VERTICAL SPECIALIZATION AND THE INEQUALITY OF NATIONS

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Abstract

This paper examines the pattern of production and trade between countries that differ in capital-labor ratios and that have a production sector subject to international increasing returns. Three main predictions emerge: first, compared to autarky, the number of firms increases in a capital-abundant country and decreases in a labor-abundant country. Second, vertical specialization between countries differing in capital-labor ratios is determined by endowment differences and capital-abundant country becomes the net exporter of components. The third and most important result of the paper establishes that vertical specialization under free trade will result in a capital-abundant country accumulating a more-than proportionate share of the differentiated goods industry. I also show that the welfare implications of trade are affirmative, but the expansion of the increasing returns sector in the capital-abundant country will not, in general, make it gain more from trade.

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2.1 Introduction

The reallocation of resources between production sectors as countries open up to trade has been a well-analyzed topic, except for the precise analysis of conditions and the outcomes that lead to vertical specialization between countries that differ in capital-labor ratios. I develop a three-sector model of final, intermediate and non-tradable goods, incorporating costly assembly and increasing returns, to study such conditions and the ensuing pattern of production and trade. The change from autarky to trade across the stages of production is relevant not only to determining the ensuing trade pattern, but more interestingly, to examining how the location of firms in the monopolistically competitive industry and the resulting industrial structure of the economy depend on relative factor proportions when trade is costless.

The main motivation for the paper stems from recent developments in the global economy, as the structure and geographical location of the production of firms has been changing considerably. In particular, a new organizational form of production has evolved according to which firms no longer engage in the whole sequence of activities necessary in getting a product to the consumer, but instead concentrate on a core of their activities and purchase or outsource the rest from outside firms. While outsourcing can and does occur within borders, it is the international outsourcing to external suppliers and affiliates that has dominated the attention of researchers in recent years. In this regard outsourcing is often viewed as trade in specialized intermediate inputs, including the intra-firm trade of multinational firms. But as Yi (2003) points out, outsourcing is also accounted for by vertical specialization, which is a related concept to trade in intermediate inputs, but not an identical one, since vertical specialization is also responsible for trade across the stages of production (import of intermediates and export of a final good). Hummels et al. (2001) try to determine the extent of vertical specialization in the world economy using input-output tables and report that growth in exports that use imported goods as inputs has accounted for 21% of the OECD countries' exports in the 1990s, and that vertical specialization grew by almost 30% between 1970 and 1990.

This work therefore aims to incorporate the concept of vertical specialization into the well-developed literature on imperfect competition, (international) increasing returns, and factor proportions by disentangling the production of a final good into separate stages of intermediate production and costly assembly. Compared to Chakraborty (2003), who undertakes an analogous separation of production, the number of firms in this study can vary as countries open up to trade instead of being pinned down by capital availability at home. It will be shown that the differences in relative factor endowments between trading partners do not only determine the pattern of trade as usual in comparative-advantage driven models of inter-industry trade, but also determine the location of component producing firms and the industrial structure of the economy.

I present three main predictions that emerge when two countries, identical in all other respects except their factor proportions, open up to trade: First, compared to autarky, the number of firms increases in a capital-abundant country and decreases in a labor-abundant country. This result has some empirical confirmation by Ng and Yeats (1999), who found that relatively low-wage East Asian countries have improved their comparative advantage in (labor-intensive) assembly operations across 60 component product groups, whereas Japan, Singapore and Taiwan have increased their specialization in the production of components.

Second, vertical specialization between countries differing in capital-labor ratios is determined by endowment differences and the capital-abundant country becomes the net exporter of components. This result relating to the pattern of production and trade is well-reflected by WTO International Trade Statistics (2004), which reports that "a dramatic change in regional trade flows resulted from the new division of labor in Asia. Many producers in Japan and other high income economies in the region no longer export their finished goods to North America and Western Europe, but ship high value-added components to China for assembly and send the end products from China through their affiliates to the Western markets" (p. 1). Hummels et al. (1998) affirm that the Japanese electronics industry has rapidly been outsourcing some stages of production, especially final assembly, to Southeast Asia and other developing countries, such that the export share of components in the whole electronics industry has reached nearly 80%. Such specialization and trade pattern between countries with different capital-labor ratios has also been verified in a recent study by Kandogan (2003), who analyzes trade between transition economies and developed countries and finds that vertical intra-industry trade (defined as the simultaneous export and import of goods in the same industry, but at different stages of production) is positively affected by the economies of scale and comparative advantage.

The third and most important result of the paper establishes that vertical specialization under free trade will result in a capital-abundant country accumulating a more-than-proportionate share of the differentiated goods industry irrespective of country size. It will contribute a less-than-proportionate share of labor to manufacturing assembly. This result would allow for empirical predictions on how the industrial structure of the economy changes when vertical specialization occurs. Specifically, the accumulation of increasing-returns sector into one of the two trading partners underlies the famous "home market" result of Krugman (1980), whereby trading costs drive a more-than-proportionate share of increasing-returns sector into a larger country. Here trade is costless, but an analogous industrial structure evolves because of possible trade across the stages of production when countries differ in their relative factor proportions.

Finally, I show that the welfare implications of trade are always positive, but the expansion of the increasing-returns sector in the capital-abundant country will not, in general, make it gain more than the labor-abundant country, whose increasing-returns sector contracts.

The model, as will be formally presented shortly, has a few specific characteristics that allow the results to expand those currently in the literature. First, two factors of production adds to the discussion of country size versus relative factor proportions of both monopolistic competition in international trade and the "home market" effect (the determination of industrial structure). Second, the addition of a third (non-tradable good) sector to the model shows why it matters which good is traded; it also allows deriving precise results of vertical specialization between two countries that differ in relative factor proportions. Such results cannot be derived if the economy consists of only an intermediate good sector and a related downstream final good sector. In particular, I show that the number of firms in an imperfectly competitive industry does not stay constant, but changes in accordance with factor abundance once trade ensues. The presence of a third sector also assures that net and gross factor intensity rankings are well-defined, as it can be shown that in a two-sector model where the intermediate good is monopolistically competitive, factor intensity rankings depend on parameter values. And third, non-homothetic technology in component production allows firm size to vary in the equilibrium since factor prices do not cancel out; instead they change to reflect the adjustment in relative factor endowments and as a result, in firm size.

The rest of the paper is structured as follows. Section 2.2 develops a three sector of production model and solves for the general equilibrium outcomes. Section 2.3 allows free trade in specialized intermediate inputs and a final manufacturing good to study the pattern of trade and the resulting effect on specialization. Section 2.4 presents the welfare implications of trade and Section 2.5 offers concluding remarks. Appendix B contains proofs and figures.

2.2 The Model

I subsequently present the structure of the model and the most relevant closed economy general equilibrium outcomes. The model here builds on the Heckscher-Ohlin-type economy by having two tradable good sectors that differ in their factor intensities; the presence of an additional constant-returns non-tradable good sector allows for the derivation of precise results. The imperfectly competitive intermediate good sector employs labor (at a variable cost) and capital (at a fixed cost) and supplies its composite output to the downstream constant-returns manufacturing good sector, which uses labor to assemble the intermediates into the final good. Consumers allocate their income between this final manufacturing good and the non-tradable good, which is being produced by primary factors capital and labor. I now set up the model formally.

2.2.1. Production

Consider an economy consisting of three sectors of production: a final manufacturing good sector Q_m, an intermediate good sector I_m and a non-tradable good sector Q_s. The final and non-tradable good sectors are perfectly competitive with constant returns to scale and have firms that are price takers in both input and output markets. The intermediate good sector, on the other hand, exhibits Ethier's (1982) formulation of the economies of scale founded on the Dixit-Stiglitz love-of-variety approach.

The downstream final manufacturing good sector has a Cobb-Douglas production function of labor and intermediates with $0 < \gamma < 1$ as the factor share of labor in output. The price of the final good is denoted by p_m. I assume that the production of the final good is composed of two separate production stages: input manufacturing (intermediates) and input processing (assembly by labor). An analogous idea has been applied empirically by Hanson et al. (2004), as it allows envisaging input manufacturing to involve producing relatively capital intensive specialized components, while input processing from the perspective of assembly can be thought of as being relatively labor intensive. Previous literature has termed a similar relationship as being between an upstream industry (component producers) and a downstream industry (final good producers), allowing for the study of linkage effects (Krugman and Venables, 1995). Unlike Ethier (1982), the assembly of intermediate goods into the final good in the model is not costless, but requires labor input. Components are assembled into the final good by many competitive firms.

The CES-type intermediate good sector's production function requires some elaboration, as it is expressed by $I_m = n^{\frac{1}{\rho}-\frac{\sigma}{\sigma-1}}\left(\sum_{i=1}^{n} x_i^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$. The main difference from the standard functional form used in the literature is the utilization of the Benassy (1998) term, which allows disentangling the elasticity of substitution between the components from the elasticity of output with respect to the level of technology. Specifically, $\sigma > 1$ denotes the elasticity of substitution between the various components allowing for imperfect substitutability, and $0 < \rho < 1$ implies scale economies resulting from an increased division of labor, as addressed by Ethier (1982). Here x_i is the output of an individual intermediate component and n is the number of suppliers of specialized components. Given the symmetry by which individual components enter the production function of the intermediate good and the same cost functions (discussed below), in the equilibrium the amount of output of each component producer will be the same, or $x_i = x$.

I let the technology of individual component production to be non-homothetic. This serves the purpose of allowing the firm size to vary and to depend on the relative factor proportions. The production of an individual component x_i hence requires both capital and labor input in this monopolistically competitive industry, where capital is used for fixed and labor for variable cost. The fixed cost is small enough to ensure that the number of components produced is sufficiently large to make oligopolistic interactions between firms negligible. Following the standard Chamberlinian framework, and for simplicity, I let the technology used by all individual firms be identical. The cost function of a component-producing firm is then expressed by

$$c_i = r\theta + w\lambda x_i \quad , \tag{1}$$

where $\theta > 0$ denotes a fixed capital requirement, λx_i $(\lambda > 0)$ is labor demanded by each component producer, r is the capital rental rate, and w is the wage rate. Due to the presence of a fixed cost no two firms produce the exact same component in the equilibrium, as goods can be differentiated costlessly.

Production of the non-tradable good takes the Cobb-Douglas form of $Q_s = AL_s^{\beta}K_s^{1-\beta}$, where L_s is the amount of labor and K_s the amount of capital employed. $A = \frac{1}{\beta^{\beta}(1-\beta)^{1-\beta}}$ is a scale parameter utilized for simplification and $0 < \beta < 1$ is the factor share of labor in non-tradable output. The non-tradable good is the *numéraire* in the autarkic model.

2.2.2. Preferences and Demand

On the demand side I assume that all individuals in the economy have the same Cobb-Douglas utility functions; then due to identical and homothetic preferences the aggregate utility function takes the form $U = Q_m^{\alpha}Q_s^{1-\alpha}$, where $0 < \alpha < 1$. Consumers in the economy maximize their utility subject to the budget constraint $p_mQ_m + Q_s = I$, where I stands for national income, comprised of total wage and capital rental payments.

2.2.3. Factor Markets

The full employment of labor and capital in the economy implies that

$$\lambda nx + L_m + L_s = L \tag{2}$$

and

$$\theta n + K_s = K \quad , \tag{3}$$

where λnx is the amount of labor and θn is the amount of capital demanded by the whole intermediate good sector producing components; and L_m is labor used in the assembly. Finally, L denotes the labor endowment and K the size of the total capital stock given in the economy. The model is completed by an assumption that both factors are perfectly mobile across all three production sectors, but not across borders.

2.2.4. Firm Behavior

Producers of the non-tradable good maximize their profits in the perfectly competitive environment by choosing the optimal input mix of labor and capital, taking the prices of inputs and the output as given. Competition in the non-tradable good industry brings about marginal cost (equals average cost) pricing, and since the unit cost is $c_s = \frac{1}{A}\left(\frac{w}{\beta}\right)^{\beta}\left(\frac{r}{1-\beta}\right)^{1-\beta}$, one obtains $w = r^{\frac{\beta-1}{\beta}}$.

Firms that produce various components take the composite price index for the intermediate good as well as the national income as given and each firm maximizes its profit by choosing the price of a component. As there is no asymmetry in the substitutability of components, the choice of the degree of differentiation relative to other products is not introduced at entry and firms simply decide whether to enter or not. Profit maximization equates marginal revenue to marginal cost. Hence I assume in the standard Chamberlinian fashion that each producer conjectures that the other firms in the sector will not change their output in response to that firm's price change, and that there is a large enough number of firms producing components unable to influence the total output of the intermediate good sector (Rivera-Batiz and Rivera-Batiz, 1990). Then the demand for each component by manufacturing producers faces a constant price elasticity of σ that is exogenously given by the elasticity of substitution. This price elasticity in turn determines the markup that the firms charge. Hence the price of each component is a constant markup over the marginal cost or $p_i = \frac{\sigma}{\sigma-1} w\lambda$. It can immediately be seen that with identical technology all firms charge the same price for each component or $p_i = p$.

Free entry, on the other hand, does not allow the firms to charge a price higher than the average cost, driving profits to zero and making it unprofitable to share the demand for any given component with any other firm. Chamberlinian properties of this equilibrium require the tangency condition between demand and the average cost curve to hold, as marginal revenue equals marginal cost and price equals average cost simultaneously (Neary, 2003b). Free entry thus results in $x_i = \frac{r\theta}{w\lambda}(\sigma-1)$, implying that each firm operating in this monopolistically competitive sector produces the same level of output in the equilibrium, or $x_i = x$.

With the same prices and output levels for the components in intermediate good production, total output $I_m = n^{\frac{1}{\rho}-\frac{\sigma}{\sigma-1}}\left(\sum_{i=1}^{n} x_i^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$ reduces to $I_m = n^{\frac{1}{\rho}} x$ and the composite price index $P_I = n^{(\frac{\sigma}{\sigma-1}-\frac{1}{\rho})}[\sum_{i=1}^{n} p_i^{1-\sigma}]^{\frac{1}{1-\sigma}}$ reduces to $P_I = n^{1-\frac{1}{\rho}} p$. This implies that in a symmetric equilibrium $P_I I_m = npx$ or the input to the manufacturing assembly from the whole intermediate good sector equals total revenue from manufacturing all the individual components.

Producers of the final manufacturing good maximize their profits in the perfectly competitive environment by choosing the optimal input mix of labor and intermediate goods, taking the prices of inputs and the output as given.

I solve for the equilibrium in this autarkic economy by utilizing $P_I I_m = npx$ and by noting that the zero profit condition equates total revenue with total cost in each component-producing firm. The first-order conditions of the final assembly good producers' profit maximization imply that the total spending of the manufacturing good sector on intermediate inputs equals an exogenous share of its revenue. Since the share of income spent by consumers on the assembled manufacturing good must equal the sales in that industry, $npx = (1-\gamma)\alpha I$. This allows expressing n as the function of exogenous parameters, capital and labor endowments in the economy, and the wage rate. The first-order conditions from profit maximization in non-tradable production allow deriving labor utilized in the non-tradable sector, whereas the full employment of capital in the economy implies an expression for capital. Then the solution for the wage rate results in

$$w = \left(\frac{K(\sigma - (1-\gamma)\alpha - (1-\beta)\sigma(1-\alpha))}{L((1-\beta)\sigma(1-\alpha) + (1-\gamma)\alpha)} \right)^{1-\beta} . \tag{4}$$

Equation (4) shows that the wage rate in the economy is influenced by capital and labor endowments, parameters, and the elasticity of substitution σ. An increase in the capital stock (labor force) *ceteris paribus* would lead to an increase (decrease) in the wage rate. Hence it is the country that is relatively more capital-abundant that has a higher wage, while the size of the country has no impact. Also note that $\frac{\partial w}{\partial \sigma} > 0$, implying that greater substitutability in the production of intermediates has a positive effect on the economy-wide wage. Another result worth pointing out is that $\frac{\partial^2 w}{\partial\left(\frac{K}{L}\right)\partial\sigma} > 0$ or a higher capital-labor ratio has a greater impact on wage the more substitutable are the components in production.

The outcome for the rental rate depends on the same variables as the wage rate. Here an increase in the capital stock (labor force) *ceteris paribus* would lead to a decrease (increase) in the rental rate, identifying the factor price effect of the change in endowment. Now a country that is relatively more capital-abundant has a lower rental rate. However, $\frac{\partial r}{\partial \sigma} < 0$, implying that greater complementarity in the production of intermediates affects the economy-wide rental rate positively.

Equation (4) subsequently allows deriving the solution for endogenous n in the economy that has a monopolistically competitive sector with exogenous markups. A short-run equilibrium with a fixed number of firms will not be studied as the focus of the analysis is on the change in specialization pattern brought about by opening up to trade. Hence, due to the presence of a fixed cost, there can only be a finite number of firms operating in the equilibrium. Specifically (ignoring the integer constraint),

$$n = \frac{(1-\gamma)\alpha}{\theta}\frac{1}{(1-\beta)\sigma(1-\alpha)+(1-\gamma)\alpha}K \quad . \tag{5}$$

Note that the number of firms in the sector producing components (the equilibrium degree of specialization) depends only on the stock of capital in the economy and parameter values, being independent of the labor endowment. This parallels the solution reached by Rivera-Batiz and Rivera-Batiz (1990) for a two-sector economy that also utilizes two factors of production in the monopolistically competitive sector. On the other hand, such a solution diverges from the more common result that is derived from using only one factor of production in the monopolistically competitive sector, labor. Moreover, the dependency of n solely on capital endowment does not result from the particular form of the final good production function. Rivera-Batiz and Rivera-Batiz (1990) show, in a model where the final good is a Cobb-Douglas composite of labor, capital, and intermediate goods that the exact same relationship holds. The intuition here is that the number of firms in the intermediate good sector is driven by fixed costs, hence the absolute endowment of capital matters. It is also clear from (5) that the number of firms is increasing in the greater complementarity in the production of intermediates.

The solution for the output in the component producing sector results in

$$x = \frac{\theta}{\lambda}(\sigma-1)\left(\frac{L((1-\beta)\sigma(1-\alpha)+(1-\gamma)\alpha)}{K(\sigma-(1-\gamma)\alpha-(1-\beta)\sigma(1-\alpha))}\right) \quad , \tag{6}$$

implying that the output level of a component producer or the size of a firm is not fixed, but varies depending on the relative factor endowments in the economy. An increase in the capital stock (labor force) *ceteris paribus* would lead to a decrease (increase) in the output of each component. The aggregate output quantity of all produced components in industry nx is, however, independent of the capital stock in the economy, though directly related to the labor force. The reason is that as the size of the market expands, an increasing labor force would lead to a decrease in the wage-rental ratio and thereby to an increase in the ratio of fixed to variable costs in the component-producing firms. There would also be an increased demand for final manufactures and therefore intermediates. Then an expansion in the intermediate production would force each component producer to increase the quantity supplied, as specialization is kept unaffected and total quantity supplied expands.

Finally, note how an increase in competition brought about by capital augmentation lowers the final good price p_m for consumers. Since $p_m = \frac{1}{\gamma^{\gamma}(1-\gamma)^{1-\gamma}}(w)^{\gamma}(P_I)^{1-\gamma}$ due to competitive pricing, an increase in n lowers the final manufacturing good price, even though $\frac{\partial^2 p_m}{\partial n \partial w} < 0$, implying that increasing specialization has a weaker impact on the final good price when the wage rate is also increasing.

To complete the autarkic equilibrium of this model I focus on factor allocations. Capital used in the non-tradable sector of this economy follows from the full-employment condition. Labor employed in the manufacturing final good sector can be derived from the first-order conditions of the manufacturing production. Namely, $L_m = nx\lambda\left(\frac{\gamma}{1-\gamma}\right)\left(\frac{\sigma}{\sigma-1}\right)$ and since the amount of labor employed in the intermediate good sector $L_I = nx\lambda$, it follows that the allocation of labor between manufacturing and the intermediate's production is determined solely by the parameters of the model.

2.3 Free Trade

Consider next that countries can open up to trade. I begin the analysis by examining the pattern of production and by determining factor price equalization. I next concentrate on the pattern of specialization (firm location) and trade to show how vertical specialization between countries differing in their relative factor endowments evolves. I then explain the formation of industrial structure under free trade and conclude by discussing the possibility of factor mobility.

Let there be two countries, home and foreign, that have three industries as presented above and make use of two factors of production and utilize non-homothetic technology in producing components. In accord with the standard Heckscher-Ohlin assumption the countries are identical in all respects (in terms of preferences and technology) except possibly their relative factor endowments. The factors of production (capital and labor) are perfectly mobile across three production sectors, but not across countries.

2.3.1. Integrated Equilibrium and Factor Price Equalization

Given the technologies, preferences, and closed economy equilibrium outcomes presented in the previous section, I am now ready to study the equilibrium of an integrated world economy and the characteristics of the factor price equalization set of endowment distributions that allow a replication of such an economy when countries engage in free trade.

2.3.2. Pattern of Production and Factor Price Equalization

In what follows I allow trade in the manufacturing final good Q_m and individual specialized components x. The purpose of this exercise is to analyze how trade develops between the final manufacturing good and individual intermediate components, implying vertical specialization between the countries. Note that if instead of the non-tradable final good sector intermediate components were non-tradable, then the integrated economy could only be reproduced if all components and assembly were located in one country as studied by Helpman and Krugman (1985). If there were trade in intermediate good bundles, but not in individual components, then the integrated equilibrium could be replicated only if the number of firms is equal; if there is also trade in individual components, it would make intermediate good bundle trade redundant, as shown by Markusen (1989). If the tradability of the final goods is reversed, then it can be shown that the number of component producers will be proportionate to relative country size in the trading equilibrium and the only trade that takes place is intra-industry trade in components, hence there is no vertical specialization. I therefore focus on the analysis of the tradability of individual components and the final good that utilizes these intermediates for its output.

In a free trade equilibrium, the output of each component would be concentrated in only one country and the two countries would produce a distinct variety of components, for the same reason that each component is produced by only one firm in autarky (Ethier, 1982). Then the same number of components $n^* = n^h + n^f$ (where superscript h denotes home and f foreign and $*$ relates to the world variable) becomes available to both countries' final manufacturing good sector for intermediate usage as the countries open up to trade.

The pattern of production (when both countries produce the components) can be studied by examining how much of the total value of the output of components is utilized by final good producers at home and abroad. In this way the setup is different from what is usually considered, namely that in the consumption case the total value of output at home is equal to domestic residents' and foreign residents' expenditure on the goods (which is the home number of firms to total firms fraction of income both home and abroad). Here instead what happens is that domestic final good producers will exhaust a fraction $\frac{n^f}{n^h + n^f}$ of their total intermediates' spending on those components that are produced abroad and a fraction $\frac{n^h}{n^h + n^f}$ on those that are produced domestically. Then the total value of output of domestically produced components equals the sum of domestic and foreign final good firms' respective expenditures, or $n^h p^h x^h = \frac{n^h}{n^h + n^f} P_I^h I_m^h + \frac{n^h}{n^h + n^f} P_I^f I_m^f$, and similarly for the components produced abroad. This expression determines market clearing at the intermediate good market when countries open up to trade.

Since there are no barriers to trade and no transportation costs under consideration, relative prices of traded goods equalize. Utilizing the expression for the final good price and intermediate good price at home and abroad, this would imply $\frac{P_I^h}{P_I^f} = \frac{w^h}{w^f}$. Note that the composite price index is the same at the world level (due to the intermediate good sector having a total of $n^* = n^h + n^f$ components available for manufacturing input), or $P_I^h = P_I^f$. A formal way to see this is to substitute the expression of the composite price index to the outcome above, which would imply that the number of firms in the composite price index has to be the same across countries. Factor price equalization (equalization of wages) then ensues.

There is another way to show that factor price equalization holds. The demand for each component can straightforwardly be derived from the cost function, corresponding to the production function for intermediate goods and making use of Shepard's lemma, resulting in $x^h = n^{(\frac{1}{\rho}-\frac{\sigma}{\sigma-1})(\sigma-1)}(p^h)^{-\sigma}\left[\left(P_I^h\right)^{\sigma} I_m^h + \left(P_I^f\right)^{\sigma} I_m^f\right]$ for a single home component. An analogous expression holds for the foreign variable. Dividing the demand for components both at home and abroad results in $\frac{x^h(p^h)^{\sigma}}{x^f(p^f)^{\sigma}} = \left(\frac{n^h}{n^f}\right)^{(\frac{1}{\rho}-\frac{\sigma}{\sigma-1})(\sigma-1)}$. Simplifying this expression by substituting the solutions for individual component output and price, on the other hand, implies $\left(\frac{w^h}{w^f}\right)^{\frac{\beta}{\beta-1}+(\sigma-1)} = \left(\frac{n^h}{n^f}\right)^{(\frac{\sigma-1}{\rho}-\sigma)}$. Since the number of firms is not (necessarily) equal in the two countries, the wage rates have to equal. It is also clear that the output of specialized intermediate good production is also the same in both countries as is the price of the intermediate good.

Note that since the number of firms can differ at home and abroad, free trade in components imposes a parameter restriction on the model, since the above straightforwardly implies $\rho = \frac{\sigma-1}{\sigma}$. This parameter restriction allows considerable simplification, since the prices and outputs of specialized components are equalized across countries, the expression for the total world output of intermediate goods evolves into $I_m^* = x^*\left(n^{h\left(\frac{1}{\rho}\frac{\sigma-1}{\sigma}\right)} + n^{f\left(\frac{1}{\rho}\frac{\sigma-1}{\sigma}\right)}\right)^{\frac{\sigma}{\sigma-1}}$ and the respective composite price index becomes $P_I^* = p^*\left(n^{h\left(\frac{\sigma-1}{\rho}-\sigma+1\right)} + n^{f\left(\frac{\sigma-1}{\rho}-\sigma+1\right)}\right)^{\frac{1}{1-\sigma}}$. When $\rho = \frac{\sigma-1}{\sigma}$, the total world output in the intermediate good sector simplifies to $I_m^* = \left(n^h + n^f\right)^{\frac{1}{\rho}} x^*$ and the composite price index solves for $P_I^* = \left(n^h + n^f\right)^{1-\frac{1}{\rho}} p^*$. Moreover, even when the number of firms at home and abroad happens to be the same, the parameter restriction still holds. For that it suffices to examine market clearing at the intermediate good market when there is trade, utilizing the demand as derived from Shephard's lemma and substituting for the expression for the composite price index. Hence it is opening up to trade across the two markets and allowing components to be exchanged costlessly that drives the parameter restriction between the elasticity of substitution and scale economies. Lemma 1 follows.

Lemma 1 *Free trade in individual components and final assembly goods results in* $\rho = \frac{\sigma - 1}{\sigma}$*, due to market clearing in the intermediate good industry at the world level. This parameter restriction implies that the elasticity of substitution and scale economies are tied up in a manner commonly (unsatisfactorily) assumed in the monopolistically competitive models (see Neary (2003b) for a discussion).*

Proof See Appendix B2. ■

In order to comply with the integrated equilibrium factor price equalization, the countries' endowments have to be sufficiently similar in the sense that their relative endowments lie in between the integrated equilibrium gross factor intensities of tradable sectors (Helpman and Krugman, 1985).

The factor price equalization set for the model has been depicted in Figure B1 in Appendix B for certain parameter values, such that the black line depicts gross factor intensity (in terms of labor-capital ratios) for the final assembled manufacturing good and the red line for intermediate component production in the integrated equilibrium. Factor intensities are dependent on parameter values; I have presented outcomes for various elasticities of substitution and two types of labor cost shares of non-tradable good. It then follows that both countries' relative endowments must lie in between the two depicted lines to ensure factor price equalization in free trade.

2.3.3. Free Trade Equilibrium and the Location of Firms

Under autarky, a relatively labor-abundant country would have a lower wage and higher rental rate, whereas opening up to trade would lead to the convergence of factor prices as countries specialize. Hence opening up to trade leads to a higher wage rate and lower rental rate as compared to autarky for a labor-abundant country and conversely for a capital-abundant one. It can be shown that the common wage rate becomes

$$w^* = \left(\frac{(K^h + K^f)(\sigma - (1-\gamma)\alpha - (1-\beta)\sigma(1-\alpha))}{(L^h + L^f)((1-\beta)\sigma(1-\alpha) + (1-\gamma)\alpha)} \right)^{1-\beta}. \tag{7}$$

The expression for the number of component-producing firms or the equilibrium degree of specialization at home can be derived by making use of the non-tradable sector equilibrium and equalized factor prices, resulting in

$$n^h = \frac{(1-(1-\alpha)(1-\beta))K^h}{\theta} - \\ - \frac{(1-\alpha)(1-\beta)(\sigma-(1-\gamma)\alpha-(1-\beta)\sigma(1-\alpha))}{\theta((1-\beta)\sigma(1-\alpha)+(1-\gamma)\alpha)} \frac{L^h(K^h+K^f)}{(L^h+L^f)}. \tag{8}$$

Proposition 1 *Free trade in intermediate components and the final manufacturing good between two countries that are identical in all other respects than their relative factor endowments will increase the number of firms in a relatively capital-abundant country and decrease it in a relatively labor-abundant country.*

Proof Subtract (5) from (8) to reach $n^{h(trade)} > n^{h(autarky)}$ if and only if $\frac{K^h}{L^h} > \frac{K^f}{L^f}$. ■

Hence when trade opens up and countries do not differ in their relative factor endowments, but differ for example in size, each of them will continue to produce exactly the same number of components as in autarky. The fact that the pattern of production remains unchanged forms a basis for a well-known result in intra-industry trade under monopolistic competition in that similar countries are the ones to engage in such trade, increasing the volume of trade (Krugman, 1981). Here the pattern of production changes in accordance with relative factor endowments, but clearly if countries' factor proportions are close to each other, then the change in the pattern of production is smaller and hence the volume of trade in intermediate goods is larger.

Note how, compared to autarky, equation (8) reveals that the number of components produced no longer depends solely on the parameter values and domestic capital endowment. In fact, even though $\frac{\partial n^h}{\partial K^h} > 0$ as before, $\frac{\partial n^h}{\partial K^f} < 0$, $\frac{\partial n^h}{\partial L^h} < 0$ and $\frac{\partial n^h}{\partial L^f} > 0$. Thus an increase in capital endowment in another country hinders domestic horizontal specialization, while an enlargement in labor endowment abroad encourages it. A population increase at home also discourages an increase in the number of firms, as it raises the ratio of fixed to variable costs. The total number of firms to produce components in the world nevertheless remains the same as before trade. This is due to the price elasticity of demand for components being exogenously given.

The output for individual components also changes, and this will have implications on labor readjustment across the sectors of production. The output of an individual component under free trade becomes

$$x^* = \frac{\theta}{\lambda}(\sigma - 1)\left(\frac{(L^h + L^f)((1-\beta)\sigma(1-\alpha) + (1-\gamma)\alpha)}{(K^h + K^f)(\sigma - (1-\gamma)\alpha - (1-\beta)\sigma(1-\alpha))} \right). \tag{9}$$

Compared to autarky, the output of each component would fall in the labor-abundant country and increase in the capital-abundant country. The price of components, on the other hand, would increase in the labor-abundant country and decrease in the capital-abundant country. The world aggregate output quantity of all produced components $(n^h + n^f)x$ behaves analogously to its autarky counterpart. The remaining endogenous variables under trade can straightforwardly be derived.

2.3.4. The Pattern of Trade

In order to determine how the pattern of trade evolves in this model, I start by analyzing the balance of payments in the exchange of components. The trade balance for components in the home country is specified by the difference between its total exports and imports (net exports) in component trade, which is formally given by $C = \frac{n^h}{n^h + n^f} P_I^f I_m^f - \frac{n^f}{n^h + n^f} P_I^h I_m^h = n^h p^* x^* - \frac{n^h}{n^h + n^f} P_I^h I_m^h - \frac{n^f}{n^h + n^f} P_I^h I_m^h =$ $= n^h p^* x^* - P_I^h I_m^h$. It is difficult to conceptualize at first glance what exactly the total input value of the intermediate good sector in assembly at home reveals, but since the price index is the same for both countries (home and foreign superscripts are retained for clarity), it is this part of the intermediates' output that is the share of the world's output of intermediate goods that enters assembly at home. Let us denote this share by g^h, such that $g^h = \frac{I_m^h}{I_m^h + I_m^f}$. In other words, we can express the trade balance in component trade at home as $C = n^h p^* x^* - g^h P_I^* I_m^*$. Next, given profit maximization in final assembly good production, it can readily be seen that share g^h is equal to another share, denoted by l^h, which specifies the amount of labor used for assembly at home relative to the total amount of labor used for assembly in the world, or $l^h = \frac{L_m^h}{L_m^h + L_m^f}$. This share, however, can be derived from the full-employment condition for labor as a function of parameters, the share of home capital relative to world capital, and the share of home labor relative to the world labor force size (shown in Appendix B3). After substituting to the expression above, it can be shown that $g^h P_I^* I_m^* = l^h P_I^* I_m^* = \frac{1-\gamma}{\gamma}\alpha I^h - \frac{1-\gamma}{\gamma} n^h p^* x^*$. This in turn implies that there is another way to express the component trade balance, or $C = \frac{1}{\gamma} n^h p^* x^* - \frac{1-\gamma}{\gamma}\alpha I^h$. This expression now allows for analytical clarity. In particular, it follows after some manipulation that $n^h p^* x^* > (1-\gamma)\alpha I^h$ if and only if $\frac{K^h}{L^h} > \frac{K^f}{L^f}$ or when the home country is more capital-abundant than the foreign country. In other words, a capital-abundant country produces more intermediates than it consumes, exporting the difference. In addition, note that the total demand for the final manufacturing good at home is given by αI^h. Then for balanced trade one needs the capital-abundant home country to contribute less labor to manufacturing assembly than would be the case in autarky, given the number of components produced domestically.[1] I verify that $w^* L_m^h < \gamma\alpha I^h$ if and only if $\frac{K^h}{L^h} > \frac{K^f}{L^f}$ or when the home country is more capital-abundant than the foreign country. As a result, balanced trade between specialized components and the final assembled manufacturing good develops.

I have hence identified the equilibrium with intra-industry trade as well as with trade across stages of production, since the same pattern of trade applies for all allocation points within the factor price equalization set.

Proposition 2 *The pattern of trade between the final assembled manufacturing good and individual components is such that the capital-abundant country will become a net exporter of components and an importer of the final manufacturing good. Hence vertical specialization of production evolves between countries differing in capital-labor ratios.*

Proof See Appendix B3. ■

[1] This implies that the relationship between labor employed in component production and assembly would no longer hold, i.e. $L_m{}^h \neq n^h x^* \lambda \left(\frac{\gamma}{1-\gamma}\right)\left(\frac{\sigma}{\sigma-1}\right)$ as can be shown by contradiction.

This outcome may seem rather obvious, but it is not straightforward given the international economies of scale present in intermediate good production and trading equilibrium vertical specialization. The complication arises due to the number of firms changing from their autarky values and the subsequent difficulty in examining how much of the intermediate good bundle is used for assembly in which country. In this regard, in Chakraborty (2003) an analogous conclusion could have been drawn by just observing that since the number of firms in his model does not change due to trade, any adjustment in the output of component production has to be matched by an opposite adjustment in assembly labor to keep the full-employment condition intact. Hence it is straightforward to see how the pattern of trade develops in Chakraborty's (2003) setup. Here I have shown that the number of firms does not stay constant when countries open up to trade, but changes due to the differences in the relative factor endowments of trading partners. Nevertheless, the pattern of trade is sustained in accordance with comparative advantage; moreover, larger differences in relative factor endowments reinforce more significant vertical specialization of production.

To conclude the discussion, note that each country consumes the final manufacturing good proportionally to its income, or in the home country $Q_m^{hD} = s^h Q_m^*$, where $s^h = \frac{I^h}{I^h + I^f}$ is the home country's share in the world income. It is also known how much labor in each country is employed in the intermediate good and final manufacturing good sectors. At the world level $Q_m{}^* = \left(L_m{}^*\right)^{\gamma}\left(I_m{}^*\right)^{1-\gamma}$, where $L_m^* = (n^h + n^f)x^*\lambda\left(\frac{\gamma}{1-\gamma}\right)\left(\frac{\sigma}{\sigma-1}\right)$.

Two clarifications are called for. First, when relative factor endowments do not differ across countries, then there is no vertical specialization, each country would continue to have its autarky number of firms, and only intra-industry trade in components would take place.

Second, the pattern of production and trade as derived above applies only when both countries produce individual components or when relative factor endowments are similar enough such that they lie within the factor price equalization set. If this is not the case and relative factor endowments lie outside of this set, then there is no replication of the integrated equilibrium. Factor prices would then be unequal, but even if a relatively labor-abundant country has so little capital that it produces no components, a capital-abundant country that produces all the components would still continue to assemble. It can be shown that there is never a full agglomeration of production.

2.3.5. Industrial Structure under Free Trade

Given the comparative advantage-based specialization between countries as discussed above, more can be said about the significance of this change from autarky. It is well-known with one factor of production increasing-returns industries that when there are no trade (transport) costs, then whichever country is larger would produce all the differentiated products. On the other hand, when there are trade costs only on increasing-returns goods, then a "home market" effect ensues, such that all else being equal producers would concentrate in the larger market and the larger market would be a net exporter of this good (Krugman, 1980; Krugman and Helpman, 1985). Equivalently, the large country would acquire a share in the world's production of differentiated goods that would exceed its share in world income. Davis (1998) yet showed that when there are trade costs on both increasing-returns and homogeneous good, the "home market" effect disappears and instead proportional equilibrium holds.

I next show that industrial structure replicating the accumulation of the increasing-returns sector is also the outcome of vertical specialization, but it is not the market size and trade costs that determine the outcome, but simply the differences in relative factor endowments with no trade costs present. I already demonstrated that it is the capital-abundant country that is the net exporter of the increasing-returns industry. Note that the outcome $n^h p^* x^* > (1-\gamma)\alpha I^h$ and $w^* L_m^h < \gamma\alpha I^h$ for a capital-abundant country implies, due to the equilibrium of demand and supply at the world level, that $\frac{n^h}{n^h + n^f} > s^h$ and $l^h < s^h$.

This means that vertical specialization leads to a more-than-proportional increase in the number of component producers in a capital-abundant country, since the number of firms does not stay constant, but changes in response to the difference in relative factor proportions as countries open up to trade. The exact expressions for the shares of the home country in the total number of firms and world income are presented in Appendix B4.

Proposition 3 *Vertical specialization under free trade implies that a capital-abundant country accumulates a more-than-proportionate share of differentiated goods* *industry and it contributes a less-than-proportionate share of labor to final good assembly irrespective of country size. Formally, a capital-abundant country will have* $\frac{n^h}{n^h + n^f} > s^h > l^h$ *and a labor-abundant country* $\frac{n^h}{n^h + n^f} < s^h < l^h$.

For comparison, now let the final good tradability be reversed, such that the final manufacturing good becomes non-tradable and the currently non-tradable sector becomes tradable (such that there is no vertical specialization). Then it can be shown that factor price equalization would still ensue and it would be known that home production of the final manufacturing good would have to equal home consumption, formally $Q_m^{hS} = Q_m^{hD} = sQ_m^*$.

This in turn implies that $\frac{n^h}{n^h + n^f} = s^h = l^h$. But then $\frac{n^h}{n^f} = \frac{I^h}{I^f}$ or the equilibrium is proportional. The only trade that takes place is the intra-industry trade in components. Clearly, the equilibrium is also proportional when there are no endowment differences between countries and trade takes place between the components and the final assembled good. The latter represents the best-known trade outcome of the monopolistic competition models when there are no trade costs.

2.3.6. Factor Mobility

Even though the model is analyzed assuming immobile factor endowments between countries, factor mobility without any impediments substitutes for the outcomes of free trade.

In this regard it is interesting to relate the model of vertical specialization as derived above to the "footloose capital" model as introduced by Martin and Rogers (1995). If there is free trade and free capital movement, such that the ownership of capital does not change, but physical location will, then the change in the number of firms from autarky as discussed earlier can be interpreted as occurring due to the relocation of firms. Then the mobility of capital would imply that the firms tend to relocate to a capital-abundant country irrespective of country size and that bigger differences in countries' relative factor endowments would enforce such relocation.

2.4 Welfare Implications of Trade

It is well known that welfare analyses conducted in the “home market” presence give particular advantage to the large country, partly due to the lower composite price index for differentiated manufactures. In the present model the welfare advantage from a lower price index is utilized by both countries since both use the same number of intermediates in assembling the final good. As a result, the outcomes of gains from trade and the respective differences between countries operate mainly through changes in factor prices.

Since factor prices here change in opposite directions, there are divergent effects for countries differing in their capital-labor ratios when countries open up to trade. In particular, a relatively labor-abundant country would gain from an increase in the wage rate, but lose from a decrease in the rental rate as a result of trade. A relatively capital-abundant country, on the other hand, would gain from an increase in the rental rate and lose from a decrease in the wage rate. The resulting outcome on welfare will therefore depend on which effect dominates.

Utilizing an indirect utility function it is straightforward to show that a change in welfare can be expressed by $\hat{V} = \hat{I} - \alpha \hat{p}_m$, where a hat denotes proportional (percentage) change. Since national income in the economy is given by $I = wL + rK$, the change in income in proportional terms can be expressed by $\hat{I} = \Theta_L \widehat{w} + \Theta_K \widehat{r}$ (assuming there is no change in domestic endowments), where $\Theta_L = \frac{wL}{I}$ and $\Theta_K = \frac{rK}{I}$. Note that the proportional change in the home rental rate can be calculated to equal $\widehat{r} = \left(\frac{L^h + L^f}{K^h + K^f} \right)^{\beta} \cdot \left(\frac{K^h}{K^h} \right)^{\beta} - 1$, whereas the proportional change in the home wage rate is $\widehat{w} = \left(\frac{K^h + K^f}{L^h + L^f} \right)^{1-\beta} \cdot \left(\frac{L^h}{K^h} \right)^{1-\beta} - 1$ (and analogously for the foreign country). On the other hand $\hat{p}_m = \widehat{w} + (1-\gamma)(1-\frac{1}{\rho})\hat{n}$.

It is then clear that the trade-off between the income change accruing from the rental rate and the wage rate will depend on parameter value β (the factor share of labor in non-tradable output) and how much the domestic relative factor endowment differs from the foreign one. In order to comply with integrated equilibrium factor price equalization, the countries' endowments have to be sufficiently similar in the sense that their relative endowments lie in between the integrated equilibrium factor intensities of tradable sectors. I have illustrated in Figure 2B in Appendix B some possible welfare outcomes corresponding to a factor price equalization set with $\beta = 0.6$, where the magnitude of gain is represented on the vertical axis.

In general, a labor-abundant country is likely to gain more from trade than a capital-abundant country. When relative factor endowments are similar (home capital stock is low), then a capital-abundant country gains more. When factor proportions diverge, a labor-abundant country is able to gain significantly from trade. In any case, both countries gain from vertical specialization. Note that a country's income decomposition also matters. A labor-abundant country is yet more likely to gain, *ceteris paribus*, if it has a large labor share of income.

It is interesting to observe that even though productivity in the intermediate good production increases and reallocations due to trade allow the capital-abundant country to expand its increasing-returns sector, it does not in general gain as much from trade as a labor-abundant country.

2.5 Conclusions

The reallocation of resources as countries open up to trade has been a well-analyzed topic, except for the precise analysis of conditions that lead to vertical specialization between countries that differ in capital-labor ratios. I develop a three-sector model of final, intermediate and non-tradable goods, incorporating costly assembly and increasing returns, to study such conditions and the ensuing trade pattern. Inclusion of the third sector in the model allows me to derive precise predictions on factor reallocations as well as to show that welfare outcomes do not depend solely on scale effects.

Three main predictions emerge: First, compared to autarky, the number of firms increases in a capital-abundant country and decreases in a labor-abundant country. Second, vertical specialization between countries differing in capital-labor ratios is determined by endowment differences and a capital-abundant country becomes the net exporter of components. The third and most important result establishes that vertical specialization under free trade will result in a capital-abundant country accumulating a more-than-proportionate share of differentiated goods industry irrespective of country size. It will contribute a less-than-proportionate share of labor to manufacturing assembly.

I also show that the welfare implications of trade are always positive, but the expansion of the increasing-returns sector in the capital-abundant country will not in general make it gain more than the labor-abundant country, whose increasing-returns sector contracts.

Future research would need to examine how the inclusion of trade costs changes the results above, in particular how the location of firms and industrial structure is dependent on country size once trade costs are included in the analysis.

2.6 Appendix B

B1. Proof of $\sigma-(1-\gamma)\alpha-(1-\beta)\sigma(1-\alpha)>0$

Since $\sigma-(1-\gamma)\alpha-(1-\beta)\sigma(1-\alpha)=\sigma(1-(1-\beta)(1-\alpha))-(1-\gamma)\alpha$ is increasing in σ and $\sigma>1$, this expression achieves its minimum at $\sigma\to 1$. Rewrite the above with $\sigma=1$ to reach $1-(1-\beta)(1-\alpha)-(1-\gamma)\alpha=\beta(1-\alpha)+\alpha\gamma>0$. ■

B2. Proof of Lemma 1

One way to see that Lemma 1 holds follows directly from observing the equality $\left(\frac{w^h}{w^f}\right)^{\frac{\beta}{\beta-1}+(\sigma-1)}=\left(\frac{n^h}{n^f}\right)^{(\frac{\sigma-1}{\rho}-\sigma)}$. On the other hand I can also make use of the expressions for the world intermediate good output $I_m^*=x^*\left(n^{h\left(\frac{1}{\rho}\frac{\sigma-1}{\sigma}\right)}+n^{f\left(\frac{1}{\rho}\frac{\sigma-1}{\sigma}\right)}\right)^{\frac{\sigma}{\sigma-1}}$ and the world composite price index $P_I^*=p^*\left(n^{h\left(\frac{\sigma-1}{\rho}-\sigma+1\right)}+n^{f\left(\frac{\sigma-1}{\rho}-\sigma+1\right)}\right)^{\frac{1}{1-\sigma}}$. Note that at the world level, $P_I^*I_m^*=(n^h+n^f)p^*x^*$ since components from both countries are available as inputs. But then $P_I^*I_m^*=p^*x^*\left(n^{h\left(\frac{1}{\rho}\frac{\sigma-1}{\sigma}\right)}+n^{f\left(\frac{1}{\rho}\frac{\sigma-1}{\sigma}\right)}\right)^{\frac{\sigma}{\sigma-1}}\cdot\left(n^{h\left(\frac{\sigma-1}{\rho}-\sigma+1\right)}+n^{f\left(\frac{\sigma-1}{\rho}-\sigma+1\right)}\right)^{\frac{1}{1-\sigma}}=(n^h+n^f)p^*x^*$. Rewrite this expression to reach $n^{h\left(\frac{\sigma-1}{\rho}-\sigma+1\right)}+n^{f\left(\frac{\sigma-1}{\rho}-\sigma+1\right)}=(n^h+n^f)^{1-\sigma}\left(n^{h\left(\frac{1}{\rho}\frac{\sigma-1}{\sigma}\right)}+n^{f\left(\frac{1}{\rho}\frac{\sigma-1}{\sigma}\right)}\right)^{\sigma}$.

These two sides are equal if and only if $\rho=\frac{\sigma-1}{\sigma}$. ■

B3. Proof of Proposition 2

First note from the full-employment condition for labor that $L_m^h=L^h-\lambda n^h x^*-\frac{\beta(1-\alpha)I^h}{w^*}$ and total labor used for assembly $L_m^*=\frac{(L^h+L^f)\sigma\alpha\gamma}{(\sigma-(1-\gamma)\alpha-(1-\beta)\sigma(1-\alpha))}$. From this it can be shown that $l^h=\frac{L_m^h}{L_m^*}=$

$= \frac{\alpha - \sigma(1-(1-\alpha)(1-\beta))}{\sigma\alpha\gamma}((1-\beta)\sigma(1-\alpha)+(1-\gamma)\alpha)\frac{K^h}{K^h+K^f} + \frac{\alpha+\sigma(1-\alpha)(1-\beta)}{\sigma\alpha\gamma}\cdot$ $\cdot(\sigma-(1-\gamma)\alpha-(1-\beta)\sigma(1-\alpha))\frac{L^h}{L^h+L^f}$. I substitute this to express g^h and derive the outcome for trade balance.

Next, to determine the direction of trade as specified in Proposition 2, I focus on the balance of component trade $C = \frac{1}{\gamma}n^h p^* x^* - \frac{1-\gamma}{\gamma}\alpha I^h$. Noticing that $n^h p^* x^* = n^h r^* \theta\sigma$ and substituting for n^h allows us to reach $C = ((1-\alpha)\sigma(1-\beta)+(1-\gamma)\alpha)\frac{1}{\gamma}w^*\frac{L^*}{K^*}K^h - ((1-\alpha)\sigma(1-\beta)+(1-\gamma)\alpha)\frac{1}{\gamma}w^*\overline{L}^h =$ $= (L^f K^h - L^h K^f)\left((1-\alpha)\sigma(1-\beta)+(1-\gamma)\alpha\right)\frac{1}{\gamma}\frac{w^*}{K^*}$. Here $K^* = K^h + K^f$ and respectively for labor. This expression is positive for $\frac{L^f}{K^f} > \frac{L^h}{K^h}$ and negative for $\frac{L^f}{K^f} < \frac{L^h}{K^h}$.

To show what sign $w^* L_m^h - \gamma\alpha I^h$ takes, note again that $L_m^h = L^h - \lambda n^h x^* - \frac{\beta(1-\alpha)I^h}{w^*}$ and $L_s = \beta(1-\alpha)\frac{I^h}{w^*}$. After substituting, $w^* L_m^h - \gamma\alpha I^h = ((1-\alpha)\sigma(1-\beta)+(1-\gamma)\alpha)w^*\overline{L}^h -$ $-((1-\alpha)\sigma(1-\beta)+(1-\gamma)\alpha)w^*\frac{L^*}{K^*}K^h = (L^h K^f - L^f K^h)\cdot\left((1-\alpha)\sigma(1-\beta)+(1-\gamma)\alpha\right)\frac{w^*}{K^*}$. This expression is positive for $\frac{L^f}{K^f} < \frac{L^h}{K^h}$ and negative for $\frac{L^f}{K^f} > \frac{L^h}{K^h}$. ■

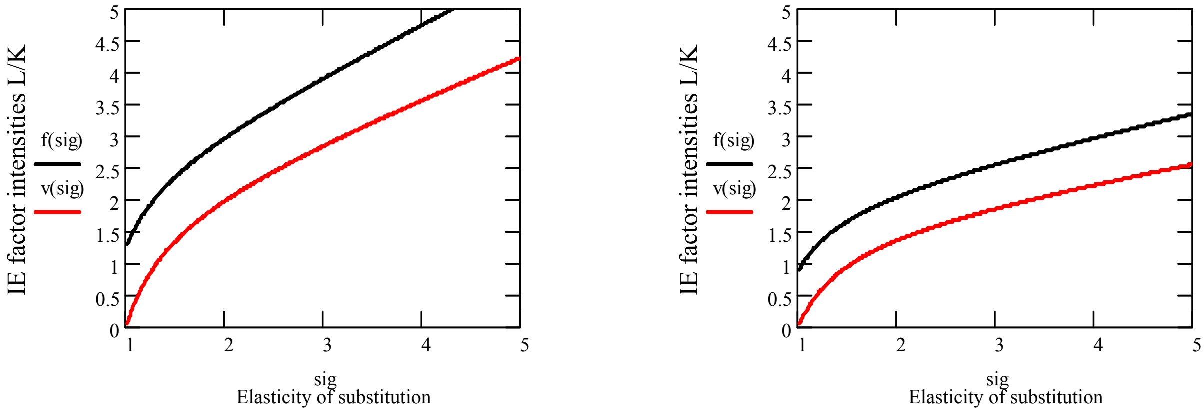
B4. Expressions for shares $\frac{n^h}{n^h+n^f}$ and s^h

From $l^h P_I^* I_m^* = \frac{1-\gamma}{\gamma}\alpha I^h - \frac{1-\gamma}{\gamma}n^h p^* x^*$ in the text it can readily be seen that $l^h = \frac{1}{\gamma}s^h - \frac{1-\gamma}{\gamma}\frac{n^h}{n^h+n^f}$. Then express $s^h = \gamma l^h - (1-\gamma)\frac{n^h}{n^h+n^f}$.

The share for the number of firms can be derived by dividing the outcome for the home number of firms by the total number of firms, which after some manipulation results in $\frac{n^h}{n^h+n^f} = \frac{1-(1-\alpha)(1-\beta)}{(1-\gamma)\alpha}((1-\beta)\sigma(1-\alpha)+(1-\gamma)\alpha)\frac{K^h}{K^h+K^f} -$ $-\frac{(1-\alpha)(1-\beta)}{(1-\gamma)\alpha}(\sigma-(1-\gamma)\alpha-(1-\beta)\sigma(1-\alpha))\frac{L^h}{L^h+L^f}$.

Substitution to the home share in world income, on the other hand, results in

$$s^h = \frac{1}{\sigma}((1-\beta)\sigma(1-\alpha)+(1-\gamma)\alpha)\frac{K^h}{K^h+K^f}+\frac{1}{\sigma}(\sigma-(1-\gamma)\alpha-(1-\beta)\sigma(1-\alpha))\frac{L^h}{L^h+L^f}.$$

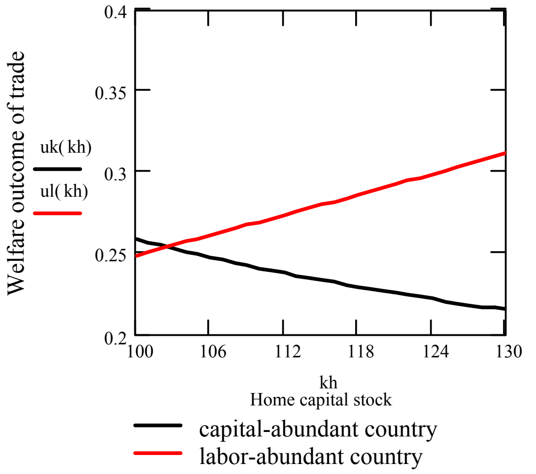


$\beta = 0.6$ $\beta = 0.8$

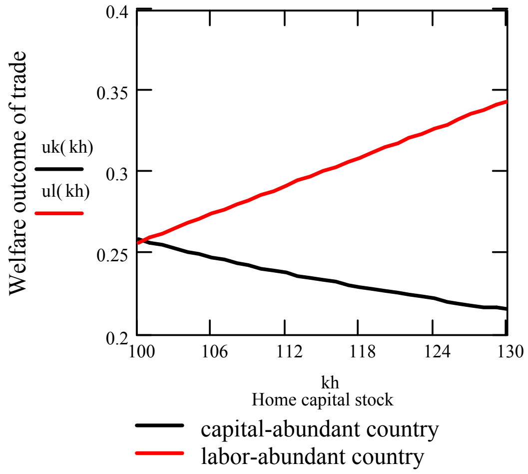
The parameter values in the above figure are as follows: $\alpha = 0.57$ and $\gamma = 0.2$. The share of tradable goods in consumption (α) is calculated as an average for Canada, Italy, the U.K. and the U.S. from 1970 and 2002 data based on OECD Annual National Accounts. The share of assembly cost (γ) in total cost is taken as an approximate average, as the electronics industry reports assembly costs in the range of 10% and the motor vehicle industry in the range of 30% (WTO). β is the labor cost share of non-tradable final good Q_s.

Capital and labor endowments in the figure are as follows: $K^h = 120$, $K^f = 100$, $L^h = 300$ and $L^f = 350$. Foreign endowments correspond to Romalis' (2004) mean labor-capital ratio of 3.5. The home country is more capital-abundant than the mean.

Figure B1. Factor price equalization set



$\beta = 0.6$



$\beta = 0.6$

The parameter values in the above figure are as follows: $\Theta_L = 0.72$, $\alpha = 0.57$, $\gamma = 0.2$ and $\sigma = 2.8$. The labor share of total income (Θ_L) is taken as a historic average of the U.S. labor share (total compensation) of national income. The share of tradable goods in consumption (α) is calculated as an average for Canada, Italy, the U.K. and the U.S. from 1970 and 2002 data based on OECD Annual National Accounts. The share of assembly cost (γ) in total cost is taken as an approximate average, as the electronics industry reports assembly costs in the range of 10% and the motor vehicle industry in the range of 30% (WTO). β is the labor cost share of final good Q_s.

Capital and labor endowments in the figure are as follows: $K^f = 100$, $L^h = 320$ and $L^f = 350$ (home capital endowment varies). Foreign endowments correspond to Romalis' (2004) mean labor-capital ratio of 3.5. The home country is more capital-abundant than the mean.

The left panel depicts both countries with labor share of income $\Theta_L = 0.72$, but the right panel changes the labor-abundant country's labor share of income to $\Theta_L = 0.9$, while the capital-abundant country has kept the previous labor share of income.

Figure B2. Welfare implications of trade

2.7 References

ACEMOGLU, D., P. ANTRAS and E. HELPMAN (2007). "Contracts and technology adoption", *American Economic Review*, 97, 916-943.

AMITI, M. (2005). "Location of vertically linked industries: agglomeration versus comparative advantage", *European Economic Review*, 49, 809-832.

ANTRAS, P. and E. HELPMAN (2004). "Global sourcing", *Journal of Political Economy,* 112, 552-580.

BATRA, R.N. and F. CASAS (1973). "Intermediate products and the pure theory of international trade: A neo-Heckscher-Ohlin framework", *American Economic Review*, 63, 297-311.

BENASSY, J.-P. (1998). "Is there always too little research in endogenous growth with expanding product variety?", *European Economic Review*, 42, 61-69.

BERGOEING, R., T. KEHOE, V. STRAUSS-KAHN and K.-M. YI (2004). "Why is manufacturing trade rising even as manufacturing output is falling?", *American Economic Review*, 94, 134-138.

BERNARD, A., S. REDDING and P. SCHOTT (2007). "Comparative advantage and heterogeneous firms", *Review of Economic Studies*, 74, 31-66.

CHAKRABORTY, B.S. (2003). "Trade in intermediate goods in a model with monopolistic competition", *Economica*, 70, 551-566.

CHIPMAN, J. (1970). "External economies of scale and competitive equilibrium", *Quarterly Journal of Economics*, 84, 347-385.

DAVIS, D. (1998). "The home market, trade, and industrial structure", *American Economic Review*, 88, 1264-1276.

DEARDORFF, A. (2001). "Fragmentation in simple trade models", *North American Journal of Economics and Finance*, 12, 121-137.

DIXIT, A.K. and J.E. STIGLITZ (1977). "Monopolistic competition and optimum product diversity", *American Economic Review*, 67, 297-308.

ETHIER, W. (1986). "The multinational firm", *Quarterly Journal of Economics*, 80, 805-833.

ETHIER, W. (1982). “National and international returns to scale in the modern theory of international trade”, *American Economic Review*, 72, 389-405.

FEENSTRA, R. (1998). “Integration of trade and disintegration of production in the global economy”, *Journal of Economic Perspectives*, 12, 31-50.

FEENSTRA, R. and G. HANSON (1996). ”Globalization, outsourcing, and wage inequality”, *American Economic Review*, 86, 240-245.

FRANCOIS, J. and D. NELSON (1998). “A geometry of specialization”, Centre for International Economic Studies, University of Adelaide, Seminar Paper 98-01.

GROSSMAN, G. and E. HELPMAN (2002a). “Integration versus outsourcing in industry equilibrium”, *Quarterly Journal of Economics*, 117, 85-120.

GROSSMAN, G. and E. HELPMAN (2005). “Outsourcing in a global economy”, *Review of Economic Studies*, 72, 135-159.

GROSSMAN, G. and E. HELPMAN (2002b). “Outsourcing versus FDI in industry equilibrium”, *Journal of the European Economic Association*, 1, 317-327.

HANSON, G., R. MATALONI and M. SLAUGHTER (2005). “Vertical production networks in multinational firms”, *Review of Economics and Statistics,* 87, 664-678.

HELPMAN, E. (1984). “A simple theory of international trade with multinational corporations”, *Journal of Political Economy*, 92, 451-471.

HELPMAN, E. (2006). “Trade, FDI, and the organization of firms”, *Journal of Economic Literature*, 44, 589-630.

HELPMAN, E. and P. KRUGMAN (1985). *Market structure and foreign trade: Increasing returns, imperfect competition, and the international economy* (MIT Press).

HUMMELS, D., J. ISHII and K.-M. YI (2001). “The nature and growth of vertical specialization in world trade”, *Journal of International Economics*, 54, 75-96.

HUMMELS, D., D. RAPOPORT and K.-M. YI (1998). “Vertical specialization and the changing nature of world trade”, *Federal Reserve Bank of New York Economic Policy Review.*

JONES, R. (1965). “The structure of simple general equilibrium models”, *Journal of Political Economy*, 73, 557-572.

KANDOGAN, Y. (2003). “Intra-industry trade of transition countries: trends and determinants”, William Davidson Institute Working Paper 566.

KRUGMAN, P. (1981). “Intra-industry specialization and the gains from trade”, *Journal of Political Economy*, 89, 959-973.

KRUGMAN, P. (1980). “Scale economies, product differentiation, and the pattern of trade”, *American Economic Review*, 70, 950-959.

KRUGMAN, P. (1991). “Increasing returns and economic geography”, *Journal of Political Economy*, 99, 483-499.

KRUGMAN, P. and A. VENABLES (1995). “Globalization and the inequality of nations”, *Quarterly Journal of Economics,* 4, 857-880.

MARKUSEN, J. (1995). “The boundaries of multinational enterprises and the theory of international trade”, *Journal of Economic Perspectives*, 9, 169-189.

MARKUSEN, J. (1990). “Micro-foundations of external economies”, *Canadian Journal of Economics*, 23, 494-508.

MARKUSEN, J. (1989). “Trade in producer services and in other specialized intermediate inputs”, *American Economic Review*, 79, 85-95.

MARKUSEN, J. and J. MELVIN (1981). “Trade, factor prices, and the gains from trade with increasing returns to scale”, *Canadian Journal of Economics*, 14, 450-469.

MARKUSEN, J., T.F. RUTHERFORD and D. TARR (2005). “Trade and direct investment in producer services and the domestic market for expertise”, *Canadian Journal of Economics*, 38, 758-777.

MARKUSEN, J. and A. VENABLES (2000). “The theory of endowment, intra-industry and multi-national trade”, *Journal of International Economics*, 52, 209-234.

MARTIN, P. and C. A. ROGERS (1995). “Industrial location and public infrastructure”, *Journal of International Economics*, 39, 335-351.

NEARY, J.P. (2003a). “Globalization and market structure”, *Journal of the European Economic Association*, 1, 245-271.

NEARY, J.P. (2003b). “Monopolistic competition and international trade theory”, in *The Monopolistic Competition Revolution in Retrospect* (eds.) S. Brakman, B.J. Heijdra (Cambridge University Press).

NEARY, J.P. (2003c). "The road less traveled: oligopoly and competition policy in general equilibrium", in *Economics for an Imperfect World: Essays in Honor of Joseph Stiglitz* (eds.) R. Arnott, B. Greenwald, R. Kanbur, B. Nalebuff (MIT Press).

NG, F. and A. YEATS (1999). "Production sharing in East Asia: Who does what for whom and why?", World Bank mimeo.

OTTAVIANO, G., TABUCHI T. and J.-F. THISSE (2002). "Agglomeration and trade revisited", *International Economic Review*, 43, 409-436.

RIVERA-BATIZ, F.L. and L.A. RIVERA-BATIZ (1991). "The effects of direct foreign investment in the presence of increasing returns due to specialization", *Journal of Development Economics*, 34, 287-307.

ROMALIS, J. (2004). "Factor proportions and the structure of commodity trade", *American Economic Review*, 94, 67-97.

SUTTON, J. (1991). *Sunk cost and market structure* (MIT Press).

VENABLES, A. (1996). "Equilibrium locations of vertically linked industries", *International Economic Review*, 37, 341-359.

VENABLES, A. (1999). "Fragmentation and multinational production", *European Economic Review*, 43, 935-945.

VENABLES, A. (1996). "Trade policy, cumulative causation, and industrial development", *Journal of Development Economics*, 49, 179-197.

YI, K.-M. (2003). "Can vertical specialization explain the growth of world trade?", *Journal of Political Economy*, 111, 52-102.