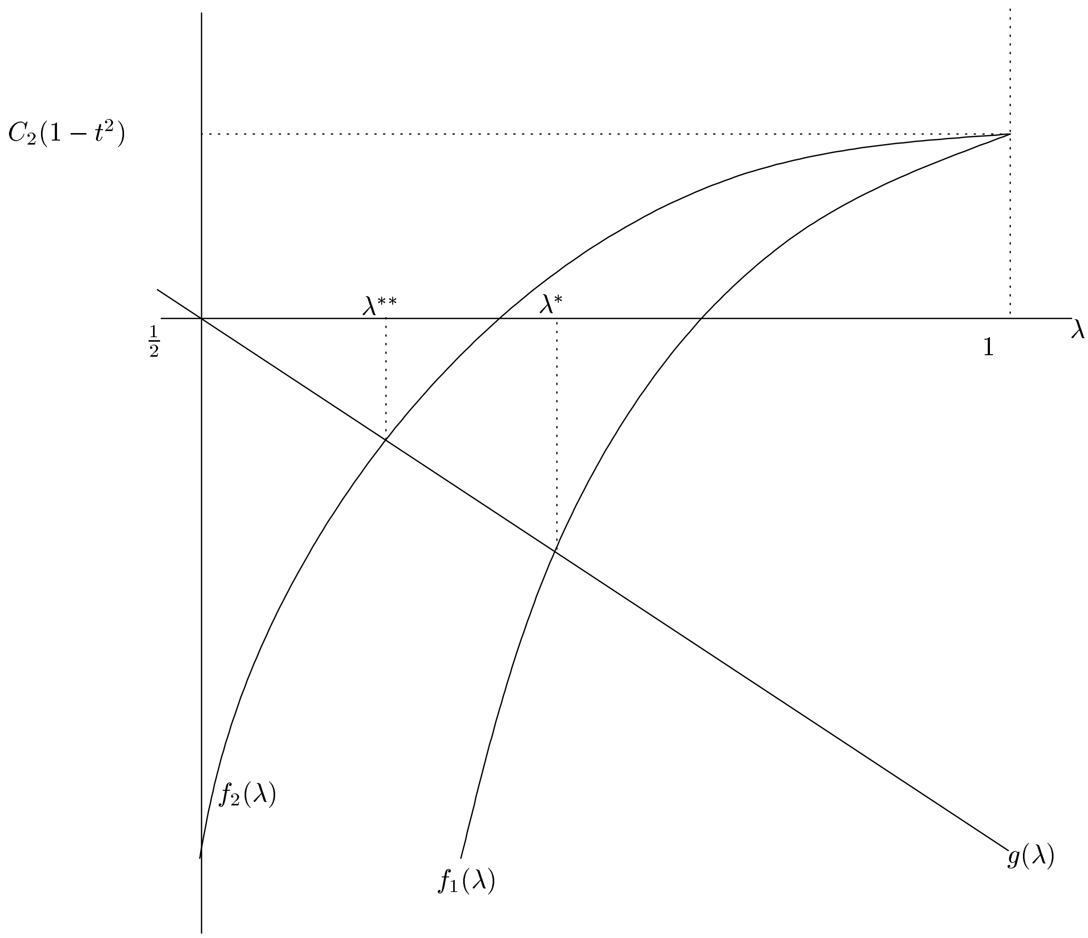


Figure 3: High transportation cost case

distribution when the transportation cost is high. Actually, $f_1(\lambda)$ is the case in which technological differences between regions is large. On the other hand, $f_2(\lambda)$ represents the case in which the technological difference between regions is small. In this case, the equilibrium labor distribution under $f_1(\lambda)$ and $f_2(\lambda)$ are, respectively, $\lambda^*$, $\lambda^{**}$. Moreover, we can know that $\lambda^*$ is a stable equilibrium because of Fig. 3. Assuming that the amount of transboundary pollution is common between regions and that it is fixed, then the difference of pollution reduction technology affects the labor distribution between regions. Presuming that $\theta$ is larger than one, the pollution reduction technology in region $F$ is inferior to that in region $H$. When the transportation cost is high, the economy approaches autarky. Consequently, although the utility from goods consumption is equal between regions, the damage caused by pollution in respective areas is different. Households in region $F$ with inferior reduction technology enjoy more pollution damage. Therefore, they have an incentive to move to the other region. Taking account of the environmental damage, we know that the equilibrium in this model differs from that of the OTT model.

Moreover, we consider the case in which the technology transfer of pollution reduction is conducted and analyze the effect of technology transfer between regions on the long-run labor distribution. Following Takarada (2005) and Ito and Tawada (2003), we describe the effect of technology transfer between regions. Namely, $\theta$ converges to one as the technological difference decreases with technology transfer. Presuming that the technological difference decreases with technology transfer, $g(\lambda)$, which is independent of $\theta$, does not change its location. On the other hand, $f(\lambda)$ moves above as $\theta$ gets smaller. In Fig. 3, $f_1(\lambda)$ shifts to $f_2(\lambda)$ as $\theta$ converges to one and the equilibrium labor distribution moves from $\lambda^*$ to $\lambda^{**}$. Therefore, the technology transfer of pollution reduction is effective in relaxing the agglomeration of workers between areas. We derive the following proposition.

**Proposition 1** ***Presuming that the transportation cost of manufactured goods is high ($\tau > \tau^*$), a stable equilibrium of labor distribution between regions exists between 0 and 1. When the technology transfer of pollution reduction is conducted, it is effective in relaxing the agglomeration of workers between areas.***

#### 4.2.2 Case of low transportation cost

Next we consider the case in which the transportation cost of manufactured goods is low. When the transportation cost of manufactured goods is low ($\tau^* > \tau$), the shape of $g(\lambda)$ is an increasing function with respect to $\lambda$. However, the effects caused by agglomeration (forward and backward linkages) are small as $\tau$ approaches zero and the utility with goods consumption is independent of the household's location. Therefore, we consider the transportation cost to be the effects caused by agglomeration of (forward and backward linkages). For the case in which the transportation cost is high, $g(\lambda)$ is a decreasing function in the range, in which $\lambda$ exists in $\lambda \in [\frac{1}{2}, 1]$. On the other hand, $f(\lambda)$ is an increasing function with respect to $\lambda$ in the same range. Consequently, a unique point of intersection of two functions and its $\lambda$ exists as a stable equilibrium. However, we must consider qualitative analysis because it is possible to achieve equilibrium of some types in the long run when the transportation cost is low. Actually, $g(\lambda)$ and $f(\lambda)$ respectively represent an increasing function and a decreasing function of $\lambda$. Moreover, $g(\frac{1}{2})$ is satisfied with zero. Consequently, the property of the long-run equilibrium depends on whether there is a point of intersection of $g(\lambda)$ and $f(\lambda)$ between $\frac{1}{2}$ to one, or not. Considering that the $\lambda$ to maximize $f(\lambda)$ is greater than one and that $f(\frac{1}{2}) < 0$, we compare $f(1)$ with $g(1)$ to confirm whether or not a point of intersection of $g(\lambda)$ and $f(\lambda)$ exists between $\frac{1}{2}$ to one. Because $f(1)$ and $g(1)$ are $C_2(1-t^2)$ and $\frac{C\tau(\tau^*-\tau)}{2}$, respectively, the following condition is necessary to satisfy $g(1) < f(1)$.

$$\frac{C\tau(\tau^* - \tau)}{2} < C_2(1-t^2) \tag{48}$$

We can describe $f(\lambda)$ and $g(\lambda)$ in Fig. 4 when (48) is satisfied. Here, the long-

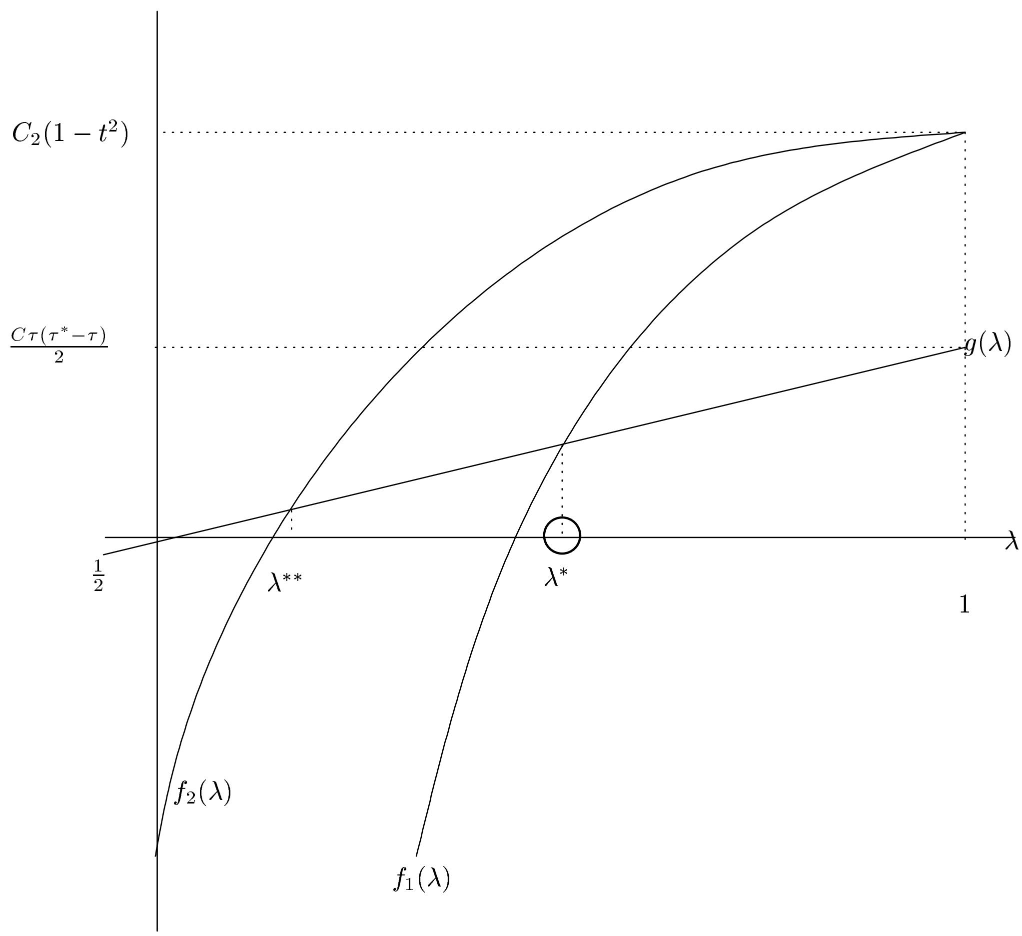


Figure 4: Case in which the transportation cost is high (1)

run equilibrium labor distribution is given as $\lambda^*$. As in the previous section, we consider the case in which the technological difference of pollution reduction between regions becomes smaller because of technology transfer. Presuming that the pollution reduction technology in region $H$ is superior to that in region $F$ ($\theta > 1$), we assume that the pollution reduction technology in region $H$ is transferred from region $H$ to region $F$. The technological difference of pollution between regions gets smaller because of technology transfer. Therefore, $f_1(\lambda)$ in Fig. **??** shifts to $f_2(\lambda)$. Consequently, the point of intersection of $g(\lambda)$ and $f(\lambda)$ moves from $\lambda^*$ to $\lambda^{**}$. We know that the smaller difference between regions of the pollution reduction technology relaxes the agglomeration of the particular region.

**Proposition 2** ***Presuming that (48) is satisfied, the equilibrium labor distribution between regions $\lambda$ exists between $\frac{1}{2}$ to one; the agglomeration of labor in the particular region is relaxed because of the shrinking difference of the pollution reduction technology between regions.***

Next we consider the case in which (48) is not satisfied. The condition which does not satisfy (48) is the following.

$$\frac{C\tau(\tau^* - \tau)}{2} \geq C_2(1 - t^2) \tag{49}$$

Presuming that (48) is not satisfied, the property of equilibrium in the long run depends on the relation locations of $f(\lambda)$ and $g(\lambda)$. Namely, (1) the case in which there is no intersection of $f(\lambda)$ and $g(\lambda)$ between $\lambda$ from $\frac{1}{2}$ and one. All labor agglomerates to region $H$ in this case. (2) The case in which $f(\lambda)$ and $g(\lambda)$ mutually come into contact. (3) The case in which $f(\lambda)$ and $g(\lambda)$ intersect in the range of $\lambda$ from $\frac{1}{2}$ and one. The following figure depicts the three cases above. When the regional difference of pollution reduction technology, then $\lambda = 1$ is the stable equilibrium given as $f_1(\lambda)$ and all laborers agglomerate to region $H$. When $f(\lambda)$ and $g(\lambda)$ mutually come in contact, the stable equilibria are given as $\lambda^*$, $\lambda^{**}$ and 1. Here we consider the effect of transfer of pollution reduction on labor distribution between regions. First, we consider the case in which the amount of transboundary pollution is large: $t$ is nearly equal to one. When $t$ is sufficiently near one, $f(1) = C_2(1 - t^2)$ is sufficiently near zero. In this case, no intersection of the functions exists even though the technological difference of pollution reduction function smaller. Consequently, the long-run labor distribution does not change because of technology transfer and agglomeration in region $H$, as shown in Fig. 6. On the other hand, the value of $g(1) - f(1)$ is small when the amount of transboundary pollution is small. Presuming that the technology transfer of pollution reduction is conducted in this situation, then $f(\lambda)$ shifts from $f_1(\lambda)$ to $f_3(\lambda)$ in Fig. 5. Moreover, if $\lambda^*$ or $\lambda^{**}$ is a stable equilibrium before technology transfer, then the situation is not an equilibrium and all laborers agglomerate in region $H$ when the technological difference of pollution reduction decreases. In other words, the technology transfer of the pollution reduction technology promotes agglomeration adversely. Therefore, we derive the following proposition.

**Proposition 3** ***Presuming that (49) is satisfied, the amount of transboundary pollution is large, and the transportation cost is low, then***

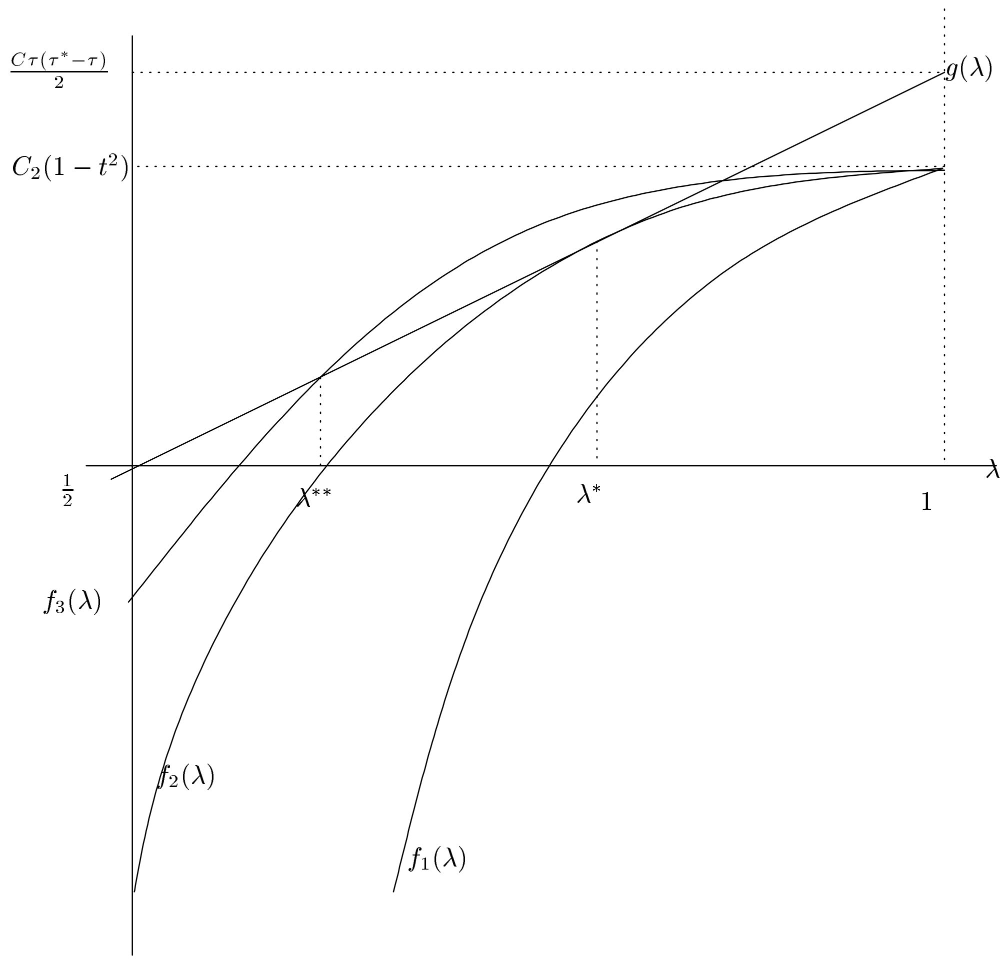


Figure 5: Case in which (49) is satisfied, the amount of transboundary pollution is small, and the transportation cost is high

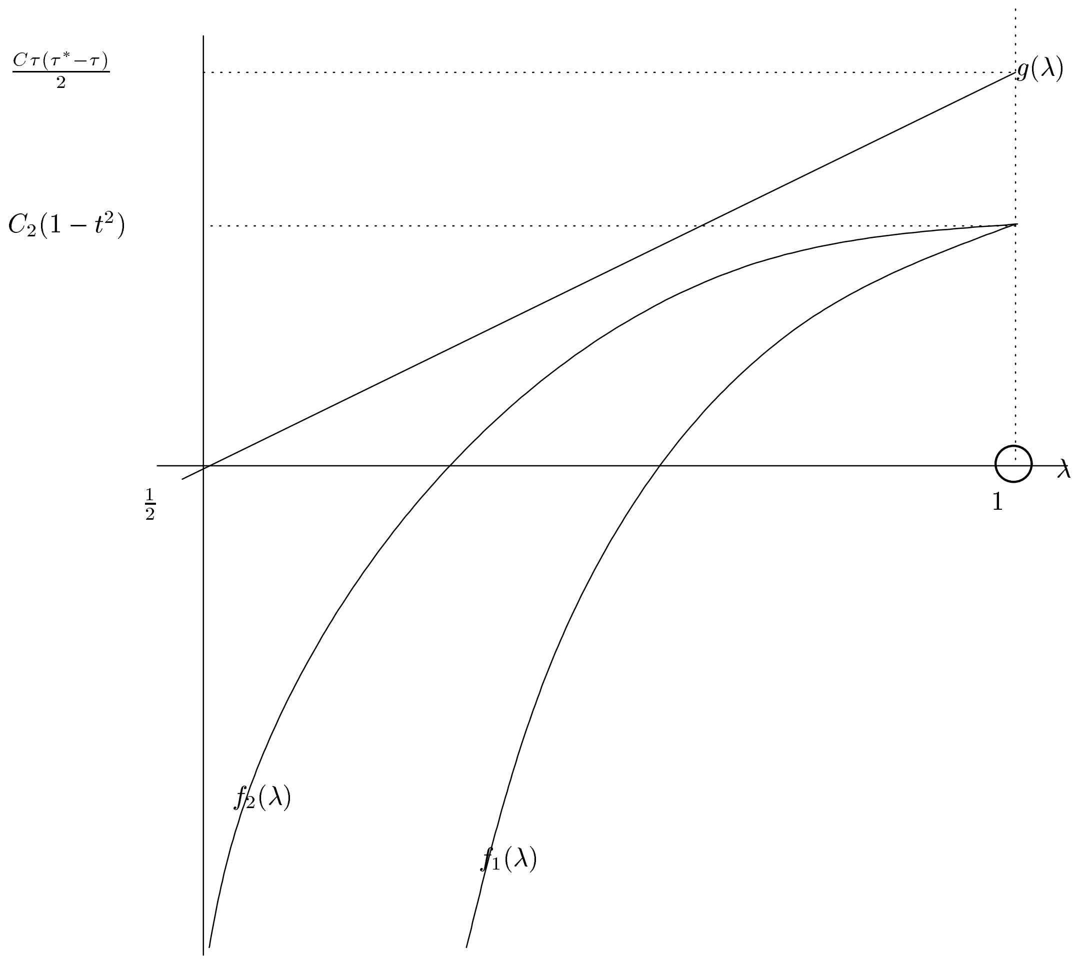


Figure 6: Case in which (49) is satisfied, the amount of transboundary pollution is large, and the transportation cost is low.

***labor agglomerates in region with superiority in pollution reduction technology. Consequently, the technology transfer of pollution reduction does not affect the equilibrium labor distribution. On the other hand, the technology transfer of the pollution reduction technology promotes labor agglomeration when the amount of transboundary pollution is not large.***

## 5 Concluding remarks

As described herein, we introduced transboundary pollution and asymmetric technology of pollution reduction into the OTT model and analyze the properties of this extended model. Consequent to analyzing the model, some interesting knowledge about pollution reduction technology is obtained. First, the stable equilibrium of labor distribution exists between regions within $\lambda \in (\frac{1}{2}, 1)$. Moreover, it is possible to relax the agglomeration of labor in the particular region as the technological difference of the pollution reduction technology decreases. Secondly, presuming that the transportation cost is low, the technology transfer of pollution reduction does not affect the equilibrium labor distribution in the long run when the amount of transboundary pollution is large. On the other hand, the stable equilibrium before technology transfer is no longer a stable equilibrium because its extent is not large. Consequently, it is possible to promote regional agglomeration through environmental support by programs such as ODA. We show that whether technology transfer of pollution reduction promotes regional agglomeration depends on the amount of transboundary pollution. Even if the same technology is transferred, the effects differ according to economic circumstances. Consequently, it is important to carry out environmental support more carefully.

We highlighted to analyses of the effect of technology transfer of pollution reduction on regional agglomeration. Therefore, we omitted arguments related to the optimal pollution level and environmental taxation. We must consider economic methods when we draft an environmental policy.[7] Moreover, we do not analyze social welfare herein. Each equilibrium must be compared in terms of social welfare; empirical analysis must be done to show the robustness of results derived in this paper. It is possible to extend our model in future studies.

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