Tourism Infrastructure and the Environment: The effects of pollution tax on welfare, production, and domestic wage inequality*

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Abstract

This paper provides a general equilibrium model of a small open developing economy with pollution generated by tourism industry. The national government imposes a pollution tax on pollution emission and constructs tourism infrastructure for the tourism sector. We investigate the effects of an increase in pollution tax rate on welfare, production, and income distribution. When the elasticity of substitution in the tourism sector is sufficiently low, an increase in pollution tax paradoxically expands the tourism sector and narrows domestic wage inequality under the constant tourism terms-of-trade. In addition to the two traditional channels, there is a new channel through which pollution tax affects the tourism terms-of-trade and domestic welfare. The new channel, which arises from the difference between the marginal value product of tourism infrastructure and its price, improves the tourism terms-of-trade and domestic welfare if (a) the marginal value product of tourism infrastructure is greater than its price, (b) the output of tourism infrastructure is increased by higher pollution tax rate, and (c) the excess supply of tourism service decreases with the pollution tax. Given the above three conditions, starting from a Pigouvian level, the increase in pollution tax improves the tourism terms-of-trade and domestic welfare.

Keywords: Tourism infrastructure, Pollution tax, Welfare, Wage inequality, Tourism terms-of-trade

JEL Classification: D33, F18, Q38

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*This paper is an extension of Shimizu and Okamoto (2023) which analyzes the effect of a rduction in emission permits in a similar setting to this paper. The idea of this extension was suggested by Shigemi Yabuuchi at the 78th annual meeting of the Japan Society of International Economics.

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1 Introduction

The tourism industry plays an important role for both developed and developing countries as it creates employment opportunities and attracts foreign currency. To attract a large number of tourists, tourism industry requires a large-scale investment, for example, water supply, sewerage systems, ports, airports, parks, highways, and tourism promotion by authorities (e.g., Visit Japan, Incredible India, and Malaysia Truly Asia), which is difficult to be financed only by the private sector. Therefore, a national government needs to construct public infrastructure for the tourism industry, which is referred to as the tourism infrastructure. At the same time, the tourism sector causes environmental damage. For example, the concentration of people degrades the water quality in the local community, and traffic congestion pollutes the air by the emission of fumes. To mitigate these negative effects, the government imposes pollution tax on the tourism industry. Then the government uses this tax revenue to construct the tourism infrastructure.

Initiated by Copeland (1991), there are many theoretical studies on the analysis of international tourism. We fucus on the studies that consider environmental problems, including Beladi et al. (2009), Chao et al. (2008), Chao et al. (2012), Furukawa et al. (2019), Gupta and Dutta (2018), Kondoh and Kurata (2021), Yabuuchi (2013), Yabuuchi (2015), Yabuuchi (2018), Yanase (2017). However, these studies do not consider public infrastructure.

Although Yanase (2015) introduces public infrastructure in a tourism economy, he does not consider environmental problem. Shimizu (2022a) and Shimizu (2022b) construct a model of public infrastructure that contributes to both tourism and manufacturing industry. Some infrastructures, such as wireless network, highway, or airport, contribute to many industries as well as tourism industry. Shimizu (2022b) develops a model of public infrastructure that includes congestion effect, that is, an increase in users reduced efficiency, while Shimizu (2022a) a model without congestion effect. Shimizu and Okamoto (2023) develops a model of tourism infrastructure that contributes only to the tourism industry and analyzes the effect of decrease in emission permits issued to tourism industry. This paper analyzes the effect of pollution tax in a similar setting to Shimizu and Okamoto (2023). Main results of this paper are as follows. When the elasticity of substitution in the tourism sector is sufficiently small, an increase in pollution tax paradoxically expands the tourism sector and narrows domestic wage inequality under the constant tourism terms-of-trade. When the tourism terms-of-trade are endogenous, there are two traditional channels through which pollution tax affects the tourism terms-of-trade and domestic welfare. In this paper, there is a new channel, in addition to the two traditional channels. The new channel, which arises from the difference between the marginal value product of tourism infrastructure and its price, improves the tourism terms-of-trade and domestic welfare if (a) the marginal value product of tourism infrastructure is greater than its price, (b) the output of tourism infrastructure is increased by higher pollution tax, and (c) the excess supply of tourism service decreases with the pollution tax. Given the above three conditions, starting from a Pigouvian level, the increase in pollution tax improves the tourism terms-of-trade and domestic welfare.

The remainder of this paper is organized as follows. In section 2, we describe the setup of the model. Section 3 conducts a comparative static analysis of the supply side of the economy. In section 4, we examine the total effects of an increase in pollution tax by considering both the supply and demand sides of the economy. Section 5 concludes.

2 The model

Consider a small open economy that produces a manufacturing good X, tourism service T, and tourism infrastructure M. The manufacturing good is traded while the tourism infrastructure is non-traded. The service is also non-traded in the absence of foreign tourists. Unlike the tourism infrastructure, the service is exported through international tourism. Thus the manufacturing good is imported. We call the price of tourism service as the tourism terms-of-trade, which plays an important role in welfare analysis. Suppose that the production of the manufacturing good requires capital K and skilled labor H, while the production of the tourism service requires unskilled labor L and emits pollution Z. The national government imposes pollution tax on tourism industry. The government uses this revenue to construct tourism infrastructure. For simplicity, suppose that the tourism infrastructure requires only capital input, and further assume that the formation of tourism infrastructure only enhances the productivity of the tourism industry.[1]

The production function of the manufacturing good (or traded good) X is given by

$$X = X(K_X, H),$$

where K_j denotes the capital input into good j and H is the endowment of skilled labor. Function X is assumed to be the neoclassical type of production function that exhibits homogeneity of degree one, and to be strictly quasi-concave.

[1] Yanase (2015) made the same assumption.

The production function of the tourism service T is

$$T = g(M)Y(L, Z),$$

where the function g represents the positive externality of the infrastructure and the function Y has the same properties as function X. M is the amount of tourism infrastructure devoted only to the tourism industry, L is the endowment of unskilled labor, and Z is the amount of pollution. Keeping M constant and doubling both L and Z, the output of tourism service T doubles. This implies that the tourism infrastructure in this study has no congestion effect and is the creation atmosphere type in the terminology of Meade (1952). Another type of tourism infrastructure is unpaid factor of production type, which has a congestion effect.[2]

We assume the function g is twice continuously differentiable and has the following properties:

$$g(M) > 0, \quad g'(M) > 0, \quad g''(M) < 0 \quad \forall M > 0, \quad \lim_{M \to 0} g'(M) = \infty, \quad \lim_{M \to \infty} g'(M) = 0.$$

The production function of the tourism infrastructure is given by

$$M = K_M / a_{KM}, \tag{1}$$

where a_{ij} is the amount of factor $i(= L, H, K, Z)$ to produce one unit of good $j(= X, T, M)$. We assume a linear production function for tourism infrastructure and, thus, a_{KM} is constant.

We now examine the equilibrium conditions for the supply side of the economy. Let us assume that perfect competition prevails in the manufacturing and tourism industries. The zero-profit condition (the price of the good is equal to its unit cost) for the traded good industry is

$$a_{HX} w_H + a_{KX} q = p_X, \tag{2}$$

where p_X is the price of traded good, w_H the wage rate of skilled labor, and q the rental rate of capital.

The zero profit condition for the tourism service industry is

$$a_{LT} w_L + a_{ZT} s = p_T, \tag{3}$$

where p_T is the price of tourism service, w_L the wage rate of unskilled labor, s the pollution tax rate.

[2] See Shimizu (2022b) for an analysis of this type of public infrastructure (not tourism infrastructure). In this case, the production function of tourism service is $T = T(M, L, Z)$, where T is homogeneous of degree one in (M, L, Z).

The zero profit condition for the public infrastructure sector is

$$a_{KM}q = p_M, \tag{4}$$

where p_M is the price of tourism infrastructure.

The market clearing condition of capital is

$$a_{KX}X + a_{KM}M = K, \tag{5}$$

where K is the endowment of capital.

The demand-supply equality of skilled labor requires

$$a_{HX}X = H. \tag{6}$$

The market equilibrium condition of unskilled labor requires

$$a_{LT}T = L. \tag{7}$$

The amount of pollution emission is given by

$$a_{ZT}T = Z. \tag{8}$$

The budget constraint of the government is

$$sZ = p_M M, \tag{9}$$

where the left-hand side (LHS) denotes the pollution tax revenue, and the right-hand side (RHS) represents the cost of constructing tourism infrastructure.[3] Equations (2) - (9) include eight unknowns: X, T, M, w_H, w_L, q, Z, and p_M. Given p_T, these eight equations determine eight unknowns.[4] Note that the price of tourism infrastructure p_M is determined to satisfy the government's budget constraint (9). It follows that the traditional Lindahl pricing rule (i.e., the price of tourism infrastructure is equal to its marginal value product) does not necessarily hold; thus, we will obtain different properties from the standard trade theory.

To facilitate the following analysis, we introduce the elasticity of factor substitution. The elasticity of substitution in each sector σ_j is defined as

$$\sigma_X = \frac{\widehat{a}_{KX} - \widehat{a}_{HX}}{\widehat{w}_H - \widehat{q}}, \tag{10}$$

[3]Equations (1) and (4) imply that $p_M M = qK_M$.

[4]The price of tourism service p_T is to be determined by the demand and supply of domestic tourism service in section 4. This approach is also adopted by Chao et al. (2010).

$$\sigma_T = \frac{\widehat{a}_{ZT} - \widehat{a}_{LT}}{\widehat{w}_L - \widehat{s}}. \tag{11}$$

A hat over a variable implies the rate of change: for example, $\widehat{w}_H \equiv dw_H/w_H$.

The cost minimization in each sector requires

$$\theta_{HX}\widehat{a}_{HX} + \theta_{KX}\widehat{a}_{KX} = 0, \tag{12}$$

$$\theta_{LT}\widehat{a}_{LT} + \theta_{ZT}\widehat{a}_{ZT} = -\widehat{g}, \tag{13}$$

where θ_{ij} represents the cost share of factor i in sector j. We define $\xi \equiv g'M/g > 0$ as the elasticity of g with respect to M, or the productivity improvement rate of the tourism industry by additional tourism infrastructure. By the definition, we have $\widehat{g} = \xi\widehat{M}$.

Solving (10) and (12), we obtain

$$\widehat{a}_{HX} = -\theta_{KX}\sigma_X(\widehat{w}_H - \widehat{q}), \tag{14}$$

$$\widehat{a}_{KX} = \theta_{HX}\sigma_X(\widehat{w}_H - \widehat{q}). \tag{15}$$

Similarly, solving (11) and (13), we have

$$\widehat{a}_{LT} = -\theta_{ZT}\sigma_T(\widehat{w}_L - \widehat{s}) - \widehat{g}, \tag{16}$$

$$\widehat{a}_{ZT} = \theta_{LT}\sigma_T(\widehat{w}_L - \widehat{s}) - \widehat{g}. \tag{17}$$

Differentiating (2) totally and taking into account (12), we obtain

$$\theta_{HX}\widehat{w}_H + \theta_{KX}\widehat{q} = \widehat{p}_X. \tag{18}$$

Differentiating (3) totally and substituting (13), we obtain

$$\theta_{LT}\widehat{w}_L + \theta_{ZT}\widehat{s} - \xi\widehat{M} = \widehat{p}_T, \tag{19}$$

Since a_{KM} is constant, Equation (4) implies

$$\widehat{p}_M = \widehat{q}. \tag{20}$$

Differentiating (5) and substituting (15), we obtain

$$\lambda_{KX}\widehat{X} + \lambda_{KX}\theta_{HX}\sigma_X(\widehat{w}_H - \widehat{q}) + \lambda_{KM}\widehat{M} = \widehat{K}, \tag{21}$$

where λ_{ij} is the share of factor i in the production of good j.

Differentiating (6) and substituting (14), we obtain

$$-\theta_{KX}\sigma_X(\widehat{w}_H - \widehat{q}) + \widehat{X} = \widehat{H}. \tag{22}$$

Differentiating (7) and substituting (16), we have

$$-\theta_{ZT}\sigma_T(\widehat{w}_L - \widehat{s}) - \xi\widehat{M} + \widehat{T} = \widehat{L}. \tag{23}$$

Differentiating (8) and substituting (17) yield

$$\theta_{LT}\sigma_T(\widehat{w}_L - \widehat{s}) - \xi\widehat{M} + \widehat{T} = \widehat{Z}. \tag{24}$$

Differentiating (9) and considering (20), we obtain

$$\widehat{q} + \widehat{M} - \widehat{s} = \widehat{Z}. \tag{25}$$

Equations (18), (19), (21) - (25) are expressed in the matrix form as

$$\begin{pmatrix} 0 & 0 & 0 & \theta_{HX} & 0 & \theta_{KX} & 0 \\ 0 & 0 & -\xi & 0 & \theta_{LT} & 0 & 0 \\ \lambda_{KX} & 0 & \lambda_{KM} & \lambda_{KX}\theta_{HX}\sigma_X & 0 & -\lambda_{KX}\theta_{HX}\sigma_X & 0 \\ 1 & 0 & 0 & -\theta_{KX}\sigma_X & 0 & \theta_{KX}\sigma_X & 0 \\ 0 & 1 & -\xi & 0 & -\theta_{ZT}\sigma_T & 0 & 0 \\ 0 & 1 & -\xi & 0 & \theta_{LT}\sigma_T & 0 & -1 \\ 0 & 0 & 1 & 0 & 0 & 1 & -1 \end{pmatrix} \begin{pmatrix} \widehat{X} \\ \widehat{T} \\ \widehat{M} \\ \widehat{w}_H \\ \widehat{w}_L \\ \widehat{q} \\ \widehat{Z} \end{pmatrix} = \begin{pmatrix} 0 \\ -\theta_{ZT} \\ 0 \\ 0 \\ -\theta_{ZT}\sigma_T \\ \theta_{LT}\sigma_T \\ 1 \end{pmatrix} \widehat{s} + \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \widehat{p}_T. \tag{26}$$

Let the determinant of the 7×7 matrix on the LHS of (26) be Δ. Then, $\Delta > 0$ by the stability of the system (see Appendix A).

3 Comparative statics: supply side analysis

Utilizing Equation (26), we analyze the effects of an increase in pollution tax and an improvement in the tourism terms-of-trade. For the purpose of making the analysis as simple as possible, we examine the relationship between endogenous variables.

From (18), we have

$$\widehat{q} = -\frac{\theta_{HX}}{\theta_{KX}}\widehat{w}_H. \tag{27}$$

Since the price of traded good is constant under the assumption of a small open economy, an increase in the skilled wage is balanced by a decrease in the rental rate of capital. Equation (27) implies $\widehat{w}_H - \widehat{q} = \widehat{w}_H/\theta_{KX}$. From (22), we have

$$\widehat{X} = \theta_{KX}\sigma_X(\widehat{w}_H - \widehat{q}) = \sigma_X\widehat{w}_H. \tag{28}$$

Equation (28) means that an increase in the output of traded good X raises the wage of skilled labor, which is a specific input to that sector.

Substituting (27) and (28) into (21), we obtain

$$\widehat{M} = -\frac{\lambda_{KX}\sigma_X}{\lambda_{KM}\theta_{KX}}\widehat{w}_H = -\frac{\lambda_{KX}}{\lambda_{KM}\theta_{KX}}\widehat{X}, \tag{29}$$

which states that an increase in the output of traded good reduces the output of tourism infrastructure by extracting capital input from that industry. Equations (27) - (29) show that $\widehat{q}$, $\widehat{X}$, and $\widehat{M}$ are proportional to $\widehat{w}_H$.

3.1 Pollution tax

Keeping the price of tourism service unchanged, we examine the effects of an increase in pollution tax. Note that Equations (27) - (29) hold.

Solving (26), we have

$$\frac{\widehat{T}}{\widehat{s}} = \frac{\xi\theta_{LT}Q - \sigma_T[(\theta_{ZT} + \xi\theta_{LT})Q + \theta_{ZT}P]}{\Delta}, \tag{30}$$

$$\frac{\widehat{w}_H}{\widehat{s}} = \frac{\theta_{KX}\lambda_{KM}(\sigma_T - \theta_{LT})}{\Delta} \gtreqless 0 \text{ iff. } \sigma_T \gtreqless \theta_{LT}, \tag{31}$$

$$\frac{\widehat{w}_L}{\widehat{s}} = \frac{\xi Q(1-\sigma_T) - \theta_{TZ}(P+Q)}{\Delta}, \tag{32}$$

$$\frac{\widehat{Z}}{\widehat{s}} = -\frac{\sigma_T[(1-\xi)Q + P]}{\Delta} < 0, \tag{33}$$

where $P \equiv \lambda_{KM}\theta_{HX}$ and $Q \equiv \lambda_{KX}\sigma_X$. From the assumptions $g(M) > 0$ and $g''(M) < 0$, we have $\xi < 1$ for $M > 0$.

The qualitative effects of an increase in pollution tax, which are determined by the signs of equations (30) - (33), are ambiguous and depend on the elasticity of substitution in the tourism sector σ_T. From (30), an increase in pollution tax expands the tourism sector if and only if

$$\sigma_T < \frac{\xi\theta_{LT}Q}{(\theta_{ZT} + \xi\theta_{LT})Q + \theta_{ZT}P} \equiv A.$$

We can immediately show that $A < \theta_{LT}$.

From (32), the necessary and sufficient condition for the increased pollution tax to push the wage of unskilled labor up is

$$\sigma_T < 1 - \frac{\theta_{ZT}}{\xi} - \frac{\theta_{ZT} P}{\xi Q} \equiv B.$$

It is straightforward to show that $A > B$ since

$$A - B = \frac{(\theta_{ZT})^2}{\xi} \frac{P+Q}{Q} \frac{P + (1-\xi)Q}{\theta_{ZT}(P+Q) + \xi \theta_{LT} Q} > 0.$$

Therefore, we have the following relationship in magnitude:

$$B < A < \theta_{LT}.$$

The above results are summarized in Table 1, which shows how the comparative static results with respect to s depend on σ_T, with threshold values such as A, B, and θ_{LT}.[5]

Thus, we have the following proposition.

Proposition 1 *Suppose that the price of tourism service p_T is constant. When the elasticity of substitution in the tourism sector is sufficiently low, an increase in the pollution tax expands the tourism and tourism infrastructure sectors and contracts the manufacturing sector. This narrows the wage inequality between skilled and unskilled labor. The rental rate of capital and the price of emission permits rise. As the elasticity of substitution in the tourism sector increases, all the above results are reversed.*

The intuition is as follows. When the elasticity of substitution in the tourism sector σ_T is sufficiently low, an increase in pollution tax raises the tax revenue sZ since a decrease in emission is small. Then the output of tourism infrastructure M increases (see (9)).[6] If an increase in M is significant, the output of tourism service T rises despite the reduction in emission permits Z. Consequently, the wage of unskilled labor, which is a specific factor into the tourism sector, increases. At the same time, capital flows from the manufacturing sector, leading to a decrease in the output of manufacturing good X. The decrease in the output of manufacturing good reduces the wage of skilled labor, which is a specific input into that industry. Since the price of the manufacturing good

[5] The stability condition ($\Delta > 0$) imposes the restriction on the value of σ_T: $\sigma_T < C \equiv \theta_{LT}/\xi + \theta_{LT} P/(\xi Q)$ (notice that $\Delta = \theta_{LT}(P+Q) - \xi \sigma_T Q$). Since $\xi < 1$, it is straightforward to show that $C > \theta_{LT}$. Thus, this restriction is not binding for the range of σ_T considered here.

[6] From (33), we have $\widehat{s} + \widehat{Z} = [(\theta_{LT} - \sigma_T)(P+Q)/\Delta]\widehat{s}$. Therefore, if σ_T is less than θ_{LT}, an increase in pollution tax raises tax revenue sZ.

σ_T	$\cdots$	B	$\cdots$	A	$\cdots$	θ_{LT}	$\cdots$
$\partial X/\partial s$	$-$	$-$	$-$	$-$	$-$	0	$+$
$\partial T/\partial s$	$+$	$+$	$+$	0	$-$	$-$	$-$
$\partial M/\partial s$	$+$	$+$	$+$	$+$	$+$	0	$-$
$\partial w_H/\partial s$	$-$	$-$	$-$	$-$	$-$	0	$+$
$\partial w_L/\partial s$	$+$	0	$-$	$-$	$-$	$-$	$-$
$\partial q/\partial s$	$+$	$+$	$+$	$+$	$+$	0	$-$

Table 1: Effects of pollution tax (the tourism terms-of-trade are constant)

is constant, the decrease in the wage of skilled labor is offset by the increase in the rental rate of capital (see (18) or (27)).

When σ_T is sufficiently high, the increase in pollution tax decreases pollution tax revenue since the amount of emission decreases significantly. Then the output of tourism infrastructure decreases. It follows that the output of the tourism service falls due to a decrease in both emission and positive externality of tourism infrastructure. The wage of unskilled labor, which is a specific factor to the tourism service sector, decreases despite the increase in demand. Meanwhile, capital flows from the tourism infrastructure sector to the manufacturing sector, leading to an increase in the output of the manufacturing good. The increased output of the manufacturing sector raises the wage of skilled labor, which is a specific input to that sector.

3.2 Improvement in the tourism terms-of-trade

We examine the effects of an improvement in the tourism terms-of-trade. Note that (27), (28), and (29) still hold. Comparative statics procedure is given in Appendix B.

The effects of an increase in p_T are summarized in Table 2 and Proposition 2.

$\partial X/\partial p_T$	$\partial T/\partial p_T$	$\partial M/\partial p_T$	$\partial w_H/\partial p_T$	$\partial w_L/\partial p_T$	$\partial q/\partial p_T$	$\partial Z/\partial p_T$
$-$	$+$	$+$	$-$	$+$	$+$	$+$

Table 2: The effects of an increase in p_T

Proposition 2 *An improvement in the tourism terms-of-trade expands the tourism service and tourism infrastructure sectors, while it contracts the manufacturing sector. This narrows the wage inequality between skilled and unskilled labor. The rental rate of capital and the amount of emission rise.*

The intuition is straightforward. The improvement in the tourism terms-of-trade expands the tourism service sector and, thus, the wage of unskilled labor and the amount of pollution rise. The tax revenue sZ and the output of tourism infrastructure increase at the expense of the manufacturing sector; this leads to a decrease in the wage of skilled labor. Since the price of manufacturing good is unchanged, the rental rate of capital rises.

4 The total effect of pollution tax

The previous section treated the price of tourism service p_T as a constant. However, p_T must be determined by the market equilibrium condition of the domestic tourism service, that is, supply and demand for it. We examine the effects of pollution tax, considering that p_T is endogenously determined.

4.1 The effects on the tourism terms-of-trade and welfare

To determine the price of tourism service, we need to introduce the demand side of the economy. Suppose that both domestic residents and foreign tourists consume the manufacturing good and the domestic tourism service. The demand side of the economy is described by the expenditure function of domestic residents and the ordinary demand function of foreign tourists. The expenditure function is defined as

$$E(p_T, Z, u) \equiv \min[p_X C_X + p_T C_T : u = (C_X)^b + f(Z) \cdot (C_T)^b],$$

where C_X is the consumption of the manufacturing good by domestic residents, C_T the consumption of tourism service by domestic residents, and u the level of utility. $b \in (0, 1)$ is a parameter and $f'(Z) < 0$. The utility function has the property that the marginal utility of the tourism service (resp. the manufacturing good) decreases with (resp. is not affected by) the amount of pollution. The expenditure function is derived as follows (see Appendix C):

$$E = u^{1/b} \left[(\Phi_X)^{-b} + f \cdot (\Phi_T)^{-b} \right]^{-1/b},$$

where $\Phi_X \equiv p_X + (f p_X)^{\frac{1}{1-b}} (p_T)^{-\frac{b}{1-b}}$ and $\Phi_T \equiv p_T + (p_T/f)^{\frac{1}{1-b}} (p_X)^{-\frac{b}{1-b}}$.

The compensated demand for tourism service is given by (see Appendix C)

$$C_T = \frac{u^{1/b}}{\Phi_T \left[\frac{1}{(\Phi_X)^b} + \frac{f}{(\Phi_T)^b}\right]^{1/b}} = \frac{u^{1/b}}{[(\Phi_T/\Phi_X)^b + f]^{1/b}}. \tag{34}$$

The envelope theorem implies $C_T = \partial E/\partial p_T \equiv E_T$. Then the downward demand function ensures $E_{TT} \equiv \partial^2 E/\partial p_T^2 = \partial C_T/\partial p_T < 0$. Since $\partial[(\Phi_X)^{-b} + f \cdot (\Phi_T)^{-b}]/\partial Z = (\Phi_T)^{-b} f'$, [7] we have

$$\begin{aligned} E_Z \equiv \frac{\partial E}{\partial Z} &= u^{1/b}\left(-\frac{1}{b}\right)[(\Phi_X)^{-b} + f \cdot (\Phi_T)^{-b}]^{-\frac{1}{b}-1}\frac{\partial}{\partial Z}[(\Phi_X)^{-b} + f \cdot (\Phi_T)^{-b}] \\ &= -\frac{1}{b}E[(\Phi_X)^{-b} + f \cdot (\Phi_T)^{-b}]^{-1}(\Phi_T)^{-b} f' \\ &= -\frac{1}{b}\frac{E}{[(\Phi_T/\Phi_X)^b + f]} f' > 0, \end{aligned}$$

which denotes the marginal damage to domestic residents caused by pollution. $E_u \equiv \partial E/\partial u > 0$ represents the inverse of the marginal utility of income. $E_{Tu} \equiv \partial^2 E/\partial u \partial p_T = \partial C_T/\partial u > 0$ is the (positive) income effect on the demand for the tourism service.

We examine the effect of an increase in pollution on the compensated demand for the tourism service. Differentiating equation (34) with respect to Z, we obtain

$$\begin{aligned} E_{TZ} \equiv \frac{\partial^2 E}{\partial Z \partial p_T} = \frac{\partial C_T}{\partial Z} &= -\frac{1}{b}\frac{C_T}{[(\Phi_X)^{-b} + f(\Phi_T)^{-b}]}\frac{\partial\left[(\Phi_X)^{-b} + f(\Phi_T)^{-b}\right]}{\partial Z} - \frac{C_T}{\Phi_T}\frac{\partial \Phi_T}{\partial Z} \\ &= -\frac{1}{b}\frac{C_T}{[(\Phi_X)^{-b} + f(\Phi_T)^{-b}]}(\Phi_T)^{-b} f' - \frac{C_T}{\Phi_T}\frac{\partial \Phi_T}{\partial Z} \\ &= -\frac{1}{b}\frac{C_T}{[(\Phi_T/\Phi_X)^b + f]} f' - \frac{C_T}{\Phi_T}\frac{\partial \Phi_T}{\partial Z}, \end{aligned}$$

where $\partial \Phi_T/\partial Z > 0$ (see Appendix Appendix D). The first term indicates the effect that an increase in pollution raises the amount of compensated demand required to offset the disutility of pollution, while the second term reflects that the increase in pollution decreases the attractiveness of the tourism service. If the latter effect dominates the former, the compensated demand for tourism service decreases with the amount of pollution.

Foreign tourists also consume the manufacturing good and domestic tourism service. Their utility function is given by

$$u^* = (D_X)^\beta + f^*(Z) \cdot (D_T)^\beta$$

where D_X is the consumption of the manufacturing good by foreign tourists, and D_T is the consumption of the domestic tourism service by foreign tourists. $\beta \in (0, 1)$ is a parameter and $f^{*\prime}(Z) < 0$. Foreign tourists' ordinary demand for the domestic tourism service is derived as

[7] See Appendix Appendix D.

$D_T = I^*/\Phi_T^*$ (see Appendix C), where I^* is the exogenously given budget of foreign tourists and $\Phi_T^* \equiv p_T + (p_T/f^*)^{1/(1-\beta)}(p_X)^{-\beta/(1-\beta)}$. Note that $\partial D_T/\partial Z < 0$ because an increase in pollution reduces the attractiveness of the tourism service.

Following Beladi et al. (2009), Chao and Sgro (2013), Chao et al. (2008), Copeland and Taylor (2003), and Yanase (2017), we define the "after-tax" or "net" revenue function:

$$R(p_T, s) = \max[p_X X + p_T T - sZ : K_X + K_M = K, X = X(K_X, S), T = g(K_M/a_{KM})Y(L, Z)].$$

The properties of the net revenue function with a positive externality of tourism infrastructure are given in Appendix E. Note that standard envelope theorem does not hold in the absence of the Lindahl pricing rule.

Now, we can derive the equilibrium conditions for both the demand and supply sides of the economy. First, the budget constraint of the economy is given by

$$E(p_T, Z, u) = R(p_T, s) + sZ(p_T, s), \tag{35}$$

which states that the total expenditure equals the total revenue. The second term on the RHS denotes the reward on capital devoted to tourism infrastructure sector.

Second, the market equilibrium condition of the tourism service is

$$E_T(p_T, Z, u) + D_T(p_T, Z) = T(p_T, s). \tag{36}$$

The LHS denotes the demand for the domestic tourism service and the RHS its supply.

(35) and (36) simultaneously determine the tourism terms-of-trade p_T and domestic welfare u. Utilizing these two equations, we analyze the effects of pollution tax on p_T and u. Totally differentiating equations (35) and (36), we obtain

$$\begin{pmatrix} -D_T - \Gamma\frac{\partial M}{\partial p_T} + (E_Z - s)\frac{\partial Z}{\partial p_T} & E_u \\ -S_T + \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial p_T} & E_{Tu} \end{pmatrix} \begin{pmatrix} dp_T \\ du \end{pmatrix} = \begin{pmatrix} \Gamma\frac{\partial M}{\partial s} - (E_Z - s)\frac{\partial Z}{\partial s} \\ \frac{\partial T}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial s} \end{pmatrix} ds, \tag{37}$$

where $\Gamma \equiv p_T \cdot (\partial T/\partial M) - p_M$ is the difference between the marginal value product of tourism infrastructure and its price, $S_T \equiv \partial T/\partial p_T - E_{TT} - \partial D_T/\partial p_T > 0$ denotes the slope of the excess supply function of the tourism service, and subscripts with respect to the expenditure function denote partial derivatives, for example, $E_{Tu} \equiv \partial^2 E/\partial u \partial p_T$. Note that $\partial Z/\partial s < 0$, $\partial M/\partial p_T > 0$, $\partial T/\partial p_T > 0$, and $\partial Z/\partial p_T > 0$ from the analyses in sections 3.1 and 3.2. Notice that the Lindahl pricing rule implies $\Gamma = 0$. Let Δ^* be the determinant of the 2×2 matrix of the LHS of (37). The stability condition then requires $\Delta^* > 0$.[8]

We assume three conditions: (a) $\Gamma > 0$ (the marginal value product of tourism infrastructure is greater than its price), (b) $\partial M/\partial s > 0$ (the output of tourism infrastructure is increased by higher pollution tax rate)[9], and (c) $\partial(T - C_T - D_T)/\partial s = \partial T/\partial s - E_{TZ} \cdot (\partial Z/\partial s) - (\partial D_T/\partial Z)(\partial Z/\partial s) = \partial T/\partial s - (E_{TZ} + \partial D_T/\partial Z)(\partial Z/\partial s) < 0$ (the excess supply of the tourism service decreases with the pollution tax).

Solving equation (37), we obtain

$$\Delta^* \frac{dp_T}{ds} = -(E_Z - s)\frac{\partial Z}{\partial s}E_{Tu} - \left[\frac{\partial T}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial s}\right]E_u + \Gamma\frac{\partial M}{\partial s}E_{Tu}, \tag{38}$$

$$\begin{aligned} \Delta^* \frac{du}{ds} = &\left[-D_T - \Gamma\frac{\partial M}{\partial p_T} + (E_Z - s)\frac{\partial Z}{\partial p_T}\right]\left[\frac{\partial T}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial s}\right] \\ &- \left[-S_T + \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial p_T}\right]\left[\Gamma\frac{\partial M}{\partial s} - (E_Z - s)\frac{\partial Z}{\partial s}\right]. \end{aligned} \tag{39}$$

Equation (39) is rewritten as (see Appendix F):

$$\begin{aligned} \Delta^* \frac{du}{ds} = &(E_Z - s)\left[\frac{\partial Z}{\partial s}\left(E_{TT} + \frac{\partial D_T}{\partial p_T}\right) + \frac{ZT}{p_T s}\xi\Psi\right] - D_T\left[\frac{\partial T}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial s}\right] \\ &+ \Gamma\left\{\frac{M}{p_T s}\Psi\left[T\theta_{ZT} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)Z\right] - \frac{\partial M}{\partial s}\left(E_{TT} + \frac{\partial D_T}{\partial p_T}\right)\right\}, \end{aligned} \tag{40}$$

where $\Psi \equiv Q\sigma_T/\Delta > 0$. In Appendix F, we also show that $T\theta_{ZT} - (E_{TZ} + \partial D_T/\partial Z)Z > 0$ if the conditions (b) and (c) are satisfied. An increase in pollution tax affects the tourism terms-of-trade and domestic welfare through two traditional channels, as stated by Beladi et al. (2009) and Yanase (2017). On the one hand, if the marginal damage of pollution to domestic residents is greater than the pollution tax rate ($E_Z > s$), the pollution reduction caused by an increase in pollution tax raises the real income of domestic residents (see Copeland (1994)).[10] This positive income effect improves the tourism terms-of-trade. On the other hand, if a pollution tax decreases the domestic excess supply of the tourism service ($\partial(T - C_T - D_T)/\partial s = \partial T/\partial s - (E_{TZ} + \partial D_T/\partial Z)(\partial Z/\partial s) < 0$), the price of the tourism service rises (see Yanase (2017)). These positive terms-of-trade effects improve domestic welfare. We call the former channel the "pollution distortion" channel and the latter the

[8] Let $\Omega \equiv E_T + D_T - T$ be the domestic excess demand for tourism service. From (35) and (36), we have $dp_T/d\Omega = -E_u/\Delta^*$. Hence, the stability of tourism service market requires $\Delta^* > 0$.

[9] From equations (28), (29), and (31), this condition is equivalent to $\sigma_T < \theta_{LT}$.

[10] Recall that $\partial Z/\partial s < 0$ from the analysis of section 3.1.

"excess supply" channel. In (38) or (40), the first (resp. second) term corresponds to the "pollution distortion" (resp. "excess supply") channel.

This paper includes the third channel. If the marginal value product of tourism infrastructure is higher than its price, an increase in tourism infrastructure raises real income, which improves the tourism terms-of-trade. We call this the "tourism infrastructure" channel, which is represented by the third term in (38) or (40). If the conditions (b) and (c) are satisfied, an increase in pollution tax rate increases the tourism infrastructure both directly and indirectly. In addition, if the condition (a) holds, the increase in tourism infrastructure improves welfare. Therefore, if the conditions (a) - (c) are satisfied, the tourism infrastructure channel improves the tourism terms-of-trade and welfare.

Thus, we have the following proposition.

Proposition 3 *The tourism infrastructure channel, which arises from the difference between the marginal value product of tourism infrastructure and its price, improves the tourism terms-of-trade and domestic welfare if the following three conditions are satisfied: (a) the marginal value product of tourism infrastructure is greater than its price, (b) the output of tourism infrastructure is increased by higher pollution tax, and (c) the excess supply of tourism service decreases with the pollution tax.*

The condition (a) is likely to hold when the marginal value product of the tourism infrastructure is sufficiently high. The condition (b) is satisfied if and only if the elasticity of substitution in the tourism industry is sufficiently low to increase the pollution tax revenue. The condition (c) tends to hold when the output of the tourism service decreases with the pollution tax, which occurs if the elasticity of substitution in that sector if not very low. Therefore, for both the conditions (b) and (c) to hold simultaneously, the elasticity of substitution in the tourism sector must be a moderately small value. By numerical simulations in Appendix G, we show that there exist parameter values that satisfy the conditions (a), (b), and (c).

Similar to Yanase (2017), we consider a departure from the Pigouvian tax rate. Setting $s = E_Z$ in (38) and (40), respectively, we obtain

$$\Delta^* \frac{dp_T}{ds}\bigg|_{s=E_Z} = -\left[\frac{\partial T}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial s}\right] E_u + \Gamma \frac{\partial M}{\partial s} E_{Tu}, \tag{41}$$

$$\begin{aligned}\Delta^* \frac{du}{ds}\bigg|_{s=E_Z} = & -D_T \left[\frac{\partial T}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial s}\right] \\ & + \Gamma \left\{ \frac{M}{p_T s} \frac{Q\sigma_T}{\Delta} \left[T\theta_{ZT} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right) Z\right] - \frac{\partial M}{\partial s}\left(E_{TT} + \frac{\partial D_T}{\partial p_T}\right)\right\}.\end{aligned} \tag{42}$$

Thus, we have a corollary to Proposition 3.

Corollary 1 *Suppose that the conditions (a) - (c) hold. Starting from a Pigouvian level, an increase in pollution tax unambiguously improves the tourism terms-of-trade and domestic welfare.*

At the Pigouvian tax level, the pollution distortion channel vanishes. If the condition (c) is satisfied, the excess supply channel is positive. In addition, if the conditions (a) - (c) are satisfied, the tourism infrastructure channel is positive. Therefore, an increase in pollution tax unambiguously improves the tourism terms-of-trade and domestic welfare.

Corollary 1 is a generalization of Corollary 2 in Yanase (2017). Yanase (2017) does not consider the tourism infrastructure. Thus, in his model, starting from the Pigouvian pollution tax level and free trade, the effect of pollution tax is solely determined by the excess supply channel.[11]

4.2 Effects on outputs, pollution, and factor prices

We now examine the effects of the increase in pollution tax on outputs, pollution, and factor prices, considering that the tourism terms-of-trade are endogenous. The total effect (including the change in the tourism terms-of-trade) of the increased pollution tax on each endogenous variable is

$$\frac{d\Theta}{ds} = \frac{\partial \Theta}{\partial s} + \frac{\partial \Theta}{\partial p_T}\frac{dp_T}{ds}$$

or

$$\frac{s}{\Theta}\frac{d\Theta}{ds} = \frac{s}{\Theta}\frac{\partial \Theta}{\partial s} + \frac{p_T}{\Theta}\frac{\partial \Theta}{\partial p_T}\frac{s}{p_T}\frac{dp_T}{ds}, \tag{43}$$

where $\Theta = X, T, M, w_H, w_L, q, Z$. The first term on the RHS of (43) represents the direct effect, while the second term represents the indirect effect that arises from the change in the tourism terms-of-trade. Since the sign of the direct effect is ambiguous except for the amount of pollution, we consider the necessary and sufficient conditions for the indirect effect to be dominant. The indirect effect is proportional to the change in the tourism terms-of-trade and, thus, the indirect effect dominates the direct effect if the absolute value of the tourism terms-of-trade effect is sufficiently high.

Substituting (31) and (B.1) into (43) for $\Theta = w_H$, the increased pollution tax raises the wage of skilled labor if and only if

$$\frac{s}{p_T}\frac{dp_T}{ds} < \frac{\sigma_T - \theta_{LT}}{\sigma_T} \equiv D. \tag{44}$$

From (27), (28), (29), and (43), the total effects on q, X, and M are proportional to those on w_H.

[11] Yanase (2017) introduces import tariff, which yields the trade distortion. The trade distortion vanishes when import tariff rate is zero.

Similarly, substituting (30), (B.6), and (B.1) into (43) for $\Theta = T$, the necessary and sufficient condition for the increase in pollution tax rate to increase the production of tourism service is

$$\frac{s}{p_T}\frac{dp_T}{ds} > 1 - \frac{\xi Q(\sigma_T\theta_{ZT} + \theta_{LT})}{\sigma_T[\theta_{ZT}P + (\theta_{ZT} + \xi)Q]} \equiv F. \tag{45}$$

Substituting (32), (B.5), and (B.1) into (43) for $\Theta = w_L$, the pollution tax rate and the wage of unskilled labor move in the same direction if and only if

$$\frac{s}{p_T}\frac{dp_T}{ds} > \frac{[\theta_{ZT} + \xi(\sigma_T - 1)]Q + \theta_{ZT}P}{P + Q} \equiv G. \tag{46}$$

Substituting (33), (B.2), and (B.1) into (43) for $\Theta = Z$, a stricter environmental policy in the form of increasing the pollution tax rate raises the amount of pollution if and only if

$$\frac{s}{p_T}\frac{dp_T}{ds} > \frac{(1 - \xi)Q + P}{P + Q} \equiv H > 0. \tag{47}$$

If the tourism terms-of-trade effect is positive and sufficiently large, the increase in pollution tax rate can increase the amount of pollution. This possibility is also pointed out by Yanase (2017, p. 615).

In Appendix H, we show that $D < F < H$ and $G < H$. There are three cases to be considered: (i) when $\sigma_T < \xi Q/[\theta_{ZT}(P+Q)+\xi Q]$, $D < F < G < H$; (ii) when $\xi Q/[\theta_{ZT}(P+Q)+\xi Q] < \sigma_T < 1$, $D < G < F < H$; and (iii) when $\sigma_T > 1$, $G < D < F < H$. The results are summarized in Tables 3 - 5.

Thus, we have the following proposition.

Proposition 4 *When* $(s/p_T)(dp_T/ds) \geq H$*, an increase in pollution tax expands the tourism and tourism infrastructure sectors while it contracts the manufacturing sector. It narrows the wage inequality between skilled and unskilled labor. The rental rate of capital and the amount of pollution increase. If* $(s/p_T)(dp_T/ds) \leq \min(D, G)$*, all the above results are reversed.*

Focusing on the total effect on domestic wage inequality, we have the following proposition.

Proposition 5 *When* $(s/p_T)(dp_T/ds) \geq \max(D, G)$*, an increase in pollution tax unambiguously narrows domestic wage inequality. If* $(s/p_T)(dp_T/ds) \leq \min(D, G)$*, domestic wage inequality unambiguously widens.*

From Proposition 5, when the absolute value of the tourism terms-of-trade effect is sufficiently large, there is a trade-off between reducing pollution and narrowing domestic wage inequality.

For a double dividend in narrowing wage inequality and reducing pollution to exist, the tourism terms-of-trade effect must be moderate. More specifically, if $(s/p_T)(dp_T/ds) < \min(D, G)$ or $(s/p_T)(dp_T/ds) > H$, there is a trade-off; for $(s/p_T)(dp_T/ds) \in [\max(D, G), H)$, there is a double dividend.

If the conditions (a), (b), and (c) are satisfied, a pollution tax can provide a further benefit in improving domestic welfare (see Proposition 3).

When the production of the tourism sector is Cobb-Douglas (i.e., $\sigma_T = 1$), the above analysis becomes quite simple (see Appendix I). In this case, at constant tourism terms-of-trade, an increase in pollution tax reduces the tax revenue, leading to a decrease in the output of tourism infrastructure. This results in a decline in the output of tourism service and the wage of unskilled labor. At the same time, capital flows from the tourism infrastructure sector to the traded good sector. It follows that the output of traded good and the wage of skilled labor go up. Since the price of traded good is constant, the rental rate of capital goes down.

$(s/p_T)(dp_T/ds)$	$\cdots$	D	$\cdots$	F	$\cdots$	G	$\cdots$	H	$\cdots$
dT/ds	−	−	−	0	+	+	+	+	+
dw_H/ds	+	0	−	−	−	−	−	−	−
dw_L/ds	−	−	−	−	−	0	+	+	+
dZ/ds	−	−	−	−	−	−	−	0	+

Table 3: The case of $\sigma_T < \xi Q/[\theta_{ZT}(P + Q) + \xi Q]$

$(s/p_T)(dp_T/ds)$	$\cdots$	D	$\cdots$	G	$\cdots$	F	$\cdots$	H	$\cdots$
dT/ds	−	−	−	−	−	0	+	+	+
dw_H/ds	+	0	−	−	−	−	−	−	−
dw_L/ds	−	−	−	0	+	+	+	+	+
dZ/ds	−	−	−	−	−	−	−	0	+

Table 4: The case of $\xi Q/[\theta_{ZT}(P + Q) + \xi Q] < \sigma_T < 1$

$(s/p_T)(dp_T/ds)$	$\cdots$	G	$\cdots$	D	$\cdots$	F	$\cdots$	H	$\cdots$
dT/ds	$-$	$-$	$-$	$-$	$-$	0	$+$	$+$	$+$
dw_H/ds	$+$	$+$	$+$	0	$-$	$-$	$-$	$-$	$-$
dw_L/ds	$-$	0	$+$	$+$	$+$	$+$	$+$	$+$	$+$
dZ/ds	$-$	$-$	$-$	$-$	$-$	$-$	$-$	0	$+$

Table 5: The case of $\sigma_T > 1$

5 Conclusions

This paper sets up a small open developing tourism economy with tourism infrastructure and examines the welfare, production, and income distribution effects of an increase in pollution tax. The tourism service is non-traded in the absence of foreign tourists. The tourism sector emits pollution and its productivity is enhanced by tourism infrastructure. Since the Lindahl pricing rule is not assumed, the usual envelope theorem and reciprocity relationship do not necessarily hold. Thus, we can obtain interesting comparative static results. In particular, if the elasticity of substitution in the tourism sector is sufficiently low, an increase in pollution tax paradoxically expands tourism sector at the constant tourism terms-of-trade. Furthermore, the wage inequality between skilled and unskilled labor narrows.

This paper provides new insights regarding welfare effect of pollution tax. In addition to two traditional channels pointed out by Beladi et al. (2009) and Yanase (2017), this paper contains an additional channel through which an increase in pollution tax affects the tourism terms-of-trade and domestic welfare. The new channel, which arises from the difference between the marginal value product of tourism infrastructure and its price, increases the tourism terms-of-trade and domestic welfare if (a) the marginal value product of tourism infrastructure is greater than its price, (b) the output of tourism infrastructure is increased by the increase in pollution tax, and (c) the excess supply of a tourism service decreases with pollution tax. Given the above three conditions, starting from a Pigouvian level, the increase in pollution tax improves the tourism terms-of-trade and domestic welfare.

Appendix A Stability condition

Following Chao et al. (2012), Okamoto (1985), Yabuuchi (2015), and Yabuuchi (2018), we consider the following adjustment process:

$$\dot{X} = a_1(p_X - a_{HX}w_H - a_{KX}q), \tag{A.1}$$

$$\dot{T} = a_2(p_T - a_{LT}w_L - a_{ZT}s), \tag{A.2}$$

$$\dot{M} = a_3(p_M - qa_{KM}), \tag{A.3}$$

$$\dot{w}_H = a_4(a_{HX}X - H), \tag{A.4}$$

$$\dot{w}_L = a_5(a_{LT}T - L), \tag{A.5}$$

$$\dot{q} = a_6(a_{KX}X + a_{KM}M - K). \tag{A.6}$$

The first three equations assume a Marshallian quantity adjustment while the last three equations a Walrasian price adjustment. A dot over a variable represents the differentiation with respect to time, and a parameter a_k $(k = 1, \cdots, 6)$ measures the speed of adjustment.

The Jacobian matrix associated with (A.1) - (A.6) is[12]

$$\begin{aligned} J &= a \begin{pmatrix} 0 & 0 & 0 & -a_{HX} & 0 & -a_{KX} \\ 0 & 0 & \xi\frac{p_T}{M} & 0 & -a_{LT} & 0 \\ 0 & \frac{sa_{ZT}}{M} & -\frac{sZ}{M^2}\xi - \frac{sZ}{M^2} & 0 & \frac{sZ}{Mw_L}\theta_{LT}\sigma_T & -a_{KM} \\ a_{HX} & 0 & 0 & -\theta_{KX}\sigma_X\frac{H}{w_H} & 0 & \theta_{KX}\sigma_X\frac{H}{q} \\ 0 & a_{LT} & -\xi\frac{L}{M} & 0 & -\theta_{ZT}\sigma_T\frac{L}{w_L} & 0 \\ a_{KX} & 0 & a_{KM} & \theta_{HX}\sigma_X\frac{K_X}{w_H} & 0 & -\theta_{HX}\sigma_X\frac{K_X}{q} \end{pmatrix} \\ &= aV\tilde{J}W, \end{aligned}$$

where

$$a = \begin{pmatrix} a_1 & 0 & 0 & 0 & 0 & 0 \\ 0 & a_2 & 0 & 0 & 0 & 0 \\ 0 & 0 & a_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & a_4 & 0 & 0 \\ 0 & 0 & 0 & 0 & a_5 & 0 \\ 0 & 0 & 0 & 0 & 0 & a_6 \end{pmatrix},$$

[12] From (8) and (9), we have

$$p_M = \frac{sZ}{M} = \frac{sa_{ZT}(w_L, s, M)T}{M}.$$

This equation is substituted into (A.3).

$$V = \begin{pmatrix} p_X & 0 & 0 & 0 & 0 & 0 \\ 0 & p_T & 0 & 0 & 0 & 0 \\ 0 & 0 & p_M & 0 & 0 & 0 \\ 0 & 0 & 0 & H & 0 & 0 \\ 0 & 0 & 0 & 0 & L & 0 \\ 0 & 0 & 0 & 0 & 0 & K \end{pmatrix},$$

$$W^{-1} = \begin{pmatrix} X & 0 & 0 & 0 & 0 & 0 \\ 0 & T & 0 & 0 & 0 & 0 \\ 0 & 0 & M & 0 & 0 & 0 \\ 0 & 0 & 0 & w_H & 0 & 0 \\ 0 & 0 & 0 & 0 & w_L & 0 \\ 0 & 0 & 0 & 0 & 0 & q \end{pmatrix},$$

$$\tilde{J} = \begin{pmatrix} 0 & 0 & 0 & -\theta_{HX} & 0 & -\theta_{KX} \\ 0 & 0 & \xi & 0 & -\theta_{LT} & 0 \\ 0 & 1 & -\xi-1 & 0 & \theta_{LT}\sigma_T & -1 \\ 1 & 0 & 0 & -\theta_{KX}\sigma_X & 0 & \theta_{KX}\sigma_X \\ 0 & 1 & -\xi & 0 & -\theta_{ZT}\sigma_T & 0 \\ \lambda_{KX} & 0 & \lambda_{KM} & \lambda_{KX}\theta_{HX}\sigma_X & 0 & -\lambda_{KX}\theta_{HX}\sigma_X \end{pmatrix}.$$

A necessary condition for the stability is $|\tilde{J}| > 0$.

It is straightforward to show that $\Delta = |\tilde{J}| > 0$.

$$\Delta = \begin{vmatrix} 0 & 0 & 0 & \theta_{HX} & 0 & \theta_{KX} & 0 \\ 0 & 0 & -\xi & 0 & \theta_{LT} & 0 & 0 \\ \lambda_{KX} & 0 & \lambda_{KM} & \lambda_{KX}\theta_{HX}\sigma_X & 0 & -\lambda_{KX}\theta_{HX}\sigma_X & 0 \\ 1 & 0 & 0 & -\theta_{KX}\sigma_X & 0 & \theta_{KX}\sigma_X & 0 \\ 0 & 1 & -\xi & 0 & -\theta_{ZT}\sigma_T & 0 & 0 \\ 0 & 1 & -\xi & 0 & \theta_{LT}\sigma_T & 0 & -1 \\ 0 & 0 & 1 & 0 & 0 & 1 & -1 \end{vmatrix}.$$

Substract the seventh row from the sixth row to obtain

$$= \begin{vmatrix} 0 & 0 & 0 & \theta_{HX} & 0 & \theta_{KX} & 0 \\ 0 & 0 & -\xi & 0 & \theta_{LT} & 0 & 0 \\ \lambda_{KX} & 0 & \lambda_{KM} & \lambda_{KX}\theta_{HX}\sigma_X & 0 & -\lambda_{KX}\theta_{HX}\sigma_X & 0 \\ 1 & 0 & 0 & -\theta_{KX}\sigma_X & 0 & \theta_{KX}\sigma_X & 0 \\ 0 & 1 & -\xi & 0 & -\theta_{ZT}\sigma_T & 0 & 0 \\ 0 & 1 & -\xi-1 & 0 & \theta_{LT}\sigma_T & -1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & -1 \end{vmatrix}.$$

Expand ty the seventh column to obtain

$$= - \begin{vmatrix} 0 & 0 & 0 & \theta_{HX} & 0 & \theta_{KX} \\ 0 & 0 & -\xi & 0 & \theta_{LT} & 0 \\ \lambda_{KX} & 0 & \lambda_{KM} & \lambda_{KX}\theta_{HX}\sigma_X & 0 & -\lambda_{KX}\theta_{HX}\sigma_X \\ 1 & 0 & 0 & -\theta_{KX}\sigma_X & 0 & \theta_{KX}\sigma_X \\ 0 & 1 & -\xi & 0 & -\theta_{ZT}\sigma_T & 0 \\ 0 & 1 & -\xi-1 & 0 & \theta_{LT}\sigma_T & -1 \end{vmatrix}.$$

The interchange of the third and sixth rows yields

$$= \begin{vmatrix} 0 & 0 & 0 & \theta_{HX} & 0 & \theta_{KX} \\ 0 & 0 & -\xi & 0 & \theta_{LT} & 0 \\ 0 & 1 & -\xi-1 & 0 & \theta_{LT}\sigma_T & -1 \\ 1 & 0 & 0 & -\theta_{KX}\sigma_X & 0 & \theta_{KX}\sigma_X \\ 0 & 1 & -\xi & 0 & -\theta_{ZT}\sigma_T & 0 \\ \lambda_{KX} & 0 & \lambda_{KM} & \lambda_{KX}\theta_{HX}\sigma_X & 0 & -\lambda_{KX}\theta_{HX}\sigma_X \end{vmatrix}$$

$$= (-1)^2 \begin{vmatrix} 0 & 0 & 0 & -\theta_{HX} & 0 & -\theta_{KX} \\ 0 & 0 & \xi & 0 & -\theta_{LT} & 0 \\ 0 & 1 & -\xi-1 & 0 & \theta_{LT}\sigma_T & -1 \\ 1 & 0 & 0 & -\theta_{KX}\sigma_X & 0 & \theta_{KX}\sigma_X \\ 0 & 1 & -\xi & 0 & -\theta_{ZT}\sigma_T & 0 \\ \lambda_{KX} & 0 & \lambda_{KM} & \lambda_{KX}\theta_{HX}\sigma_X & 0 & -\lambda_{KX}\theta_{HX}\sigma_X \end{vmatrix}$$

$$= |\tilde{J}|.$$

Then the stability of the system requires $\Delta > 0$.

Appendix B Proof of Proposition 2

Solving (26), we have

$$\frac{\widehat{w}_H}{\widehat{p}_T} = -\frac{\theta_{KX}\lambda_{KM}\sigma_T}{\Delta} < 0. \tag{B.1}$$

We can show that the effects on other endogenous variables are proportional to the effect on w_H. Equation (28) implies

$$\text{sgn } \widehat{X}/\widehat{p}_T = \text{sgn } \widehat{w}_H/\widehat{p}_T.$$

From (29), we have

$$\text{sgn } \widehat{M}/\widehat{p}_T = -\text{sgn } \widehat{w}_H/\widehat{p}_T.$$

Substituting (27) and (29) into (25), we obtain

$$\frac{\widehat{Z}}{\widehat{p}_T} = \frac{\widehat{q}}{\widehat{p}_T} + \frac{\widehat{M}}{\widehat{p}_T} = -\frac{\theta_{HX}}{\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T} - \frac{\lambda_{KX}\sigma_X}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T} = -\frac{\lambda_{KM}\theta_{HX} + \lambda_{KX}\sigma_X}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T} = -\frac{P+Q}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T}. \tag{B.2}$$

From (23) and (24), we have

$$\sigma_T(\widehat{w}_L - \widehat{s}) = \widehat{Z}. \tag{B.3}$$

From (B.3), we obtain

$$\sigma_T\frac{\widehat{w}_L}{\widehat{p}_T} = \frac{\widehat{Z}}{\widehat{p}_T}. \tag{B.4}$$

Substituting (B.2) into (B.4), we have

$$\frac{\widehat{w}_L}{\widehat{p}_T} = -\frac{P+Q}{\sigma_T\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T}. \tag{B.5}$$

From (B.2) and (B.5), it follows that

$$\text{sgn } \widehat{w}_L/\widehat{p}_T = \text{sgn } \widehat{Z}/\widehat{p}_T = -\text{sgn } \widehat{w}_H/\widehat{p}_T.$$

Substituting (29) and (B.5) into (23), we have

$$\widehat{T}/\widehat{p}_T = -\frac{\theta_{ZT}P + (\theta_{ZT}+\xi)Q}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T}. \tag{B.6}$$

Thus, we have

$$\text{sgn } \widehat{T}/\widehat{p}_T = -\text{sgn } \widehat{w}_H/\widehat{p}_T.$$

Appendix C Consumer problem

Consider the following utility maximization problem:

$$\max u = (C_X)^b + f(Z) \cdot (C_T)^b$$

$$\text{subject to } E = p_X C_X + p_T C_T.$$

The usual optimal condition requires that the relative price equals the marginal rate of substitution:

$$\frac{p_T}{p_X} = \frac{\partial u / \partial C_T}{\partial u / \partial C_X} = f \cdot \left(\frac{C_X}{C_T} \right)^{1-b}. \tag{C.1}$$

Solving the utility maximization problem, we obtain the ordinary demand function: $\widetilde{C}_X = E/\Phi_X$ and $\widetilde{C}_T = E/\Phi_T$ where $\Phi_X \equiv p_X + (f p_X)^{1/(1-b)} (p_T)^{-b/(1-b)}$ and $\Phi_T \equiv p_T + (p_T/f)^{1/(1-b)} (p_X)^{-b/(1-b)}$. Then, the indirect utility function is given by $u = \left[(\Phi_X)^{-b} + f \cdot (\Phi_T)^{-b} \right] E^b$. Solving the indirect utility for E, we obtain the expenditure function $E = u^{1/b} \left[(\Phi_X)^{-b} + f \cdot (\Phi_T)^{-b} \right]^{-1/b}$. Substituting the expenditure function into the ordinary demand for tourism service, we have the compensated demand function of tourism service:

$$C_T = \frac{u^{1/b}}{\Phi_T \left[\frac{1}{(\Phi_X)^b} + \frac{f}{(\Phi_T)^b} \right]^{1/b}} = \frac{u^{1/b}}{\left[(\Phi_T/\Phi_X)^b + f \right]^{1/b}}.$$

Substituting $C_X/C_T = \Phi_T/\Phi_X$ into equation (C.1) yields

$$\frac{p_T}{p_X} = f \cdot \left(\frac{\Phi_T}{\Phi_X} \right)^{1-b}. \tag{C.2}$$

Appendix D Marginal damage to domestic residents by pollution

$$\begin{aligned}
\frac{\partial}{\partial Z} [(\Phi_X)^{-b} + f \cdot (\Phi_T)^{-b}] &= -b (\Phi_X)^{-b-1} \frac{\partial \Phi_X}{\partial Z} + f' \cdot (\Phi_T)^{-b} - f b (\Phi_T)^{-b-1} \frac{\partial \Phi_T}{\partial Z} \\
&= -b \left[(\Phi_X)^{-b-1} \frac{\partial \Phi_X}{\partial Z} + f \cdot (\Phi_T)^{-b-1} \frac{\partial \Phi_T}{\partial Z} \right] + f' \cdot (\Phi_T)^{-b} \\
&= f' \cdot \Phi_T^{-b},
\end{aligned}$$

where

$$
\begin{aligned}
(\Phi_X)^{-b-1}\frac{\partial \Phi_X}{\partial Z} + f\cdot(\Phi_T)^{-b-1}\frac{\partial \Phi_T}{\partial Z} &= (\Phi_X)^{-b-1}\frac{1}{1-b}\left(\frac{\Phi_X}{\Phi_T}\right)^b p_X f' - f\cdot(\Phi_T)^{-b-1}\frac{1}{1-b}f^{-2}p_T\left(\frac{\Phi_T}{\Phi_X}\right)^b f' \\
&= \frac{f'}{1-b}\left[(\Phi_X)^{-1}\left(\frac{1}{\Phi_T}\right)^b p_X - f^{-1}\cdot(\Phi_T)^{-1}p_T\left(\frac{1}{\Phi_X}\right)^b\right] \\
&= \frac{f'}{1-b}\frac{1}{\Phi_X\Phi_T}\left[(\Phi_T)^{1-b}p_X - f^{-1}\cdot(\Phi_X)^{1-b}p_T\right] \\
&= \frac{f'}{1-b}\frac{p_X f^{-1}}{\Phi_X\Phi_T}\left[(\Phi_T)^{1-b}f - (\Phi_X)^{1-b}\frac{p_T}{p_X}\right] \\
&= 0 \quad \because \text{(C.2)}
\end{aligned}
$$

since

$$
\begin{aligned}
\frac{\partial \Phi_X}{\partial Z} &= \frac{1}{1-b}f^{\frac{1}{1-b}-1}f'(p_X)^{\frac{1}{1-b}}(p_T)^{-\frac{b}{1-b}} \\
&= \frac{1}{1-b}f^{\frac{b}{1-b}}(p_X)^{\frac{1}{1-b}}(p_T)^{-\frac{b}{1-b}}f' \\
&= \frac{1}{1-b}\left(\frac{f}{p_T}\right)^{\frac{b}{1-b}}p_X^{\frac{1}{1-b}}f' \\
&= \frac{1}{1-b}\left(\frac{f p_X}{p_T}\right)^{\frac{b}{1-b}}p_X^{-\frac{b}{1-b}}p_X^{\frac{1}{1-b}}f' \\
&= \frac{1}{1-b}\left(\frac{\Phi_X}{\Phi_T}\right)^b p_X f' \quad \because \text{(C.2)}
\end{aligned}
$$

and

$$
\begin{aligned}
\frac{\partial \Phi_T}{\partial Z} &= -\frac{1}{1-b}f^{-\frac{1}{1-b}-1}f' p_T^{\frac{1}{1-b}}p_X^{-\frac{b}{1-b}} \\
&= -\frac{1}{1-b}f^{-\frac{2-b}{1-b}}p_T^{\frac{1}{1-b}}\left(\frac{p_T}{p_X f}\right)^{\frac{b}{1-b}}p_T^{-\frac{b}{1-b}}f^{\frac{b}{1-b}}f' \\
&= -\frac{1}{1-b}f^{-\frac{2-2b}{1-b}}p_T\left(\frac{\Phi_T}{\Phi_X}\right)^b f' \quad \because \text{(C.2)} \\
&= -\frac{1}{1-b}f^{-2}p_T\left(\frac{\Phi_T}{\Phi_X}\right)^b f' > 0.
\end{aligned}
$$

Appendix E Properties of the "net" revenue function

The first-order conditions for profit maximization in the manufacturing sector are

$$
p_X\frac{\partial X}{\partial H} = w_H, \tag{E.1}
$$

$$p_X \frac{\partial X}{\partial K_X} = q. \tag{E.2}$$

Similarly, the first-order conditions for profit maximization in the tourism sector are

$$p_T \frac{\partial T}{\partial L} = w_L, \tag{E.3}$$

$$p_T \frac{\partial T}{\partial Z} = s. \tag{E.4}$$

Utilizing (4), (5), (E.1) - (E.4), we have

$$p_X dX + p_T dT = w_H dH + w_L dL + s dZ + q dK + \Gamma dM, \tag{E.5}$$

where $\Gamma \equiv p_T \cdot (\partial T/\partial M) - p_M$ is the difference between the marginal value product of tourism infrastructure and its price.

The "after-tex" or "net" revenue is

$$R = p_X X + p_T T - sZ.$$

Taking (E.5) into account, the change in the "net" revenue is given by

$$dR = X dp_X + T dp_T + w_H dH + w_L dL - Z ds + q dK + \Gamma dM. \tag{E.6}$$

The last term in (E.6) implies that an increase in tourism infrastructure raises the net revenue R if and only if the marginal value of product of tourism infrastructure is larger than its price (i.e., $p_T \cdot (\partial T/\partial M) > p_M$).

From (E.6), we have

$$R_T \equiv \frac{\partial R}{\partial p_T} = T + \Gamma \frac{\partial M}{\partial p_T}, \tag{E.7}$$

$$R_s \equiv \frac{\partial R}{\partial s} = -Z + \Gamma \frac{\partial M}{\partial s}. \tag{E.8}$$

Thus, the envelope theorem holds if $\Gamma = 0$.

Appendix F Welfare effect of pollution tax

The numerator of du/ds is

$$
\begin{vmatrix}
-D_T - \Gamma \frac{\partial M}{\partial p_T} + (E_Z - s)\frac{\partial Z}{\partial p_T} & \Gamma \frac{\partial M}{\partial s} - (E_Z - s)\frac{\partial Z}{\partial s} \\
-S_T + \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial p_T} & \frac{\partial T}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial s}
\end{vmatrix}
$$

$$
\begin{aligned}
&= -\left(D_T + \Gamma\frac{\partial M}{\partial p_T}\right)\left[\frac{\partial T}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial s}\right] + (E_Z - s)\frac{\partial Z}{\partial p_T}\left[\frac{\partial T}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial s}\right] \\
&\quad + S_T\left[\Gamma\frac{\partial M}{\partial s} - (E_Z - s)\frac{\partial Z}{\partial s}\right] - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial p_T}\left[\Gamma\frac{\partial M}{\partial s} - (E_Z - s)\frac{\partial Z}{\partial s}\right] \\
&= -D_T\left[\frac{\partial T}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial s}\right] - \Gamma\frac{\partial M}{\partial p_T}\left[\frac{\partial T}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial s}\right] + (E_Z - s)\frac{\partial Z}{\partial p_T}\frac{\partial T}{\partial s} \\
&\quad + S_T\left[\Gamma\frac{\partial M}{\partial s} - (E_Z - s)\frac{\partial Z}{\partial s}\right] - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial p_T}\Gamma\frac{\partial M}{\partial s} \\
&= -D_T\left[\frac{\partial T}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial s}\right] - \Gamma\frac{\partial M}{\partial p_T}\left[\frac{\partial T}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial s}\right] + (E_Z - s)\left(\frac{\partial Z}{\partial p_T}\frac{\partial T}{\partial s} - S_T\frac{\partial Z}{\partial s}\right) \\
&\quad + S_T\Gamma\frac{\partial M}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial p_T}\Gamma\frac{\partial M}{\partial s} \\
&= -D_T\left[\frac{\partial T}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial s}\right] - \Gamma\left(\underbrace{\frac{\partial M}{\partial p_T}\frac{\partial T}{\partial s} - S_T\frac{\partial M}{\partial s}}_{\text{(i)}}\right) + \Gamma\left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\left(\underbrace{\frac{\partial M}{\partial p_T}\frac{\partial Z}{\partial s} - \frac{\partial Z}{\partial p_T}\frac{\partial M}{\partial s}}_{\text{(ii)}}\right) \\
&\quad + (E_Z - s)\left(\underbrace{\frac{\partial Z}{\partial p_T}\frac{\partial T}{\partial s} - S_T\frac{\partial Z}{\partial s}}_{\text{(iii)}}\right) \\
&= -D_T\left[\frac{\partial T}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial s}\right] - \Gamma\left[-\frac{MT}{p_T s}\theta_{ZT}\Psi + \frac{\partial M}{\partial s}\left(E_{TT} + \frac{\partial D_T}{\partial p_T}\right)\right] - \Gamma\left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{MZ}{p_T s}\Psi \\
&\quad + (E_Z - s)\left[\frac{ZT}{p_T s}\xi\Psi + \frac{\partial Z}{\partial s}\left(E_{TT} + \frac{\partial D_T}{\partial p_T}\right)\right], \quad \Psi \equiv Q\sigma_T/\Delta > 0 \\
&= -D_T\left[\frac{\partial T}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial s}\right] + \Gamma\frac{MT}{p_T s}\theta_{ZT}\Psi - \Gamma\frac{\partial M}{\partial s}\left(E_{TT} + \frac{\partial D_T}{\partial p_T}\right) - \Gamma\left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{MZ}{p_T s}\Psi \\
&\quad + (E_Z - s)\frac{ZT}{p_T s}\xi\Psi + (E_Z - s)\frac{\partial Z}{\partial s}\left(E_{TT} + \frac{\partial D_T}{\partial p_T}\right) \\
&= -D_T\left[\frac{\partial T}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial s}\right] - \Gamma\frac{\partial M}{\partial s}\left(E_{TT} + \frac{\partial D_T}{\partial p_T}\right) + (E_Z - s)\frac{\partial Z}{\partial s}\left(E_{TT} + \frac{\partial D_T}{\partial p_T}\right) \\
&\quad + \Gamma\frac{M}{p_T s}\Psi\left[T\theta_{ZT} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)Z\right] + \xi(E_Z - s)\frac{ZT}{p_T s}\Psi,
\end{aligned}
$$

which is equation (40) in the main text. The terms (i), (ii), and (iii) can be calculated as follows.

- The term (i)

$$
\begin{aligned}
\frac{\partial M}{\partial p_T}\frac{\partial T}{\partial s} - S_T\frac{\partial M}{\partial s} &= \frac{\partial M}{\partial p_T}\frac{\partial T}{\partial s} - \left(\frac{\partial T}{\partial p_T} - E_{TT} - \frac{\partial D_T}{\partial p_T}\right)\frac{\partial M}{\partial s} \\
&= \frac{\partial M}{\partial p_T}\frac{\partial T}{\partial s} - \frac{\partial T}{\partial p_T}\frac{\partial M}{\partial s} + \frac{\partial M}{\partial s}\left(E_{TT} + \frac{\partial D_T}{\partial p_T}\right) \\
&= \frac{MT}{p_T s}\left(\frac{\widehat{M}}{\widehat{p}_T}\frac{\widehat{T}}{\widehat{s}} - \frac{\widehat{M}}{\widehat{s}}\frac{\widehat{T}}{\widehat{p}_T}\right) + \frac{\partial M}{\partial s}\left(E_{TT} + \frac{\partial D_T}{\partial p_T}\right) \\
&= -\frac{MT}{p_T s}\theta_{ZT}\Psi + \frac{\partial M}{\partial s}\left(E_{TT} + \frac{\partial D_T}{\partial p_T}\right)
\end{aligned}
$$

since

$$
\begin{aligned}
\frac{\widehat{M}}{\widehat{p}_T}\frac{\widehat{T}}{\widehat{s}} - \frac{\widehat{M}}{\widehat{s}}\frac{\widehat{T}}{\widehat{p}_T} &= \frac{Q}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T}\frac{\sigma_T[(\theta_{ZT}+\xi\theta_{LT})Q+\theta_{ZT}P]-\xi\theta_{LT}Q}{\Delta} \\
&\quad - \frac{Q}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{s}}\frac{\theta_{ZT}P+(\theta_{ZT}+\xi)Q}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T} \qquad \because (29), (30), \text{ and (B.6)} \\
&= \frac{Q}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T}\left[\frac{\sigma_T[(\theta_{ZT}+\xi\theta_{LT})Q+\theta_{ZT}P]-\xi\theta_{LT}Q}{\Delta}\right. \\
&\quad \left. + \frac{\theta_{KX}\lambda_{KM}(\theta_{LT}-\sigma_T)}{\Delta}\frac{\theta_{ZT}P+(\theta_{ZT}+\xi)Q}{\lambda_{KM}\theta_{KX}}\right] \qquad \because (31) \\
&= \frac{Q}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T}\frac{1}{\Delta}\theta_{ZT}[\underbrace{Q(\theta_{LT}-\sigma_T\xi)+\theta_{LT}P}_{\Delta}] \\
&= \frac{Q}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T}\theta_{ZT} \\
&= -\frac{Q}{\lambda_{KM}\theta_{KX}}\frac{\theta_{KX}\lambda_{KM}\sigma_T}{\Delta}\theta_{ZT} \qquad \because \text{(B.1)} \\
&= -\theta_{ZT}\frac{Q\sigma_T}{\Delta} \\
&= -\theta_{ZT}\Psi.
\end{aligned}
$$

- The term (ii)

$$
\frac{\partial M}{\partial p_T}\frac{\partial Z}{\partial s} - \frac{\partial Z}{\partial p_T}\frac{\partial M}{\partial s} = \frac{MZ}{p_T s}\left(\frac{\widehat{M}}{\widehat{p}_T}\frac{\widehat{Z}}{\widehat{s}} - \frac{\widehat{Z}}{\widehat{p}_T}\frac{\widehat{M}}{\widehat{s}}\right) = -\frac{MZ}{p_T s}\Psi,
$$

since

$$
\begin{aligned}
\frac{\widehat{M}}{\widehat{p}_T}\frac{\widehat{Z}}{\widehat{s}} - \frac{\widehat{Z}}{\widehat{p}_T}\frac{\widehat{M}}{\widehat{s}} &= -\frac{Q}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T}\frac{\widehat{Z}}{\widehat{s}} + \frac{Q}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{s}}\frac{\widehat{Z}}{\widehat{p}_T} \quad \because (29) \\
&= \frac{Q}{\lambda_{KM}\theta_{KX}}\left[-\frac{\widehat{w}_H}{\widehat{p}_T}\frac{\widehat{Z}}{\widehat{s}} + \frac{\widehat{w}_H}{\widehat{s}}\frac{\widehat{Z}}{\widehat{p}_T}\right] \\
&= \frac{J}{\lambda_{KM}\theta_{KX}}\left[-\frac{\widehat{w}_H}{\widehat{p}_T}\frac{\widehat{Z}}{\widehat{s}} - \frac{\widehat{w}_H}{\widehat{s}}\frac{\lambda_{KM}\theta_{SX} + \lambda_{KX}\sigma_X}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T}\right] \quad \because (\text{B.2}) \\
&= \frac{Q}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T}\left[-\frac{\widehat{Z}}{\widehat{s}} - \frac{\widehat{w}_H}{\widehat{s}}\frac{\lambda_{KM}\theta_{SX} + \lambda_{KX}\sigma_X}{\lambda_{KM}\theta_{KX}}\right] \\
&= \frac{Q}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T}\left[\frac{\sigma_T[(1-\xi)Q + P]}{\Delta} + \frac{\theta_{KX}\lambda_{KM}(\theta_{LT} - \sigma_T)}{\Delta}\frac{P+Q}{\lambda_{KM}\theta_{KX}}\right] \\
&\quad \because (31) \text{ and } (33) \\
&= \frac{Q}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T}\frac{1}{\Delta}\{\sigma_T[(1-\xi)Q + P] + (\theta_{LT} - \sigma_T)(P+Q)\} \\
&= \frac{Q}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T}\frac{1}{\Delta}[Q(\theta_{LT} - \xi\sigma_T) + \theta_{LT}P] \\
&= \frac{Q}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T} \\
&= -\frac{Q}{\lambda_{KM}\theta_{KX}}\frac{\theta_{KX}\lambda_{KM}\sigma_T}{\Delta} \quad \because (\text{B.1}) \\
&= -\frac{Q\sigma_T}{\Delta} \\
&= -\Psi.
\end{aligned}
$$

- The term (iii)

  From (30), (33), and (B.6), we obtain

$$
\begin{aligned}
\frac{\partial Z}{\partial p_T}\frac{\partial T}{\partial s} - S_T\frac{\partial Z}{\partial s} &= \frac{\partial Z}{\partial p_T}\frac{\partial T}{\partial s} - \left(\frac{\partial T}{\partial p_T} - E_{TT} - \frac{\partial D_T}{\partial p_T}\right)\frac{\partial Z}{\partial s} \\
&= \frac{\partial Z}{\partial p_T}\frac{\partial T}{\partial s} - \frac{\partial T}{\partial p_T}\frac{\partial Z}{\partial s} + \frac{\partial Z}{\partial s}\left(E_{TT} + \frac{\partial D_T}{\partial p_T}\right) \\
&= \frac{ZT}{p_T s}\left(\frac{\widehat{Z}}{\widehat{p}_T}\frac{\widehat{T}}{\widehat{s}} - \frac{\widehat{T}}{\widehat{p}_T}\frac{\widehat{Z}}{\widehat{s}}\right) + \frac{\partial Z}{\partial s}\left(E_{TT} + \frac{\partial D_T}{\partial p_T}\right) \\
&= \frac{ZT}{p_T s}\xi\Psi + \frac{\partial Z}{\partial s}\left(E_{TT} + \frac{\partial D_T}{\partial p_T}\right),
\end{aligned}
$$

since

$$
\begin{aligned}
\frac{\widehat{Z}}{\widehat{p}_T}\frac{\widehat{T}}{\widehat{s}} - \frac{\widehat{T}}{\widehat{p}_T}\frac{\widehat{Z}}{\widehat{s}} &= \frac{P+Q}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T}\frac{\sigma_T[(\theta_{ZT}+\xi\theta_{LT})Q+\theta_{ZT}P]-\xi\theta_{LT}Q}{\Delta} \\
&\quad - \frac{\theta_{ZT}P+(\theta_{ZT}+\xi)Q}{\lambda_{KM}\theta_{KX}}\frac{\widehat{w}_H}{\widehat{p}_T}\frac{\sigma_T[(1-\xi)Q+P]}{\Delta} \qquad \because (30), (33), (\text{B.2}), \text{ and } (\text{B.6}) \\
&= \frac{1}{\lambda_{KM}\theta_{KX}\Delta}\frac{\widehat{w}_H}{\widehat{p}_T}\{(P+Q)\{\sigma_T[(\theta_{ZT}+\xi\theta_{LT})Q+\theta_{ZT}P]-\xi\theta_{LT}Q\} \\
&\quad - [\theta_{ZT}P+(\theta_{ZT}+\xi)Q]\sigma_T[(1-\xi)Q+P]\} \\
&= \frac{1}{\lambda_{KM}\theta_{KX}\Delta}\frac{\theta_{KX}\lambda_{KM}\sigma_T}{\Delta}\xi Q\Delta \quad \because (\text{B.1}) \\
&= \frac{\xi\sigma_T Q}{\Delta} \\
&= \xi\Psi,
\end{aligned}
$$

where

$$
\begin{aligned}
&(P+Q)\{\sigma_T[(\theta_{ZT}+\xi\theta_{LT})Q+\theta_{ZT}P]-\xi\theta_{LT}Q\} - [\theta_{ZT}P+(\theta_{ZT}+\xi)Q]\sigma_T[(1-\xi)Q+P] \\
&= \sigma_T\{(P+Q)[(\theta_{ZT}+\xi\theta_{LT})Q+\theta_{ZT}P] - [\theta_{ZT}P+(\theta_{ZT}+\xi)Q][(1-\xi)Q+P]\} - (P+Q)\xi\theta_{LT}Q \\
&= \sigma_T\xi^2Q^2 - (P+Q)\xi\theta_{LT}Q \\
&= -\xi Q[(P+Q)\theta_{LT} - \sigma_T\xi Q] \\
&= -\xi Q\Delta.
\end{aligned}
$$

From the condition (c):

$$
\begin{aligned}
&\frac{\partial T}{\partial s} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{\partial Z}{\partial s} < 0 \\
&\leftrightarrow \frac{T}{s}\frac{\widehat{T}}{\widehat{s}} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)\frac{Z}{s}\frac{\widehat{Z}}{\widehat{s}} < 0 \\
&\leftrightarrow -T\frac{\theta_{ZT}\sigma_T[(1-\xi)Q+P]+\xi(\sigma_T-\theta_{LT})Q}{\Delta} + \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)Z\frac{\sigma_T[(1-\xi)Q+P]}{\Delta} < 0 \quad \because (30) \text{ and } (33) \\
&\leftrightarrow \sigma_T[(1-\xi)Q+P]\left[-T\theta_{ZT} + \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)Z\right] - T\xi(\sigma_T-\theta_{LT})Q < 0 \\
&\leftrightarrow \sigma_T[(1-\xi)Q+P]\left[T\theta_{ZT} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)Z\right] - T\xi(\theta_{LT}-\sigma_T)Q > 0 \\
&\leftrightarrow \left[T\theta_{ZT} - \left(E_{TZ} + \frac{\partial D_T}{\partial Z}\right)Z\right] > \frac{T\xi(\theta_{LT}-\sigma_T)Q}{\sigma_T[(1-\xi)Q+P]} > 0.
\end{aligned}
$$

Note that $\theta_{LT} - \sigma_T > 0$ from the condition (b).

Appendix G Numerical Simulations

We conduct numerical simulations to find out a set of parameter values that satisfy the conditions from (1) to (3). Numerical simulations utilize MATLAB 2021a.

For this purpose, we specify the production function. Suppose that the production function of the traded good is a Cobb-Douglas function:

$$X = A_X H^{\delta}(K_X)^{1-\delta}, \tag{G.1}$$

where A_X is productivity parameter for the traded good sector, and we specify $A_X \equiv \delta^{-\delta}(1-\delta)^{-(1-\delta)}$ for the notational simplicity. $\delta \in (0,1)$ is the factor cost share of skilled labor. Thus, we have $\theta_{HX} = \delta$ and $\theta_{KX} = 1-\delta$. The associated unit cost is then given by $(w_H)^{\delta} q^{1-\delta}$.

The production function of the tourism service is assumed to be the constant elasticity of substitution (CES) function:

$$T = M^{\xi}[\eta L^{-\rho} + (1-\eta)Z^{-\rho}]^{-1/\rho}, \tag{G.2}$$

where $\eta \in (0,1)$ and $\rho \geq -1$ are parameters. It is well known that the elasticity of substitution is $\sigma_T = 1/(1+\rho)$. We specify $g(M) = M^{\xi}$, where $\xi \in (0,1)$ is a constant. The associated unit cost is derived as $M^{-\xi}[\eta^{1/(1+\rho)}(w_L)^{\rho/(1+\rho)} + (1-\eta)^{1/(1+\rho)} s^{\rho/(1+\rho)}]^{(1+\rho)/\rho}$.

From (7) and (8), we obtain

$$\frac{a_{LT}}{a_{ZT}} = \frac{L}{Z}. \tag{G.3}$$

The cost minimization in the tourism sector yields

$$\frac{w_L}{s} = \frac{\eta}{1-\eta}\left(\frac{a_{ZT}}{a_{LT}}\right)^{1+\rho} = \frac{\eta}{1-\eta}\left(\frac{Z}{L}\right)^{1+\rho}. \tag{G.4}$$

Utilizing Shephard's lemma, we obtain the unit requirement of emission in the tourism sector by differentiating the unit cost function with respect to pollution tax rate:

$$a_{ZT} = M^{-\xi}[\eta(Z/L)^{\rho} + (1-\eta)]^{1/\rho}. \tag{G.5}$$

Using (G.4), the factor cost share of emission in the tourism sector is

$$\theta_{ZT} = \frac{(1-\eta)^{\frac{1}{1+\rho}} s^{\frac{\rho}{1+\rho}}}{\eta^{\frac{1}{1+\rho}}(w_L)^{\frac{\rho}{1+\rho}} + (1-\eta)^{\frac{1}{1+\rho}} r^{\frac{\rho}{1+\rho}}} = \frac{(1-\eta)L^{\rho}}{\eta Z^{\rho} + (1-\eta)L^{\rho}}$$

The zero-profit condition for the traded good sector (2) becomes

$$(w_S)^{\delta} q^{1-\delta} = p_X. \tag{G.6}$$

Using (G.4), the zero-profit condition for the tourism sector becomes

$$\frac{s}{1-\eta}M^{-\xi}[\eta(Z/L)^{\rho}+1-\eta]^{\frac{1+\rho}{\rho}}=p_T \tag{G.7}$$

Substituting (4), the budget constraint of the government (9) becomes

$$sZ=qa_{KM}M. \tag{G.8}$$

Substituting (G.5) into (8), we have

$$M^{-\xi}[\eta(Z/L)^{\rho}+(1-\eta)]^{1/\rho}T=Z. \tag{G.9}$$

Substituting (G.8) and taking into account that the factor cost share of capital in the traded good sector is $1-\delta$, the market clearing condition of capital (5) can be rewritten as

$$(1-\delta)p_X X+sZ=qK. \tag{G.10}$$

Recalling that the factor cost share of skilled labor in the trade good sector is δ, the demand-supply equality of skilled labor (6) becomes

$$\delta p_X X=w_H H. \tag{G.11}$$

The utility function of domestic residents is specified as

$$u=\sqrt{C_X}+\frac{1}{Z}\sqrt{C_T}.$$

The utility maximization yields

$$Zp_T\sqrt{C_T}=p_X\sqrt{C_X}. \tag{G.12}$$

Suppose that the utility function of foreign tourists is given by

$$u^*=\sqrt{D_X}+\frac{1}{Z}\sqrt{D_T}.$$

The tourists' ordinary demand function of the tourism service is derived as

$$D_T=\frac{I^*}{p_T(1+\frac{p_T}{p_X}Z^2)}. \tag{G.13}$$

The market-clearing condition for the tourism service is given by

$$C_T+D_T=T. \tag{G.14}$$

The budget constraint of the economy requires

$$p_X X+p_T T=p_X C_X+p_T C_T. \tag{G.15}$$

Equations (G.6) - (G.15) determine X, T, M, w_H, q, Z p_T, C_X, C_T, and D_T. We set the parameter values as follows: $p_X = 1$, $\delta = \eta = 0.6$, $\xi = 0.8$, $\rho = 2$, $L = 3$, $H = 1$, $K = 25$, $a_{KM} = 2$, $I^* = 4$, and $s = 0.5$. The elasticity of substitution in the tourism sector is $\sigma_T = 1/(1+\rho) = 0.3333$. The factor cost share of pollution tax is $\theta_{ZT} = (1-\eta)L^\rho/[\eta Z^\rho + (1-\eta)L^\rho] = 0.4164$. Since $\xi > \theta_{ZT}$, the condition (a) is satisfied. By the definition, $\theta_{LT} = 1 - \theta_{ZT} = 0.5836$. Then, $\sigma_T < \theta_{LT}$, implying that the condition (b) holds. Finally, $\partial(T - C_T - D_T)/\partial s = \partial T/\partial s - (E_{TZ} + \partial D_T/\partial Z)\partial Z/\partial s = -3.5241 < 0$. Therefore, the condition (c) holds.

Appendix H Proofs of Proposition 4 and Proposition 5

$$
\begin{aligned}
F - D &= \frac{\theta_{LT}}{\sigma_T} - \frac{\xi Q(\sigma_T\theta_{ZT} + \theta_{LT})}{\sigma_T[\theta_{ZT}P + (\theta_{ZT} + \xi)Q]} \\
&= \frac{1}{\sigma_T}\left[\theta_{LT} - \frac{\xi Q(\sigma_T\theta_{ZT} + \theta_{LT})}{\theta_{ZT}P + (\theta_{ZT} + \xi)Q}\right] \\
&= \frac{1}{\sigma_T}\frac{\theta_{LT}\theta_{ZT}P + \theta_{LT}(\theta_{ZT} + \xi)Q - \xi Q(\sigma_T\theta_{ZT} + \theta_{LT})}{\theta_{ZT}P + (\theta_{ZT} + \xi)Q} \\
&= \frac{1}{\sigma_T}\frac{\theta_{LT}\theta_{ZT}P + \theta_{LT}\theta_{ZT}Q - \xi Q\sigma_T\theta_{ZT}}{\theta_{ZT}P + (\theta_{ZT} + \xi)Q} \\
&= \frac{\theta_{ZT}}{\sigma_T}\frac{\Delta}{\theta_{ZT}P + (\theta_{ZT} + \xi)Q} > 0.
\end{aligned}
$$

$$
\begin{aligned}
H - G &= \frac{(1-\xi)Q + P - [\theta_{ZT} + \xi(\sigma_T - 1)]Q - \theta_{ZT}P}{P + Q} \\
&= \frac{[1 - \xi - \theta_{ZT} - \xi\sigma_T + \xi]Q + \theta_{LT}P}{P + Q} \\
&= \frac{\Delta}{P + Q} > 0.
\end{aligned}
$$

$$
\begin{aligned}
H - F &= \frac{P + Q - \xi Q}{P + Q} - 1 + \frac{\xi Q(\sigma_T\theta_{ZT} + \theta_{LT})}{\sigma_T[\theta_{ZT}P + (\theta_{ZT} + \xi)Q]} \\
&= -\frac{\xi Q}{P + Q} + \frac{\xi Q(\sigma_T\theta_{ZT} + \theta_{LT})}{\sigma_T[\theta_{ZT}P + (\theta_{ZT} + \xi)Q]} \\
&= \xi Q\left\{\frac{\sigma_T\theta_{ZT} + \theta_{LT}}{\sigma_T[\theta_{ZT}P + (\theta_{ZT} + \xi)Q]} - \frac{1}{P + Q}\right\} \\
&= \xi Q\frac{(P + Q)(\sigma_T\theta_{ZT} + \theta_{LT}) - \sigma_T[\theta_{ZT}P + (\theta_{ZT} + \xi)Q]}{\sigma_T[\theta_{ZT}P + (\theta_{ZT} + \xi)Q](P + Q)} \\
&= \xi Q\frac{(P + Q)(\sigma_T\theta_{ZT} + \theta_{LT}) - \sigma_T[\theta_{ZT}(P + Q) + \xi Q]}{\sigma_T[\theta_{ZT}P + (\theta_{ZT} + \xi)Q](P + Q)} \\
&= \xi Q\frac{\Delta}{\sigma_T[\theta_{ZT}P + (\theta_{ZT} + \xi)Q](P + Q)} > 0.
\end{aligned}
$$

$$
\begin{aligned}
H - D &= \frac{P + Q - \xi Q}{P + Q} - 1 + \frac{\theta_{LT}}{\sigma_T} \\
&= -\frac{\xi Q}{P + Q} + \frac{\theta_{LT}}{\sigma_T} \\
&= \frac{-\xi Q \sigma_T + \theta_{LT}(P + Q)}{\sigma_T(P + Q)} \\
&= \frac{\Delta}{\sigma_T(P + Q)} > 0.
\end{aligned}
$$

$$
\begin{aligned}
G - D &= \frac{[\theta_{ZT} + \xi(\sigma_T - 1)]Q + \theta_{ZT} P}{P + Q} - 1 + \frac{\theta_{LT}}{\sigma_T} \\
&= \theta_{ZT} + \frac{\xi(\sigma_T - 1)Q}{P + Q} - 1 + \frac{\theta_{LT}}{\sigma_T} \\
&= -\theta_{LT} + \frac{\xi(\sigma_T - 1)Q}{P + Q} + \frac{\theta_{LT}}{\sigma_T} \\
&= -\theta_{LT}\frac{\sigma_T - 1}{\sigma_T} + \frac{\xi(\sigma_T - 1)Q}{P + Q} \\
&= (\sigma_T - 1)\left(-\frac{\theta_{LT}}{\sigma_T} + \frac{\xi Q}{P + Q}\right) \\
&= (1 - \sigma_T)\left(\underbrace{\frac{\theta_{LT}}{\sigma_T} - \frac{\xi Q}{P + Q}}_{(H-D)}\right) \\
&= (1 - \sigma_T)\frac{(\theta_{LT} - \xi\sigma_T)Q + \theta_{LT} P}{\sigma_T(P + Q)} \\
&= (1 - \sigma_T)\frac{\Delta}{\sigma_T(P + Q)}.
\end{aligned}
$$

Therefore, $G > D$ if and only if $1 - \sigma_T > 0$.

$$
\begin{aligned}
F - G &= 1 - \frac{\xi Q(\sigma_T \theta_{ZT} + \theta_{LT})}{\sigma_T[\theta_{ZT}P + (\theta_{ZT} + \xi)Q]} - \frac{\theta_{ZT}(P+Q) + Q\xi(\sigma_T - 1)}{P+Q} \\
&= \theta_{LT} - \frac{\xi Q(\sigma_T \theta_{ZT} + \theta_{LT})}{\sigma_T[\theta_{ZT}P + (\theta_{ZT} + \xi)Q]} - \frac{Q\xi(\sigma_T - 1)}{P+Q} \\
&= -\frac{\xi Q(\sigma_T \theta_{ZT} + \theta_{LT})}{\sigma_T[\theta_{ZT}P + (\theta_{ZT} + \xi)Q]} + \theta_{LT} - (\sigma_T - 1)\frac{\theta_{LT}}{\sigma_T} + (\sigma_T - 1)\frac{\theta_{LT}}{\sigma_T} - \frac{Q\xi(\sigma_T - 1)}{P+Q} \\
&= \underbrace{-\frac{\xi Q(\sigma_T \theta_{ZT} + \theta_{LT})}{\sigma_T[\theta_{ZT}P + (\theta_{ZT} + \xi)Q]} + \frac{\theta_{LT}}{\sigma_T}}_{F-D} + (\sigma_T - 1)\left(\underbrace{\frac{\theta_{LT}}{\sigma_T} - \frac{Q\xi}{P+Q}}_{H-D}\right) \\
&= \frac{\theta_{ZT}}{\sigma_T}\frac{\Delta}{\theta_{ZT}P + (\theta_{ZT} + \xi)Q} + (\sigma_T - 1)\frac{\Delta}{\sigma_T(P+Q)} \\
&= \frac{\Delta}{\sigma_T}\left[\frac{\theta_{ZT}}{\theta_{ZT}P + (\theta_{ZT} + \xi)Q} + \frac{\sigma_T - 1}{P+Q}\right] \\
&= \frac{\Delta}{\sigma_T}\left[\frac{\theta_{ZT}}{\theta_{ZT}(P+Q) + \xi Q} + \frac{\sigma_T - 1}{P+Q}\right] \\
&= \frac{\Delta}{\sigma_T}\frac{\theta_{ZT}(P+Q) + (\sigma_T - 1)[\theta_{ZT}(P+Q) + \xi Q]}{(P+Q)[\theta_{ZT}(P+Q) + \xi Q]} \\
&= \frac{\Delta}{\sigma_T}\frac{\sigma_T[\theta_{ZT}(P+Q) + \xi Q] - \xi Q}{(P+Q)[\theta_{ZT}(P+Q) + \xi Q]}.
\end{aligned}
$$

Then, the necessary and sufficient condition for $F > G$ is

$$
\sigma_T > \frac{\xi Q}{\theta_{ZT}(P+Q) + \xi Q}.
$$

Appendix I The case where the production function of the tourism sector is Cobb-Douglas

When the production function of the tourism industry is Cobb-Douglas, that is, $\sigma_T = 1$, the comparative static results in section 3.1, where the tourism terms-of-trade are fixed, are simplified as

$$
\frac{\widehat{T}}{\widehat{s}} = \frac{\widehat{w}_L}{\widehat{s}} = -\frac{\theta_{ZT}(P+Q)}{\Delta} < 0, \tag{I.1}
$$

$$
\frac{\widehat{w}_H}{\widehat{s}} = \frac{\theta_{ZT}\lambda_{KM}\theta_{KX}}{\Delta} > 0, \tag{I.2}
$$

$$
\frac{\widehat{Z}}{\widehat{s}} = -\frac{[(1-\xi)Q + P]}{\Delta} < 0. \tag{I.3}
$$

$\partial X/\partial s$	$\partial T/\partial s$	$\partial M/\partial s$	$\partial w_H/\partial s$	$\partial w_L/\partial s$	$\partial q/\partial s$	$\partial Z/\partial s$
$+$	$-$	$-$	$+$	$-$	$-$	$-$

Table 6: The effects of pollution tax (the tourism terms-of-trade are constant and $\sigma_T = 1$)

The total effect

Now, consider the total effect of an increase in pollution tax, taking into account the indirect effect induced by the change in the tourism terms-of-trade. Letting σ_T be unity in equation (44), the necessary and sufficient condition for an increase in pollution tax raise the wage of skilled labor is

$$\frac{s}{p_T}\frac{dp_T}{ds} < \theta_{ZT}.$$

Similarly, from (45), the increase in pollution tax expands the tourism sector if and only if

$$\frac{s}{p_T}\frac{dp_T}{ds} > 1 - \frac{\xi Q(\theta_{ZT} + \theta_{LT})}{\theta_{ZT}P + (\theta_{ZT} + \xi)Q} \equiv F'.$$

From (46), the necessary and sufficient condition for raising pollution tax to increase the wage of unskilled labor is

$$\frac{s}{p_T}\frac{dp_T}{ds} > \theta_{ZT}.$$

From (47), the pollution tax rate and the amount of pollution move in the same direction if and only if

$$\frac{s}{p_T}\frac{dp_T}{ds} > \frac{(1-\xi)Q + P}{P + Q} = H > 0.$$

It is straightforward to show that

$$\theta_{ZT} < F' < H.$$

$\frac{s}{p_T}\frac{dp_T}{ds}$	$\cdots$	θ_{ZT}	$\cdots$	F'	$\cdots$	H	$\cdots$
dT/ds	$-$	$-$	$-$	0	$+$	$+$	$+$
dw_H/ds	$+$	0	$-$	$-$	$-$	$-$	$-$
dw_L/ds	$-$	0	$+$	$+$	$+$	$+$	$+$
dZ/ds	$-$	$-$	$-$	$-$	$-$	0	$+$

Table 7: The case of $\sigma_T = 1$

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