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Paths of Development and Wage Variations

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Abstract

In analyzing the relationship between factor endowments and sectoral per-capita output (the path of development), Schott (2003) showed empirically that the number of cones was neither one nor three but two, and that all countries fall into one of these two cones. This is a puzzle because it is inconsistent with large wage variations across economies. This paper attempts to solve this puzzle, introducing complete and incomplete specialization into a multiple-cone model. Empirical results reveal that factor endowments can explain Heckscher-Ohlin specialization and the wage variations across economies at the same time once the multiple-cone model allows the complete specialization. (100 words)

Key words: Paths of Development; Complete Specialization; Multiple Cones; Factor Price Equalization; Intra-industry Heterogeneity; Wage Variations; Japan
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1 Introduction

The relationship between factor endowments and sectoral per-capita output (the path of development) is an important question in international trade and development economics.[1] There have been a number of studies that have examined the paths of development.[2] Significant progress has been made by Schott (2003), who provided evidence for multiple cones (i.e., multiple factor-price-equalization (FPE) sets).[3] While previous studies on the paths of development relied on the assumption of a single cone, Schott extended the analysis to a multiple-cone model. Using cross-country data for 1990 and introducing a new aggregation technique for adjusting industry output to reflect product variations, he found that the multiple-cone model performed better than the single-cone model. Moreover, his results supported the empirical validity of Heckscher-Ohlin (HO) specialization (i.e., output is a function of factor endowments).

The existence of multiple FPE sets has an important implication. This is because the failure of a single FPE set is regarded as one of the important reasons why the HO model sometimes performs poorly in empirical analysis as noted by Davis, Weinstein, Bradford, and Shimpo (1997). Multiple cones mean that economies that locate in different cones face different factor prices. Schott's study suggests that the HO model performs poorly because of the single-cone assumption. Once the HO model is extended to multiple cones, it performs well.[4]

While Schott's study is insightful, it raises another puzzle. His result supported the existence of two cones rather than three cones. In other words, the number of FPE sets is neither one nor three, but two. In his framework, this in turn implies that all countries are included in one

[1]This paper defines "development" as the accumulation of capital (everything else held fixed) as in Leamer (1987).

[2]See, for example, Leamer (1984) and Harrigan (2003).

[3]The "cone" means the cone of diversification that is defined as: "for given prices in the Heckscher-Ohlin model, a set of factor endowment combinations that are consistent with producing the same set of goods and having the same factor prices (Deardorff, 2006, p. 72)." The number of cones thus is equivalent to the number of FPE sets. The Heckscher-Ohlin (HO) model with a single diversification cone (single FPE set) is called a single-cone model while the model with multiple diversification cones (multiple FPE sets) is called a multiple-cone model.

[4]Debaere and Demiroglu (2003) and Xiang (2007) also confirmed the evidence of multiple cones, although their studies focused on aspects different from the paths of development.

of two FPE sets. This finding is, however, inconsistent with the empirical evidence of the vast differences in wages in the world (e.g., Leamer and Levinsohn, 1995).

The violation of the single FPE set has been confirmed not only among countries but also among regions in a country.[5] For example, Figure 1 presents the differences of manufacturing wages across regions in Japan in 1995,[6] which follow the conventionally used format to explain wage differences across economies (e.g., Leamer and Levinsohn, 1995; Leamer and Schott, 2005). Each region is represented by a horizontal line segment. The average regional wage in manufacturing is indicated by the vertical position whose length indicates the regional share of the labor force. The figure clearly indicates that wage differences exist in Japan: the wage rate in Kanagawa region is twice as much as the wage rate in Aomori region. Even though existing empirical evidence supports two FPE sets, wage variations exist. In other words, the number of cones is not large enough to explain the wage variations. How do we explain this puzzle?[7]

=== Figure 1 ===

This paper attempts to solve this puzzle. I propose an alternative approach to explain the wage variations across economies as well as the paths of development at the same time. Previous empirical studies on the paths of development such as Leamer (1987) and Schott (2003) relied on the assumption that the production technology was Leontief. In this paper, I specify the production function as Cobb-Douglas rather than Leontief so that the model can accommodate both complete and incomplete specialization.[8] With this simple modification, I show that the two-cone model becomes consistent with wage variations across economies. Following several studies such as Davis et al. (1997) and Bernstein and Weinstein (2002) that utilized Japanese

[5] See, for example, Bernard, Redding, and Schott (2005) for the United States and Tomiura (2005) for Japan.

[6] The detail description about the data is provided in Section 3.

[7] Although one may argue that there may exist a large number of cones, Schott (2003) found that "there is strong evidence for the two-cone model but little evidence for three cones" (p. 701). This paper thus focuses on (and assumes) the two-cone world, given that the Schott's finding is correct.

[8] In this paper, “complete specialization” means the production of only one type of goods such as labor- or capital-intensive goods that are classified as actual factor use rather than the similarity of end use. The detailed definition for the empirical analysis is provided in Section 3.2.

regional data in testing the Heckscher-Ohlin-Vanek (HOV) model, I then apply the two-cone model to data that cover 21 manufacturing industries in 47 Japanese regions for 1995.

The major findings are threefold. First, HO specialization is confirmed across regions in Japan. This finding supports the finding of Schott (2003) that utilized international data and, therefore, adds another national perspective to the available evidence. Second, the multiple-cone model with complete specialization fits better than the multiple-cone model without complete specialization. Finally, the factor endowments can explain HO specialization and the wage variations across economies at the same time once the multiple-cone model allows the complete specialization. As regions accumulate capital, they shift their production from labor- to capital-intensive goods, which ultimately results in increased regional per-capita output. Some of the regions specialize completely in the production of capital-intensive goods, which generates the variations in wages across regions. My results thus suggest that economies do not necessarily locate within cones.

In what follows, I attempt to address the foregoing puzzle by introducing complete specialization in a multiple-cone model. The rationale for my analysis stems from the theoretical literature on the multiple-cone model in a neoclassical growth model that has been explored by Deardorff (1974, 2001a, b) together with aforementioned estimation of the multiple-cone model by Schott (2003). This makes it possible to introduce complete and incomplete specialization at the same time. The paper proceeds as follows. Section 2 explains the model. Section 3 describes the data and regression equations. Section 4 presents the estimation results. Concluding remarks are in Section 5.

2 Model

2.1 Incomplete-specialization model

For the multiple-cone model without complete specialization, I follow the model presented in Schott (2003) that extends the standard HOV model to the multiple-cone model. I refer to his model as an incomplete-specialization model because the model does not allow complete specialization.

Consider the standard HOV model. To simplify the discussion, suppose that there are three goods (labor-intensive goods Y_1, intermediate capital-intensive goods Y_2, and capital-intensive goods Y_3) and two factors (labor L and capital K).[9] Let the capital-labor ratios that make the borders between cones label $\tau_j,\ j = 0,1,2\ (\tau_0 = 0)$, which is referred to as a "knot." Let per-capita output and the capital-labor ratio in industry n be $y_n = Y_n/L_n$ and $k_n = K_n/L_n$, respectively ($K_1 + K_2 + K_3 = K$ and $L_1 + L_2 + L_3 = L$). Let p_n be the price of good n, w the wage rate, and r the capital rental rate. Assume that each economy is a small open economy such that the price p_n is given and fixed. Thus, $Z_n(= p_nY_n)$ stands for income from good n. I refer to income as output to simplify the discussion. Denote output of goods n divided by *total* labor (i.e., labor endowment) as $z_n(= p_nY_n/L)$.

In extending the standard HOV model, Schott (2003) introduced two assumptions. First, each sector has Leontief technology. Second, each cone has an equal number of goods and factors. Figure 2 presents the three-good two-cone Lerner Diagram that illustrates the path of a small open economy accumulating capital (relative to labor). When the economy's capital-labor ratio lies between τ_0 and τ_1, it produces intermediate capital- and labor-intensive goods while it does not produce any capital-intensive goods. Similarly, when the economy's capital-labor ratio lies between τ_1 and τ_2, it produces capital- and intermediate capital-intensive goods while it does not

[9] Although the extension to any number of goods is rather straightforward from the theoretical point of view, computational constraints prevent estimating more than three goods.

produce any labor-intensive goods. Capital accumulation moves countries into cones with higher wages ($w' \to w''$) and lower capital-rental rates ($r' \to r''$).[10]

=== Figure 2 ===

Figure 3 rewrites this relationship in terms of per-capita output z and capital-labor ratio k. The envelope $w'AB$ indicates the per-capita output, which is defined as output divided by labor endowment ($z = z_1 + z_2 + z_3$). The interval between τ_1 and τ_2 can be interpreted as a diversification cone (and therefore an FPE set) because it is analogous to the Lerner diagram. As the economy accumulates capital (relative to labor), its production shifts from labor- to capital-intensive goods. The envelope $w'AB$ indicates that the per-capita output increases as the economy shifts production from one cone to the other cone.

Figure 3 also shows the relationship between factor prices and the capital-labor ratio. Because of linear homogeneity and perfectly competitive markets, the return to capital $r = f'(k)$ is provided by the slope while the wage $w = f(k) - rk$ is provided by the vertical intercept of the tangent to it. Both are constant throughout the cone at the values shows as w' and r' in the first cone and w'' and r'' in the second cone.

=== Figure 3 ===

Figure 4 presents the sectoral output divided by *total* labor, or the industry paths of development, and wages. The paths of development are given by $w'\tau_1\tau_2$ for labor-intensive goods, $0A\tau_2$ for intermediate capital-intensive goods, and $0\tau_1 B$ for capital-intensive goods. The wage rate is constant at w' when the economy's capital-labor ratio lies between 0 and τ_1 and w'' when the economy's capital-labor ratio lies between τ_1 and τ_2.

=== Figure 4 ===

[10]Note that the wages are different from the per-capita income. For the relationship between factor endowments and the difference of the per-capita income, see for example Krueger (1968).

2.2 Deardorff model

The model with complete specialization builds upon the theoretical studies by Deardorff (1974, 2001a, b).[11] I refer to this model as a Deardorff model because his model accommodates complete- as well as incomplete-specialization.

Suppose that there are three goods (labor-intensive goods Y_1, intermediate capital-intensive goods Y_2, and capital-intensive goods Y_3) and two factors (labor L and capital K). Assume that the production function of goods n is represented by a Cobb-Douglas form: $Y_n = \phi_n K_n^{\theta_n} L_n^{1-\theta_n}, n = 1,2,3$, where $\phi_n (> 0)$ is a productivity parameter and $\theta_n (0 < \theta_n < 1)$ is capital intensity. Because of linear homogeneity and fixed prices, the per-capita production function is written in terms of output per worker: $\tilde{z}_n = \delta_n k_n^{\theta_n}$, where $\delta_n = p_n \phi_n$ and $\theta_1 < \theta_2 < \theta_3$. Other assumptions are the same as those of the incomplete-specialization model.

Figure 5 shows the relationship between per-capita output and the capital-labor ratio in the three-good single-cone Deardorff model. The production functions of labor-intensive goods, intermediate capital-intensive goods, and capital-intensive goods are represented by $\tilde{z}_1 (= p_1 Y_1 / L_1)$, $\tilde{z}_2 (= p_2 Y_2 / L_2)$, and $\tilde{z}_3 (= p_3 Y_3 / L_3)$, respectively.[12] These production functions are connected by their common tangents AB and CD.[13] The corresponding intervals of capital-labor ratios $\tau_1 \tau_2$ and $\tau_3 \tau_4$ are the diversification cones. In other words, there are two cones (two FPE sets) in this model. Similar to the case of the incomplete-specialization model, the envelope $0ABCDE$ indicates the per-capita income.[14] Recall that since the wages are provided by the vertical intercept of the tangent to the per-capita output diagram, the wage can be derived as the curve labeled w.[15]

[11] Similarly, Ishikawa (1992) also examined theoretically the relationship between factor endowments and the sectoral production patterns. This paper employs Deardorff's framework because Deardorff's model allows a positive relationship between complete specialization and per-capita income growth.

[12] The sectoral output divided by *total* labor is represented by $z_n (= p_n Y_n / L)$ while the sectoral output divided by *sectoral* labor is represented by $\tilde{z}_n (= p_n Y_n / L_n)$.

[13] When there is no common tangent, one of the values of the per-capita production functions must be above the other for all k and, therefore, the economy has only one sector. I assume that this complication does not arise.

[14] Because price is given and fixed, output and income are regarded as interchangeable in the present paper.

[15] Note that Figure 5 is consistent with several well-established results in the pure theory of international trade. The FPE theorem holds in the region of incomplete specialization where the common tangent AB determines factor prices. The Rybczynski theorem can be confirmed by $A\tau_2$ and $\tau_1 B$. A version of the Stolper-Samuelson theorem is

Figure 6 shows the industry development paths in the three-good two-cone Deardorff model. The economy specializes completely in the production of labor-intensive goods, when its capital-labor ratio $k(=K/L)$ lies between 0 and τ_1. Similarly, it specializes completely in the production of intermediate capital-intensive goods and capital-intensive goods when $\tau_2 \leq k < \tau_3$ and $k \geq \tau_4$. The economy produces both goods when its capital-labor ratio lies between τ_1 and τ_2 or between τ_3 and τ_4.[16]

=== Figure 6 ===

The production pattern of labor-intensive goods is $0A\tau_2\tau_3\tau_4H$. Similarly, the production pattern for intermediate capital-intensive goods is $0\tau_1BC\tau_4H$ while that for capital-intensive goods is $0\tau_1BC\tau_4H$ and $0\tau_1\tau_2\tau_3DE$. As an economy accumulates capital, its production shifts from labor-intensive goods to intermediate capital-intensive goods and from intermediate capital-intensive goods to capital-intensive goods. The wages are constant in the cones but now have a positive relationship with the capital-labor ratio outside the cones.

3 Methodology

3.1 Data

As mentioned above, the data cover 21 manufacturing industries in 47 regions in Japan for 1995. An advantage in using Japanese regional data is that identical technology across regions is plausible within a country as compared to across countries. For example, Harrigan (1997) found that technology differences as well as factor supplies were important determinants of the international

also verified once the model allows for price changes (Deardorff, 1974). Although I am focusing on the production side, the patterns of trade and the existence of the steady-state can be also explained if the model introduces an investment good and (exogenous) saving rate (Deardorff, 2001a).

[16] Note also that the industry development paths take linear forms in both the incomplete-specialization and Deardorff models. This in turn implies that the underlying functional form of the production function does not matter so long as the analysis focuses on the industry development paths within a single cone.

specialization of production.[17] Bernstein and Weinstein (2002) pointed out that the use of international data was sometimes subject to problems such as measurement error and government policy. The use of national data can overcome some of these problems.

On the other hand, there is a disadvantage in so far as factors are more mobile than in a cross-country analysis. Thus, the concern is that FPE is more likely to hold within Japan than across countries, implying that factor endowments are similar in the sense that they locate in the same single diversification cone. Note, however, that the violation of FPE has been confirmed not only among countries but also among regions in a country. Thus, Bernard, Redding, and Schott (2005) examined the relative wages between skilled- and unskilled-workers across 181 areas in the United States in 1972 and 1992, and they found that there were significant variations in relative wages across skill-scarce and skill-abundant areas. Similarly, Tomiura (2005) tested the equality of regional wages in Japan, and he rejected FPE, even when the analysis controlled for productivity differences among regions. Indeed, labor mobility is relatively low in Japan. According to the Ministry of International Affairs and Communications (MIC) (2000), the migration rate of manufacturing workers among regions was 6.6 percent from 1995 to 2000.[18] This implies that the annual migration rate is about one percent, which is almost the same as the migration rates of some OECD countries such as Switzerland.[19]

The major source of data is the Japan Industrial Productivity database 2006 (JIP 2006 database), which was compiled as a part of a research project of the Research Institute of Economy, Trade and Industry (RIETI) and Hitotsubashi University. The database runs annually from 1970 to 2002, covering 52 manufacturing and 55 non-manufacturing industries. The major sources of the database are government statistics and, therefore, the industrial classification of the JIP database is based on the Japan Standard Industry Classification (JSIC) that complies with the International

[17] A recent study by Xiang (2007) addressed the technology differences across countries, estimating the cumulative distribution functions of factor intensities.

[18] The migration rate refers to the inflows divided by the total labor force in manufacturing.

[19] For more detail, see OECD (2006, p. 32, Chart I.1.).

Standard Industry Classification (ISIC) developed by the United Nations and JSIC. The database includes detailed information on sectoral output and inputs, including information on capital stocks.[20] From the JIP 2006 database, I use value-added for outputs and labor and capital for inputs. Value-added is defined as real gross output minus real intermediate inputs. Labor is defined as the number of workers. Because real wage data are not available, I use the cross-section data for 1995. Wages are defined as the total regional wage payments divided by the number of workers and from *the Census of Manufactures* by the Ministry of Economy, Trade and Industry (METI) (1995).

The JIP 2006 database is not available at the regional level while *the Census of Manufactures* is available at the regional level. Using the region-industry shares of output and inputs from *the Census of Manufactures* as weights, I calculated value-added, the number of workers, and capital for each region:

$$Z_{nr} = s_{nr}^{Z} Z_n, \; K_{nr} = s_{nr}^{K} K_n, \text{ and } L_{nr} = s_{nr}^{L} L_n, \tag{1}$$

where Z_{nr} is the value-added of industry n $(n = 1, ..., N)$ in region r $(r = 1, ..., R)$; K_r and L_r are the endowments of capital and labor in region r, respectively; s_{nr}^{Z}, s_{nr}^{K}, and s_{nr}^{L} are the region-industry shares of nominal value-added, the value of tangible assets, and the number of workers, respectively.[21] The JIP 2006 database was aggregated into 21 sectors to match the industries available in *the Census of Manufactures*. Therefore, the data cover 21 manufacturing sectors in 47 regions in Japan in 1995.

3.2 Evidence of cross-region, intra-industry heterogeneity

A concern arises in using the "standard" industry classification such as the ISIC and the JSIC. This relates to the point made by Schott (2003), who identified the potential problem in using the

[20]For more details about the JIP data, see Fukao, Hamagata, Inui, Kwon, Makino, Miyagawa, and Tokui (2006).

[21]When the number of establishment is very small, *the Census of Manufactures* does not report those information. I assume that the amount of output for the industry is also negligibly small enough to be regarded as zero production. The sum of value-added, labor, and capital are the same as the manufacturing total of the JIP 2006 database.

"standard" industry classification because the ISIC categories group output loosely, according to the similarity of end use (e.g., textiles, transportation machinery) rather than actual factor use (e.g., capital-intensive goods, labor-intensive goods). The actual industry capital intensity, therefore, may be different across regions.

Table 1 shows the sectoral capital intensities across regions. Denote $k_{nr}(= K_{nr}/L_{nr})$ as the capital intensity of industry n in region r and $k_r(= K_r/L_r)$ as the capital intensity in region r. The capital intensity of a given industry in a given region k_{nr} is represented by the color of each cell. White, light gray, gray, and dark gray indicate capital intensities for $k_{nr} = 0$ (i.e., no production), $0 < k_{nr} \leq 5$, $5 < k_{nr} \leq 15$, and $k_{nr} > 15$, respectively.[22] The industries and the regions are sorted in order of capital intensity and relative capital abundance, respectively. When homogeneous goods are produced across regions, cells gradually become dark from left to right and from top to bottom in Table 1. The actual distribution of the color is, however, totally different from expectations. That is, capital intensity is different across industries and different across regions.[23]

=== Table 1 ===

One may think that the difference of capital intensity across regions is not a problem because capital intensity can be different if each region is operating with a different combination of labor and capital although the production function is the same across regions. Table 1, however, also suggests intra-industry heterogeneity: different regions produce different products. If intra-industry heterogeneity exists in the actual data, the "standard" industry classification is not consistent with the set up of the model.

Table 2 presents the correlation of ranking of capital intensities between two different regions. The number of region pairs is 1081 $(= 46 + 45 + ... + 1)$. If industries are homogeneous

[22] Unit is millions of yen per worker.

[23] Table 1 shows the uneven distribution of capital (relative to labor) among regions. It indicates that Chiba is more than three times more capital-abundant region than Kagoshima. Such uneven distribution of factors among regions suggests what Courant and Deardorff (1992) have called the "lumpiness" of regions in Japan.

across regions, the ranking of sectoral capital intensities will not change across different regions. Therefore, the rank correlation between two different regions will be one.

=== Table 2 ===

Table 2 indicates that only 5.6 percent of the region pairs show greater than 0.9 rank correlations and 26.8 percent of industries show less than 0.5 rank correlations. This low rank correlation suggests cross-region, intra-industry heterogeneity. For example, although all regions have a transportation machinery industry, this does not necessarily mean that they have automobile plants. Some regions do not have automobile plants but plants for ships. The use of the "standard" industry classification thus poses problems because it does not reflect the similarity of capital intensity. A more theoretically appropriate classification is needed.

To adjust industry output in a more theoretically appropriate way, I adapt the "HO aggregates" developed by Schott (2003). This procedure aggregates industries based on the region-industry capital intensities rather than the "standard" industry classification. That is, this procedure aggregates industries with similar capital intensities. Let h_i be the i's boundaries of the HO aggregates: h_i and h_{i-1} are the maximum and minimum capital intensity for i-th aggregates, respectively ($h_0 = 0$). Based on Schott's (2003) finding, this paper aggregates 21 manufacturing sectors into three HO aggregates:

$$i = \begin{cases} 1 \text{ (labor-intensive aggregate)} & \text{if } 0 < k_{nr} < h_1; \\ 2 \text{ (intermediate capital-intensive aggregate)} & \text{if } h_1 \leq k_{nr} < h_2; \\ 3 \text{ (capital-intensive aggregate)} & \text{if } k_{nr} \geq h_2. \end{cases} \quad (2)$$

Note that the aggregates for industries whose capital intensity is zero (i.e., $k_{nr} = 0$) cannot be determined. When $k_{nr} = 0$, I use the industry average capital intensity k_n rather than k_{nr} to determine the aggregates.[24]

[24]The industry average capital intensity is calculated based on the regions that have positive region-industry capital

Let Z_{ir} denote value-added of the HO aggregate i in region r, which is the sum of value-added of all industries with capital intensity between h_{i-1} and h_i (irrespective of region):

$$Z_{ir} = \sum_{k_{nr} \in (h_{i-1}, h_i]} Z_{nr}. \tag{3}$$

Using this classification, I aggregate 21 manufacturing industries into three aggregates (labor-, intermediate capital-, and capital-intensive aggregates) in estimating the three-good model.

3.3 Regression Equations

3.3.1 Incomplete-specialization model

In the three-good two-cone incomplete-specialization model, the expected paths of development take the spline functional form as in Figure 4: $w'\tau_1\tau_2$ for the labor-intensive aggregate, $0A\tau_1$ for the intermediate capital-intensive aggregate, and $0\tau_1 B$ for the capital-intensive aggregate. Let d_j be a dummy variable that takes value one if k_r lies in the interval between τ_{j-1} and τ_j $(\tau_0 = 0)$ and zero otherwise. Regression equations take the following forms:[25]

Labor-intensive aggregate

$$z_{1r} = \beta_1(k_r - \tau_1)d_1 + \varepsilon_{1r}. \tag{4}$$

Intermediate capital-intensive aggregate

$$z_{2r} = \beta_2 \left\{ k_r d_1 + \frac{\tau_1}{\tau_1 - \tau_2}(k_r - \tau_2)d_2 \right\} + \varepsilon_{2r}. \tag{5}$$

Capital-intensive aggregate

$$z_{3r} = \beta_3(k_r - \tau_1)d_2 + \varepsilon_{3r}. \tag{6}$$

Wages

intensities.

[25] The detailed manipulation is provided in Appendix.

$$w_r = -\beta_1 \tau_1 d_1 + \frac{1}{\tau_2 - \tau_1} \{\beta_3(\tau_2 - \tau_1) - \beta_2 \tau_1\} d_2 + \varepsilon_{4r}. \tag{7}$$

Parameters to be estimated are β_1, β_2, and β_3. Note that the error terms of the equations may be correlated with each other because the region-level factor endowment is included in the equations. The system of the development paths therefore is estimated, using a seemingly unrelated regressions (SUR) model. The locations of boundaries, knots, and capital intensities are determined by a grid search in which the Akaike's Information Criterion (AIC) takes smallest values. [26]

3.3.2 Deardorff model

In the three-good two-cone Deardorff model, the expected paths of development are non-linear as in Figure 6: $0A\tau_2\tau_3\tau_4H$ for the labor-intensive aggregate, $0\tau_1BC\tau_4H$ for the intermediate capital-intensive aggregate, and $0\tau_1\tau_2\tau_3DE$ for the capital-intensive aggregate. Note that, unlike the three-good two-cone incomplete-specialization model, the paths of development take the combination of non-linear and linear functional forms. Regression equations take the following forms:[27]

Labor-intensive aggregate

$$z_{1r} = \delta_1 \left\{ k_r^{\theta_1} d_1 + \frac{\tau_1^{\theta_1}}{\tau_1 - \tau_2}(k_r - \tau_2) d_2 \right\} + \varepsilon_{1r}. \tag{8}$$

Intermediate capital-intensive aggregate

$$z_{2r} = \delta_1 \frac{\theta_1 \tau_1^{\theta_1 - 1}}{\theta_2 \tau_2^{\theta_2 - 1}} \left\{ \frac{\tau_2^{\theta_2}}{\tau_2 - \tau_1}(k_r - \tau_1) d_2 + k_r^{\theta_2} d_3 + \frac{\tau_3^{\theta_2}}{\tau_3 - \tau_4}(k_r - \tau_4) d_4 \right\} + \varepsilon_{2r}. \tag{9}$$

[26] For an interval size, I use a grid interval of 3 million yen for boundaries ($3 \leq h_i \leq 273$), 1 million yen for knots ($1 \leq \tau_1 \leq 26$), and that of 0.05 for capital intensities ($0.05 \leq \theta_i \leq 0.95$). To facilitate the computation, I assume that about less than 95 percent of the industries are classified as labor-intensive or capital-intensive aggregates ($3 \leq h_1 < h_2 \leq 54$). Note that τ_2 (τ_4) are determined once τ_1 (τ_3), θ_1, θ_2, and θ_3 are determined because of the parameter restrictions (see Appendix). The AIC is a log-likelihood criterion with degrees of freedom adjustment and defined as $-2\ln L + 2p$, where $\ln L$ is the log likelihood of the model and p is the number of parameters. The model with the smallest AIC is preferred. For more details, see Cameron and Trivedi (2005, pp. 278-279).

[27] The detailed manipulation is provided in Appendix.

Capital-intensive aggregate

$$z_{3r} = \delta_1 \frac{\theta_1}{\theta_2} \frac{\tau_1^{\theta_1 - 1}}{\tau_2^{\theta_2 - 1}} \frac{\tau_3^{\theta_2} - 1}{\tau_4^{\theta_3 - 1}} \left\{ \frac{\tau_4^{\theta_3}}{\tau_4 - \tau_3} (k_r - \tau_3) d_4 + k_r^{\theta_3} d_5 \right\} + \varepsilon_{3r}, \tag{10}$$

where $\tau_2 = \{\theta_1/(1-\theta_1)\}\{(1-\theta_2)/\theta_2\}\tau_1$ and $\tau_4 = \{\theta_2/(1-\theta_2)\}\{(1-\theta_3)/\theta_3\}\tau_1$. Similarly, regression equation for the wages is as follows.

Wages

$$\begin{aligned} w_r &= \delta_1 \Bigg[(1-\theta_1) k_r^{\theta_1} d_1 + (1-\theta_1)\tau_1^{\theta_1} d_2 \\ &+ \left[\frac{1}{\tau_3 - \tau_2} \left\{ \frac{\theta_1}{\theta_2} \frac{\tau_1^{\theta_1 - 1}}{\tau_2^{\theta_2 - 1}} (1-\theta_3)\tau_3^{\theta_2} - (1-\theta_1)\tau_1^{\theta_1} \right\} (k_r - \tau_2) + (1-\theta_1)\tau_1^{\theta_1} \right] d_3 \\ &+ \frac{\theta_1}{\theta_2} \frac{\tau_1^{\theta_1 - 1}}{\tau_2^{\theta_2 - 1}} (1-\theta_2)\tau_3^{\theta_2} d_4 + (1-\theta_3) \frac{\theta_1}{\theta_3} \frac{\tau_1^{\theta_1 - 1}}{\tau_2^{\theta_2 - 1}} \frac{\tau_3^{\theta_2 - 1}}{\tau_4^{\theta_3 - 1}} k_r^{\theta_3} d_5 \Bigg] + \varepsilon_{4r}. \end{aligned} \tag{11}$$

Like the three-good two-cone incomplete-specialization model, the locations of boundaries, knots, and capital intensities are determined by a grid search in which the AIC takes the smallest values. Because of the parameter restrictions, δ_1 is only a parameter to be estimated.

4 Estimation Results

4.1 Case I: Japan produced all types of aggregates in 1995

I estimated regression equations (4)-(7) for the three-good two-cone incomplete-specialization model and (8)-(11) for the three-good two-cone Deardorff model, using the Japanese regional data for 1995. The AIC is computed to compare the performance in explaining the paths of development and wages. Each model is estimated by SUR, searching the location of boundaries and that of knots by the grid interval of 3 millions yen and 1 millions of yen per worker, respectively, and the intensities of capital by the grid interval of 0.05. The locations of boundaries, those of knots, and the intensities of capital are determined in terms of empirical fit. Specifically, the locations are chosen where the AIC takes minimum values among all the possible combination of boundaries, knots, and capital intensities. Also, the best fitted model is chosen only from the results that satisfy the parameter restrictions

Figure 7 indicates the estimation results of the paths of development for incomplete-specialization model. Two findings stand out from this Figure. First, HO specialization is confirmed across regions in Japan. With capital accumulation, regions shift their production from labor- to capital-intensive goods. This finding supports the finding of Schott (2003). Second, most of the Japanese regions are included in the same FPE set in 1995. Figure 7 indicates that economies whose capital-labor ratio is between 0 and 8 millions of yen are located in the first cone while economies whose capital-labor ratio is between 8 and 26 millions of yen are located in the second cone. All regions except Kagoshima and Kochi are expected to be in the same cone. As we confirmed from Figure 1, however, there are large wage variations across regions in Japan. Indeed, the correlation between predicted and actual wages is 0.287. The model explains well the paths of development but not the wage variations across regions in Japan.

=== Figure 7 & Table 3 ===

Figure 8 presents the paths of development for the Deardoff model. The estimated parameter values and the location of boundaries, knots, and capital intensities are reported in Table 3. Like Figure 7, HO specialization is also confirmed. The shape of the development paths is, however, slightly different. The estimated paths of development are the combinations of linear and non-linear forms because of complete specialization. As the economy accumulates capital (relative to labor), it shifts its production from labor- to capital-intensive goods. Some of the regions specialize completely in the production of capital-intensive goods. This finding is consistent with the theoretical prediction by Courant and Deardorff (1992), who showed that complete specialization of the regions within a country would occur when there exists "lumpiness" in the geographical distribution of factors (in a single-cone world).[28]

=== Figure 8 ===

Figure 8 also shows that the predicted wage variations are small. Like the result of the incomplete-specialization model, regions are expected to be in the same cone if the capital-labor ratio lies between 9 and 26. Table 3 indicates that the correlation between predicted and actual wages is 0.453. Although the correlation slightly improves, the AIC indicates that the overall fit of the model is better for the incomplete-specialization model than for the Deardorff model. These results seem to suggest that neither the incomplete-specialization nor the Deardorff models explain the wage variation across regions well.

However, the estimated development paths contain a hint of underlying specialization patterns. In both the incomplete-specialization and Deardorff models, no production is expected for labor-intensive aggregate in almost all regions. While the analysis implicitly assumes that Japan produced all three types of aggregates in 1995, it may be more plausible to assume that Japan is capital-abundant enough not to produce the labor-intensive aggregate.[29] Next section examines this possibility in more detail.

4.2 Case II: Japan did not produce the labor-intensive aggregate in 1995

The previous sub-section implicitly assumed that Japan produced all three types of aggregate. Provided that Japan is a capital-abundant country, however, it may be more plausible to assume that Japan did not produce the labor-intensive aggregate in 1995. Therefore, this sub-section

[28]This finding is different from that of Debaere (2004), who found that regional factor endowments do not vary enough to induce specialization across regions in Japan. Note, however, that my data are different from those of Debaere (2004), who aggregated 47 regions into nine regions. Bernard, Robertson, and Schott (2004) argued that the "lumpiness" is more likely to hold when regions are relatively aggregated vis-à-vis goods.

[29]Indeed, the minimum value of the region capital-labor ratio in Japan is larger than the boundary for the labor-intensive aggregate used in Schott (2003), in which the boundary is $500 for the labor-intensive aggregate. Besides, his result suggested that Japan did not produce the labor-intensive aggregate in 1990. These results imply that no regions in Japan produced the labor-intensive aggregate in 1995.

estimates the paths of development, assuming that only intermediate capital-intensive and capital-intensive aggregates were produced.[30]

Figures 9 and 10 indicate estimation results for the incomplete-specialization and Deardorff models, respectively.[31] Estimated parameter values and the locations of boundaries, knots, and capital intensities are reported in Table 4. Note that the models in Case II become simpler than the models in Case II in the sense that the number of estimated equations (and parameters) decreases. Two findings stand out from these results. First, the fit of the model significantly improves for the Deardorff model despite that the model becomes simpler. Table 4 indicates that the AIC for the Deardorff model is 181.6, which is smaller than the AICs obtained from other models in Tables 3 and 4.[32] This improvement suggests that Japan did not produce labor-intensive aggregate in 1995.

=== Figure 9 & Figure 10 & Table 4 ===

Second, the wage variations across regions are now explained well by the Deardorff model. Figure 10 shows that many regions specialize completely in the production of the capital-intensive aggregate as they accumulate capital.[33] When the regions specialize completely, they face different factor prices according to their capital endowment. Table 4 indicates that the correlation between predicted and actual wages is 0.666, which is higher than the correlations presented in Table 3. In sum, like the incomplete-specialization model, the Deardorff model can explain HO specialization, which is consistent with the finding of Schott (2003). In addition, unlike the incomplete-specialization model, the Deardorff model can explain the wage variations.[34]

[30]Specifically, the incomplete-specialization model is estimated assuming that τ_1 is not observed while the Deardoff model is estimated assuming that τ_1, τ_2, and τ_3 are not observed.

[31]Regression equations are easily obtained from a similar exercise to Appendix.

[32]This conclusion does not change even when I use Schwarz's Bayesian Information Criteria (BIC) instead of the AIC. The BIC is defined as $-2\ln L + p\ln N$, where $\ln L$ is the log likelihood of the model, p is the number of parameters, and N is the sample size.

[33]Note that some regions, whose capital-labor ratio is less than $\tau_3(=9)$, locate within the cone and thus produce intermediate capital-intensive aggregate as well as capital-intensive aggregate. These regions are Kagoshima, Kochi, Tottori, Miyazaki, Akita, and Nagasaki. See Table 1 for the region capital-labor ratio.

[34]Note that the Deardorff in this paper is the specialization to the group of goods aggregated by the actual factor

5 Concluding Remarks

In analyzing the paths of development, Schott (2003) empirically showed that the number of cones (FPE sets) was neither one nor three but two. In his framework, this implies that all countries were classified into one of these two cones. However, this is a puzzle because wages are widely different across countries (e.g., Leamer and Levinsohn, 1995; Leamer and Schott, 2005). This paper attempts to solve this puzzle. Previous studies on the paths of development such as Leamer (1987) and Schott (2003) relied on the assumption that the production function was Leontief. In this paper, I specify the production function as Cobb-Douglas rather than Leontief. With this simple modification, I show that the two-cone model becomes consistent with wage variations across economies. The model is applied to data from 47 Japanese regions for 1995.

The major findings are threefold. First, HO specialization is confirmed across regions in Japan. This finding supports the finding of Schott (2003) that utilized international data. Second, the Deardorff model fits better than the incomplete-specialization model. Finally, the Deardorff model explains HO specialization and the wage variations across economies at the same time. Some of the wage variations across regions can be explained by factor endowments. As regions accumulate capital (relative to labor), they shift their production from labor- to capital-intensive goods, which ultimately results in increased regional per-capita income. Some of the regions specialize completely in the production of capital-intensive goods, which causes the variations in wages across regions. The results of Schott (2003) imply that the number of cones is not large enough to explain the large variations of wages. My results suggest that the puzzle is solved once the multiple-cone model introduces complete specialization. This in turn implies that economies do not necessarily locate within cones.

In conclusion, there are several future issues worth mentioning. First, the application of

use (e.g., capital-intensive goods, labor-intensive goods) rather than the end use (e.g., textiles, transportation machinery). My approach thus is different from other empirical studies such as Haveman and Hummels (2004) that supported the incomplete-specialization models based on the end-use industry classification.

the model to international data rather than national data would be an important extension. HO specialization and the wage variations across countries can be explained by factor endowments once the multiple-cone model introduces complete specialization. Second, the extension to more than two factors is also important if one can overcome the complexity of the estimation and the computation capacity.[35] The unexplained part of the wage variations in this paper may be attributable to a third-factor such as human capital (or skill mixes). Finally, this paper assumed that the world consisted of two cones, given that the Schott's (2003) finding is correct. However, it is also interesting to step back and ask how many cones exist and examine whether or not the single-cone model performs better than the multiple-cone model, based on the Deardorff model rather than the complete-specialization model.

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[35]For the complexity of the estimation of three-factor multiple-cone model, see Schott (2003).

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Appendix Derivation of the Regression Equations

Appendix 1 Incomplete-specialization model

This appendix explains the derivation of the regression equations for the three-good two-cone incomplete-specialization model. In the three-good two-cone incomplete-specialization model, the expected paths of development take the spline functional form as in Figure 4: $w'\tau_1\tau_2$ for the labor-intensive aggregate, $0A\tau_1$ for the intermediate capital-intensive aggregate, and $0\tau_1B$ for the capital-intensive aggregate. Regression equations thus take the following forms:

Labor-intensive aggregate

$$z_{1r} = \begin{cases} \alpha_1 + \beta_1 k_r + \varepsilon_{1r} & \text{if } 0 \leq k_r < \tau_1; \\ 0 & \text{if } k_r \geq \tau_1. \end{cases} \tag{A-1}$$

Intermediate capital-intensive aggregate

$$z_{2r} = \begin{cases} \beta_2 k_r + \varepsilon_{2r} & \text{if } 0 \leq k_r < \tau_1; \\ \alpha_2 + \gamma k_r + \varepsilon_{2r} & \text{if } \tau_1 \leq k_r < \tau_2; \\ 0 & \text{if } k_r \geq \tau_2. \end{cases} \tag{A-2}$$

Capital-intensive aggregate

$$z_{3r} = \begin{cases} 0 & \text{if } 0 \leq k_r < \tau_1; \\ \alpha_3 + \beta_3 k_r + \varepsilon_{2r} & \text{if } k_r \geq \tau_1. \end{cases} \tag{A-3}$$

Because the wage rate is provided by the vertical intercept of the lines $w'A$ and AB in Figure 3, the regression equation for the wages is written as follows.

Wages

$$w_r = \begin{cases} \alpha_1 + \varepsilon_{4r} & \text{if } 0 \leq k < \tau_1; \\ \frac{\alpha_3 + \beta_3 \tau_2 - \beta_2 \tau_1}{\tau_2 - \tau_1} + \varepsilon_{4r} & \text{if } k_r \geq \tau_1. \end{cases} \tag{A-4}$$

Because the development paths are piecewise continuous, the following parameter restrictions are required to join the line segment of each development path at the knots:

$$\underset{\text{Labor-intensive aggregate}}{\alpha_1 + \beta_1 \tau_1 = 0} \qquad \overset{\text{Intermediate capital-intensive aggregate}}{\begin{cases} \beta_2 \tau_1 = \alpha_2 + \gamma \tau_1 \\ \alpha_2 + \gamma \tau_2 = 0 \end{cases}} \qquad \underset{\text{Capital-intensive aggregate}}{\alpha_2 + \beta_3 \tau_2 = 0} \tag{A-5}$$

Let d_j be a dummy variable that takes value one if k_r lies in the interval between τ_{j-1} and τ_j $(\tau_0 = 0)$ and zero otherwise. The following regression equations are obtained by plugging (A-5) into (A-1)-(A-4).

Labor-intensive aggregate

$$z_{1r} = \beta_1 (k_r - \tau_1) d_1 + \varepsilon_{1r}. \tag{A-4}$$

Intermediate capital-intensive aggregate

$$z_{2r} = \beta_2 \left\{ k_r d_1 + \frac{\tau_1}{\tau_1 - \tau_2} (k_r - \tau_2) d_2 \right\} + \varepsilon_{2r}. \tag{A-5}$$

Capital-intensive aggregate

$$z_{3r} = \beta_3 (k_r - \tau_1) d_2 + \varepsilon_{3r}. \tag{A-6}$$

Wages

$$w_r = -\beta_1 \tau_1 d_1 + \frac{1}{\tau_2 - \tau_1} \{ \beta_3 (\tau_2 - \tau_1) - \beta_2 \tau_1 \} d_2 + \varepsilon_{4r}. \tag{A-7}$$

Appendix 2 Deardorff model

This appendix explains the derivation of the regression equations for the three-good two-cone Deardorff model. In the three-good two-cone incomplete-specialization model, unlike the three-good two-cone incomplete-specialization model, the paths of development take the combination of non-linear and linear functional forms. Regression equations take the following forms:

Labor-intensive aggregate

$$z_{1r} = \begin{cases} \delta_1 k_r^{\theta_1} + \varepsilon_{1r} & \text{if } 0 \leq k_r < \tau_1; \\ \alpha_1 + \beta_1 k_r + \varepsilon_{1r} & \text{if } \tau_1 \leq k_r < \tau_2; \\ 0 & \text{if } k_r \geq \tau_2. \end{cases} \tag{A-17}$$

Intermediate capital-intensive aggregate

$$z_{2r} = \begin{cases} 0 & \text{if } 0 \leq k < \tau_1; \\ \alpha_{21} + \beta_{21} k_r + \varepsilon_{2r} & \text{if } \tau_1 \leq k_r < \tau_2; \\ \delta_2 k_r^{\theta_2} + \varepsilon_{2r} & \text{if } \tau_2 \leq k_r < \tau_3; \\ \alpha_{22} + \beta_{22} k_r + \varepsilon_{2r} & \text{if } \tau_3 \leq k_r < \tau_4; \\ 0 & \text{if } k_r \geq \tau_4. \end{cases} \tag{A-18}$$

Capital-intensive aggregate

$$z_{3r} = \begin{cases} 0 & \text{if } 0 \leq k_r < \tau_3; \\ \alpha_3 + \beta_3 k_r + \varepsilon_{3r} & \text{if } \tau_3 \leq k_r < \tau_4; \\ \delta_3 k_r^{\theta_3} + \varepsilon_{3r} & \text{if } k_r \geq \tau_4. \end{cases} \tag{A-19}$$

In addition, the regression equation for the wages is written as follows.

Wages

$$w_r = \begin{cases} (1-\theta_1)\delta_1 k_r^{\theta_1} + \varepsilon_{4r} & \text{if } 0 \le k < \tau_1; \\ \alpha_1 + \varepsilon_{4r} & \text{if } \tau_1 \le k_r < \tau_2; \\ \alpha_4 + \beta_4 k_r + \varepsilon_{4r} & \text{if } \tau_2 \le k_r < \tau_3; \\ \alpha_3 + \varepsilon_{4r} & \text{if } \tau_3 \le k_r < \tau_4; \\ (1-\theta_3)\delta_3 k_r^{\theta_3} + \varepsilon_{4r} & \text{if } k_r \ge \tau_4. \end{cases} \quad \text{(A-20)}$$

Because the regression equations are piecewise continuous, the following parameter restrictions are required:

$$\overbrace{\begin{cases} \delta_1 \tau_1^{\theta_1} = \alpha_1 + \beta_1 \tau_1 \\ \alpha_1 + \beta_1 \tau_2 = 0 \end{cases}}^{\textit{Labor-intensive aggregate}} \quad \overbrace{\begin{cases} \alpha_{21} + \beta_{21}\tau_1 = 0 \\ \alpha_{21} + \beta_{21}\tau_2 = \delta_2 \tau_2^{\theta_2} \\ \delta_2 \tau_3^{\theta_2} = \alpha_{22} + \beta_{22}\tau_3 \\ \alpha_{22} + \beta_{22}\tau_4 = 0 \end{cases}}^{\textit{Intermediate capital-intensive aggregate}} \quad \overbrace{\begin{cases} \alpha_3 + \beta_3 \tau_3 = 0 \\ \alpha_3 + \beta_3 \tau_4 = \delta_3 \tau_4^{\theta_3} \end{cases}}^{\textit{Capital-intensive aggregate}}$$

These restrictions imply that all parameters of α and β can be rewritten as follows:

$$\overbrace{\begin{cases} \alpha_1 = -\delta_1 \frac{\tau_1^{\theta_1}\tau_2}{\tau_1-\tau_2} \\ \beta_1 = \delta_1 \frac{\tau_1^{\theta_1}}{\tau_1-\tau_2} \end{cases}}^{\textit{Labor-intensive aggregate}} \quad \overbrace{\begin{cases} \alpha_{21} = -\delta_2 \frac{\tau_2^{\theta_2}\tau_1}{\tau_2-\tau_1} \\ \beta_{21} = \delta_2 \frac{\tau_2^{\theta_2}}{\tau_2-\tau_1} \\ \alpha_{22} = -\delta_2 \frac{\tau_3^{\theta_2}\tau_4}{\tau_3-\tau_4} \\ \beta_{22} = \delta_2 \frac{\tau_3^{\theta_2}}{\tau_3-\tau_4} \end{cases}}^{\textit{Intermediate capital-intensive aggregate}} \quad \overbrace{\begin{cases} \alpha_3 = -\delta_3 \frac{\tau_4^{\theta_3}\tau_3}{\tau_4-\tau_3} \\ \beta_3 = \delta_3 \frac{\tau_4^{\theta_3}}{\tau_4-\tau_3} \end{cases}}^{\textit{Capital-intensive aggregate}} \quad \text{(A-21)}$$

By plugging (A-21) into (A-17)-(A-20), following equations are obtained.

Labor-intensive aggregate

$$z_{1r} = \delta_1 \left\{ k_r^{\theta_1} d_1 + \frac{\tau_1^{\theta_1}}{\tau_1 - \tau_2}(k_r - \tau_2) d_2 \right\} + \varepsilon_{1r}. \quad \text{(A-8)}$$

Intermediate capital-intensive aggregate

$$z_{2r} = \delta_2 \left\{ \frac{\tau_2^{\theta_2}}{\tau_2 - \tau_1}(k_r - \tau_1)d_2 + k_r^{\theta_2} d_3 + \frac{\tau_3^{\theta_2}}{\tau_3 - \tau_4}(k_r - \tau_4)d_4 \right\} + \varepsilon_{2r}. \tag{A-22}$$

Capital-intensive aggregate

$$z_{3r} = \delta_3 \left\{ \frac{\tau_4^{\theta_3}}{\tau_4 - \tau_3}(k_r - \tau_3)d_4 + k_r^{\theta_3} d_5 \right\} + \varepsilon_{3r}. \tag{A-23}$$

Wages

$$\begin{aligned} w_r &= (1-\theta_1)\delta_1 k_r^{\theta_1} d_1 + (1-\theta_1)\delta_1 \tau_1^{\theta_1} d_2 \\ &+ \left[\frac{1}{\tau_2 - \tau_3} \left\{ \delta_1 (1-\theta_1)\tau_2^{\theta_1 - 1} - \delta_2 (1-\theta_2)\tau_3^{\theta_2 - 1} \right\} (k_r - \tau_3) + \delta_2 (1-\theta_2)\tau_3^{\theta_2 - 1} \right] d_3 \\ &+ \delta_2 (1-\theta_2)\tau_3^{\theta_2 - 1} d_4 + (1-\theta_3)\delta_3 k_r^{\theta_3} d_5 + \varepsilon_{4r}. \end{aligned} \tag{A-24}$$

To obtain the shape of the per-capita output envelope $0BCDE$ in Figure 6, the following parameter restrictions are required. Because HO aggregate 2 (HO aggregate 3) is more capital-intensive than HO aggregate 1 (HO aggregate 2), $\theta_1 < \theta_2 < \theta_3$. Linear homogeneity implies $\tilde{z}_i = \delta_i k_i^{\theta_i}$, where $\delta_i = p_i \phi_i (> 0)$. The slope of the per-capita production function at τ_j is obtained from the following partial derivatives:

$$\frac{\partial \tilde{z}_1}{\partial \tau_1} = \delta_1 \theta_1 \tau_1^{\theta_1 - 1} \quad \frac{\partial \tilde{z}_2}{\partial \tau_2} = \delta_2 \theta_2 \tau_2^{\theta_2 - 1} \quad \frac{\partial \tilde{z}_2}{\partial \tau_3} = \delta_2 \theta_2 \tau_3^{\theta_2 - 1} \quad \frac{\partial \tilde{z}_3}{\partial \tau_4} = \delta_3 \theta_3 \tau_4^{\theta_3 - 1} \tag{A-25}$$

To obtain the tangents AB and CD in Figure 5,

$$\begin{cases} \delta_1 \theta_1 \tau_1^{\theta_1 - 1} &= \delta_2 \theta_2 \tau_2^{\theta_2 - 1} \\ \delta_2 \theta_2 \tau_3^{\theta_2 - 1} &= \delta_3 \theta_3 \tau_4^{\theta_3 - 1} \end{cases} \quad \text{and} \quad \begin{cases} \delta_1 \tau_1^{\theta_1}(1-\theta_1) &= \delta_2 \tau_2^{\theta_1}(1-\theta_2) \\ \delta_2 \tau_3^{\theta_2}(1-\theta_2) &= \delta_3 \tau_4^{\theta_3}(1-\theta_3) \end{cases}$$

where $0 < \tau_1 < \tau_2 < \tau_3 < \tau_4$. Note that $0 < \theta_1 < \theta_2 < \theta_3 < 1$ and $\delta_i > 0$.

$$\delta_2 = \delta_1 \frac{\theta_1}{\theta_2} \frac{\tau_1^{\theta_1 - 1}}{\tau_2^{\theta_2 - 1}} > 0 \quad \text{and} \quad \delta_3 = \delta_1 \frac{\theta_1}{\theta_3} \frac{\tau_1^{\theta_1 - 1}}{\tau_2^{\theta_2 - 1}} \frac{\tau_3^{\theta_2 - 1}}{\tau_4^{\theta_3 - 1}} > 0, \tag{A-26}$$

where $\tau_2 = \{(1-\theta_1)/\theta_1\}\{\theta_2/(1-\theta_2)\}\tau_1$ and $\tau_4 = \{(1-\theta_2)/\theta_2\}\{\theta_3/(1-\theta_3)\}\tau_3$. Condition (A-26) should be satisfied to obtain the two common tangents when the production function is Cobb-Douglas.[36] Therefore, the regression equations of the intermediate capital-intensive and the capital-intensive aggregate are obtained by plugging (A-26) into (A-22)-(A-24), respectively.

Intermediate capital-intensive aggregate

$$z_{2r} = \delta_1 \frac{\theta_1 \tau_1^{\theta_1 - 1}}{\theta_2 \tau_2^{\theta_2 - 1}} \left\{ \frac{\tau_2^{\theta_2}}{\tau_2 - \tau_1}(k_r - \tau_1) d_2 + k_r^{\theta_2} d_3 + \frac{\tau_3^{\theta_2}}{\tau_3 - \tau_4}(k_r - \tau_4) d_4 \right\} + \varepsilon_{2r}. \tag{A-9}$$

Capital-intensive aggregate

$$z_{3r} = \delta_1 \frac{\theta_1}{\theta_2} \frac{\tau_1^{\theta_1 - 1}}{\tau_2^{\theta_2 - 1}} \frac{\tau_3^{\theta_2} - 1}{\tau_4^{\theta_3 - 1}} \left\{ \frac{\tau_4^{\theta_3}}{\tau_4 - \tau_3}(k_r - \tau_3) d_4 + k_r^{\theta_3} d_5 \right\} + \varepsilon_{3r}, \tag{A-10}$$

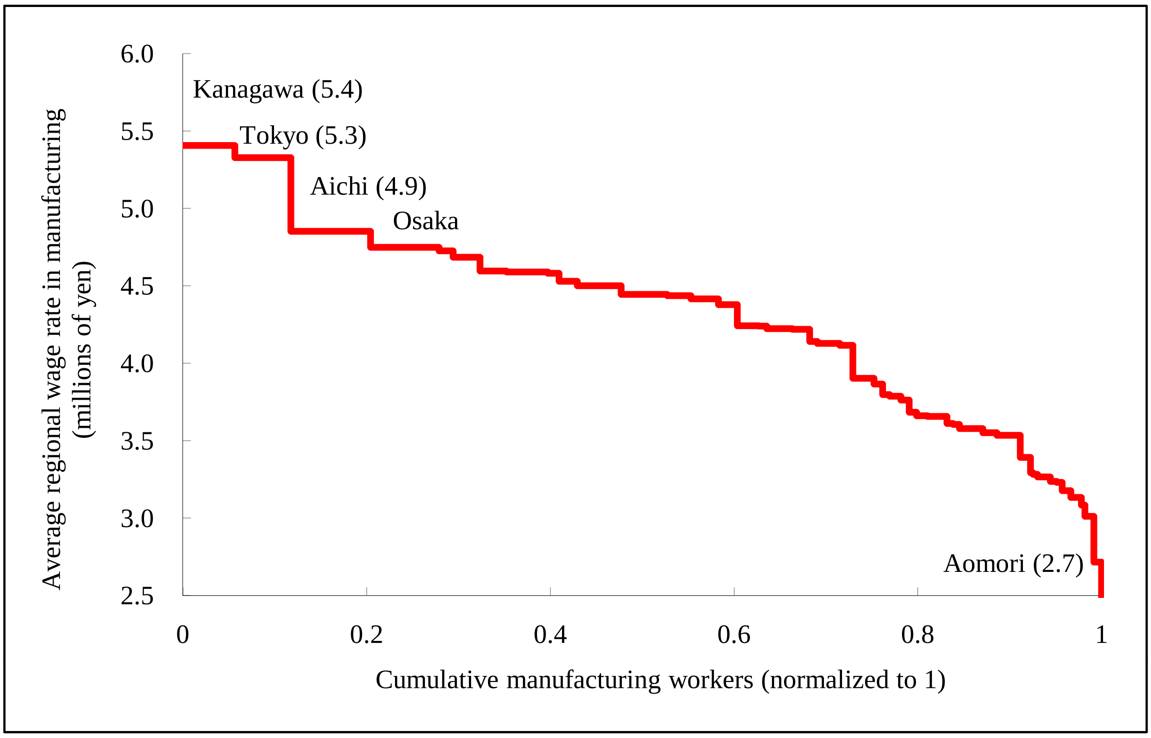
where $\tau_2 = \{\theta_1/(1-\theta_1)\}\{(1-\theta_2)/\theta_2\}\tau_1$ and $\tau_4 = \{\theta_2/(1-\theta_2)\}\{(1-\theta_3)/\theta_3\}\tau_1$. Similarly, regression equation for the wages is as follows.

Wages

$$\begin{aligned} w_r &= \delta_1 \Bigg[(1-\theta_1) k_r^{\theta_1} d_1 + (1-\theta_1)\tau_1^{\theta_1} d_2 \\ &+ \left[\frac{1}{\tau_3 - \tau_2} \left\{ \frac{\theta_1}{\theta_2} \frac{\tau_1^{\theta_1 - 1}}{\tau_2^{\theta_2 - 1}} (1-\theta_3)\tau_3^{\theta_2} - (1-\theta_1)\tau_1^{\theta_1} \right\} (k_r - \tau_2) + (1-\theta_1)\tau_1^{\theta_1} \right] d_3 \\ &+ \frac{\theta_1}{\theta_2} \frac{\tau_1^{\theta_1 - 1}}{\tau_2^{\theta_2 - 1}} (1-\theta_2)\tau_3^{\theta_2} d_4 + (1-\theta_3) \frac{\theta_1}{\theta_3} \frac{\tau_1^{\theta_1 - 1}}{\tau_2^{\theta_2 - 1}} \frac{\tau_3^{\theta_2 - 1}}{\tau_4^{\theta_3 - 1}} k_r^{\theta_3} d_5 \Bigg] + \varepsilon_{4r}. \end{aligned} \tag{A-11}$$

[36] Note also that it is very difficult to add non-equality restrictions to the system of equations. In the estimation, I first estimate the system of equations for all possible combinations of boundaries, knots, and capital intensities, and then check whether the estimated parameters satisfy the non-equality restrictions.

Figure 1. Average Regional Wage in Manufacturing for 1995



Source: METI (various years)

Figure 2. Three-good Two-cone Lerner Diagram

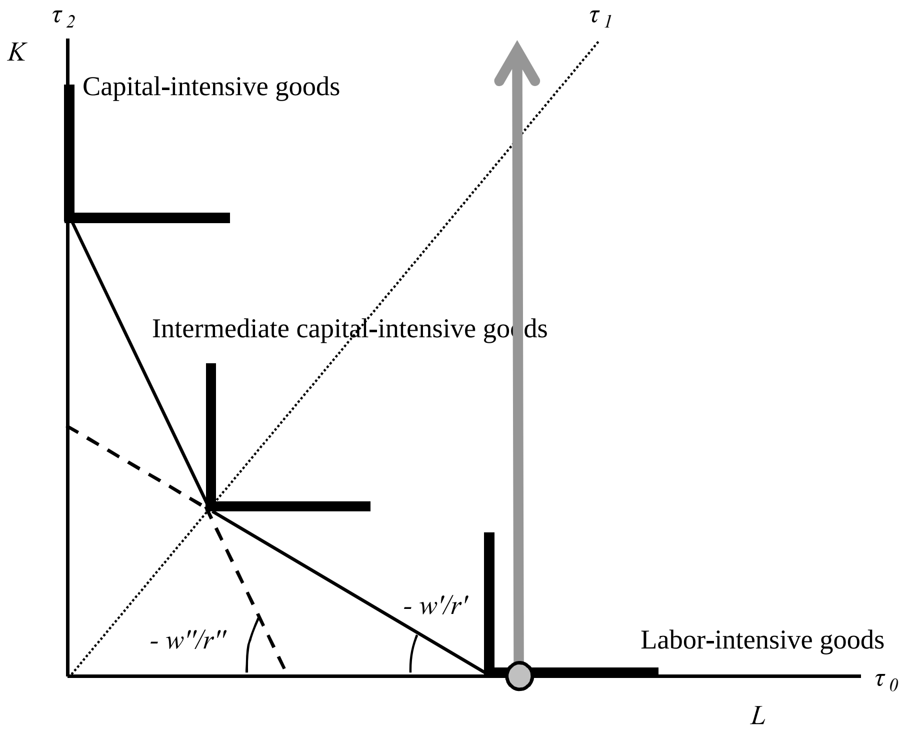


Figure 3. Relationship between Per-capita Output and Capital-labor Ratio: Three-good Two-cone Incomplete-specialization Model

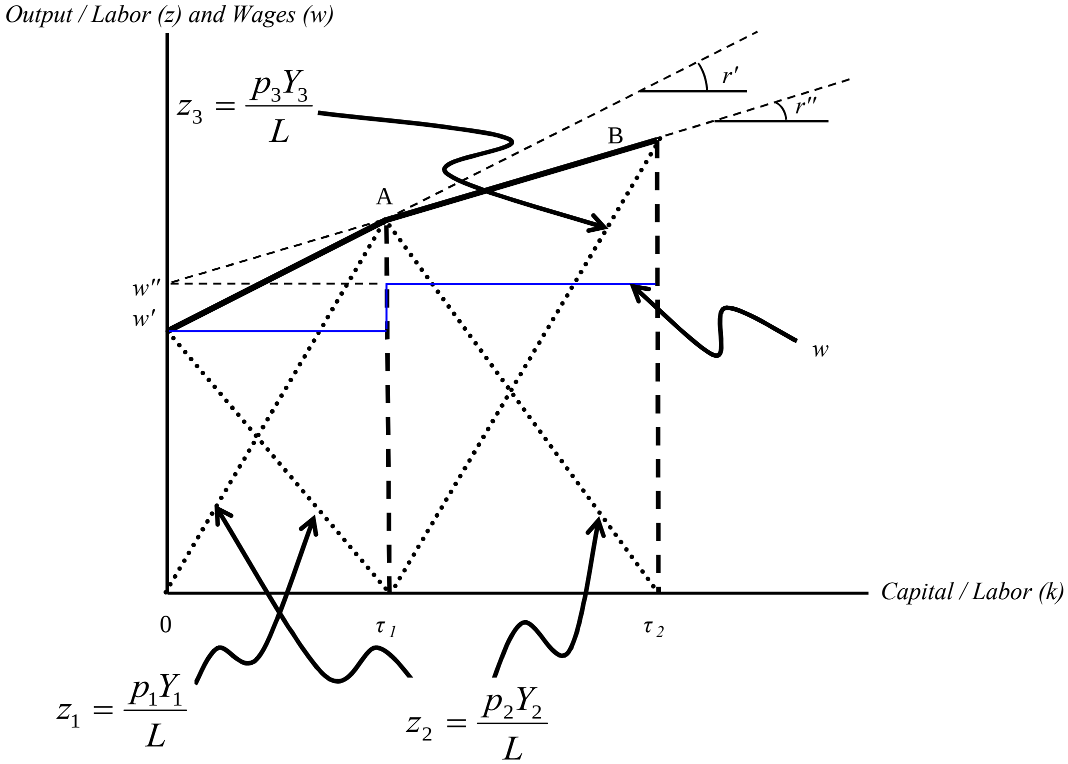


Figure 4. Industry Development Paths and Wages Implied by Figure 3

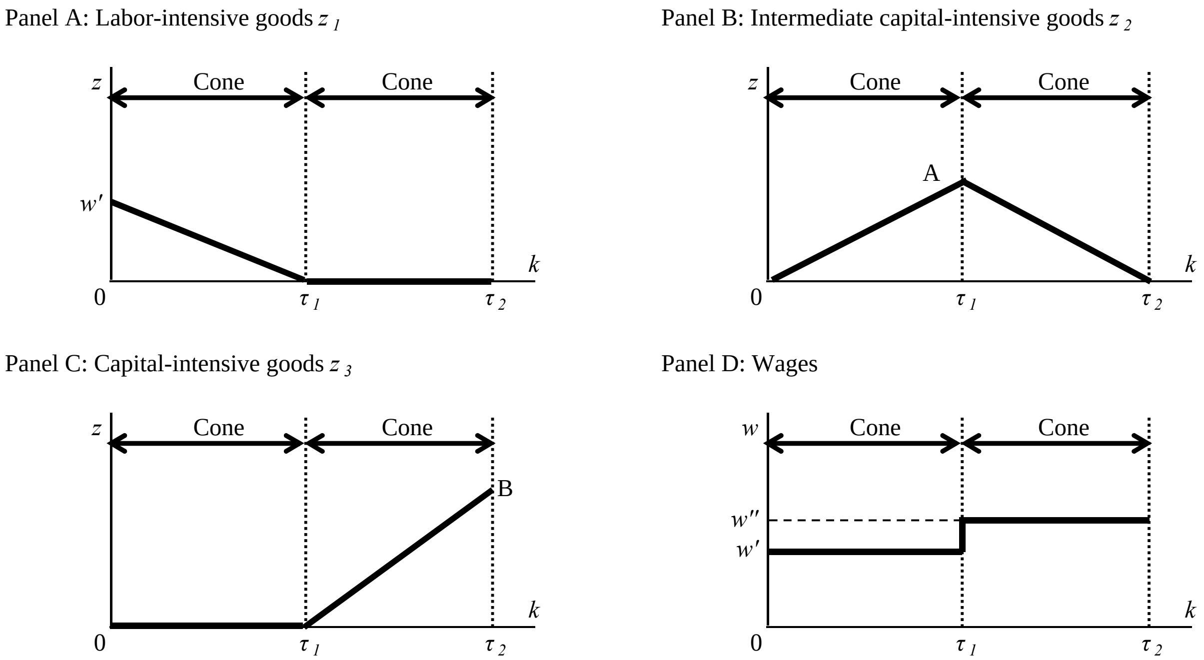


Figure 5. Relationship between Per-capita Output and Capital-labor Ratio: Three-good Two-cone Deardorff Model

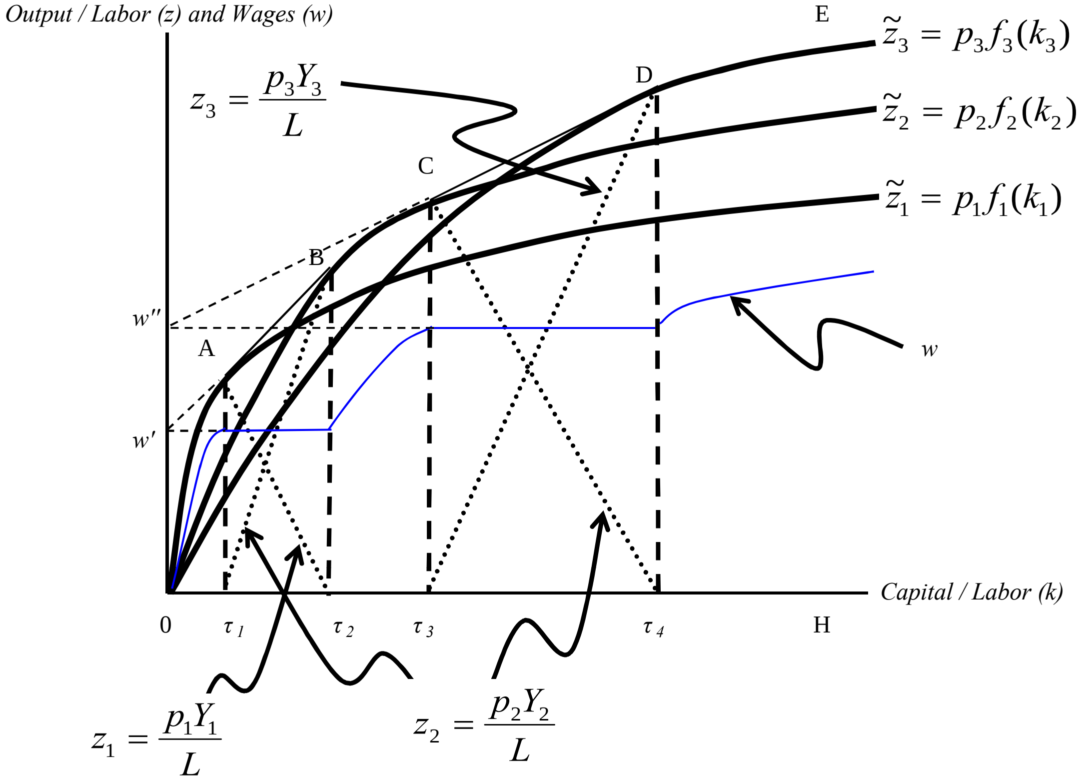
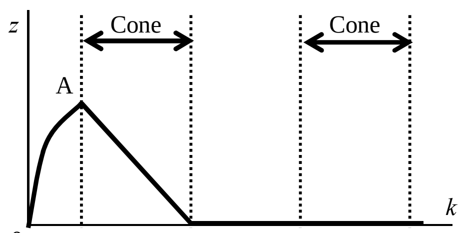
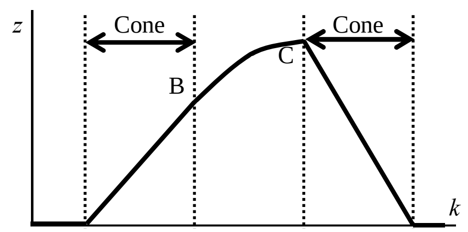


Figure 6. Industry Development Paths and Wages Implied by Figure 5

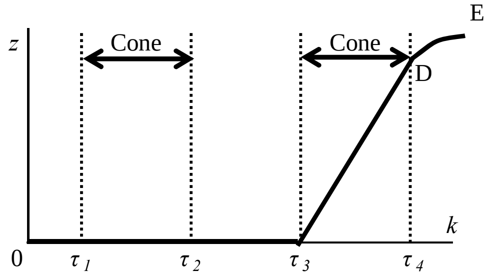
Panel A: Labor-intensive goods z_1



Panel B: Intermediate capital-intensive goods z_2



Panel C: Capital-intensive goods z_3



Panel D: Wages

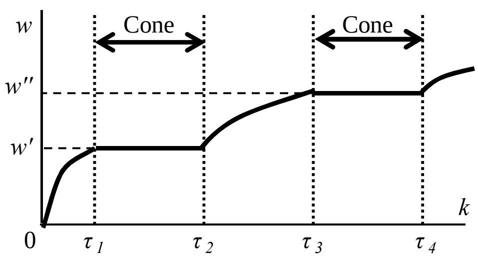
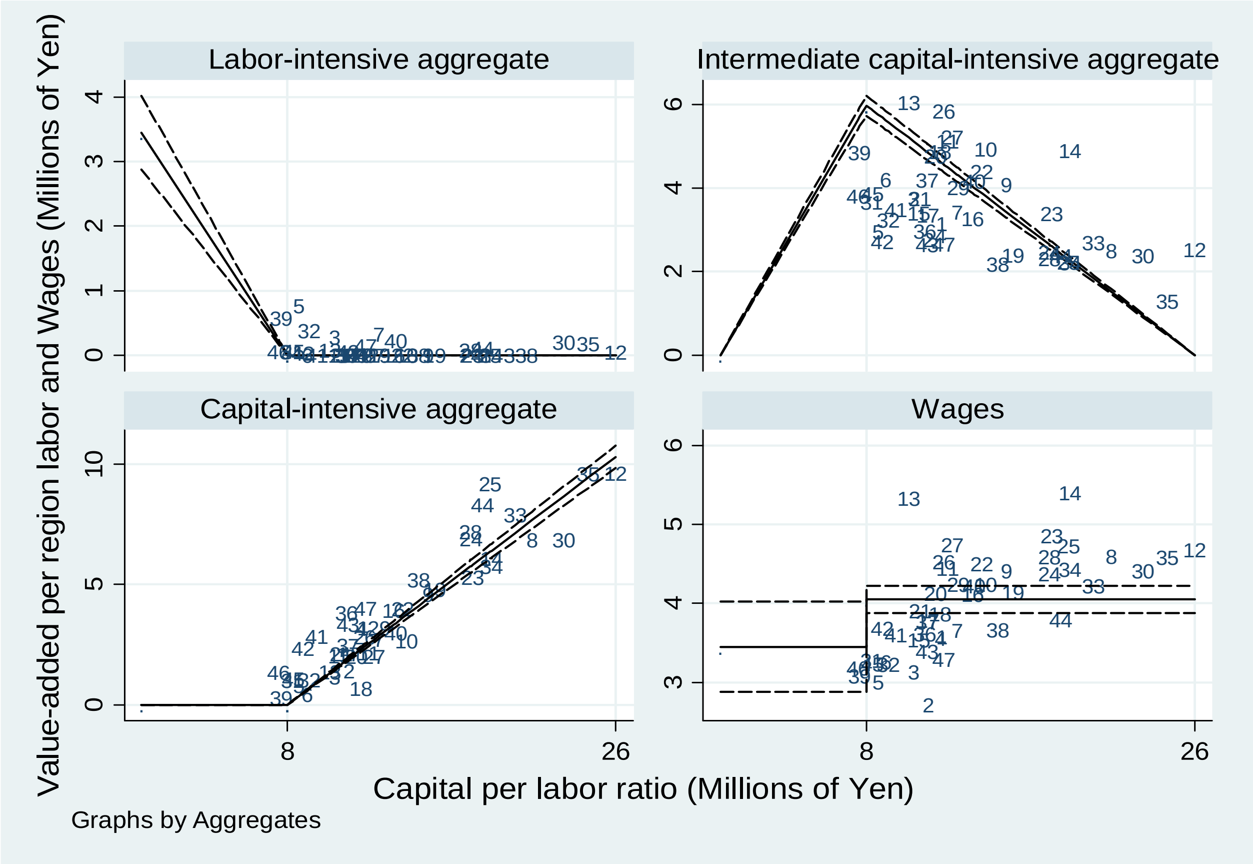
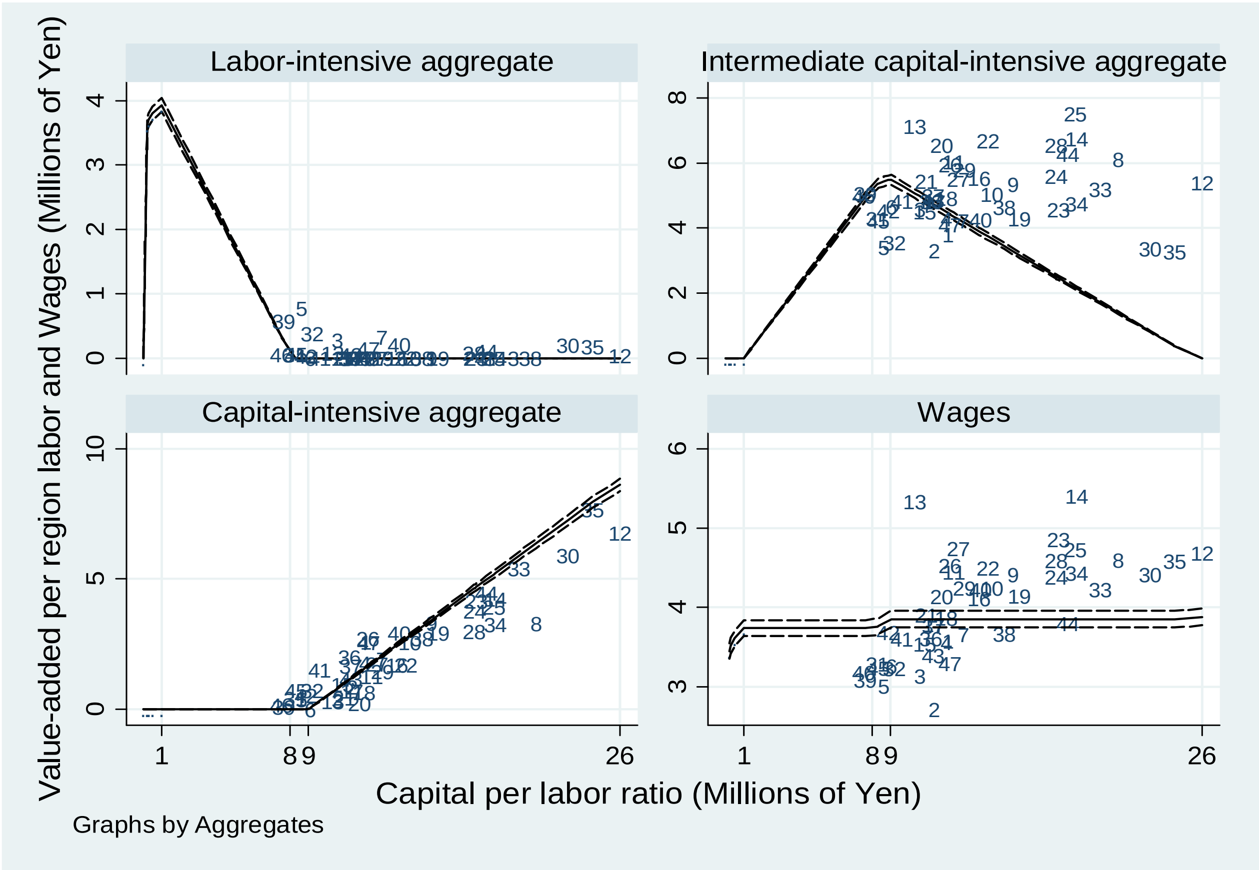


Figure 7. Case I: Incomplete-specialization Model When Japan Produced the Labor-intensive Aggregate



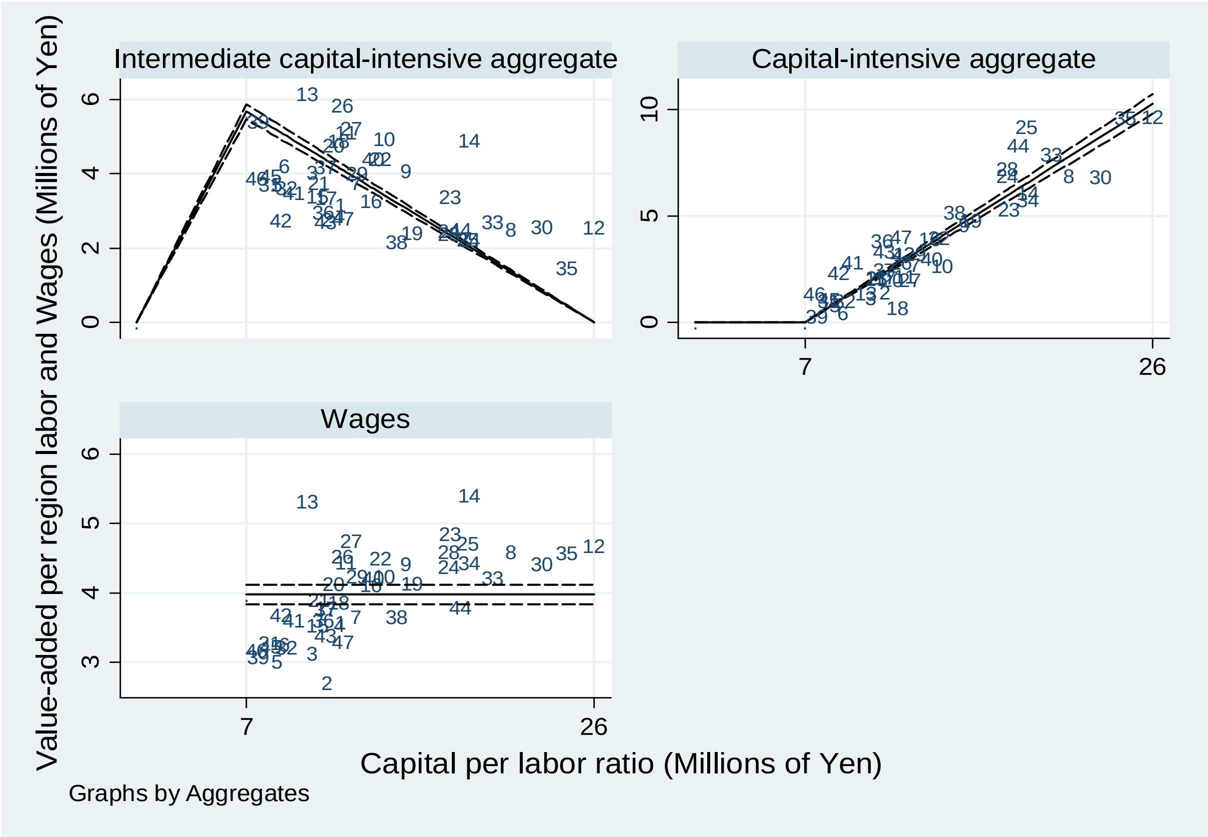
Note: Panels report the estimated development paths for three HO aggregates and wages. The dashed lines represent the 95-percent confidence interval. Estimated parameter values are presented in Table 3. The number indicates the region number corresponding to Table 1. The fitted values are kinked and piecewise continuous because of the parameter restriction of spline functions.

Figure 8. Case I: Deardorff Model When Japan Produced the Labor-intensive Aggregate



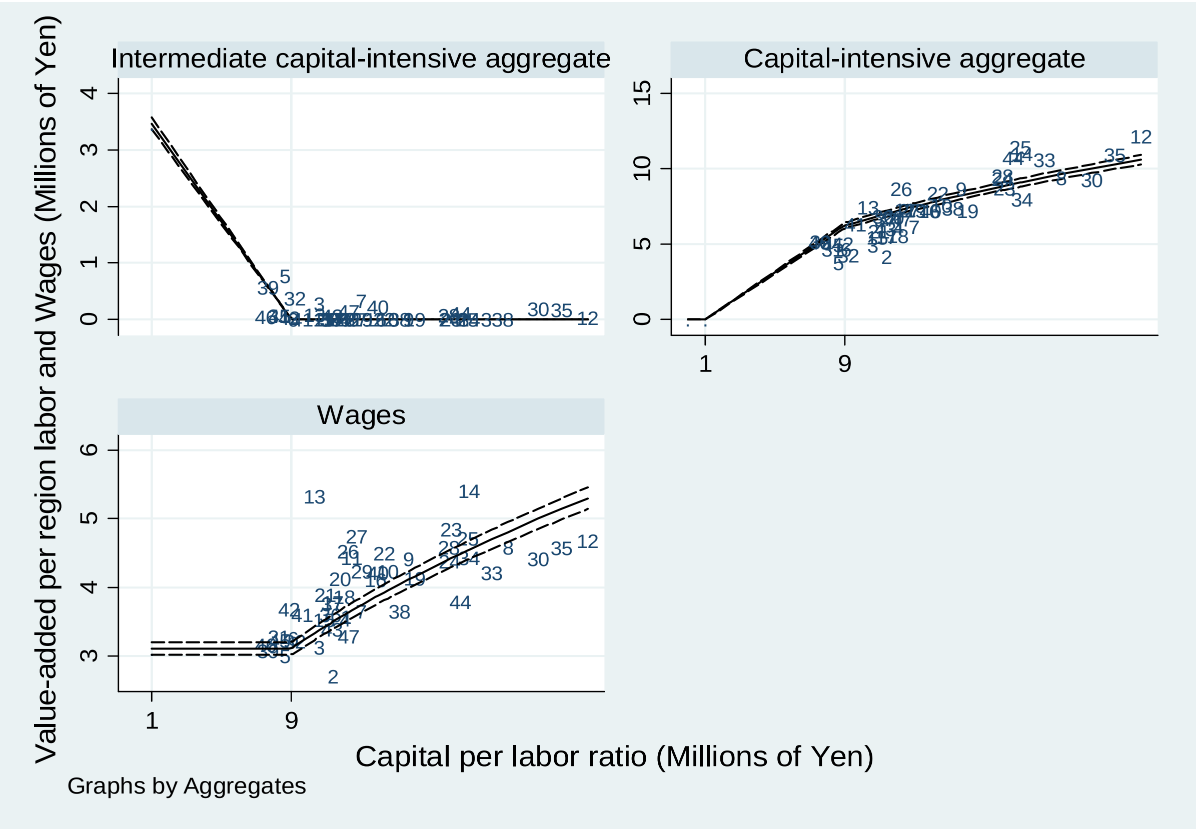
Note: Panels report the estimated development paths for three HO aggregates and wages. The dashed lines represent the 95-percent confidence interval. Estimated parameter values are presented in Table 3. The number indicates the region number corresponding to Table 1. The fitted values are kinked and piecewise continuous because of the parameter restriction of spline functions.

Figure 9. Case II: Incomplete-specialization Model When Japan Did Not Produce the Labor-intensive Aggregate



Note: Panels report the estimated development paths for three HO aggregates and wages. The dashed lines represent the 95-percent confidence interval. Estimated parameter values are presented in Table 4. The number indicates the region number corresponding to Table 1. The fitted values are kinked and piecewise continuous because of the parameter restriction of spline functions.

Figure 10. Case II: Deardorff Model When Japan Did Not Produce the Labor-intensive Aggregate



Note: Panels report the estimated development paths for three HO aggregates and wages. The dashed lines represent the 95-percent confidence interval. Estimated parameter values are presented in Table 4. The number indicates the region number corresponding to Table 1. The fitted values are kinked and piecewise continuous because of the parameter restriction of spline functions.

Table 1. Region-Industry Capital Intensity, 1995

No.	Region	Region capital-labor ratio (endowment)	Leather tanning and leather products (4.1)	Furniture and fixtures (4.6)	Food products (5.1)	Textile products (5.8)	Publishing and printing (5.8)	Timber and wooden products (6.5)	Fabricated metal products (6.8)	Rubber products (8.8)	Other manufacturing (9.0)	Ceramic, stone and clay products (10.9)	Plastic products (11.9)	Precision machinery (13.0)	Electrical machinery (15.1)	General machinery (15.5)	Pulp and paper (19.8)	Beverages and Tobacco (27.1)	Transportation machinery (27.3)	Non-ferrous metals (28.9)	Chemical products (39.3)	Iron and steel (51.8)	Petroleum and coal products (90.3)
46	Kagoshima	7.55																					
39	Kochi	7.65																					
31	Tottori	8.28																					
45	Miyazaki	8.34																					
5	Akita	8.64																					
42	Nagasaki	8.87																					
6	Yamagata	9.06																					
32	Shimane	9.20																					
41	Saga	9.62																					
13	Tokyo	10.32																					
3	Iwate	10.57																					
15	Niigata	10.88																					
21	Gifu	10.96																					
36	Tokushima	11.23																					
43	Kumamoto	11.33																					
37	Kagawa	11.35																					
2	Aomori	11.36																					
17	Ishikawa	11.38																					
20	Nagano	11.78																					
18	Fukui	12.05																					
4	Miyagi	12.06																					
1	Hokkaido	12.12																					
26	Kyoto	12.25																					
47	Okinawa	12.27																					
11	Saitama	12.47																					
27	Osaka	12.72																					
7	Fukushima	12.98																					
29	Nara	13.03																					
16	Toyama	13.83																					
40	Fukuoka	13.93																					
22	Shizuoka	14.33																					
10	Gunma	14.53																					
38	Ehime	15.20																					
9	Tochigi	15.68																					
19	Yamanashi	16.06																					
28	Hyogo	18.05																					
24	Mie	18.06																					
23	Aichi	18.15																					
44	Oita	18.68																					
25	Shiga	19.10																					
34	Hiroshima	19.18																					
14	Kanagawa	19.18																					
33	Okayama	20.48																					
8	Ibaraki	21.40																					
30	Wakayama	23.16																					
35	Yamaguchi	24.50																					
12	Chiba	26.01																					

Industry average capital-labor ratio shown in parentheses after each industry name.

Notes:
- (white) : no production
- (light grey) : capital intensity is between 0 and 5.
- (grey) : capital intensity is between 5 and 15.
- (dark grey) : capital intensity is greater than 15.

Table 2. Rank Correlation of Industry Capital Intensities for Different Region Pairs, 1995

Spearman's rank correlation (ρ)	Number of region pairs for 23 years	Share (%)
$\rho = 1.0$	0	0.0
$0.9 \leq \rho < 1.0$	60	5.6
$0.8 \leq \rho < 0.9$	240	22.2
$0.7 \leq \rho < 0.8$	166	15.4
$0.6 \leq \rho < 0.7$	151	14.0
$0.5 \leq \rho < 0.6$	174	16.1
$0.4 \leq \rho < 0.5$	162	15.0
$0.3 \leq \rho < 0.4$	89	8.2
$0.2 \leq \rho < 0.3$	33	3.1
$0.1 \leq \rho < 0.2$	5	0.5
$0 \leq \rho < 0.1$	1	0.1
$\rho < 0$	0	0.0
Total	1081	100.0

Note: Rank correlation of capital intensities is calculated for different region pairs in 1995. The number of correlations is 1081 (= the number of region pairs (46 + 45 + … + 1)).

Table 3. Case I: Estimation Results When Japan Produced All Types of Aggregates

Three-good two-cone incomplete-specialization model

Threshold of the HO aggregates: $h_1 = 3$, $h_2 = 15$ — AIC = 269.3

The locations of knots: $\tau_1 = 8$, $\tau_2 = 26$ — BIC = 274.9

Correlation between predicted and actual wages: 0.287

	Coefficient	S.E.	*p*-value	*N*	RMSE
Labor-intensive aggregate	-0.431	0.036	0.000	47	0.167
Intermediate capital-intensive aggregate	0.747	0.015	0.000	47	1.456
Capital-intensive aggregate	0.573	0.013	0.000	47	1.038
Wages	3.449	0.291	0.000	47	0.600
	4.049	0.090	0.000		

Three-good two-cone Deardorff model

Threshold of the HO aggregates: $h_1 = 3$, $h_2 = 24$

The locations of knots: $\tau_1 = 1$, $\tau_2 = 8.1$, $\tau_3 = 9$, $\tau_4 = 25.7$ — AIC = 296.6

Capital-intensities: $\theta_1 = 0.05$, $\theta_2 = 0.30$, $\theta_3 = 0.55$ — BIC = 298.4

Correlation between predicted and actual wages: 0.453

	Coefficient	S.E.	*p*-value	*N*	RMSE
Labor-intensive aggregate	3.933	0.055	0.000	47	0.165
Intermediate capital-intensive aggregate	3.933	0.055	0.000	47	2.228
Capital-intensive aggregate	3.933	0.055	0.000	47	0.915
Wages	3.933	0.055	0.000	47	0.622

Table 4. Case II: Estimation Results When Japan Did Not Produced Labor-intensive Aggregate

Three-good two-cone incomplete-specialization model					
Threshold of the HO aggregates: h_2 = 15					AIC = 298.5
The locations of knots: τ_1 = 7, τ_2 = 26					BIC = 302.2
Correlation between predicted and actual wages: not available					
	Coefficient	S.E.	p-value	N	RMSE
Intermediate capital-intensive aggregate	-0.298	0.005	0.000	47	1.234
Capital-intensive aggregate	0.540	0.013	0.000	47	0.950
Wages	3.977	0.072	0.000	47	0.621
Three-good two-cone Deardorff model					
Threshold of the HO aggregates: h_2 = 3					
The locations of knots: τ_3 = 1, τ_4 = 9					AIC = 181.6
Capital-intensities: θ_2 = 0.10, θ_3 = 0.50					BIC = 183.4
Correlation between predicted and actual wages: 0.666					
	Coefficient	S.E.	p-value	N	RMSE
Intermediate capital-intensive aggregate	3.463	0.052	0.000	47	0.168
Capital-intensive aggregate	3.463	0.052	0.000	47	1.162
Wages	3.463	0.052	0.000	47	0.515