The Effect of Differentiated Emission Taxes: Does an Emission Tax Favor Industry?

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Abstract

Extending a standard 2×2 Heckscher-Ohlin model to incorporate emissions, this paper investigates the effect of differentiated emission taxes on output in a small open economy. Our finding is that raising the emission tax imposed on one industry may increase the output of that industry. This result is quite surprising in the sense that such a paradoxical result can occur in a simple and standard model under plausible values of parameters. By numerical examples and using a graphical method, it is also shown that the mechanism behind the result is the factor market adjustment effects which work through two different channels.

Keywords: Emissions; the Heckscher-Ohlin model; differentiated emission taxes.

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1 Introduction

Emissions from production activities are one of the major causes of various environmental problems and regulations on emissions are regarded as an important policy subject (see, for example, UNFCCC, 1997). As a policy instrument for regulating emissions, emission tax has been attracting much attention and introduced in many countries. What should be noted is that in actual policies, such emission taxes are often implemented in a differentiated way, i.e. some industries are usually imposed lower tax than other industries or there are industries that are exempted from taxes (see OECD, 1994). Thus, it is of great importance to analyze what effects such differentiated regulations have on economies.

However, the previous theoretical studies on environmental regulations usually consider uniform emission taxes and the differentiated emission taxes have not been investigated adequately. To the author's knowledge, only exception is Hoel (1996). He considers the situation where there are both participants and non-participants to an international environmental agreement and shows that the optimal emission taxes for participants may be differentiated across industries. Although he investigates an interesting aspect in environmental regulation, he does not analyze in detail how emission tax affects outputs.

In this paper, we intend to analyze the effects of differentiated emission taxes in a general equilibrium setting. Extending a standard 2×2 Heckscher-Ohlin (HO) model to incorporate emissions, we focus on how the differentiated emission taxes affect output. By the term "differentiated emission tax" here, we mean a policy that changes the level of emission tax on one industry. Since we assume good prices as a given constant, our model represents a small open economy.[1] Although our model is a highly simplified one, we can show clear mechanism of how emission tax affects outputs.

[1] We can also regard the model as a production side of an economy.

2 The Model

We employ the standard 2×2 model and, as in previous literature on the subject, incorporate emissions as the third production factor.[2] Thus, the model has a structure similar to the standard 2×3 HO model employed in Batra and Casas (1976) and Jones and Easton (1983). However, there is one important difference from their models: while all factor prices are endogenously determined in the standard 2×3 model, the factor prices corresponding to emissions in our model are policy instruments (i.e. emission tax) determined exogenously.[3]

Let v_j^i denote the amount of factor $j = K, L$ employed in sector $i = 1, 2$ and v_Z^i denote the level of emission from sector i. The production function of sector i is given by $Q_i = f^i(v^i)$ where Q_i is the output of sector i and $v^i = (v_K^i, v_L^i, v_Z^i)$. We assume that $f^i(\cdot)$ is concave and homogeneous of degree one in v^i. The unit cost function of sector i is

$$c^i(w_K, w_L, w_Z^i) \equiv \min_{\{a_{Ki}, a_{Li}, a_{Zi}\}} \left[w_K a_{Ki} + w_L a_{Li} + w_Z^i a_{Zi} \mid f^i(a_{Ki}, a_{Li}, a_{Zi}) \geq 1 \right]$$

where a_{ji} $(j = K, L, Z)$ is unit factor demand, w_j $(j = K, L)$ is the price of factor j, and w_Z^i is the specific emission tax imposed on sector i. From Shephard's lemma, $a_{ji} = \partial c^i / \partial w_j$ $(j = K, L, Z)$.

At a competitive equilibrium, unit cost must be equal to price if the commodity is actually produced and capital and labor must be fully employed. Thus, for $i = 1, 2$, and $j = K, L$:

$$c^i(w_K, w_L, w_Z^i) = p_i \qquad \sum_{i=1,2} a_{ji}(w_K, w_L, w_Z^i) Q_i = v_j \tag{1}$$

where p_i is the price of good i and v_j is the endowment of factor j. Given commodity prices, factor endowments, and emission taxes, equilibrium factor prices and outputs are determined by (1). The level of emissions from sector i is given by $v_Z^i = a_{Zi} Q_i$. Let θ_{ji} denote the cost share of factor j in sector i $(\theta_{ji} \equiv w_j a_{ji} / c_i)$ and λ_{ji} denote the fraction of factor j employed

[2]This approach is commonly used in general equilibrium models for environmental analyses, for example, Yohe (1979), Copeland and Taylor (1994, 1995) and Ishikawa and Kiyono (2000).

[3]The model more similar to ours is the 2×3 model with capital mobility like Wong (1995), chapter 4 because one of the factor prices in his model (the rental rate) is also constant. See section 4 for details.

in sector i ($\lambda_{ji} \equiv Q_i a_{ji}/v_j$). Then, equations of change are given by

$$\sum_{j=K,L} \theta_{ji}\hat{w}_j = \hat{p}_i - \theta_{Zi}\hat{w}_Z^i \qquad\qquad \sum_{i=1,2} \lambda_{ji}\hat{Q}_i = \hat{v}_j - \sum_{i=1,2} \lambda_{ji}\hat{a}_{ji} \tag{2}$$

where a hat over a variable denotes the rate of change (e.g. $\hat{w}_j \equiv dw_j/w_j$). In addition, we define $|\theta_{KL}| \equiv \theta_{K1}\theta_{L2} - \theta_{L1}\theta_{K2}$, $|\lambda_{KL}| \equiv \lambda_{K1}\lambda_{L2} - \lambda_{L1}\lambda_{K2}$, $Y \equiv \sum_{i=1,2} p_i Q_i$, $\alpha_j \equiv w_j v_j/Y$, and $\gamma_i \equiv p_i Q_i/Y$. α_j and γ_i represent the factor and sector shares in GDP, respectively. By definition, we have $\lambda_{ji} = \gamma_i\theta_{ji}/\alpha_j$. In the remainder of the paper, we will focus on the effects of the change in the emission taxes and set $\hat{p}_i = \hat{v}_j = 0$. From (2) and the above notations, the following relations are derived.

$$\hat{w}_K = |\theta_{KL}|^{-1}(-\theta_{L2}\theta_{Z1}\hat{w}_Z^1 + \theta_{L1}\theta_{Z2}\hat{w}_Z^2) \qquad \hat{w}_L = |\theta_{KL}|^{-1}(\theta_{K2}\theta_{Z1}\hat{w}_Z^1 - \theta_{K1}\theta_{Z2}\hat{w}_Z^2) \tag{3}$$

$$\hat{Q}_1 = |\lambda_{KL}|^{-1}(\lambda_{L2}\hat{\beta}_K - \lambda_{K2}\hat{\beta}_L) \qquad \hat{Q}_2 = |\lambda_{KL}|^{-1}(-\lambda_{L1}\hat{\beta}_K + \lambda_{K1}\hat{\beta}_L) \tag{4}$$

where $\hat{\beta}_j \equiv -\sum_{i=1,2} \lambda_{ji}\hat{a}_{ji}$.

To derive the expression of $\hat{Q}_i/\hat{w}_Z^i$, we define further notations.

$$\varepsilon_{jl}^i \equiv \frac{w_l}{a_{ji}}\frac{\partial a_{ji}}{\partial w_l} \qquad i = 1,2 \;\; j,l = K,L,Z$$

ε_{jl}^i is the price elasticity of unit factor demand in sector i. If $\varepsilon_{jl}^i > (<)\ 0$, factor j and l are called *substitutes* (*complements*) in sector i.[4] ε_{jl}^i has the following three properties: (i) $\varepsilon_{lj}^i = \theta_{ji}\varepsilon_{jl}^i/\theta_{li}$, (ii) because of the zero homogeneity of a_{ji} with respect to (w_K,w_L,w_Z^i), $\varepsilon_{jK}^i + \varepsilon_{jL}^i + \varepsilon_{jZ}^i = 0$ for $j = K, L, Z$, (iii) because of the concavity of the cost function, $\varepsilon_{jj}^i \leq 0$ and $\varepsilon_{jj}^i\varepsilon_{ll}^i - \varepsilon_{jl}^i\varepsilon_{lj}^i \geq 0$. From these properties, if ε_{jl}^i is negative, both ε_{jk}^i and ε_{lk}^i must be positive, that is, there is at most one pair of complementary factors. Moreover, property (ii) and (iii) imply that the following inequality holds for $i = 1, 2$, $j, l, k = K, L, Z$, $j \neq l$, $l \neq k$, $k \neq j$:

$$\varepsilon_{jl}^i \geq -\frac{\theta_{li}\varepsilon_{jk}^i\varepsilon_{lk}^i}{\theta_{ji}\varepsilon_{jk}^i + \theta_{li}\varepsilon_{lk}^i} \tag{5}$$

[4] $\varepsilon_{jl}^i/\theta_{li}$ is the well-known Allen's partial elasticity of substitution (see Chambers, 1988, p. 95). While most papers including Batra and Casas (1976), Yohe (1979), and Siebert, Eichverger, Gronych and Pethig (1980) use this Allen's measure of elasticity, we use ε_{jl}^i as Jones and Easton (1983) do.

This means that even if $\varepsilon^i_{jl} < 0$ (i.e. factor j and l are complements), the degree of complementarity is limited by some bound.

In addition, we define $\varepsilon_{jl} \equiv \lambda_{j1}\varepsilon^1_{jl} + \lambda_{j2}\varepsilon^2_{jl}$. ε_{jl} expresses the price elasticity of *total* factor demand and has the properties similar to ε^i_{jl}: (i) $\varepsilon_{lj} = \alpha_j\varepsilon_{jl}/\alpha_l$, (ii) $\varepsilon_{jK} + \varepsilon_{jL} + \varepsilon_{jZ} = 0$, (iii) $\varepsilon_{jj} \leq 0$. Using these notations, we can rewrite $\hat{\beta}_j$ as follows

$$-\hat{\beta}_j = \varepsilon_{jK}\hat{w}_K + \varepsilon_{jL}\hat{w}_L + \lambda_{j1}\varepsilon^1_{jZ}\hat{w}^1_Z + \lambda_{j2}\varepsilon^2_{jZ}\hat{w}^2_Z \tag{6}$$

In the rest of the paper, we consider only the change in the emission tax on sector 1 without loss of generality. The same argument is applicable to the other case. Combining (3), (4), and (6), we can derive the expression of $\hat{Q}_1$:

$$\hat{Q}_1 = (|\theta_{KL}||\lambda_{KL}|)^{-1}A_1\hat{w}^1_Z \tag{7}$$

where
$$A_1 = -B_1\theta_{Z1} + |\theta_{KL}|(\lambda_{K2}\lambda_{L1}\varepsilon^1_{LZ} - \lambda_{L2}\lambda_{K1}\varepsilon^1_{KZ})$$
$$B_1 = \frac{\gamma_2}{\alpha_L}(\theta_{K2} + \theta_{L2})^2\varepsilon_{KL} + \frac{\gamma_2}{\alpha_L}(\theta_{L2})^2\varepsilon_{KZ} + \frac{\gamma_2}{\alpha_K}(\theta_{K2})^2\varepsilon_{LZ}$$

Since both $|\theta_{KL}|$ and $|\lambda_{KL}|$ have the same signs, $|\theta_{KL}||\lambda_{KL}| > 0$ always holds.

3 Analysis

Since (7) includes a lot of parameters, we cannot derive analytical propositions from it except for extreme cases.[5] However, we can show the following paradoxical proposition by numerical examples.

Propostion *The sign of $\hat{Q}_i/\hat{w}^i_Z$ may be positive, that is, raising emission tax imposed on an industry may increase its output.*

[5]For example, we can show that when K and L are perfect complements in both sectors, $\hat{Q}_1/\hat{w}^1_Z < 0$ always holds.

Table 1: Three numerical examples illustrating proposition 1.

	θ_{K1}	θ_{L1}	θ_{K2}	θ_{L2}	γ_1	ε^1_{KL}	ε^1_{LZ}	ε^1_{KZ}	ε^2_{KL}	ε^2_{LZ}	ε^2_{KZ}
Case 1	0.5	0.45	0.3	0.65	0.6	0.5	0.5	-0.118	0.5	0.5	-0.171
Case 2	0.7	0.25	0.3	0.65		2.5	1.5	-0.309			
Case 3	0.3	0.65	0.5	0.45	0.7	0.5	0.5	2.5	1	0.5	1

$\theta_{Z1} = \theta_{Z2} = 0.05$ in all cases.

We show and explain this proposition by giving three numerical examples.[6] The values of the parameters in the three cases are shown in Table 1 and we have $\hat{Q}_1/\hat{w}^1_Z > 0$ in all three cases (see Appendix 1).[7] In Case 1, I assume that K and Z are complements in both sectors, which is consistent with the empirical result in Chambers (1988, p. 98).

The proposition is quite counter-intuitive because the rise in emission tax should have the cost-push effect and thus lead to the downward pressure on the output of the industry. However, a close look at A_1 in (7) reveals that, in addition to the cost-push effect, the rise in the emission tax has another effect. Two effects can be explained as follows. First, the sector specific rise in emission tax alters factor prices in the same way as the fall in the commodity price (see the RHS of (2)). These changes in factor prices lead to the changes in factor demand and the output is adjusted so as to clear the factor markets. This effect, which we call *the cost-push*, is represented by the first term in A_1. In addition, the change in emission tax directly affects factor demand through substitution (or complementarity) between factors. This *substitution* is represented by the second term[8].

For example, suppose that w^1_Z rises by one percent. This has the same impact on factor prices as a θ_{Z1} percent fall of p_1, and its impact on Q_1 is represented by $-B_1\theta_{Z1}$. We can show that this cost-push effect of the rise in w^1_Z through factor price adjustment always decreases the output, i.e. $B_1 \geq 0$, (see Appendix 2 for the proof). On the other hand, one percent

[6]Of course, one can easily find other various cases in which the paradoxical result happens.

[7]The constraint (5) is satisfied in all cases.

[8]Although we use the term *substitution*, it does not mean that complementarity is excluded. We use the term to represent the effects which work through substitution and complementarity between factors.

rise in w_Z^1 raises the demands for capital and labor by $\lambda_{K1}\varepsilon_{KZ}^1$ and $\lambda_{L1}\varepsilon_{LZ}^1$ respectively (or reduces them if they are complements). If, for example, sector 1 has a higher capital-labor ratio than sector 2 (i.e. $|\theta_{KL}| > 0$), the increased demand for capital gives rise to a downward pressure on the output of sector 1 and the increased demand for labor gives rise to a upward pressure. This effect is represented by the second term. The proposition says that if the substitution effect works strongly in the opposite direction to the cost-push effect, the rise in the emission tax on an industry may raise the output of the industry.

Using Case 1, let us explain the intuition of two effects above. In Case 1, it is assumed that emissions are complement with capital but substitute with labor ($\varepsilon_{KZ}^1 < 0$, $\varepsilon_{LZ}^1 > 0$), and that sector 1 is more capital intensive than sector 2 ($|\theta_{KL}| > 0$). Suppose that the emission tax on sector 1 is raised. First, this raises the cost of sector 1 and generates the downward pressure on the output of that sector. On the other hand, the rise in emission tax on sector 1 decreases capital demand and increases labor demand through substitution effect and this leads to the fall in the rental rate and the rise in the wage. As a result of this, more resource is allocated to the capital intensive industry (sector 1) and the output of that sector tends to increase. What we have showed that under the numerical values of Case 1, the latter effect indeed dominates the former effect and the output of that industry increases.

Next, using Case 2 and the figure 1, we explain two effects above in detail. In Case 2, we assume, for graphical exposition, that capital and labor are perfect complements in sector 2 (i.e. $\varepsilon_{Kj}^2 = \varepsilon_{Lj}^2$ for $j = K, L, Z$).[9] Figure 1 depicts the equilibrium in the output space. The horizontal and vertical axes represent the outputs of sector 1 and 2 respectively. Let the full employment lines for capital and labor at the initial equilibrium be denoted by line K*K and L*L whose slopes are given by a_{K1}/a_{K2} and a_{L1}/a_{L2}. Since in Case 2, the capital-labor ratio in sector 1 is higher than that in sector 2, line K*K is steeper than line L*L. The outputs at the initial equilibrium are given by the point Q where both factor markets are cleared.

[9]Note that perfect complementarity does not mean Leontief technology (i.e., no substitution). Leontief technology is represented by $\varepsilon_{jl}^i = 0$.

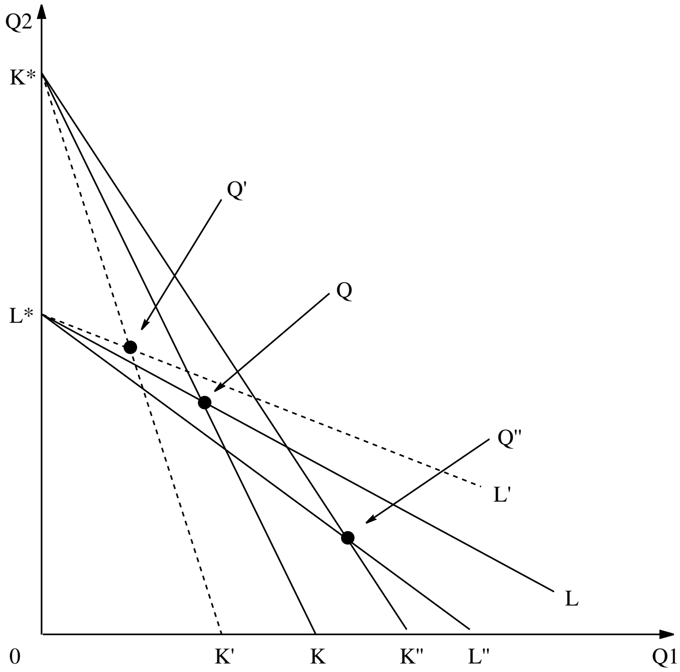

Figure 1:

Now suppose that the emission tax on sector 1 is raised by 1%. First, let us consider the cost-push effect. From (3), 1% rise in w_Z^1 leads to (0.0235/0.38)% fall in w_K and (0.015/0.38)% rise in w_L because the capital-labor ratio in sector 1 is higher than that in sector 2 (the Stolper–Samuelson effect). Since capital and labor are substitutes in sector 1, these changes in factor prices lead to the rise in a_{K1} and the fall in a_{L1}: $\hat{a}_{K1}^{\mathrm{CP}} = 0.28609$ and $\hat{a}_{L1}^{\mathrm{CP}} = -0.93421$ (the superscript CP means cost-push effect).[10] On the other hand, from the perfect complementarity between K and L in sector 2, both $\hat{a}_{K2}^{\mathrm{CP}}$ and $\hat{a}_{L2}^{\mathrm{CP}}$ are zero. Therefore, by the cost-push effect, the full employment lines shift to K*K' and L*L', and outputs shift to Q' where the output of sector 1 decreases. As has already been pointed out,

[10]From the definition of $a_{ji} = a_{ji}(w_K, w_L, w_Z^i)$,

$$\hat{a}_{ji} = \varepsilon_{jK}^i \hat{w}_K + \varepsilon_{jL}^i \hat{w}_L + \varepsilon_{jZ}^i \hat{w}_Z^i$$

From this, $\hat{a}_{ji}$ is decomposed as follows: $\hat{a}_{ji} = \hat{a}_{ji}^{\mathrm{CP}} + \hat{a}_{ji}^{\mathrm{ST}}$ where $\hat{a}_{ji}^{\mathrm{CP}} = \varepsilon_{jK}^i \hat{w}_K + \varepsilon_{jL}^i \hat{w}_L$ and $\hat{a}_{ji}^{\mathrm{ST}} = \varepsilon_{jZ}^i \hat{w}_Z^i$. $\hat{a}_{ji}^{\mathrm{ST}}$ represents the substitution effect of the change in emission tax on input coefficients and $\hat{a}_{ji}^{\mathrm{CP}}$ represents the cost-push effect through factor price adjustment.

the cost-push effect always works in this direction.

Next, consider the substitution effect. The substitution effect of a tax on input coefficients in sector 1 is given by $\hat{a}_{K1}^{\mathrm{ST}} = \varepsilon_{KZ}^{1} \times 1 = -0.309$ and $\hat{a}_{L1}^{\mathrm{ST}} = \varepsilon_{LZ}^{1} \times 1 = 1.5$. Thus, the substitution effect works in the opposite direction to the cost-push effect. Moreover, since the size of the substitution effects is larger than that of the cost-push effects (i.e. $|\hat{a}_{K1}^{\mathrm{ST}}| > |\hat{a}_{K1}^{\mathrm{CP}}|$ and $|\hat{a}_{L1}^{\mathrm{ST}}| > |\hat{a}_{L1}^{\mathrm{CP}}|$), the substitution effect dominates the cost-push effect. Taking account of two effects, the full employment lines shift to K*K" and L*L" and the new equilibrium output shifts to Q". Therefore, in the example above, the rise in the emission tax on sector 1 increases the output of sector 1.

Both Case 1 and 2 include complementary factors. However, it does not mean that complementary factors are necessary for the paradoxical result to occur. This is shown by Case 3 in which all factors are substitutes in both sectors.

4 Further Discussions

In this section, we provide further discussions on our model and its results so as to make our contribution clear. The first point is the relation between our model and the standard 2 $\times$ 3 model. Since our model includes two primary factors and incorporates emission as the third production factor, it has the structure similar to the standard 2 $\times$ 3 model employed in Batra and Casas (1976) and Jones and Easton (1983). But there is one important difference between the standard 2 $\times$ 3 model and ours. In the standard 2 $\times$ 3 model, all primary factors are treated symmetrically: endowments of three factors are given exogenously and all factor prices are determined endogenously. On the other hand, the price of emission in our model (emission tax) is given exogenously and the volume of emission is determined endogenously. Due to this difference, the results from the standard 2 $\times$ 3 model are not applicable to our analysis.

The model more similar to ours is the 2 $\times$ 3 model with international capital movements employed in Wong (1995, Chap. 4). In his model, the country is assumed to be a small open economy and the rental price for capital is exogenously given. This means that Wong's model has one exogenously given factor price like ours. However, he assumes uniform rental prices among industries and therefore our result of differentiated emission taxes cannot be derived from his analysis.

The second point is the relation between our model and a model with 2×2 structure. A lot of theoretical analyses employ a 2×2 model with one primary factor and emissions (e.g. Rauscher, 1994; Ishikawa and Kiyono, 2000). Due to the simplicity of the model, they often analyze more complicated policy issues than ours such as optimal emission tax and international trade etc. But as long as such a structure is employed, the result derived in this paper are excluded because when emission tax is imposed in a small open economy with such a structure, the production is always specialized to one sector and one cannot analyze the interaction of two production sectors.[11] In this sense, the model of 2×2 structure is not suited to our purpose and our results of differentiated emission taxes cannot be derived in such a model.

The third point is concerned with the effect of emission taxes on the volume of emissions. Although our analysis focuses on the effect of emission tax on output, it is also interesting to see the effect on the volume of emissions. In our model, one can easily show that differentiated emission taxes may increase the total amount of emissions: raising the emission tax imposed on one industry may increase the total volume of emissions.[12] The intuitive reasoning for this is very simple. If the industry imposed higher emission tax is less emission intensive industry, the decrease in emissions from the regulated industry can be cancelled out by the increase in emissions from the less regulated industry and therefore the total amount of emissions may increase.[13] Along with the result derived in this paper, this implies that emission tax is likely to bring about unintended and detrimental effects on an economy.

As all above arguments show, our result is a new insight and not what has been showed in the previous studies.

[11] Proposition 7 in Ishikawa and Kiyono (2000) shows this.

[12] See Takeda (2001).

[13] This is analogous to the so-called 'carbon-leakage'.

5 Concluding remarks

In this paper, we have considered the two sector economy with two primary factors and emissions and have explored the effects of differentiated emission taxes on output. Our finding is rather surprising: raising the emission tax imposed on an industry may increase the output of the industry. In addition, it is surprising in the sense that such a paradoxical result can arise in a simple and standard model under fairly plausible values of parameters. We have also showed that the mechanism behind this result is the general equilibrium effect through the factor market adjustment and that the emission tax affects the factor demand through two different effects (the cost-push and substitution effects).

As a policy instrument for regulating emissions, emission tax has been attracting much attention and introduced in many countries. However, our analysis indicates that according to the way in which emission taxes are introduced, they may have unintended and detrimental effects on an economy. In this sense, greater attention should be paid to how emission taxes are introduced in an economy.

Appendix 1

A_1 can be rewritten as $A_1 = -\gamma_2(\gamma_1 X_1 + \gamma_2\theta_{Z1}\theta_{K2}X_2)/\alpha_K\alpha_L$ where $X_1 = (\theta_{K2}+\theta_{L2})^2\theta_{Z1}\theta_{K1}\varepsilon^1_{KL} + \theta_{L2}\theta_{K1}[\theta_{L2} - \theta_{L1}(\theta_{K2} + \theta_{L2})]\varepsilon^1_{KZ} + \theta_{K2}\theta_{L1}[\theta_{K2} - \theta_{K1}(\theta_{K2} + \theta_{L2})]\varepsilon^1_{LZ}$, and $X_2 = (\theta_{K2} + \theta_{L2})^2\varepsilon^2_{KL} + (\theta_{L2})^2\varepsilon^2_{KZ} + \theta_{K2}\theta_{L2}\varepsilon^2_{LZ}$. Inserting numerical values of Table 1 into this equation leads to $\hat{Q}_1/\hat{w}^1_Z > 0$. In Case 2, we assume the perfect complementarity between K and L in sector 2 (i.e. $\varepsilon^2_{Kj} = \varepsilon^2_{Lj}$ for $j = K, L, Z$). In this case, from the property (ii) of ε^i_{jl}, we have $\varepsilon^2_{KZ} = \varepsilon^2_{LZ} = -(1+\theta_{K2}/\theta_{L2})\varepsilon^2_{KL}$, thus $X_2 = 0$. When there is a pair of complementary factors, the constraint (5) must be satisfied. In both Case 1 and 2, this constraint is indeed satisfied.

Appendix 2

The proof of $B_1 \geq 0$. If all factors are substitutes, $B_1 \geq 0$ is clear. Thus, we have to prove $B_1 \geq 0$ when there is a pair of factors which are complements. We provide the proof in the case of $\varepsilon^i_{KL} < 0$ for $i = 1, 2$, that is, the case where capital and labor are complements in both sectors. Similar arguments can be applied to the other cases.

We can rewrite B_1 as

$$B_1 = \frac{\gamma_2}{\alpha_K\alpha_L}\sum_{i=1,2}\gamma_i[(\theta_{K2} + \theta_{L2})^2\theta_{Ki}\varepsilon^i_{KL} + (\theta_{L2})^2\theta_{Ki}\varepsilon^i_{KZ} + (\theta_{K2})^2\theta_{Li}\varepsilon^i_{LZ}]$$

Then, from (5), we have

$$\begin{aligned} B_1 &\geq \frac{\gamma_2}{\alpha_K\alpha_L}\sum_{i=1,2}\gamma_i\left[-(\theta_{K2} + \theta_{L2})^2\theta_{Ki}\frac{\theta_{Li}\varepsilon^i_{KZ}\varepsilon^i_{LZ}}{\theta_{Ki}\varepsilon^i_{KZ} + \theta_{Li}\varepsilon^i_{LZ}} + (\theta_{L2})^2\theta_{Ki}\varepsilon^i_{KZ} + (\theta_{K2})^2\theta_{Li}\varepsilon^i_{LZ}\right] \\ &= \frac{\gamma_2}{\alpha_K\alpha_L}\sum_{i=1,2}\frac{\gamma_i}{\theta_{Ki}\varepsilon^i_{KZ} + \theta_{Li}\varepsilon^i_{LZ}}(\theta_{Ki}\theta_{L2}\varepsilon^i_{KZ} - \theta_{Li}\theta_{K2}\varepsilon^i_{LZ})^2 \geq 0 \end{aligned}$$

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