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

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Abstract. The purpose of this paper is to present analyses of the effect of technology transfer to reduce pollution on regional agglomeration. The analyses extend the model presented by Ottaviano, Tabuchi, and Thisse by introducing a gap of reduction technology between regions and by assuming transboundary pollution. It is insufficient to analyse transboundary pollution problems such as acid rain within only one region. To reach an adequate solution, this problem must be considered within a sufficiently detailed economic system because various economic activities produce pollution. Recently, various factors as well as pollution have become mobile among regions because of disappearance of economic borders. Therefore, we consider environmental problems using a core–periphery model that is solvable analytically and considering the effect of pollution reduction technology transfer on regional agglomeration. The results obtained through analyses using this model are as described herein. First, it is possible to relax agglomeration through technological transfer of pollution reduction when the transportation cost of manufactured goods is high. Second, technological transfer of pollution reduction does not affect regional agglomeration when the rate of transitory pollution between regions is high.

JEL classification: Q56, R23

Key words: Agglomeration, transboundary pollution, technology transfer

1 Introduction

This paper presents analyses of the effects on the regional agglomeration of a technology transfer undertaken to reduce pollution. The model of Ottaviano et al. (2002), is extended by introducing a gap of reduction technology between regions and by considering transboundary pollution. Although many countries have examined environmental problems such as global warming and have argued for development of environmental policy, many countries have been unable to reach effective solutions. It is difficult to find such a solution because environmental policies affect not only the environmental level in one region but also various sectors aside from the environment.

'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. Nevertheless, numerous countries have taken a long time to ratify it along with its obligations for reduction of greenhouse gas emissions. Eventually, it came into effect in February 2005. One signatory nation, Japan, an economically developed country, has committed to reducing its emissions by 6 per cent from base-year emissions. Such a reduction obligation is not imposed on developing countries. Because of the idiosyncratic properties of the pollution itself, many cases exist in which the environmental problems cannot be solved according to environmental policies undertaken only for particular regions where the pollution is emitted. Pollution and acid rain are forms of transboundary pollution. The people who create the hazardous materials and the people who are affected by the materials are different. As transboundary pollution, they affect not only the region of origin but also regions aside from that region. Consequently, the environmental policy for the region of origin is often not effective for all regions. In fact, acid rain, which became recognized in the 1950s in the EU zone, is a representative example. Many countries regard any support for environmental problems in another region as important. Moreover, it is difficult for some economically developed countries whose pollution reduction technology is highly developed, to reduce more pollution. In this case, those countries support the donation of reduction technology to developing countries and attempt to convert the reduced pollution there into the reduced pollution in their own countries [clean development mechanism [CDM]). Figure 1 shows that the total Japanese official development assistance (ODA) and the ratio of environmental policy to the total sum. As might be understood from Figure 1, support for the environment accounts for 30 per cent of all Japanese ODA.

As Figure 1 shows, the environment is regarded as an important component in support of developing countries in Japanese ODA. Consequently, the presentation of theoretical grounds must show the validity of support using ODA. Because most environmental problems are caused by various economic activities, it is insufficient to argue only for environmental policy without incorporating other factors such as trade and factor mobility. It is necessary to draft a policy for

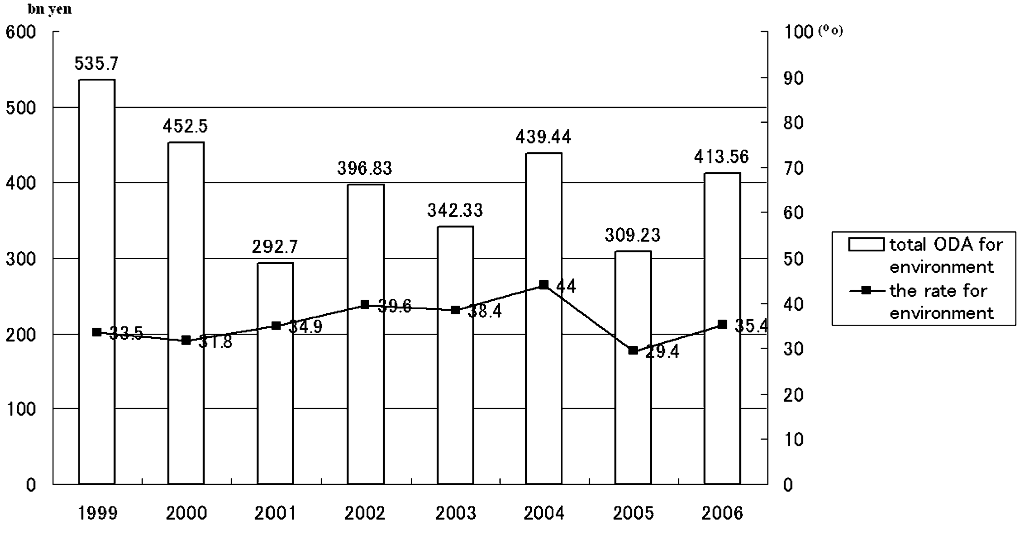

Fig. 1. Total ODA and the rate of environmental policy in Japan
Source: Homepage of The Ministry of Foreign Affairs in Japan (http://www.mofa.go.jp/mofaj/gaiko/oda/shiryo/index.html).

environment in the world, where economic boundaries separating countries are disappearing and the mobility of goods and production factors has increased markedly.

Many models incorporating spatial mobility of goods or production factors have been constructed as adjuncts of the new economic geography (NEG). Particularly after formulation of monopolistic competition by Dixit and Stiglitz (1978), many models introducing monopolistic competition have been constructed for use in urban economics or spatial economics. Krugman (1991) explained regional agglomeration theoretically with the simple model introducing monopolistic competition and describing increasing returns of scale. Although we have no room to doubt that Krugman (1991), Krugman and Elizondo (1996), and Fujita et al. (1999), contributed to the new economic geography, they constructed their models using a nonlinear general equilibrium system and derived the equilibrium through numerical analyses using a computer. Moreover, an important limitation is that the mark up rate is constant in the model, even though their formulation with Dixit and Stiglitz based on CES utility function has income effects. Those models derive the equilibrium using a computer, whereas some studies attempted to construct a model that is solved analytically, without changing the basic framework. Ottaviano et al. (2002) constructed a model using not a CES utility function, but a quasi-linear utility function instead to derive the equilibrium analytically. The Ottaviano, Tabuchi, and Thisse model (hereinafter OTT model), have as each firm's profit maximizing price a decreasing function with respect to the total number of varieties of goods. It is possible to solve the model analytically, although no income effect exists in their model. Consequently, it is possible to analyse a comparison of equilibrium with the optimum in the OTT model.

Some studies have extended the core–periphery model formulated by Krugman (1991), Fujita et al. (1999) by introducing various factors into their models. Tabuchi (1998) uses a core–periphery model to analyse a land market. In the core–periphery model, centripetal force is explained by variety; centrifugal force is shown by transportation costs or competition among firms. The decrease of transportation costs attributable to improvement of transportation technology engenders weakening of the centrifugal force and agglomerate population and firms in one region. However, it is also important to take account of centrifugal force aside from these forces and agglomeration diseconomies such as pollution and congestion. Some researchers specifically examine those diseconomies of agglomeration. Tabuchi (1998) considers the competition as a centrifugal force. Although it is important to consider these factors as diseconomies of agglomeration, it is also necessary to take account of environmental factors. Hosoe and Naito (2006), combined Copeland and Taylor (1999), with a core–periphery model to analyse the effect of pollution externalities on regional agglomeration.

Some researchers have introduced environmental factors into models in international economics and have analysed the effects of those factors on models. For example, Copeland and Taylor (1999), consider a two-sector model in which the pollution caused by one sector affects the productivity of the other sector. They analyse the production in each country and social welfare. Unteroberdoerster (2001) extended Copeland and Taylor (1999), to a model with transboundary pollution. Moreover, Hosoe and Naito (2006), consider transboundary pollution using a core–periphery model. They assess effects of regional agglomeration on the effectiveness of environmental policy and show that the stability of population distribution depends not only on transportation costs, but also on the degree of transboundary pollution between regions. However, Hosoe and Naito (2006), assume that the pollution reduction technologies of both regions are symmetric; they consider not direct regulation but regulation via tariffs as environmental policy. Ikazaki and Naito (2008) introduced the damage caused by pollution into Yamamoto (2005), in which they analysed the relation between agglomeration and technological conversion in intermediate goods sector and explain the environmental Kuznets curve under optimal taxation. The environmental Kuznets curve, 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 technological transfer between regions. For instance, Ito and Tawada (2003) or Takarada (2005) incorporate technological transfer of pollution reduction into the framework of Copeland and Taylor (1999). Our model follows those settings related to pollution reduction technology transfer.

We follow not the core–periphery model using the constant elasticity of substitution (CES) utility function proposed by Hosoe and Naito (2006), or Ikazaki and Naito (2008), but instead use a quasi-linear utility function similar to the OTT model, consider transcendent pollution and asymmetrical reduction technology of pollution, and analyse the effect of technological transfer of pollution reduction on regional agglomeration. Results of the analysis show that the technological 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 behaviours of the sectors. In Section 3, we derive the equilibrium in the short run, where labourers are immobile between regions. Section 4 presents analyses of the equilibrium in the long run, where labourers are mobile between regions, the effect of technological transfer or agglomeration, and welfare analysis. Finally, we conclude this paper and present some points that are not discussed in the text. We suggest some that remain as future subjects for examination.

2 The model

We consider a model with two-sectors and two regions in this paper. The economy comprises agricultural goods and manufactured goods produced in two regions (region H and region F). The agricultural good, labelled as A, is produced with constant returns of scale and faces a perfectly competitive market. Here we assume that this agricultural good is numeraire. The farm workers, who are the only production factor and who are always immobile between regions, are distributed equally in each region. In fact, $A/2$ farm workers reside in each region because of the assumption that the total number of farm workers is A. The manufactured goods are discriminated and face a monopolistically competitive market. The number of labourers in the economy is L; the quantities of labourers in region H and region F are, respectively, λL and $(1 - \lambda)L$. Although labourers in each region are immobile between regions in the short run, they are mobile between regions in the long run. In the long run, labourers can move to the region in which they can obtain higher utility. As for transportation costs, agricultural goods can be shipped without any transportation costs, although the transportation of manufactured goods between regions requires τ units of agricultural goods.

2.1 Households

Presuming that all households are homogeneous, then all households have the same utility function. Here we set up the household 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. The parameters in (1) are satisfied with $\alpha > 0$, $\beta > \gamma > 0$. Here,

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

α, $\beta > \gamma$, and N respectively represent the degrees of preference for discriminated manufactured goods, and the number of varieties. Moreover, regarding environmental damage, D_l means the total pollution which households in region l must endure and δ_3 is the parameter of disutility caused by pollution. The pollution 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 labour and $\overline{q}_0$ units of agricultural goods as endowment. Letting $p(i)$ represent the price of manufactured goods variety i, the budget constraint is given as:

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

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 follows:

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

2.2 *Production*

2.2.1 Agricultural goods sector

The agricultural goods sector needs labour as the only input factor to produce its goods with constant returns of scale; the agricultural good is the numeraire. Presuming that the farm workers are distributed equally throughout both regions and that they are immobile between the regions, then w_H^A and w_F^A can respectively represent the wages of farm workers in region H and region F. Assuming also that one unit of labour is necessary to produce one unit of agricultural goods without losing generality, the wages of farm workers in region H and region F are 1.[3]

2.2.2 Manufactured goods sector

Though the agricultural goods market is perfectly competitive, the manufactured goods market is a monopolistic competition model. Moreover, we assume that the manufactured goods sector emits environmental pollution as a by-product of the production process. Regarding the formulation of the manufactured goods sector, we follow the monopolistic competition of the OTT

[2] See Ottaviano et al. (2002) for the meanings of each parameter.

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

model, in which any production of each variety needs ϕ units of labour.[4] Here, let n_H and n_f respectively represent the number of varieties in region H and F. Because the total number of labourers in both regions is L and because labour is also the only input factor of manufactured goods, we derive the following quantities of variety in regions H and F because of market clearing conditions of the labour market.

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

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

As we understand from (6) or (7), n_H and n_f are decreasing functions with respect to ϕ, which is the fixed labour input of a variety, and the increasing function with respect to L, which is the total labour 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 labour is the only input factor of manufactured goods, the revenue of the manufactured goods sector is allocated to labour income in both regions. We assume that each variety can be discriminated for pricing in each region to maximize profit and that the technology of each variety is symmetric when 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 by (4):

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

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

In these equations, $P_l(l = H, F)$ represents the price index of manufactured goods in region $l(= H, F)$, namely:

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

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

Letting w_H represent the wage rate of manufactured goods sector in region H, the profit function Π_H of 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 by-products during the production process. This pollution engenders household's disutility as pollution damage in (1). Here we define d_l, $(l = H, F)$ as the pollution occurring in region $l(= H, F)$ as:

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

[4] The formulation of monopolistic competition in the OTT model differs from that of Krugman (1991) and does not consider marginal labour input. Consequently, ϕ also shows the degree of increasing returns of scale.

and

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

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 ξ is, the higher the pollution reduction is. Moreover, we assume that θ is greater than 1. That is to say, the pollution reduction function in region H is superior to that in region F. The pollution reduction technologies in both regions are equivalent when θ is 1. Although Ikazaki and Naito (2008), consider that the pollution remains within the region of origin and that there is no effect of pollution on household utility in the other regions, we take account of transboundary pollution as do 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 degree 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 0, then no transboundary pollution exists; the pollution remains within the region of origin. On the other hand, the pollution produced in one region transfers to the other region perfectly when t is 1. The former case can address 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). Moreover, neither D_H nor D_F is measured in quantity terms. They are measured in quality terms.

3 Equilibrium in the short run

One goal of this paper is to analyse the effect of technological transfer policy of pollution reduction on labour distribution between regions. Therefore, it is necessary to analyse the situation in which labour distribution between regions is fixed and no policy exists. First, we study the equilibrium in the short run, during which labourers are immobile between regions and technological transfer does not take place.

Setting up the basic model of this paper in the previous section, we derive the equilibrium in the short run, in which labourers and farm workers are immobile between regions. Therefore, we derive it by treating λ as given. Each variety sets up his discriminated price to each region. Now, let p^*_{HH}, p^*_{HF} represent p_{HH}, p_{HF} to maximize his profit function (12). Then, p^*_{HH}, p^*_{HF} is given as the function of 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 degrees of transboundary pollution in both regions are not necessarily the same value because of natural conditions. However, we assume that t has a common value in both regions for simplification.

Because we deal with λ as given, the number of varieties n_H, n_F is constant. Each variety is assigned a price to maximize profit in region H and 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 the decreasing function with respect to λ, which is the distribution of labour in region H because of (19). On the other hand, p^*_{FF} is the decreasing function with respect to λ because of (20). The increase of transportation cost between regions τ engenders increased p^*_{HH}, p^*_{FF}, p^*_{HF}, and p^*_{FH}, the effect of increasing τ on prices depends on λ. Consequently, the price set in one region differs from that in others because n_H and n_F depend on λ. Let Π^*_{HH} and Π^*_{HF} represent the profit by selling the varieties produced in region H in regions H and F, respectively. We can derive the following Π^*_{HH} and Π^*_{HF} because of (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. Incorporating symmetry, we can derive $S_F(\lambda)$ as well as $S_H(\lambda)$:

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

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

Presuming that production of variety is symmetric, we define the total manufactured goods produced in region H, Q_H, as follows:

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

Similarly, we can derive Q_F as follows:

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

Next we determine the wage rate of labour in equilibrium. Because the manufactured goods sector is a monopolistically competitive market, the zero profit condition is satisfied in equilibrium. Moreover, we can derive the wage rate in both regions because the labour is the only input in the manufactured goods sector. When the wage of labour in region H, w_H^* is given as shown below:

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

Similarly, we can derive w_F^* as follows:

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

Because we assume that the pollution is produced in the production process of manufactured goods and the total pollution is given as (15) or (16), we can derive the total pollution in region H as follows:

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

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 kinds be considered as stock, we examine the environmental damage as follows within a particular term. Presuming no technological difference of pollution reduction between regions and assuming that λ is 0.5, the household 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 Equilibrium in the long run

4.1 Equilibrium and pollution damage

We determine the endogenous variables in the short run when we investigated the labour distribution between regions, as explained in the previous section. We consider the equilibrium in the long run, in which a labourer in one region can compare his utility level with that in the other region and move to another region if necessary to get higher utility. Moreover, we assume that λ is satisfied with $\lambda \in [1/2,1]$. Now let $V_H(\lambda)$ represent the indirect utility function in the short run. When we consider the labour distribution between regions as given, we 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), the damage caused by pollution for 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 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:

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

Thus, the indirect utility function in region H is as follows:

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

Moreover, the indirect utility function in region F is the following:

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

Next we consider the labour distribution in the long-run equilibrium. Because labour is immobile between regions in the long run, every labourer enjoys the same utility level in the long run and has no incentive to move to the other region. Consequently, the labour distribution in the long run is λ 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 labourers agglomerate in region H. The labour distribution in the long run equilibrium is λ to satisfy with $\Delta V(\lambda) = 0$ if the

λ to satisfy with $\Delta V(\lambda) = 0$ exists within $\lambda \in (0,1)$.[6] Consequently, compiling the above-described argument, the labour distribution in the long-run equilibrium is λ to satisfy the following condition:

$$\dot{\lambda} \equiv \lambda/dt = \begin{cases} \Delta V(\lambda) & if \quad 0 < \lambda < 1 \\ \min\{0, \Delta V(\lambda)\} & if \quad \lambda = 1 \\ \max\{0, \Delta V(\lambda)\} & if \quad \lambda = 0. \end{cases} \tag{40}$$

Substituting (37) and (38) into (39), the following $\Delta V(\lambda)$ is given as:

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

We define C and τ^* as follows:

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

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

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

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

Consequently, $g(\lambda)$, $f(\lambda)$ are as shown below:

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

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

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 degree of transboundary pollution because of (46). The damage caused in both regions can be treated similarly to international public goods if t is equal to 1. Because this damage has no effect on determining labour's residence in this case, we can obtain the same result as Ottaviano et al. (2002). Therefore, we assume that the pollution in one region does not transfer to the other region perfectly. That is to say, t exists within (0,1).

[6] We do not refer to the specific λ in order to satisfy $\Delta V(\lambda) = 0$.

4.2 *Effect of technological transfer on regional agglomeration*

We consider a case with a technological gap of pollution reduction between regions and assess the effects (on agglomeration) of inter-regional technological transfer of pollution reduction functions. Now we assume that the technological transfer is costless. It is reasonable to presume that the technological transfer has some positive cost until the region with inferior technology obtains the high technology of pollution reduction from the other region. However, these technological transfers are often executed as national projects by mechanisms such as ODA and the costs are managed using lump sum transfers from all households to the projects. Consequently, as long as we particularly examine the situation after the superior technology of pollution reduction is absorbed in the region with inferior technology, we need not consider the transfer cost of the high-technology of pollution reduction.

4.2.1 Case of high transportation cost

To begin with, 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 λ, or not. When the transportation cost is high ($\tau > \tau^*$), the function $g(\lambda)$ is a decreasing function with respect to λ and satisfies $g(1/2) = 0$. 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 θ is larger than 1, we know that (47) is the inverted-U shaped function with respect to λ and that it satisfies $f(1/2) < 0$ and $f(1) > 0$. Because λ maximizes the function $f(\lambda)$ larger than 1, λ to satisfy $f(\lambda) = 0$ exists from $\frac{1}{2}$ to 1. Describing $f(\lambda)$ and $g(\lambda)$, we can derive the equilibrium labour distribution in Figure 2. Figure 2 shows the labour distribution in the long run when the transportation cost is high. In the figure, $f_1(\lambda)$ shows the case in which the technological difference between the regions is large. In contrast, $f_2(\lambda)$ shows the case in which the technological difference between the regions is small. In this case, the equilibrium labour distributions under $f_1(\lambda)$ and $f_2(\lambda)$ are, respectively, λ^*, λ^{**}. Moreover, we can know that λ^* is a stable equilibrium because of Figure 2. Next we assume that the degree of transboundary pollution is equal between the regions and that it is fixed, the difference of pollution reduction technology affects the labour distribution between the regions. Presuming that θ is larger than 1, the pollution reduction technology in region *F* is inferior to that in region *H*. When the transportation cost is high, the economy approaches autarchy. Consequently, although the utility from goods consumption is equivalent between regions, the damage caused by pollution differs. Because households in region *F* with inferior reduction technology suffer more pollution damage, they have an incentive to move to the other region. Therefore, incorporating 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 technological transfer of pollution reduction is conducted. We analyse the effect of technological transfer between regions on labour distribution in the long run. Following Takarada (2005) and Ito and Tawada (2003), we describe θ as the effect of technological transfer between regions. That is to say, θ converges to 1 as the technological gap narrows through technological transfer. Presuming that the technological gap narrows, then $g(\lambda)$, which is independent of θ, does not change its location. On the other hand,

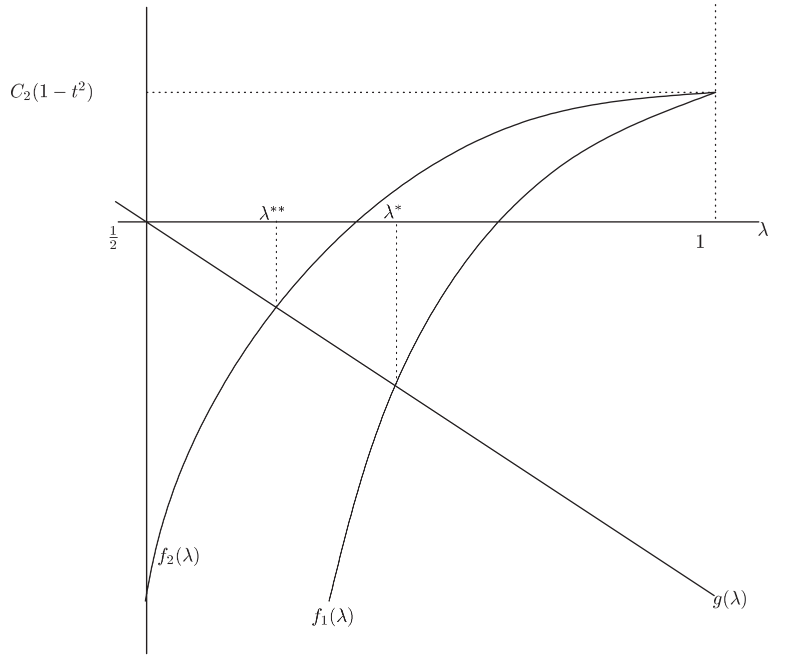

Fig. 2. Case in which the transportation cost is high

$f(\lambda)$ moves higher as θ shrinks. In Figure 2, $f_1(\lambda)$ shifts to $f_2(\lambda)$ as θ converges to 1 and the equilibrium labour distribution moves from λ^* to λ^{**}. Therefore, we know that the technological 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 ($\tau > \tau^*$), then a stable equilibrium of labour distribution between regions exists between 0 and 1. When the technological 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 the increasing function with respect to λ. However, the effects of agglomeration (forward and backward linkages) are small when τ nears zero sufficiently and the utility with goods consumption is independent of the household's residence location. Therefore, we consider the transportation cost to be the effects derived from agglomeration (forward and backward linkages). For the case in which the transportation cost is high, $g(\lambda)$ is the decreasing function in the range in which λ exists in $\lambda \in [\frac{1}{2}, 1]$. On the other hand, $f(\lambda)$ is an increasing function with respect to λ in the same range. Consequently, a unique point of intersection of the two functions and its λ is stable equilibrium. However, we must consider the results of qualitative analysis because it is possible to show some type of equilibrium in the long run when the transportation cost is low. $g(\lambda)$ and $f(\lambda)$ are increasing functions of λ. Moreover, $g(\frac{1}{2})$ is satisfied with zero. Consequently, the property of equilibrium in the long run depends whether there is a point of intersection of $g(\lambda)$

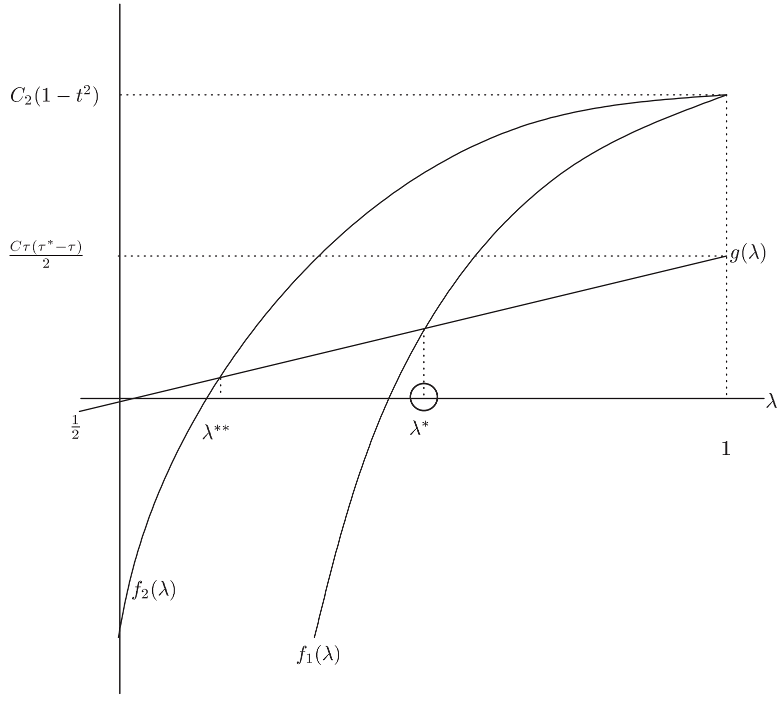

Fig. 3. Case in which (48) is satisfied and the transportation cost is low

and $f(\lambda)$ between $\frac{1}{2}$ to 1, or not. Considering that the λ to maximize $f(\lambda)$ is larger than one and $f(\frac{1}{2})<0$, we must compare $f(1)$ with $g(1)$ to check whether there is a point of intersection of $g(\lambda)$ and $f(\lambda)$ in the range from $\frac{1}{2}$ to 1, or not. Because $f(1)$ and $g(1)$ are $C_2(1-t^2)$ and $\frac{C\tau(\tau^*-\tau)}{2}$, respectively, the following condition must be satisfied by $g(1)<f(1)$:[7]

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

We can describe $f(\lambda)$ and $g(\lambda)$ in Figure 3 when (48) is satisfied. Here, the equilibrium labour distribution in the long run is given as λ^*. As described in the previous section, we consider the case in which the technological difference of pollution reduction between regions gets smaller because of technological transfer. Presuming that the pollution reduction technology in region H is superior to that in region F ($\theta>1$), we can assume that the pollution reduction technology in region H is transferred from region H to region F. Because the technological difference of pollution refection between the regions gets smaller because of technological transfer, $f_1(\lambda)$ in Figure 3 shifts to $f_2(\lambda)$. Consequently, the point of intersection of $g(\lambda)$ and $f(\lambda)$ moves from λ^* to λ^{**}. That is to say, we know that the smaller difference between regions of the pollution reduction technology relaxes the agglomeration of the particular region.

[7] Presuming that (48) is satisfied, then we can give this condition the following economic interpretation. It is possible that (48) is satisfied when the degree of transboundary pollution is small and the transportation cost is not extremely small.

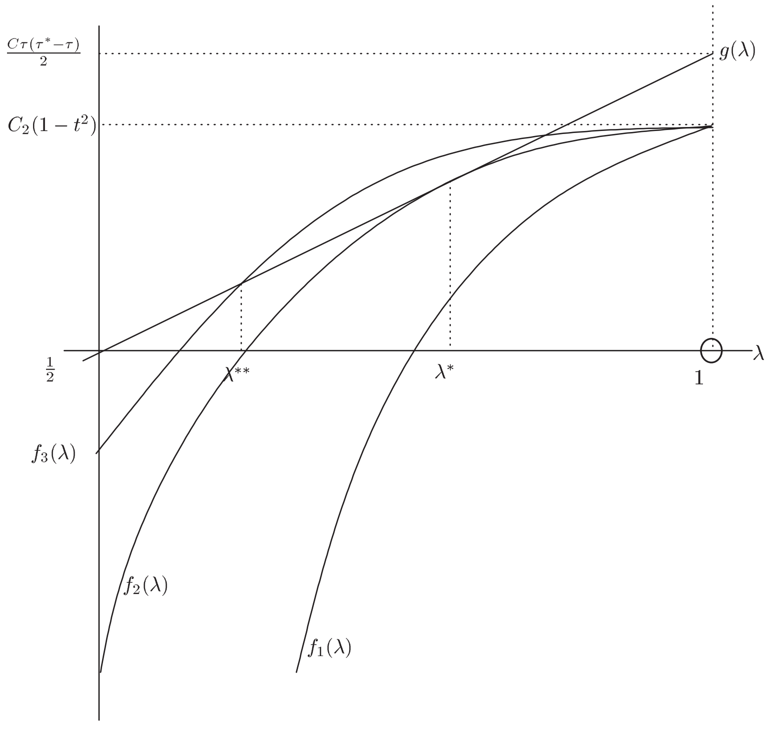

Fig. 4. Case in which (49) is satisfied, the degree of transboundary pollution is small, and the transportation cost is low

Proposition 2. *Presuming that (48) is satisfied, then the equilibrium labuor distribution between regions λ exists between $\frac{1}{2}$ to 1 and the agglomeration of labour in the particular region is relaxed because of the smaller difference between regions of the pollution reduction technology.*

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 (49) is satisfied, then the property of equilibrium in the long run depends on the relation locations of $f(\lambda)$ and $g(\lambda)$. That is to say, there exists (i), the case in which there is no intersection of $f(\lambda)$ and $g(\lambda)$ between λ from $\frac{1}{2}$ and 1. All labourers agglomerate to region H in this case. There also exists (*ii*), the case in which $f(\lambda)$ and $g(\lambda)$ come into mutual contact. (*iii*) The case in which $f(\lambda)$ and $g(\lambda)$ intersect between λ from $\frac{1}{2}$ and 1. Figure 4 depicts the three cases presented above. When there is the regional difference of pollution reduction technology, then $\lambda = 1$ is the stable equilibrium given by $f_1(\lambda)$; all labourers agglomerate to region H. When $f(\lambda)$ and $g(\lambda)$ come into mutual contact, then the stable equilibria are given by $\lambda = 1$.[8] Here we

[8] When $f(\lambda)$ and $g(\lambda)$ come into mutual contact and the initial labour distribution is smaller than λ^* in Figure 4, then λ converges to λ^*. On the other hand, when $f(\lambda)$ and $g(\lambda)$ come into mutual contact; the initial labour distribution is larger than λ^* in Figure 4, λ converges to 1. Consequently, strictly speaking, this λ^* in Figure 4 is not a stable equilibrium.

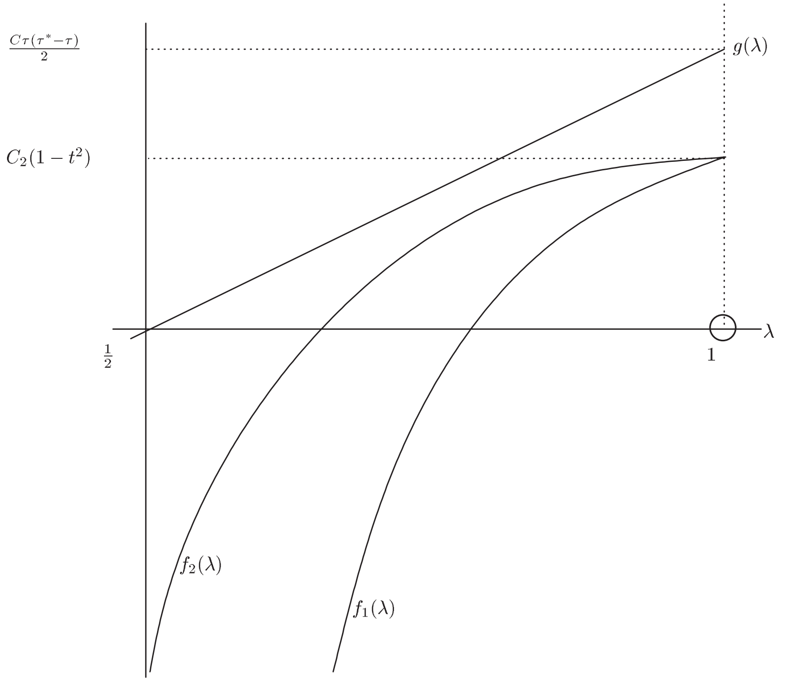

Fig. 5. Case in which (49) is satisfied, the degree of transboundary pollution is large, and the transportation cost is low

consider the effect of namely, transfer of pollution reduction on the labour distribution between regions. To begin with, we consider the case in which the degree of transboundary pollution is large, namely, where t is nearly 1. When t is sufficiently nearly equal to 1, $f(1) = C_2(1 - t^2)$ is sufficiently near 0. In this case, no intersection of functions occurs in spite of the shrinking technological difference of pollution reduction function. Consequently, the labour distribution in the long run does not change because of technological transfer and agglomerates in region H in Figure 5. On the other hand, the value of $g(1) - f(1)$ is small when the degree of transboundary pollution is small. Presuming that the technological transfer of pollution reduction is conducted in this situation, then $f(\lambda)$ shifts from $f_1(\lambda)$ to $f_3(\lambda)$ in Figure 4.

Presuming that λ^* is the initial distribution, then λ^* moves to λ^{**} to be stable because of the technological transfer of pollution reduction. In other words, the technological transfer of the pollution reduction technology promotes agglomeration. Therefore, we derive the following proposition.

Proposition 3. *Presuming that (49) is satisfied, then the degree of transboundary pollution is large and the transportation cost is low; the labour agglomerates in the region with superiority in pollution reduction technology. Consequently, the technological transfer of pollution reduction does not affect the equilibrium labour distribution.*

4.3 Welfare

Next we analyse whether the equilibria, which we derived in this paper, are socially optimal or not. Following the analysis used in the OTT model, the social planner can control λ, which is the labour distribution between the regions, and use a lump sum transfer from all households to pay for the loss that firms might incur while pricing at marginal cost. Because these equilibria presented in this paper depend on plural parameters, that is λ, t, τ, θ, and so on, we analyse the social optimum by fixing some of them. Here we address the case in which the degree of transboundary pollution is given because this parameter depends on power beyond the ability for human control and should not be considered as a policy variable. Moreover, we can argue with the incentive of technological transfer of pollution reduction between the regions by comparing the equilibrium and optimum.

Because the total number of varieties depends on factor endowment and technology, the outcome in equilibrium is equal to that in a social optimum. We assume that the social planner can use lump sum transfer from all households to pay for the losses to firms. Consequently, the social planner considers λ to maximize the following welfare function $\hat{W}$:[9]

$$\begin{aligned}\hat{W}(\lambda) \equiv& \frac{A}{2}[S_H(\lambda)+1]+\lambda L[S_H(\lambda)+w_H(\lambda)]+\frac{A}{2}[S_F(\lambda)+1]\\&+(1-\lambda)L[S_F(\lambda)+w_F(\lambda)]-\frac{A}{2}C_2[t\theta+(1-t\theta)\lambda]^2\\&-\lambda LC_2[t\theta+(1-t\theta)\lambda]^2-\frac{A}{2}C_2[\theta+(t-\theta)\lambda]^2\\&-(1-\lambda)LC_2[\theta+(t-\theta)\lambda]^2.\end{aligned} \tag{50}$$

We define the total sum of surplus and income in the economy as:

$$TS(\lambda) \equiv C^o\tau(\tau^o-\tau)\lambda(\lambda-1), \tag{51}$$

where C^o and τ^o are as shown below:

$$C^o \equiv \frac{L[2b\phi + C(A+L)]}{2\phi^2} \tag{52}$$

and

$$\tau^o \equiv \frac{4a\phi}{2b\phi+c(A+L)}. \tag{53}$$

Next we define $TD(\lambda)$ as the total environmental damage that occurs in the economy:

$$\begin{aligned}TD(\lambda) \equiv& \frac{A}{2}C_2[t\theta+(1-t\theta)\lambda]^2+\lambda LC_2[t\theta+(1-t\theta)\lambda]^2\\&+\frac{A}{2}C_2[\theta+(t-\theta)\lambda]^2+(1-\lambda)LC_2[\theta+(t-\theta)\lambda]^2.\end{aligned} \tag{54}$$

Consequently, we can rewrite (50) as follows:

$$\hat{W}(\lambda) = TS(\lambda) - TD(\lambda). \tag{55}$$

Here our analysis is similar to that used for the OTT model in terms of the migration equilibrium in the long run. When the prices of manufactured goods are marginal cost plus transfer, the prices of manufactured goods in optimum p^o_{lm} (i, $m = H$, F) is the following:[10]

[9] We define this welfare function as the sum of each indirect utility function.
[10] Regarding this argument without consideration of environmental factors, see Ottaviano et al. (2002).

$$p^o_{HH} = p^{FF} = 0, p^o_{HF} = p^{HF} = \tau. \tag{56}$$

Following the analysis used in the OTT model, (23) and (24) are equal to 0 considering (56). Consequently, $w^o_H(\lambda)$ and $w^o_F(\lambda)$ are equal to 0 in $\forall\lambda \in [1/2,1]$. First, the first term of right side in (55) is strictly convex with respect to λ when τ is less than τ^o. Consequently, this term is maximized when λ is 1. Differentiating (54) with respect to λ, we know that the sign of $dTD(\lambda)/d\lambda$ depends on t and θ and is not unique. Therefore the social planner has no incentive to carry out technological transfer policy when τ is smaller than τ^o and $dTD(\lambda)/d\lambda$ is negative. In this case, the agglomeration equilibrium is optimal.

However, the agglomeration configuration is not optimal when $dTD(\lambda)/d\lambda$ is positive. Presuming that $dTD(\lambda)/d\lambda$ is positive, it is possible to improve social welfare through the technological transfer of a pollution reduction function, except for the case in which t is large. Next we consider the case in which the transportation cost is high, namely, $\tau^* < \tau$. In this case, the first term of the right side in (55) is maximum at $\lambda = 1/2$, because it is strictly concave. Presuming that $dTD(\lambda)/d\lambda$ is positive, then the technological transfer policy of pollution reduction can improve social welfare.[11] This is true because that policy can relax agglomeration under high transportation costs. Finally, it is difficult to judge the effectiveness of technological transfer on social welfare improvement in spite of transportation cost, when the signs of $dTD(\lambda)/d\lambda$ and $dTD(\lambda)/d\lambda$ are the same, because the social welfare improvement depends on the tradeoff between the first term and the second term. Alternatively, the technological transfer policy has no effectiveness to improve social welfare when the equilibrium distribution is smaller than the socially optimal distribution.

5 Concluding remarks

As described in this paper, we introduced transboundary pollution and asymmetric technology of pollution reduction into the OTT model and analysed the properties of this extended model. As a result of analysing the model, we obtained some interesting knowledge related to the pollution reduction technology. First, a stable equilibrium of labour distribution exists between the regions within $\lambda \in (\frac{1}{2}, 1)$. Moreover, it is possible to relax the agglomeration of labour in the particular region as the technological difference of the pollution reduction technology gets smaller. Second, presuming that the transportation cost is low, the technological transfer of pollution reduction does not affect the equilibrium labour distribution in the long run when the degree of transboundary pollution is large. Moreover, it is possible to improve social welfare by a technological transfer policy according to a pollution reduction function. Consequently, it is possible to promote regional agglomeration through environmental support such as that of ODA. The results of this study show that whether the technological transfer of pollution reduction promotes regional agglomeration depends on the degree of transboundary pollution. Even if it is the same technological transfer policy, the effects differ under respective economic situations. Consequently, it is important to carry out the environmental support carefully.

Because we highlighted analyses of the effect of technological transfer of pollution reduction on regional agglomeration, we omitted arguments against the optimal pollution level or environmental taxation. We must consider the economic method when we draft the environ-

[11] The technological transfer policy has no effectiveness in a case in which the labour distribution to maximize $\hat{W}(\lambda)$ is larger than the equilibrium labour distribution.

mental policy.[12] Moreover, we have to carry the empirical analysis to show the robustness of results derived in these analyses. It may be possible to extend our model in the future.

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[12] Ikazaki and Naito (2008) consider the local government to maximize the welfare of households in his region and derive the optimal pollution.