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Industrial development in Malaysia and Singapore: Empirical analysis with multiple-cone Heckscher–Ohlin Model

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Abstract

This paper employs the multiple-cone Heckscher–Ohlin model to analyze industrial development in Malaysia and Singapore. In particular, we focus on industrial upgrading along with capital accumulation as a key determinant for the cross-country difference in production technology and income. By pooling two countries' data on factor endowment and sectoral output in manufacturing from 1990 to 2008, we estimate the common industrial development paths of the two-cone Heckscher–Ohlin model, the Rybczynski linear relationship between capital–labor ratio and sectoral output per capita. Our results demonstrate that, after controlling for quality of workers (by educational attainment), the two countries resided in different cones during our sample period, implying that Singapore succeeded in accumulating capital steadily with the support of foreign investment and upgrading its industry mix to make it more capital-intensive. The separation of cones is also consistent with the observed gap in gross domestic product per capita between the two countries. Furthermore, we implement a factor-augmenting productivity test to see the gaps in efficiency of capital and human-capital-augmented labor and confirm no significant difference between the two countries.

KEYWORDS
Industrial development, Multiple-cone Heckscher-Ohlin model

JEL CLASSIFICATION
F11; F14; F43; C33

1 | INTRODUCTION

What makes one country more developed and another country less developed? Cross-country differences in production technology and income are an important topic in the literature of development economics and international trade. This paper focuses on industrial upgrading along with capital accumulation as a key determinant for a country's economic development. In doing so, we propose to employ the multiple-cone version of the Heckscher–Ohlin (HO) model to investigate the industrial development of a set of countries which have an intimate economic relationship. One of the striking features of the multiple-cone HO model is that a country specializes in the set of industries which best fit its relative factor endowment. This allows for countries to have different sets of goods produced and factor prices depending on the countries' capital–labor ratio. In the dynamic context, the multiple-cone equilibrium can describe the industrial upgrading process: the set of industries a country specializes in becomes more capital-intensive as capital accumulates. In other words, there exists a series of industries which appear, prosper, decline, and finally disappear in succession. We refer to the industrial upgrading process as the industrial development paths *à* la Kiyota (2014). In this framework, whether a country can accumulate capital relative to labor and upgrade its industry mix is the key determinant of cross-country differences in industrial development.

With this emphasis, this paper analyzes the industrial development of Singapore and Malaysia. In particular, we assume that the two countries have primitives of the multiple-cone HO model (production functions and commodities prices determined in the world market) in common so that they follow a set of industrial development paths. There are several facts motivating the analysis of the two countries' economic development through the lens of the HO framework. First of all, the two countries were a single country, the Federation of Malaya, until 1965. Despite the same departure point, the two countries have revealed distinct patterns of economic development in the past several decades. In 2008, gross domestic product per capita in Malaysia (US$35,600) was 44% of that in Singapore ($81,508). One of the underlying reasons for this gap is the two countries' different economic policies for foreign investment. Because of its small market size and scarcity of major productive resources, Singapore has been aiming since the 1960s to foster industries with high productivity by attracting investment from overseas. In Malaysia, conversely, a low-cost export-oriented industrial strategy paid rich dividends until the late 1980s. Keen competition from low-cost producers in neighboring countries motivated the Malaysian government to shift from its primary industrial strategy. However, action by the Malaysian government to attract foreign investment has not been as effective as it has been in Singapore. The steady capital accumulation supported by foreign investment in Singapore may account for the faster economic growth, behind which there is an industrial upgrading process.

The other important observation is the economic interdependence between these two trade partners, promoted in the 1990s by the Association of Southeast Asian Nations free trade agreement (the ASEAN Free Trade Area). Their membership of the ASEAN Free Trade Area favors the HO framework, which assumes frictionless trade among countries.

By pooling the data on factor endowments and sectoral output of the two countries from 1990 to 2008, we estimate a single set of industrial development paths for the two-factor (capital and labor), three-good HO model featuring the two cones of diversification. We set the number of cones to two, given that previous studies (Kiyota, 2011, 2014; Schott, 2003) have found empirical evidence of two-cone equilibrium in both static and dynamic senses. Using the terminology of the HO framework, a single set of industrial development paths is referred to as the Rybczynski relationship between factor endowments and sectoral output. In order to ensure the linear Rybczynski relationship, we need to impose the evenness assumption such that the number of goods produced in each cone is equal to the number of factors. We adopt the empirical method proposed by Schott (2003) to re-aggregate industries (apparel, machinery, etc.) into three "HO aggregates" (labor-intensive, intermediate capital-intensive, and capital-intensive). In recasting the industry-level data into the HO aggregates, we compute the sectoral capital intensity and group together industries with similar capital intensities. This aggregation method is particularly important for elucidating the industrial upgrading process which would be obscured if we stuck with an ordinal industrial classification; for example, the production technology (capital intensity) of the apparel industry may differ across countries at a given point in time and may evolve over time. Therefore, our framework can capture the upgrading of production technologies employed along with capital accumulation over time.

Conditional on the fit of the model to the data, if two countries reside in the same cone of diversification at a given point in time, it implies that their production technologies are similar in terms of capital intensity and factor prices are equalized. In contrast, if the countries lie in different cones, it suggests that they specialize in different sets of industries and the factor price is no longer equalized between them. In a dynamic sense, we can determine whether countries upgrade their industry mix over time. Furthermore, by assessing the convergence of countries into the same cone over time, we can investigate whether they become more similar in terms of industrial structure. Furthermore, deviation of sectoral output from the estimated industrial development paths implies production (in) efficiency of the economy, which motivates our supplemental analysis testing the difference in factor-augmenting productivity across countries.

Our empirical analyses show that the two-cone HO model can illustrate the two countries' industrial upgrading process and elucidate the key factor explaining the observed economic disparity between them: that steady capital accumulation in Singapore succeeds in upgrading its industry mix to make it more capital-intensive, while Malaysia lags behind Singapore and produces a labor-intensive set of goods. This result crucially depends on the quality adjustment of labor by educational attainment. Since the HO framework assumes homogeneity of productive factors, we confirm that it is important to control for the human capital associated with workers in estimating the two countries' industrial development paths. In order to examine the difference in efficiency of productive factors which would result from differences in capital utilization rate or quality of education, we further test the factor-augmenting productivity gap across the two countries and find no significant differences between them. Our results suggest that capital accumulation plays a central role in explaining the observed gap in industrial development, which is in favor of Singaporean foreign investment policy.

2 | HECKSCHER–OHLIN FRAMEWORK IN THE CONTEXT OF INDUSTRIAL DEVELOPMENT

The theoretical approach in this paper is based on the HO model with a dynamic aspect. Oniki and Uzawa (1965) and Deardorff (1974) initiated the dynamic applications of the HO model by analyzing interactions between capital accumulation and patterns of production. In the single-cone HO framework, such as a textbook two-factor and two-good model, all countries in the world produce both goods, and factor prices equalize globally in the equilibrium with incomplete specialization. Here, a cone (or cone of diversification) refers to "a set of factor endowment combinations that are consistent with producing the same set of goods and having the same factor prices" (Deardorff, 2014). It is also called a "factor price equalization set." Leamer (1987) points out that, in this single-cone equilibrium where there exists a single cone in the economy, capital accumulation has no significant effects on the composition of outputs, because outputs of commodities are a simple linear function of factor supplies. Using the notion of the HO framework, the Rybczynski derivative is constant over the country-wide capital–labor ratio, that is, capital accumulation leads to a monotonic increase (decrease) in the output of the capital-intensive (labor-intensive) sector.

Deardorff (2000, 2001a) argues that the multiple-cone HO model may be more relevant and plausible for the real world. In the multiple-cone HO model, the number of goods exceeds the number of productive factors and countries specialize in the subset of goods most suited to their mix of endowments. When countries have sufficiently disparate factor endowments and reside in different cones, they specialize in different sets of goods and factor prices vary across countries. In the case of the two-factor (capital and labor) and three-good HO model with two cones of diversification, there is a threshold capital–labor ratio which divides countries into two groups. Countries in the labor-abundant cone produce the two most labor-intensive goods and have lower wages compared to countries in the capital-abundant cone producing the two most capital-intensive goods. This means that the Rybczynski derivatives vary across cones. More important, in the dynamic context, the multiple-cone HO model illustrates countries moving in and out of the sectors as they accumulate capital relative to labor and switch cone. Therefore, we can describe the industrial upgrading process as moving from the labor-intensive set of goods produced to a more capital-intensive set. Deardorff (2001b) highlights the multiple-cone HO model to explain the polarization of the global economy into poor and rich nations, supported by Leamer and Levinsohn (1995), Galor (1996), and Leamer and Schott (2005).

In analyzing the industrial upgrading process within the multiple-cone HO framework, Leamer (1987) introduces "paths of development," the graphical presentation of countries' industrial outputs along with the capital–labor ratio. In the multiple-cone equilibrium, the paths of development takes the form of a linear spline in which the location of knots corresponds to the threshold capital–labor ratio delineating cones. Based on Leamer's study, Schott (2003) introduces an empirical technique to test the production implications of the multiple-cone HO model using cross-sectional data across countries. By recasting the sectoral data of industries into more theoretically appropriate "HO aggregates," he estimates the paths of development of the multiple-cone HO model and finds strong support for HO specialization in favor of the two-cone equilibrium. His result illustrates rich and poor countries on the basis of the cone in which they reside. Kiyota (2014) employs Schott's empirical method to estimate a country's dynamic industrial development paths, focusing on a series of industries that appear, prosper, decline, and finally disappear in succession. We refer to Kiyota's dynamic industrial upgrading process as the "industrial development paths."

In our analysis, we extend Kiyota's (2014) analysis to a multiple-country context. Assuming that two countries have the same model primitives (i.e. production function and exogenous commodity prices), we estimate the common industrial development paths for Malaysia and Singapore. We focus mainly on the impact of capital accumulation on each country's production mix. With regard to the discussion in Leamer, Maul, Rodriguez, and Schott (1999), Schott (2003) mentions that countries with higher skill intensity tend to enter capital-intensive sectors earlier than those with lower levels of education. Furthermore, in principle, the HO framework assumes the homogeneity of productive factors. Given these emphases, in the second estimation, we control for the quality of labor (by educational attainment). Furthermore, we perform the factor-augmenting productivity test to extract the difference in efficiency of productive factors which is not captured by educational attainment.

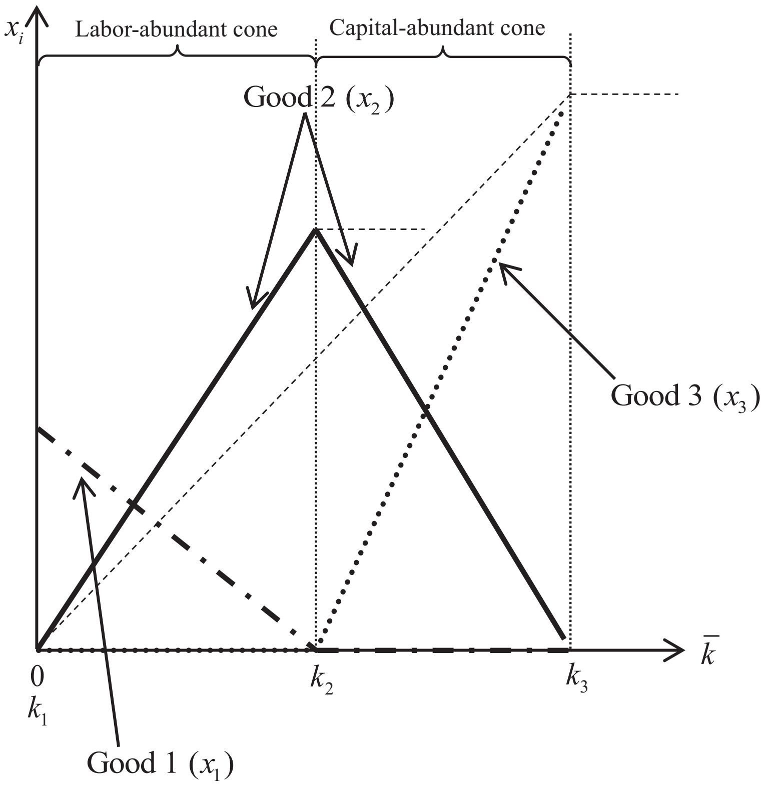

FIGURE 1 Theoretical Archetype of the Three-Good and Two-Cone Development Paths
Note: The upward-sloping dashed line starting from the origin shows the per capita production function of good 3.

3 | MODEL

To analyze the dynamic series of industrial development paths for Malaysia and Singapore, consider a three-good (a labor-intensive good 1, an intermediate capital-intensive good 2, and a capital-intensive good 3) and two-factor (capital K and labor L) HO model featuring two cones of diversification. Given that the previous studies examining the empirical validity of the multiple-cone HO model find evidence of a two-cone equilibrium in both static and dynamic senses (Schott, 2003; Kiyota, 2014), we restrict our attention to the two-cone HO model. We study the two countries' industrial upgrading process along with their common industrial development paths, assuming identical production technology and commodity prices.

We employ the standard assumptions of Dixit and Norman (1980) and impose additional assumptions from Schott (2003). First, the number of goods and factors in each cone of diversification is equal (i.e., evenness assumption holds in each cone). Second, we accept that the production function of industry i, $X_i = F_i(K_i, L_i)$, is characterized by Leontief technology, where X_i, K_i, and L_i denote value added (in dollars), capital input, and labor input, respectively. This assumption allows the factor intensity of each sector ($k_i = K_i / L_i$) to be independent of product prices and complete specialization to be ruled out. The capital intensities of the three sectors are assumed to satisfy $k_1 < k_2 < k_3$, implying that good 1 is the most labor-intensive, good 3 is the most capital-intensive, and good 2 has intermediate capital intensity. Finally, we assume that countries can access identical production functions which remain unchanged over time. In the basic setup, we assume that both productive factors (capital and labor) are homogeneous in terms of efficiency.

The two-cone HO model makes GDP-maximizing country c specialize in subsets of goods (two goods out of three) dependent on its relative factor endowments denoted by $\bar{k}_c = \bar{K}_c / \bar{L}_c$. The product mix changes when the countrywide capital–labor ratio exceeds the threshold value, which delineates the two cones of diversification. The aggregate output (GDP, Y_c) of the country can be expressed as follows:

$$\begin{aligned} Y_c &= \begin{cases} F_1(K_1,L_1) + F_2(K_2,L_2) & \text{if } k_1 < \bar{k}_c < k_2, \\ F_2(K_2,L_2) + F_3(K_3,L_3) & \text{if } k_2 < \bar{k}_c < k_3, \end{cases} \\ \text{s.t.} & \begin{cases} K_1 + K_2 = \bar{K}_c \text{ and } L_1 + L_2 = \bar{L}_c & \text{if } k_1 < \bar{k}_c < k_2, \\ K_2 + K_3 = \bar{K}_c \text{ and } L_2 + L_3 = \bar{L}_c & \text{if } k_2 < \bar{k}_c < k_3. \end{cases} \end{aligned} \tag{1}$$

In our model, good 2 is commonly produced in all countries and the countries' relative factor endowments let each country produce either good 1 or 3. The threshold capital–labor ratio is k_2, which is referred to as the knot location in the estimation. Since production functions are assumed to be constant and characterized by Leontief technology, the threshold capital–labor ratio is constant over time. This assumption is imperative in order to have a single set of industrial development paths in the economy over time. Although it might seem to be too restrictive, in the empirical analysis, we allow for a given *industry* defined by the standard industrial classification (e.g., apparel, machinery) to upgrade its capital intensity over time by introducing the theory-compatible industry aggregation method *à* la Schott (2003). We will return to this point later. Figure 1 illustrates the theoretical archetype of the industrial development paths for the three-sector and two-cone HO model. Three splines depict the relationship between countrywide capital–labor ratio ($\bar{k}$) and sectoral output per capita ($x_i = X_i / \bar{L}$). For the sake of empirical application, we assume that $k_1 = 0$.

Within this setup, capital accumulation is the source of industrial upgrading. We assume that capital accumulation consists of domestic investment and foreign investment. The capital stock of country c in year t can be expressed as

$$\bar{K}_{ct} = (1-\delta)\bar{K}_{ct-1} + I_{ct} = (1-\delta)\bar{K}_{c,t-1} + (I_{ct}^D + I_{ct}^F), \tag{2}$$

where δ is the economy-wide rate of depreciation and I_{ct} is investment. Investment can be decomposed into domestic investment I_{ct}^D and foreign investment I_{ct}^F. As in the standard Solow growth model, domestic investment is determined for given behavioral parameters. Conversely, foreign investment can be promoted by governmental policies that determine the openness of the capital market. We assume that a country can accumulate capital stock more than constant domestic investment when investment is financed from overseas. In this paper we do not formally incorporate the dynamics of capital accumulation into the empirical analysis. Our intention in presenting Equation (2) is to emphasize that a country which attracts foreign capital may attain faster industrial development than it would by relying only on domestic investment.

4 | DATA AND AGGREGATION OF INDUSTRIES

In our empirical analysis, we use country-wide data on factor endowments and sectoral data on value added, employment, and investment. We estimate the two countries' industrial development paths from 1990 to 2008. Country-wide factor endowments are from the Penn World Table Version 8.1 (Feenstra, Inklaar, & Timmer, 2015). In the second estimation and factor-augmenting productivity test, we also use data on educational attainment from Barro and Lee (2013).

Sectoral data are sourced from the United Nations Industrial Development Organization (UNIDO, 2014), and industries are classified by the International Standard Industrial Classification (ISIC). The dataset covers 23 manufacturing industries listed in Table 1. Following Koren and Tenreyro (2007), we combine five categories of ISIC industries and exclude one (category 37, recycling) to ensure the consistency of the industrial classification between the countries and over time. The total number of ISIC industries is reduced to 17.

The ISIC categorizes output loosely according to similarity of end use. As Schott (2003) points out, this classification procedure is not necessarily consistent with the conceptualization of goods in the HO framework. In this framework, goods within the same industry must have identical input intensities. Table 2 shows capital intensity by country and ISIC in 1990 and 2008. It demonstrates that the capital intensity of a given ISIC industry varies across countries and years (intra-industry product heterogeneity). We adopt the empirical technique introduced by Schott (2003) to recast industry-level data into more theoretically appropriate "HO aggregates." As mentioned above, the number of goods must be equal to the number of factors in each cone of diversification in order to have the linear Rybczynski relationship, otherwise indeterminacy arises. Since the number of HO aggregates is arbitrary, we construct three HO aggregates by defining two capital-intensity cutoffs (h_1 and h_2): a labor-intensive HO aggregate,

$$X_{1ct} = \sum\nolimits_{n \in \{ n0 \le k_{nct} < h_1 \}} Q_{nct} \tag{3}$$

an intermediate HO aggregate,

$$X_{2ct} = \sum\nolimits_{n \in \{ nh_1 \le k_{nct} < h_2 \}} Q_{nct} \tag{4}$$

and a capital-intensive HO aggregate,

$$X_{3ct} = \sum\nolimits_{n \in \{ nk_{nct} \ge h_2 \}} Q_{nct} \tag{5}$$

Let X_{ict} denote the value added of HO aggregate i in country c in year t. X_{ict} is the sum of value added of ISIC industries (Q_{nct}) with capital intensity between the maximum and minimum capital intensities ($h_{i-1} \le k_{nct} < h_i$). In recasting the ISIC-based data into HO aggregates, as in Schott (2003), we impose an additional assumption that prices are such that the unit-value isoquants of all goods within a given derived aggregate are tangent to a single isocost line. We suppose that the capital-intensity cutoffs (h_1 and h_2) are the same for the two countries and do not change over time. Therefore, for a given year, the same ISIC industry n can be classified into different HO aggregates across countries. The HO aggregate in which a given ISIC industry n is classified can be changed over time. The assumption that capital-intensity cutoffs are irrespective of country and year is consistent with our theoretical model assuming the time-invariant location of knots: in theory, the location of knots is determined by the capital intensity of the industries whose empirical counterparts are the three HO aggregates. Therefore, assuming time-invariant capital-intensity cutoffs supports the notion that the location of knots does not change over time. Furthermore, defining the industry by its capital intensity at each point in time allows for a given ISIC industry to upgrade its capital intensity over time. For example, ISIC industry n can be classified in the most labor-intensive HO aggregate in one year and in the intermediate capital-intensive HO aggregate in the next year. All the variables are measured in constant 2005 US dollars. Price deflators for output and investment are retrieved from the Penn World Table.

TABLE 1 List of ISIC Industries

ISIC No.		Description
15	15A	Food and beverages
16		Tobacco products
17		Textiles
18	18A	Wearing apparel, fur
19		Leather, leather products, and footwear
20		Wood products (excluding furniture)
21		Paper and paper products
22		Printing and publishing
23		Coke, refined petroleum products, nuclear fuel
24		Chemicals and chemical products
25		Rubber and plastics products
26		Non-metallic mineral products
27		Basic metals
28		Fabricated metal products
29	29C	Machinery and equipment not elsewhere classified
30		Office, accounting and computing machinery
31	31A	Electrical machinery and apparatus
32		Radio, television and communication equipment
33		Medical, precision and optical instruments
34	34A	Motor vehicles, trailers, semi-trailers
35		Other transport equipment
36		Furniture; manufacturing not elsewhere classified

Source: UNIDO (2014).

5 | ESTIMATING INDUSTRIAL DEVELOPMENT PATHS

In this section, we estimate the industrial development paths of Malaysia and Singapore following Schott (2003) and Kiyota (2014). The system of three equations, each of which corresponds to the respective HO aggregate, is simultaneously estimated with a seemingly unrelated regressions (SUR) model. Regression equations are specified as follows (see Appendix for the derivation): for the labor-intensive HO aggregate,

$$x_{1ct}=\beta_1\left\{\bar{k}_{ct}-I\left\{\bar{k}_{ct}>\tau_2\right\}\left(\bar{k}_{ct}-\tau_2\right)-\tau_2\right\}+\varepsilon_{1ct}; \tag{6}$$

for the intermediate HO aggregate,

$$x_{2ct}=-\beta_2\left\{\bar{k}_{ct}-\frac{\tau_3}{\tau_3-\tau_2}I\left\{\bar{k}_{ct}>\tau_2\right\}\left(\bar{k}_{ct}-\tau_2\right)\right\}+\varepsilon_{2ct}; \tag{7}$$

and for the capital-intensive HO aggregate,

$$x_{3ct}=\beta_3 I\left\{\bar{k}_{ct}>\tau_2\right\}\left(\bar{k}_{ct}-\tau_2\right)+\varepsilon_{3ct}. \tag{8}$$

TABLE 2 Capital Intensity by ISIC Level

ISIC	1990 Malaysia	1990 Singapore	2008 Malaysia	2008 Singapore
15A	42.63	90.68	42.11	71.07
17	28.31	60.78	61.88	91.48
18A	7.06	13.21	9.86	24.27
20	18.86	59.83	33.51	38.08
21	125.19	84.93	53.01	94.43
22	30.23	58.27	36.02	84.29
23	399.52	847.77	531.16	1,365.78
24	99.10	142.17	176.92	778.19
25	30.14	51.35	37.12	81.74
26	50.98	111.56	73.18	180.64
27	93.51	116.70	64.89	122.52
28	31.71	53.09	33.53	71.38
29C	48.12	36.84	65.04	129.37
31A	35.49	73.79	84.05	446.25
33	37.05	54.70	35.47	78.50
34A	29.96	50.89	63.37	32.35
36	11.04	35.92	17.25	41.50

Source: UNIDO (2014).

Note: Unit is 1,000 USD.

Here $x_{ict}=X_{ict}/\bar{L}_{ct}$ is the per capita value added of HO aggregate i and $I\{\cdot\}$ is an indicator function that takes the value 1 if the relationship in the brace is true and 0 otherwise. τ_i is the knot location corresponding to the sectoral capital intensity k_i for $i=2,3$. The εs are error terms.

In the regression equations, the two capital-intensity cutoffs (h_1 and h_2) define the dependent variables and the two knot locations (τ_2 and τ_3) are included in the right-hand side of the equations. These parameters are determined by a grid search approach. We grid the overall possible combinations of the two cutoffs (h_1 and h_2) and the interior knot (τ_2) for a given interval size and determine the triplet by comparing the model selection criterion. For interval size, we use a grid interval of $\gamma=0.05$ for capital-intensity cutoffs ($10^{0.1}\le 10^{\gamma}\le 10^{3.0}$, in thousands of US dollars). For the interior knot location, we apply an interval size of \$1,000 ($\tau_1<\tau_2<\tau_3$), where τ_1 is 0 and τ_3 is \$1,000 above the upper range of the sample's observed capital–labor ratios.

For every combination of capital-intensity cutoffs and interior knot, we estimate the slope parameters iteratively using a SUR model. In order to make our empirical specification consistent with the theoretical model, we impose the following conditions on the slope parameters:

$$-\beta_1\tau_2<\beta_2\tau_2<\beta_3(\tau_3-\tau_2). \tag{9}$$

Regarding the model selection criterion, we propose to maximize Berndt's (1991) generalized R^2, which can be seen as the squared residual index weighted by the mean deviance of regressands.

Table 3 presents our estimation results. The slope parameters are statistically significant at the 1% level and consistent with theoretical prediction. Note that estimated parameters and knot locations satisfy the theory-mandated constraint

TABLE 3 Estimated Coefficients for the Three-Good, Two-Cone Industrial Development Paths

	Coef.	Std. Error	*p*-value	NRMSE
Labor-intensive HO aggregate (β_1)	–0.023	0.002	0.000	1.891
Intermediate HO aggregate (β_2)	0.054	0.005	0.000	0.609
Capital-intensive HO aggregate (β_3)	0.069	0.003	0.000	0.276
Capital intensity cutoffs	$h_1 = 7.943 (= 10^{0.90}), h_2 = 50.119 (= 10^{1.70})$			
Knot locations	$\tau_0 = 0, \tau_1 = 54, \tau_2 = 322$			
GeneralizedR^2	0.958			
Number of observation	38			

Note: Standard errors are bootstrapped using 1,000 replications to obtain heteroskedasticity robust standard errors. NRMSE = normalized root mean square error.

$$\beta_1 \tau_2 < \frac{\tau_2}{\tau_3 - \tau_2} \left\{ \beta_3 (\tau_3 - \tau_2) - \beta_2 \tau_2 \right\}. \tag{10}$$

This constraint is derived from the theoretical insight that wages in the labor-abundant cone are lower than in the capital-abundant cone. Figure 2 depicts the estimated industrial development paths of the two countries. Dotted lines indicate the 95% confidence interval so as to provide a sense of the precision with which they are estimated. The figure demonstrates substantial deviations of actual observations from the confidence interval. For the intermediate HO aggregate, there are no Singaporean observations that fall in the confidence interval.

The interior knot location, $\tau_2 = 54$, divides the observations into labor- and capital-abundant cones. For most of our sample period, both Malaysia and Singapore reside in the same group, the capital-abundant cone. This implies that the production mix in the two countries is almost identical. Singapore accumulates capital more steadily and shifts toward capital-intensive production. Conversely, observation of Malaysia reveals that the country remains at the lower capital–labor ratio within the capital-abundant cone. However, this result does not provide clear evidence for differentiating the two countries' industrial development.

We suppose that the poor performance of our first empirical analysis result may be attributed to the missing factors besides capital accumulation. Motivated by Schott's (2003) empirical analysis, the second estimation incorporates the factor of educational attainment. As Barro and Lee (2013) observe, many studies (among them Lucas, 1998; Mankiw, Romer, & Weil, 1992) emphasize the crucial importance of human capital, particularly as attained through education, to economic progress. Furthermore, in estimating a single set of industrial development paths, it would be particularly important to control for the quality difference such that one unit of labor input is measured in terms of efficiency unit of labor.

In order to maintain our theoretical model within the two-factor and three-good framework, we follow Hall and Jones (1999) and compute a measure of human-capital-augmented labor used in production (H_{ct}) in country c in year t as

$$H_{ct} = \exp \left\{ \phi(e_{ct}) \right\} L_{ct}, \tag{11}$$

where $\phi(e_{ct})$ reflects the efficiency of a unit of labor with e_{ct} years of schooling relative to a unit with no schooling. The derivative of $\phi(e)$ is the return to schooling estimated in a Mincerian wage regression (Mincer, 1974). As Caselli (2005) explained, the function $\phi(e)$ is known to be piecewise linear with

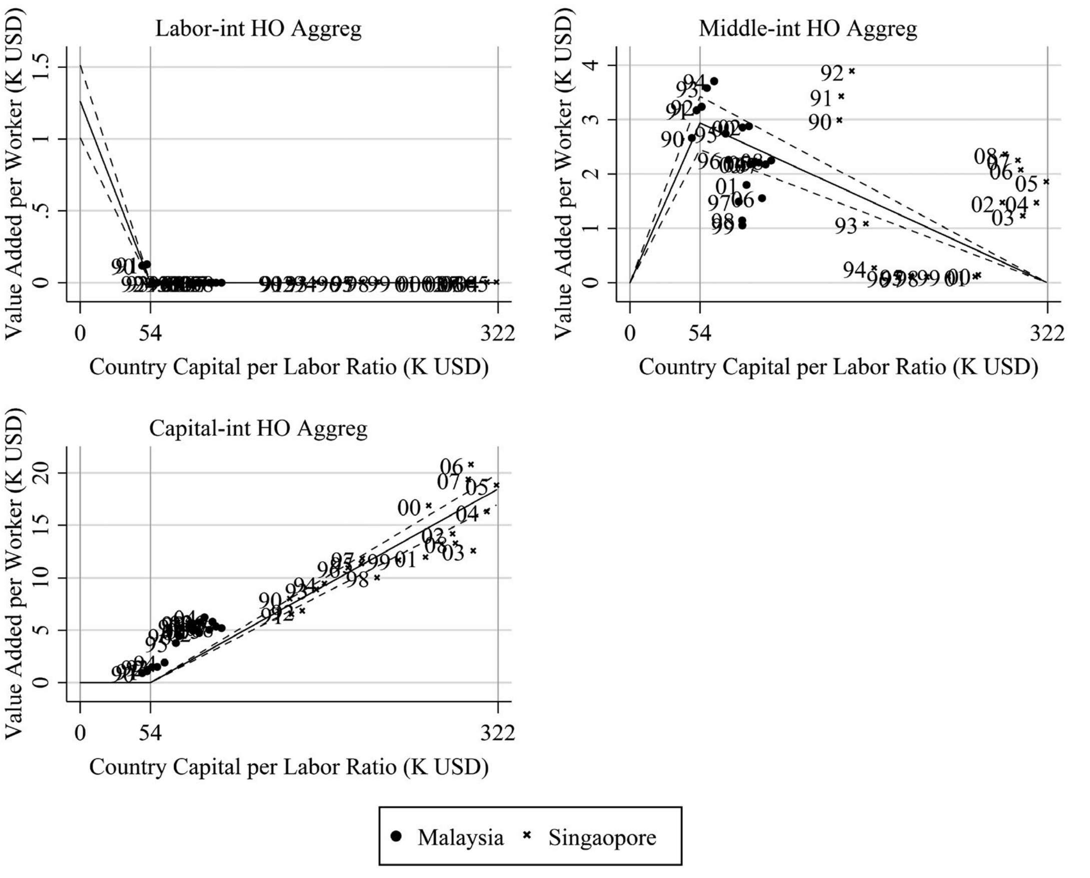

FIGURE 2 Estimated Three-Good Two-Cone Industrial Development Paths

Note: Estimation by constrained SUR. Dashed lines represent the 95% confidence interval.

different slopes, depending on the years of schooling. Following Batista and Potin (2014), suppressing the time subscript, we assume that the right-hand-side of Equation (11) is specified as, $\phi(e)$

$$\begin{aligned} H_c = & S_{c0}\exp(0)+S_{c2}\exp(2\times 0.134)+S_{c4}\exp(4\times 0.134) \\ & +S_{c6}\exp(4\times 0.134+2\times 0.101)+S_{c8}\exp(4\times 0.134+4\times 0.101) \\ & +S_{c10}\exp(4\times 0.134+4\times 0.101+2\times 0.068) \\ & +S_{c12}\exp(4\times 0.134+4\times 0.101+4\times 0.068), \end{aligned} \tag{12}$$

where S_{cE} is the fraction of the population over 25 with $e \in (E-2, E]$ years of education. Data on educational attainment with a two-year interval are constructed from Barro and Lee (2013). In the estimation below, we replace the labor endowment with human-capital-augmented labor. Sectoral employment, which is used to compute ISIC industry capital intensity, is also corrected analogously assuming that there is no heterogeneity in education attainment across ISIC industries.

Table 4 demonstrates the second estimation results. Note that the location of the rightmost knot, $\tau_3 = 141$, is different from the previous estimation due to quality adjustment of labor. All estimated coefficients are statistically significant at the 1% level and consistent with theoretical

TABLE 4 Estimated Coefficients for the Three-Good, Two-Cone Industrial Development Paths (with the Factor of Human Capital)

	Coef.	Std. Error	*p*-value	NRMSE
Labor-intensive HO aggregate (β_1)	−0.002	0.000	0.000	0.451
Intermediate HO aggregate (β_2)	0.062	0.002	0.000	0.265
Capital-intensive HO aggregate (β_3)	0.104	0.007	0.000	0.429
Capital-intensity cutoffs		$h_1 = 6.310(= 10^{0.80})$, $h_2 = 44.668(= 10^{1.65})$		
Knot locations		$\tau_0 = 0$, $\tau_1 = 76$, $\tau_2 = 141$		
GeneralizedR^2		0.913		
Number of observations		38		

Note: Standard errors are bootstrapped using 1,000 replications to obtain heteroskedasticity robust standard errors. NRMSE = normalized root mean square error.

prediction. The estimated coefficients and the location of knots satisfy the theoretical constraint in Equation (10). Figure 3 shows the development paths of the second estimation. By introducing the factor of educational attainment, the performance of the model is improved in terms of the deviation of the actual observations from the confidence interval. The better performance suggests that the industrial development of Malaysia and Singapore is well explained by the two-cone HO model.

As the figure illustrates, Malaysia and Singapore reside in different cones during our whole sample period. Therefore, the effect of capital accumulation on a given sector's output is different for the two countries. Malaysia remains in the labor-abundant cone and specializes in the labor-intensive subset of goods. In contrast, Singapore resides in the capital-abundant cone and produces the capital-intensive subset of goods. In spite of the political initiative in Malaysia promoting export-oriented industrialization in the 1990s, our result demonstrates that Malaysia remains in labor-intensive production due to stagnant capital accumulation. Conversely, steady capital growth financed by foreign investment in Singapore allows its economy to reside in the capital-abundant cone and to increase capital-intensive production.

6 | TESTING FACTOR-AUGMENTING PRODUCTIVITY

In this section we test factor-augmenting productivity differences across countries. In the previous estimation, we assume that one unit of capital (K) and human-capital-augmented labor (H) inputs has the same efficiency. Therefore, deviation of the actual output from the estimated development paths can be accounted for by the difference in efficiency of productive factors. Originating from studies on technological change, such as that by Atkinson and Stiglitz (1969), workers' productivity may vary because of their educational quality and other conditions. This implies that one unit of human capital may have different production efficiencies. Analogously, one unit of capital input may be different in productivity due to the difference in the capital utilization rate. We examine the qualitative similarity of productive factors between the two countries.

For our empirical test, we make the following assumptions. First, the factor-augmenting productivity measures are assumed to be identical across sectors and constant over time. Second, we assume that Singaporean productivity adjustments take the value 1 for normalization purposes. Inspired by Hall and Jones (1999) and Ventura (2005), we reformulate our production function as

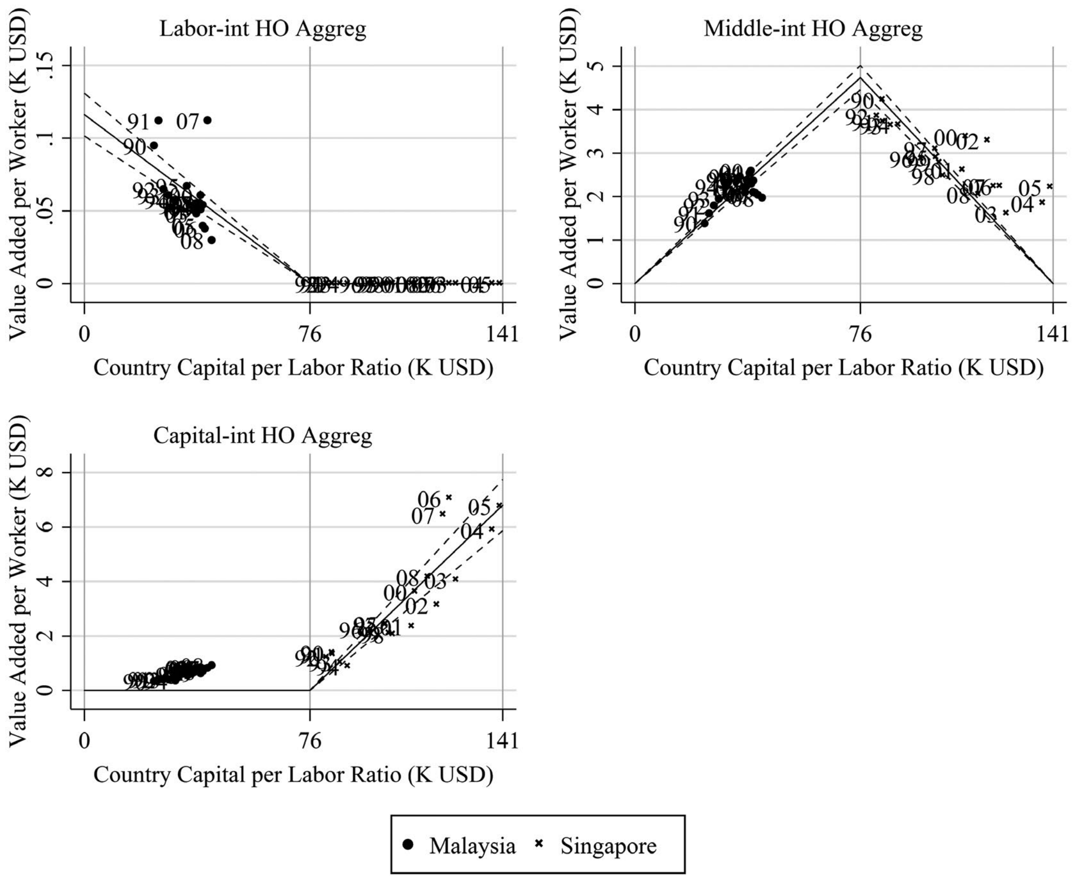

FIGURE 3 Estimated Three-Good, Two-Cone Industrial Development Paths (with the Factor of Human Capital)

Note: Estimation by constrained SUR. Dashed lines represent the 95% confidence interval.

$$X_{ict} = F_i(A_K K_{ict}, A_H H_{ict}), \quad \text{for } i = 1, 2, 3, \tag{13}$$

where A_K and A_H are capital- and labor-augmenting productivity adjustments, respectively.

With this setup, the regression equation in general form can be expressed as

$$\begin{aligned} \frac{X_{ict}}{\bar{H}_c t\left\{d_{MLY}(\alpha_H - 1) + 1\right\}} &= \beta_{1i} + \sum_{m=1}^{2} \beta_{2mi} \frac{\bar{K}_{ct}\left\{d_{MLY}(\alpha_K - 1) + 1\right\}}{\bar{H}_{ct}\left\{d_{MLY}(\alpha_H - 1) + 1\right\}} I_m\left\{\bar{k}_{ct} > \tau_m\right\} \\ \Leftrightarrow X_{ict} &= \left\{\beta_{1i} + \sum_{m=1}^{2} \beta_{2mi} \bar{k}_{ct} \frac{\left\{d_{MLY}(\alpha_K - 1) + 1\right\}}{\left\{d_{MLY}(\alpha_H - 1) + 1\right\}} I_m\left\{\bar{k}_{ct} > \tau_m\right\}\right\} \left\{d_{MLY}(\alpha_H - 1) + 1\right\} \bar{H}_{ct}, \end{aligned} \tag{14}$$

where β_{1i} and β_{2mi} are respectively the intercept and slope of the development paths of cone m for HO aggregate i. d_{MLY} is a dummy variable that takes 1 if the sample is Malaysia and 0 otherwise. α_K and α_H are factor-augmenting productivity measures with the Singapore normalization. $\alpha = 1$ implies that the

Malaysian factor input is identical in productivity with Singapore. $\alpha < 1$ means that the Malaysian factor input is less efficient compared with Singapore. By imposing the theory-mandated constraints on intercept and slopes and simplifying the notation for parameters β as described in Appendix, we obtain the regression equations for the three HO aggregates as follows: for the labor-intensive HO aggregate,

$$X_{1ct} = \left[-\beta_1 \tau_2 + \beta_1 \frac{\left\{ d_{MLY}(\alpha_K - 1) + 1 \right\}}{\left\{ d_{MLY}(\alpha_H - 1) + 1 \right\}} \left\{ \bar{k}_{ct} - I\left\{ \bar{k}_{ct} > \tau_2 \right\} \left(\bar{k}_{ct} - \tau_2 \right) \right\} \right] \left\{ d_{MLY}(\alpha_H - 1) + 1 \right\} \bar{H}_{ct}; \quad (15)$$

for the intermediate HO aggregate,

$$X_{2ct} = \left[-\beta_2 \frac{\left\{ d_{MLY}(\alpha_K - 1) + 1 \right\}}{\left\{ d_{MLY}(\alpha_H - 1) + 1 \right\}} \left\{ \bar{k}_c - \frac{\tau_3}{\tau_3 - \tau_2} I\left\{ \bar{k}_{ct} > \tau_2 \right\} \left(\bar{k}_{ct} - \tau_2 \right) \right\} \right] \left\{ d_{MLY}(\alpha_H - 1) + 1 \right\} \bar{H}_{ct}; \quad (16)$$

and for the capital-intensive HO aggregate,

$$X_{3ct} = \left[\beta_3 \frac{\left\{ d_{MLY}(\alpha_K - 1) + 1 \right\}}{\left\{ d_{MLY}(\alpha_H - 1) + 1 \right\}} I\left\{ \bar{k}_{ct} > \tau_2 \right\} \left(\bar{k}_{ct} - \tau_2 \right) \right] \left\{ d_{MLY}(\alpha_H - 1) + 1 \right\} \bar{H}_{ct}. \quad (17)$$

We test the factor-augmenting productivity on the basis of the second estimation in the previous section. Since the regression equations take nonlinear forms, the system of three equations is estimated by two-step feasible generalized nonlinear least squares. For the starting values of the iteration of the linearized regression, we choose $\alpha_K = \alpha_H = 1$. We set identical capital-intensity cutoffs and interior knot location: $h_1 = 6.310(= 10^{0.80})$, $h_2 = 44.668(= 10^{1.65})$, and $\tau_1 = 76$. In the hypothesis test for α_j, the null hypothesis is $H_0{:}\alpha_j = 1$ and the alternative hypothesis is $H_1{:}\alpha_j \neq 1$.

Table 5 presents the estimation results. Both capital- and labor-augmenting productivity measures of Malaysia relative to Singapore are not significantly different from unity. Thus, labor input is homogeneous across countries after controlling for workers' skill by educational attainment. In other words, education attainment is the key component in explaining the cross-country difference in efficiency of labor input. We also implement the joint test of $\alpha_K = 1$ and $\alpha_H = 1$, and see that it is not rejected at the 1% level. This again confirms that there are no significant gaps in factor-augmenting productivity between the two countries.

The result of the factor-augmenting productivity test validates the second estimation. The quality of labor input can be well controlled for by educational attainment. The capital utilization

TABLE 5 Estimated Coefficients (with Labor- and Capital-Augmenting Productivity)

	Coef.	Std. Err.	*p*-value	NRMSE
Labor-intensive HO aggregate (β_1)	–0.002	0.000	0.011	0.518
Intermediate HO aggregate (β_2)	0.067	0.007	0.000	0.181
Capital-intensive HO aggregate (β_3)	0.107	0.015	0.000	0.768
Capital-augmenting productivity (α_K)	0.865	0.088	0.127	–
Labor-augmenting productivity (α_H)	0.769	0.152	0. 127	–
Capital-intensity cutoffs	$h_1 = 6.310(= 10^{0.80})$, $h_2 = 44.668(= 10^{1.65})$			
Knot locations	$\tau_0 = 0$, $\tau_1 = 76$, $\tau_2 = 141$			
GeneralizedR^2	0.929			
Number of observations	38			

Note: NRMSE = normalized root mean square error.

rate (quality of capital input) is also not significantly different across two countries. Therefore, our analysis suggests that, in analyzing the industrial development of two countries, capital accumulation is the key determinant for industrial upgrading rather than differences in efficiency of productive factors. Consequently, it is ensured that the two countries' industrial upgrading process can be illustrated by a common series of industrial development paths of the two-cone HO model.

7 | CONCLUSION

This paper investigates the industrial development in Singapore and Malaysia using the multiple-cone HO framework. We argue that, within this framework, capital accumulation allows countries to upgrade their industry mix so that it becomes more capital-intensive. Therefore, capital accumulation is the key driver determining countries' industrial development and differences in production technology employed in each country. Focusing on the industries that appear, prosper, decline, and disappear along with capital accumulation, we estimate a single set of industrial development paths generated from the two-cone HO model by assuming the two countries have the same model primitives other than capital–labor ratio. Estimation utilizes the pooled data on factor endowments and sectoral output of the two countries from 1990 to 2008.

In our first estimation, we attempt to account for the two countries' industrial development purely in terms of capital accumulation. The results reveal poor performance of the estimated model in terms of deviation of actual observations from the confidence intervals. In the second estimation we control the quality of labor by taking into account the cross-country difference in education attainment. Since our analytical framework assumes that the two countries differ only in terms of capital–labor ratio, it is crucial to control for the potential heterogeneity in quality of productive factors. By replacing labor input with human-capital-augmented labor input, we re-estimate the industrial development paths and obtain a better fit to the data. We find that the two countries reside in a different cone during our sample period. The separation by cones is consistent with the observed gap in GDP per capita between the two countries. In conclusion, we confirm that the gap in economic development between the two countries can be largely attributed to the level of capital accumulation. A factor-augmenting productivity test provides non-significant evidence of the cross-country gap in factor productivities. It also proves that the quality of labor input is well corrected by the consideration of educational attainment.

With respect to the effectiveness of industrial policy, our results suggest that the political initiative in Singapore to attract foreign capital has been successful in upgrading its economy to more capital-intensive production. Conversely, we find that Malaysia remains in the capital-scarce cone, producing a labor-intensive subset of goods during the whole sample period. Focusing on the capital accumulation process, industrial development paths reveal a gap in economic development between the two countries.

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ENDNOTES

[1] An overview of the two countries' economic development in conjunction with their industrial policies is given in Kuruvilla (1996), Huff (1987), and Kuruvilla and Arudsothy (1995).

[2] If the number of goods exceeds the number of factors, there is no one-to-one relationship between factor endowments and sectoral output, that is, indeterminacy arises. For a detailed discussion of uneven cases, see Melvin (1968).

[3] We use the subscript i to indicate the theoretical notion of industry in the HO framework. In the empirical specification, this subscript is also used for the HO aggregate, which is the empirical counterpart of the industry in the theory. It is distinguished from the industry defined by the ISIC and subscripted by n.

[4] If the production functions vary over time, the location of knots also changes. The assumption of a time-invariant production function would be justified in empirical analysis by introducing HO aggregates. Furthermore, if there is another productive factor in the model (e.g., natural resource), the location of knot will vary across countries; see Leamer (1987). Since we attempt to gauge the industrial development of two countries along with a single set of industrial development paths, we stick with the assumption of time-invariant knot location and remain in the two-factor setup. Relaxing these assumptions is left for a future study.

[5] We combine the following pairs of industries: 15 + 16 as 15A, 18 + 19 as 18A, 29 + 30 as 29C, 31 + 32 as 31A, and 34 + 35 as 34A.

[6] Capital intensity is obtained by dividing sectoral capital stock by sectoral employment. To estimate the capital stock we follow Hall and Jones (1999) and employ the perpetual inventory method (PIM). We accumulate the gross fixed capital formation from 1968 and apply a constant depreciation rate of 13.3 percent following Schott (2003). See Organisation for Economic Co-operation and Development (2009) for a detailed explanation of the PIM.

[7] This relationship is derived from the condition that the per capita value added of the HO aggregate $x_1 \equiv X_i/\bar{L}$ at the corresponding knot location $\bar{k}=\tau_i$ must satisfy $x_1|_{\bar{k}=\tau_1} < x_2|_{\bar{k}=\tau_2} < x_3|_{\bar{k}=\tau_3}$.

[8] The dataset contains the percentage share of population aged 25 and over who attended primary, secondary, and tertiary education (s_j for $j = Pri, Sec, Ter$) and average years of schooling for each stage of education (E_j). Since the population is classified by the highest level of education attained but not by the years of schooling, we converted the dataset using the following procedure. First, we assumed that the average years of education at each level represent the years of schooling for all who attended that educational stage. Subsequently, we computed the cumulative years of education at each stage and classified the population by the educational level at two-year intervals. For example, if a country's average year of primary schooling is $E_{Pri}=5$, the fraction of population whose highest level of education is primary ($S_{Pri}=s_{Pri}\times\bar{L}$) can be categorized in S_6 (i.e. $5\in(6-2,6]$). If the subsequent secondary education takes 4 years on average in the country, the cumulative amount of schooling is counted as $E_{Pri}+E_{Sec}=9$. Then we label the fraction of population with secondary education ($S_{Sec}=s_{Sec}\times\bar{L}$) as S_{10} (i.e. $9\in(10-2,10]$). The population with tertiary education is classified analogously. Since the data for educational attainment are collected every 5 years, missing values are linearly interpolated. Sectoral employment is also adjusted in the same manner by assuming identical distribution of educational level for all sectors.

[9] See Green (2011) and Cameron and Trivedi (2005) for details of the nonlinear regression.

REFERENCES

Atkinson, A. B., & Stiglitz, J. E. (1969). A new view of technological change. *Economic Journal*, *79*(315), 573–578. https://doi.org/10.2307/2230384.

Batista, C., & Potin, J. (2014). Stages of diversification in a neoclassical world. *Economics Letters*, *122*(2), 276–284. https://doi.org/10.1016/j.econlet.2013.12.010.

Barro, R. J., & Lee, J. W. (2013). A new data set of educational attainment in the world, 1950–2010. *Journal of Development Economics*, *104*, 184–198. https://doi.org/10.1016/j.jdeveco.2012.10.001.

Berndt, E. R. (1991). *The practice of econometrics: Classic and contemporary*. Reading, MA: Addison-Wesley.

Cameron, A. C., & Trivedi, P. K. (2005). *Microeconometrics: Methods and applications*. Cambridge: Cambridge University Press.

Caselli, F. (2005). Accounting for cross-country income differences. In P. Aghion & S. N. Durlauf (Eds.), *Handbook of economic growth, Volume 1A* (pp. 679–741). Amsterdam: North-Holland.

Deardorff, A. V. (1974). A geometry of growth and trade. *Canadian Journal of Economics*, *7*(2), 295–306. https://doi.org/10.2307/134168.

Deardorff, A. V. (2000). Patterns of trade and growth across cones. *De Economist*, *148*(2), 141–166. https://doi.org/10.1023/A:1004096611584.

Deardorff, A. V. (2001a). Does growth encourage factor price equalization? *Review of Development Economics*, *5*(2), 169–181. https://doi.org/10.1111/1467-9361.00116.

Deardorff, A. V. (2001b). Rich and poor countries in neoclassical trade and growth. *Economic Journal*, *111*, 277–294. https://doi.org/10.1111/1468-0297.00608.

Deardorff, A. V. (2014). *Terms of trade: Glossary of international economics* (2nd ed.). Singapore: World Scientific.

Dixit, A., & Norman, V. (1980). *Theory of international trade: A dual, general equilibrium approach*. Cambridge: Cambridge University Press.

Feenstra, R. C., Inklaar, R., & Timmer, M. P. (2015). The next generation of the Penn World Table. *American Economic Review*, *105*(10), 3150–3182. https://doi.org/10.1257/aer.20130954.

Galor, O. (1996). Convergence? Inferences from theoretical models. *Economic Journal*, *106*(437), 1056–1069.

Green, W. H. (2011). *Econometric analysis* (7th ed.). Upper Saddle River. NJ: Pearson.

Hall, R. E., & Jones, C. I. (1999). Why do some countries produce so much more output per worker than others? *Quarterly Journal of Economics*, *114*(1), 83–116. https://doi.org/10.1162/003355399555954.

Huff, W. G. (1987). Patterns in the economic development of Singapore. *Journal of Developing Areas*, *21*(3), 305–326. https://doi.org/10.1017/CBO9780511470714.004.

Kiyota, K. (2011). Paths of development and wage variations. *Review of International Economics*, *19*, 697–717. https://doi.org/10.1111/j.1467-9396.2011.00976.x

Kiyota, K. (2014). Industrial upgrading in a multiple-cone Heckscher-Ohlin model: The flying geese patterns of industrial development. *Review of Development Economics*, *18*(1), 177–193. https://doi.org/10.1111/rode.12077.

Koren, M., & Tenreyro, S. (2007). Volatility and development. *Quarterly Journal of Economics*, *122*(1), 243–287. https://doi.org/10.1162/qjec.122.1.243.

Kuruvilla, S. (1996). Linkages between industrialization strategies and industrial relations/human resource policies: Singapore, Malaysia, the Philippines, and India. *Industrial & Labor Relations Review*, *49*(4), 635–657. https://doi.org/10.1177/001979399604900404.

Kuruvilla, S., & Arudsothy, P. (1995). Economic development strategy, government labour policy and firm-level industrial relations practices in Malaysia. In A. Verma, T. A. Kochan & R. D. Lansbury (Eds.), *Employment relations in the growing Asian economies* (pp. 158–193). London: Routledge.

Leamer, E. E. (1987). Paths of development in the three-factor, *n*-good general equilibrium model. *Journal of Political Economy*, *95*(5), 961–999.

Leamer, E. E., & Levinsohn, J. (1995). International trade theory: The evidence. In G. M. Grossman & K. Rogoff (Eds.), *Handbook of international economics, Volume 3*. Amsterdam: North-Holland.

Leamer, E. E., Maul, H., Rodriguez, S., & Schott, P. K. (1999). Does natural resource abundance increase Latin American income inequality? *Journal of Development Economics*, *59*(1), 3–42. https://doi.org/10.1016/S0304-3878(99)00004-8.

Leamer, E. E., & Schott, P. (2005). The rich (and poor) keep getting richer. *Harvard Business Review*, *83*, 20.

Lucas, R. E. (1998). On the mechanics of economics development. *Journal of Monetary Economics*, *22*, 3–42. https://doi.org/10.1016/0304-3932(88)90168-7.

Mankiw, G. N., Romer, D., & Weil, D. N. (1992). A contribution to the empirics of economics growth. *Quarterly Journal of Economics*, *107*(1), 407–437. https://doi.org/10.2307/2118477.

Melvin, J. R. (1968). Production and trade with two factors and three goods. *American Economic Review*, *58*(5), 1249–1268.

Mincer, J. (1974). *Schooling, experience, and earnings*. New York: National Bureau of Economic Research.

Oniki, H., & Uzawa, H. (1965). Patterns of trade and investment in a dynamic model of international trade. *Review of Economic Studies*, *32*(1), 15–38. https://doi.org/10.2307/2296328.

Organisation for Economic Co-operation and Development (2009). *Measuring capital: OECD manual 2009*. Paris: OECD Publishing.

Schott, P. K. (2003). One size fits all? Heckscher-Ohlin specialization in global production. *American Economic Review*, *93*(3), 686–708. https://doi.org/10.1257/000282803322157043.

United Nations Industrial Development Organization (UNIDO) (2014). *Industrial Statistics Database at 2-Digit Level of ISIC Rev.3* [CD-ROM].

Ventura, J. (2005). A global view of economic growth. In P. Aghion & S. N. Durlauf (Eds.), *Handbook of economic growth, Volume 1B* (pp. 1419–1497). Amsterdam: North-Holland. https://doi.org/10.1016/S1574-0684(05)01022-1.

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APPENDIX

DERIVATION OF THE REGRESSION EQUATIONS

The regression equation for the development paths of industry i in the two-cone Heckscher–Ohlin model is a spline with a knot. Suppressing the time subscript, the general specification can be expressed as

$$x_{ic} = \beta_{1i} + \sum_{t=1}^{2} \beta_{2mi} \bar{k}_c I_m \left\{ \bar{k}_c > \tau_m \right\} + \varepsilon_{ic}, \tag{A1}$$

where β_{1i} is the intercept, β_{2mi} is the slope of the mth cone, and $I_m\{\cdot\}$ is an indicator function which takes the value 1 if true and 0 otherwise. We then impose the theory-mandated constraints on parameters implied by Figure 1: for the labor-intensive HO aggregate

$$\beta_{11} = -\beta_{211}\tau_2, \quad \beta_{221} = 0;$$

for the intermediate HO aggregate,

$$\beta_{12} = 0, \quad \beta_{212}\tau_2 = -\beta_{222}(\tau_3 - \tau_2);$$

and for the capital intensive HO aggregate,

$$\beta_{13} = 0, \quad \beta_{213} = 0.$$

By plugging those conditions into Equation (A1) for each HO aggregate and constraining the line segments of each development paths to meet at the knots, we can obtain a regression equation for each of the HO aggregates. For the sake of simplification, we write β_{211} as β_1, β_{212} as β_2, and β_{223} as β_3, and suppress the indicator function subscript. Then, for the labor-intensive HO aggregate,

$$x_{1c} = -\beta_1\tau_2 + \beta_1 \left\{ \bar{k}_c - I\left\{ \bar{k}_c > \tau_2 \right\} \left(\bar{k}_c - \tau_2 \right) \right\} + \varepsilon_{1c}; \tag{A2}$$

for the intermediate HO aggregate,

$$x_{2c} = -\beta_2 \left\{ \bar{k}_c - \frac{\tau_3}{\tau_3 - \tau_2} I\left\{ \bar{k}_c > \tau_2 \right\} \left(\bar{k}_c - \tau_2 \right) \right\} + \varepsilon_{2c}; \tag{A3}$$

and for the capital-intensive HO aggregate,

$$x_{3c} = \beta_3 I\left\{ \bar{k}_c > \tau_2 \right\} \left(\bar{k}_c - \tau_2 \right) + \varepsilon_{3c}. \tag{A4}$$