Linkage Effects, Oligopolistic Competition, and Core-Periphery

Zhou, Haiwen

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Haiwen Zhou

Abstract

The impact of international trade is studied in a general equilibrium model in which firms engage in oligopolistic competition and linkage effects are present. Results are derived analytically. If countries have the same technologies and the same labor endowment, core-periphery pattern arises only if the transportation costs are sufficiently low. The impact of a change of the level of the transportation costs on the welfare of developed countries is sensitive to the level of linkage effects. When the level of linkage effects is sufficiently high, a decrease of the level of the transportation costs will never decrease the welfare of developed countries.

Keywords: Linkage effects, oligopolistic competition, core-periphery, international trade, increasing returns

JEL Classification Numbers: F10, D43, R10

1. INTRODUCTION

With the decrease of the level of the transportation costs, markets in different countries are becoming more and more integrated [Hummels, 2007]. This process of market integration has changed the relative price of manufactured goods to agricultural goods in different countries. On the one hand, an increase of the relative price of manufactured goods in a country makes the production of manufactured goods more profitable and leads to an increase of the production of manufactured goods. On the other hand, a decrease of the relative price of manufactured goods in a country leads to an expansion of the production of agricultural goods. Thus the process of market integration might be associated with the appearance of the core-periphery pattern in which the core mainly produces manufactured goods while the periphery mainly produces agricultural goods.[1] If the manufacturing sector is more desirable from a dynamic perspective in terms of growth potential, a decrease of the relative price of manufactured goods can be undesirable to the periphery even though there are static gains from international trade from the production of goods with comparative advantage. The appearance of core-periphery is discussed in detail in Williamson

[1] Core refers to countries that are the centers of world economic activities. Periphery refers to countries that are not the centers of world economic activities.

[2006]. For example, he shows that international trade led to deindustrialization in India in the nineteenth century.

This paper studies the impact of international trade in a general equilibrium model in which the core-periphery pattern can result. There are two types of goods: the agricultural good and manufacturing goods. The agricultural good is produced by a constant returns technology. There is a continuum of manufactured goods. In this model, because manufactured goods are produced by using the composite input and the composite input uses both labor and manufactured goods as inputs, there exist linkage effects similar to the input-output matrix [Jones, 2011].[2] With the existence of linkage effects, an entrepreneur located in a developing country may hesitate to start a new firm because the external economies from linkage effects may be absent in a developing country and starting a new business may be less profitable. To address the core-periphery pattern from international trade, it is valuable to incorporate linkage effects [Krugman and Venables, 1995].

In this model, firms producing manufactured goods engage in oligopolistic competition. In a modern economy, oligopolistic competition is an important type of market structure. Modern production technologies are usually associated with large-scale production and firms have significant market power. The importance of oligopolistic competition in the US economy since the end of the nineteenth century has been illustrated in detail in Chandler [1990]. He shows that with increasing returns to scale in production, distribution, and management, a firm with a first-mover advantage can establish a dominant position in an industry. With the antitrust laws established in the 1890s, normally a firm would not be allowed by the government to establish a monopoly position. Thus, many important industries such as the oil industry and the steel industry have been characterized by oligopolistic competition since the end of the nineteenth century.

Our framework of oligopolistic competition is convenient to study the impact of international trade: countries are neither required to have the same technologies, nor required to have the same size. Even with a two-sector model based on utility maximization and profit maximization, surprisingly, the model is quite tractable and results are derived analytically. With oligopolistic competition, a manufacturing firm's output changes with the fundamentals such as

[2] The level of linkage effects generated by an industry is the sum of the levels of forward linkages and backward linkages generated by this industry. Forward linkage refers to the use by one firm or industry of produced inputs from another firm or industry. Backward linkage refers to the provision by one firm or industry of produced inputs to another firm or industry.

the size of the market. We show that a manufacturing firm's level of output increases with the size of the market. Thus, a country with a higher population has a comparative advantage in the production of manufactured goods. Different from a model based on monopolistic competition, when countries have the same technologies and have the same labor endowment, the core-periphery pattern arises only if the transportation costs are sufficiently low. An increase in the size of the domestic population increases a domestic consumer's consumption of manufactured goods, but decreases a domestic consumer's consumption of the agricultural good. The impact of a change of transportation costs on the welfare of countries is sensitive to the level of linkage effects. Different from a model based on monopolistic competition, when the level of linkage effects is sufficiently high, a decrease of the level of transportation costs will never decrease the welfare of the core country.

Except that firms producing manufactured goods engage in oligopolistic competition rather than monopolistic competition, the setup of the model is very similar to that in Krugman and Venables [1995]. Oligopolistic competition has been frequently used to study various issues in international trade and economic geography, such as strategic trade policy [Brander, 1995], industrial and trade policies [Lahiri and Ono, 2004], cross-border mergers [Neary, 2007], economy geography [2007b], and the impact of globalization on the size distribution of firms [Zhou, 2010]. However, linkage effects have not been incorporated in the above studies.

The rest of the paper is organized as follows. First, we set up the model for a closed economy and study the properties of the autarky equilibrium. Second, we establish equilibrium conditions for countries engaging in trade and examine the properties of an equilibrium with international trade. Third, we conclude. Appendices A and B contain studies of some variations of the pattern of trade.

2. EQUILIBRIUM IN A CLOSED ECONOMY

There are two countries: home and foreign. In this section, we focus on the presentation of the home country as the analysis of the foreign country is similar. Since the description of the model is notation intensive, a table with a list of variables associated with the home country and their definitions is provided. Foreign variables are denoted by stars. For example, when the size of the population in the home country is L, the size of the population in the foreign country is $L*$.

Nomenclature

p_m : the price of a manufactured good

p_a : the price of the agricultural good

p_I : the price of the intermediate good

L_a : the level of employment in the agricultural sector

L_m : the level of employment in the manufacturing sector

x : the level of output of a manufacturing firm

n : the number of manufacturing firms producing the same manufactured good

w : the wage rate

c_a : per capita consumption of the agricultural good

c_m : per capita consumption of a manufactured good

z : amount of a manufactured good used in the production of the composite input

E : export of a manufactured good from the home country to the foreign country

The size of the population in the home country is L. Since an individual is assumed to have no preferences for leisure, each individual supplies one unit of labor inelastically. There are two types of goods: an agricultural good and a continuum of manufactured goods indexed by a number $\varpi \in [0,1]$ with a total measure of one. Manufactured goods are symmetric in the sense that all the manufactured goods share the same costs of production and they enter a consumer's utility function in the same way. In the following, first we study a consumer's utility maximization. Second, we study firms' profit maximization, including a firm producing the composite input and a firm producing a manufactured good. Third, we establish markets clearing conditions, including markets for labor, the agricultural good, a manufactured good, and the composite input.

2.1. Equilibrium conditions

First, we study a consumer's utility maximization. A representative consumer's consumption of the agricultural good is c_a and this consumer's consumption of manufactured good ϖ is $c_m(\varpi)$. For γ denoting a constant between zero and one, this consumer's utility function is specified as

(1) $$U = c_a{}^{1-\gamma}[\int_0^1 c_m(\varpi)^{\frac{\sigma-1}{\sigma}} d\varpi]^{\frac{\gamma\sigma}{\sigma-1}}.$$

Since firms earn profits of zero in equilibrium, the wage income w is the only source of income for consumers. The price of the agricultural good is p_a and the price of the manufactured good ϖ is $p_m(\varpi)$. A consumer's budget constraint states that her total spending on the agricultural good and manufactured goods equals her wage income:

(2) $$p_a c_a + \int_0^1 p_m(\varpi)c_m(\varpi)d\varpi = w.$$

A consumer takes the wage rate and prices of goods as given and maximizes her utility (1) subject to the budget constraint (2). From a consumer's utility maximization, the absolute value of a consumer's elasticity of demand for a given manufactured good is σ. Utility maximization requires that a consumer spends γ percent of income on manufactured goods and $1-\gamma$ percent of income on the agricultural good:

(3) $$\int_0^1 p_m(\varpi)c_m(\varpi)d\varpi = \gamma w,$$

(4) $$p_a c_a = (1-\gamma)w.$$

Second, we study firms' profit maximization. The production of each manufactured good requires a composite intermediate input. This composite input is produced by using both labor and all manufactured goods as inputs [Krugman and Venables, 1995]. The amount of labor allocated to the production of the composite input is L_m, which is endogenously determined in this model. The amount of manufactured good ϖ used in the production of the composite input is $z(\varpi)$. For a positive constant $\mu \in [0, 1)$, output of the composite input is specified as[3]

(5) $$Q = L_m{}^{1-\mu}[\int_0^1 z(\varpi)^{\frac{\sigma-1}{\sigma}} d\varpi]^{\frac{\mu\sigma}{\sigma-1}}.$$

[3] Similar to Krugman and Venables [1995], from the specification of a consumer's utility function and the above specification of the production function for the composite input, the elasticity of demand of a manufactured good for a consumer is the same as that for a firm producing the composite input. This result is used to derive equation (8).

The price of one unit of the composite intermediate input is p_I, I for intermediate. Firms producing the composite input engage in perfect competition. For a firm producing the composite input, its total revenue is $p_I L_m^{1-\mu}[\int_0^1 z(\varpi)^{\frac{1-\sigma}{\sigma}} d\varpi]^{\frac{\mu\sigma}{1-\sigma}}$. Its cost of hiring labor is wL_m and its cost of purchasing manufactured inputs is $\int_0^1 p_m(\varpi)z(\varpi)d\varpi$. Thus, the profit for a firm producing the composite input is $p_I L_m^{1-\mu}[\int_0^1 z(\varpi)^{\frac{\sigma-1}{\sigma}} d\varpi]^{\frac{\mu\sigma}{\sigma-1}} - wL_m - \int_0^1 p_m(\varpi)z(\varpi)d\varpi$. A firm producing the composite input takes the wage rate and the prices of manufactured goods as given and chooses the amount of labor and quantities of manufactured goods to maximize its profit. Optimal choice of labor and the quantities of manufactured goods for a firm producing the composite input leads to[4]

(6) $$\frac{(1-\mu)z(\varpi)}{\mu L_m} = \frac{w}{p_m}.$$

Free entry and exit in the production of the composite input leads to zero profit for a firm producing the composite input:

(7) $$p_I L_m^{1-\mu}\{\int_0^1 [z(\varpi)]^{\frac{\sigma-1}{\sigma}} d\varpi\}^{\frac{\mu\sigma}{\sigma-1}} - wL_m - \int_0^1 p_m z(\varpi)d\varpi = 0.$$

It is assumed that the production of manufactured goods uses the composite input only. To produce each manufactured good, both variable and fixed costs are needed. The marginal cost in terms of the units of the composite input needed is β and the fixed cost in terms of the units of the composite input needed is f. As a manufacturing firm's level of output is x, its total revenue is $p_m x$ and its cost of purchasing the composite input is $(f+\beta x)p_I$. Thus, this firm's profit is $p_m x - (f+\beta x)p_I$. The number of manufacturing firms producing the same good is n. Firms producing the same manufactured good are identical and they are assumed to engage in Cournot competition. A manufacturing firm takes the wage rate and the price of the composite input as given and chooses its level of output to maximize its profit. A manufacturing firm's optimal choice of output requires that marginal revenue equals marginal cost: $p_m + x\frac{\partial p_m}{\partial x} = \beta\, p_I$.[5] Combination

[4] It can be checked that the second order conditions are satisfied.
[5] It can be checked that the second order condition is satisfied.

of this equation with the result that the absolute value of the elasticity of demand of a manufactured good for a consumer and for a firm producing the composite input is σ yields

(8) $$p_m\left(1-\frac{1}{n\sigma}\right)=\beta\, p_I\,.$$

As the number of firms producing a manufactured good is real number rather than restricted to be an integer number, free entry and exit leads to zero profit for a firm producing a manufactured good:[6]

(9) $$p_m x-(f+\beta x)p_I=0\,.$$

Third, we establish market clearing conditions. The number of workers employed in the agricultural sector is L_a. The demand for labor is the sum of the demand from the agricultural sector L_a and the demand from the production of the composite input L_m. Thus, the total demand for labor is L_a+L_m. Each of the L individuals supplies one unit of labor and the total supply of labor is L. The clearance of the labor market requires that the quantity demanded equals the quantity supplied:

(10) $$L_a+L_m=L\,.$$

The agricultural good is produced by a constant returns to scale technology. An individual employed in the agricultural sector is assumed to be able to produce one unit of the agricultural good. Thus, the return for an individual employed in the agricultural sector is p_a. The return for an individual employed in the manufacturing sector is w. Since an individual may choose to be employed either in the agricultural sector or in the manufacturing sector, the returns in the two sectors should be equal:

(11) $$p_a=w\,.$$

Each consumer demands c_a units of the agricultural good and the total demand of the agricultural good is Lc_a. An individual employed in the agricultural sector supplies one unit of the agricultural good and the total supply of the agricultural good is L_a. The clearance of the market for the agricultural good requires that the quantity demanded equals the quantity supplied:

(12) $$Lc_a=L_a\,.$$

[6] For examples of oligopolistic competition with free entry, see Lahiri and Ono [2004] and Chen and Shieh [2011].

For each manufactured good, the demand is the sum of the amount used for consumption $Lc_m(\varpi)$ and the amount used in the production of the composite input $z(\varpi)$. Each of the $n(\varpi)$ firms supplies $x(\varpi)$ units of good ϖ and the total supply of this product is nx. The clearance of the market for manufactured good ϖ requires that the quantity demanded equals the quantity supplied:

(13) $$Lc_m(\varpi) + z(\varpi) = n(\varpi)\, x(\varpi) .$$

Each manufacturing firm demands $f + \beta x$ units of the composite input and the production of each manufactured good requires $n(f + \beta x)$ units of the composite input. Thus, the total demand for the composite input is $\int_0^1 n(f + \beta x) d\varpi$. Total supply of the composite input is Q. The clearance of market for the composite input requires that the quantity demanded equals the quantity supplied: $\int_0^1 n(f + \beta x) d\varpi = Q$. By combining this equation with equation (5), the clearance of market for the composite input requires that

(14) $$\int_0^1 n(\varpi)(f + \beta x) d\varpi = L_m^{1-\mu} [\int_0^1 z(\varpi)^{\frac{\sigma-1}{\sigma}} d\varpi]^{\frac{\mu\sigma}{\sigma-1}} .$$

In the following, we study the equilibrium that there is symmetry in the manufacturing sector: the number of firms producing each good n, the price p_m, per capita consumption c_m, and the output x are the same for all manufactured goods. With the symmetry among all manufactured goods, $z(\varpi)$ is simplified as z. Also, the integral can be dropped because of symmetry. Equations (3), (4), and (6)-(14) form a system of 11 equations defining a system of 11 endogenous variables p_m, p_a, p_I, L_a, L_m, x, n, w, c_a, c_m, and z as functions of exogenous parameters. An equilibrium is a vector (p_m, p_a, p_I, L_a, L_m, x, n, w, c_a, c_m, z) satisfying equations (3), (4), and (6)-(14). For the rest of this paper, the price of the agricultural good is used as the numeraire: $p_a \equiv 1$. With this normalization, the domestic wage rate is equal to one when the agricultural good is produced in the home country.

2.2. Properties of an autarky equilibrium

To study the properties of the equilibrium, we proceed by simplifying the system of eleven equations to a smaller and thus manageable number of equations by keeping variables of direct interest while eliminating other variables.

From equation (14), the number of firms producing the same manufactured good can be expressed as

$$n = \frac{L^{1-\mu} z^{\mu}}{f + \beta x}. \tag{15}$$

Plugging the value of z from equation (6) into equation (15), the number of firms producing the same manufactured good can be expressed as $n = \frac{\mu^{\mu} \gamma L}{(1-\mu)^{\mu} p_m^{\ \mu} (f + \beta x)}$. Plugging this equation into equation (8) leads to

$$\sigma \gamma \mu^{\mu} (1-\mu)^{1-\mu} L\, p_m^{\ 1-\mu} - (f + \beta x)(1-\mu) p_m - \sigma \gamma \beta L = 0. \tag{16}$$

From equations (3), (4), (6), (12), and (13), it can be shown that the value of output in the manufacturing sector $(1-\mu) p_m n x$ is equal to the percentage of income spent on manufactured goods γL:[7]

$$(1-\mu) p_m n x = \gamma L. \tag{17}$$

From equations (6) and (7), the price of the composite input can be expressed as a function of the wage rate and the price of manufactured goods:

$$p_I = \frac{1}{\mu^{\mu} (1-\mu)^{1-\mu}} w^{1-\mu} p_m^{\ \mu}. \tag{18}$$

Plugging the value of p_I from the equation (18) into equation (9) yields

$$V_1 \equiv (f + \beta x) - \mu^{\mu} (1-\mu)^{1-\mu} x\, p_m^{\ 1-\mu} = 0. \tag{19a}$$

Plugging the value of p_I from equation (19a) into equation (15) yields

$$V_2 \equiv \sigma \gamma f\, L - (1-\mu) p_m x (f + \beta x) = 0. \tag{19b}$$

[7] The percentage of income spent on manufactured goods is $\gamma w L$. Since $w=1$, so it is γL.

With the above manipulation, the system of twelve equilibrium conditions for a closed economy has been reduced to the system of two equations V_1 and V_2 defining two endogenous variables x and p_m as functions of exogenous parameters.[8]

Partial differentiation of the system of equations (19a)-(19b) with respect to x, p_m, L, and σ leads to

$$\begin{pmatrix} \frac{\partial V_1}{\partial x} & \frac{\partial V_1}{\partial p_m} \\ \frac{\partial V_2}{\partial x} & \frac{\partial V_2}{\partial p_m} \end{pmatrix} \begin{pmatrix} dx \\ dp_m \end{pmatrix} = -\begin{pmatrix} 0 \\ \partial V_2 / dL \end{pmatrix} dL - \begin{pmatrix} 0 \\ \partial V_2 / \partial \sigma \end{pmatrix} d\sigma . \tag{20}$$

For Δ denoting the determinant of the coefficient matrix, from equations (19a) and (19b), it can be shown that $\Delta = (1-\mu)(f+\beta x)[f-(1-\mu)(f+2\beta x)]$. When $\mu = 0$, $\Delta < 0$. When $\mu = 1$, $\Delta = 0$. Since Δ is a monotonic function of μ and $\mu \in [0, 1)$, it is clear that $\Delta < 0$.

Other things equal, an increase in the size of the population means an increase of the size of the market. The following proposition studies the implications of a larger market size.

Proposition 1: A manufacturing firm's level of output increases with the size of the market. The price of a manufactured good decreases with the size of the market.

Proof: An application of Cramer's rule to the system (20) leads to

$$\frac{dx}{dL} = \frac{\partial V_1}{\partial p_m} \frac{\partial V_2}{\partial L} / \Delta > 0 ,$$

$$\frac{dp_m}{dL} = -\frac{\partial V_1}{\partial x} \frac{\partial V_2}{\partial L} / \Delta < 0 . \qquad \blacksquare$$

Proposition 1 shows that an economy with a higher population has a comparative advantage in the production of manufactured goods. To understand Proposition 1, other things equal, an increase in the size of the population increases the demand for manufactured goods. The number of firms producing the same manufactured good can increase. This increased degree of

[8] Similar to models based on monopolistic competition, in general the number of equilibria may not be unique. With this point in mind, comparative statics results should be viewed as applied to either the equilibrium is unique or restricted to a stable neighborhood of an equilibrium when there are multiple equilibria. That is, a small change of parameter will not lead to a bifurcation of results such as discussed in Strogatz [2001]. Comparative statics with the possibility of multiple equilibria is illustrated in Milgrom and Roberts [1994].

competition in the product market leads to a lower markup over marginal cost for a manufacturing firm. As the markup factor is lower, a manufacturing firm's output needs to increase to make up the fixed cost of production. An increase of output leads to a lower average cost. As a firm makes a profit of zero, a lower average cost means a lower price of a manufactured good.

The impact of the size of the population in determining a country's comparative advantage is recognized by Young [1928]. Comparing United Kingdom with the United States, Young argues that the relatively higher productivity of the United States in the production of manufactured goods comes from the fact that the size of the population of United States is larger than that of the United Kingdom.

The elasticity of demand for manufactured goods plays a prominent role in Krugman and Venables [1995]. In their model, the heavy role played by the elasticity of substitution is a result that the level of output of a manufacturing firm does not change with fundamentals such as the size of the market. The elasticity of demand is a measure of the degree of markup over marginal cost of production. More controversially, it is also used to measure the degree of economies of scale.[9] In this model, the role of this parameter is simple and intuitive. The role of this elasticity is clear from equation (8). When σ increases, a manufacturing firm marks up its price over marginal cost by a lower margin. As the profit margin is lower for each unit of output, to make up the fixed cost of production, the output of a manufacturing firm needs to increase. An application of Cramer's rule to the system (20) leads to $dp_m / d\sigma < 0$ and $dx/d\sigma > 0$. Thus, in a closed economy, an increase of the elasticity of demand for manufactured goods leads to a lower markup and a lower price of a manufactured good. As the price of a manufactured good is lower, to break even, the level of output for a manufacturing firm is higher.

3. INTERNATIONAL TRADE WITH ONE COUNTRY PRODUCING THE AGRICULUTRUAL GOOD

In this section, we establish the equilibrium conditions for countries engaging in trade. Foreign consumers are assumed to have the same preferences as domestic consumers. For the remaining of this section, we assume that the labor endowment in the home country is not smaller than that in the foreign country. Thus, from Proposition 1, in autarky, other things equal, a domestic

[9] As discussed in Neary [2001] and Head and Mayer [2004], this heavy role played by the elasticity of demand may not be desirable.

consumer can enjoy a not lower level of utility than a foreign consumer. The home country may be viewed as a developed country (core) and the foreign country may be viewed as a developing country (periphery).[10]

When there is no transportation cost for both types of goods, the opening of international trade will always be beneficial to both countries, regardless of their sizes [Zhou, 2007a]. The reason is that the opening of trade has an impact similar to that of an increase of the size of the domestic population. With constant returns to scale in the agricultural sector and increasing returns to scale in the manufacturing sector, an increase of the size of the domestic population increases the level of utility of an individual.

For the remaining of this section, it is assumed that there are positive transportation costs for manufactured goods. Transportation costs for the agricultural good are assumed to be zero.[11] For t denoting a positive constant, transportation costs for manufactured goods are of the iceberg type: for $1+t$ units of a manufactured good sent out, only one unit arrives.[12]

When countries have the same technologies and the same labor endowment, the relative price of manufactured goods to the agricultural good is the same in the two countries. If there is a shock leading to different relative prices in the two countries, to make trade possible, it is necessary that $p_m^* - p_m \geq t\,p_m$. That is, the price difference in the two countries must be large enough to cover transportation costs for manufactured goods. Thus, when countries have the same technologies and the same labor endowment, the core-periphery pattern arises only if transportation costs are sufficiently low.

For two countries with the same size of the population and the same production technologies, Krugman and Venables [1995, p. 870] have argued that for some parameter values the core-periphery pattern always arises regardless of the level of transportation costs. In their model, firms engage in monopolistic competition and a firm producing the intermediate input uses all manufactured goods as inputs in the world. With homothetic preferences, a fixed percentage of income is spent on each manufactured good. Even if transportation costs are extremely high,

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[10] Since the developing country is importing manufactured goods, entrepreneurs for manufacturing firms in the developing country can suffer from the opening of international trade, as discussed in William [2006].

[11] Implications of positive transportation costs for agricultural goods are discussed in Davis [1998].

[12] The iceberg transportation cost assumption is used here because it is a simple and convenient way to model transportation costs. However, as argued in Neary [2001], this assumption does not capture increasing returns in the transportation sector.

for a manufactured good produced in the home country, there is demand for a manufactured good from the foreign country because a fixed percentage of income of foreigners has to be spent on this manufactured good and the assumption of monopolistic competition means that the foreign country is not allowed to produce this manufactured good itself. The assumption of monopolistic competition leads to their result that the core-periphery pattern arises regardless of the level of transportation costs.

In this model, when countries have the same size of the population but have access to different technologies, the core-periphery pattern may arise if transportation costs are sufficiently low. This can be demonstrated by studying the system of equations (19a) and (19b). When marginal cost β is treated as a parameter, it can be shown that a decrease of β leads to a lower price of a manufactured good. That is, a country with a better manufacturing technology (lower β) may export manufactured goods to the other country if the price difference is higher than the level of transportation costs.

3.1. Equilibrium conditions with international trade

Depending on the values of parameters such as the percentage of income spent on the agricultural good, there are different production and trade patterns for the two countries. In this section, we focus on the case that the home country specializes in the production of manufactured goods and the foreign country produces both types of goods. Other patterns of production and trade are studied in the Appendices A and B. Since the foreign country produces positive amount of the agricultural good, the wage rate in the foreign country is equal to one. Since the home country can also produce the agricultural good, the wage rate in the home country should not be lower than that in the foreign country: $w \geq w^* = 1$.

It is assumed that markets for manufactured goods in the two countries are integrated. For each manufactured good, after the opening of international trade, it is produced in both countries. For each manufactured good, part of the output in the home country is exported to the foreign country. Since the home country exports manufactured goods to the foreign country, with the iceberg transportation technology for manufactured goods, the relationship between the prices of a manufactured good in the two countries is given by

(21) $$p_m^* = (1+t)p_m.$$

For a manufactured good, let E denote the quantity exported from the home country to the foreign country. In the home country, with international trade, the demand for a manufactured good has three components: the amount used for domestic consumption Lc_m, the amount used in the production of the composite input z, and the amount used for export E. Thus, the total demand for a manufactured good is $Lc_m + z + E$. The total supply of a manufactured good in the home country is nx. The clearance of the market for a manufactured good in the home country requires that

$$Lc_m + z + E = n\,x\,. \tag{22}$$

For the E units of a manufactured good exported from the home country, only $E/(1+t)$ units arrive at the foreign country. For the foreign country, the demand for a manufactured good is the sum of the amount used for consumption $L^*c_m^*$ and the amount used in the production of the composite input z^*. Thus, total demand for a manufactured good in the foreign country is $L^*c_m^* + z^*$. The supply of a manufactured good in the foreign country is the sum of local production n^*x^* and the amount of arrived import $E/(1+t)$. Thus, total supply of a manufactured good in the foreign country is $n^*x^* + E/(1+t)$. The clearance of the market for a manufactured good in the foreign country requires that

$$L^*c_m^* + z^* = n^*x^* + \frac{E}{1+t}\,. \tag{23}$$

Equations (22) and (23) can be used to eliminate E:

$$n\,x + (1+t)n^*x^* = \frac{\gamma\, w L}{p_m} + \frac{(1+t)\gamma\, s\, L^*}{p_m^*} + z + (1+t)z^*\,. \tag{24}$$

Since a consumer's elasticity of demand for a manufactured good is the same as that for a firm producing the composite input, similar to Zhou [2007b], the optimal output choice by a domestic firm producing a manufactured good leads to

$$p_m\left(1 - \frac{x}{\sigma[n\,x + (1+t)n^*x^*]}\right) = \beta\, p_I\,. \tag{25}$$

Similarly, optimal output choice by a foreign firm producing a manufactured good leads to

$$p_m^*\left(1 - \frac{(1+t)x^*}{\sigma[n\,x + (1+t)n^*x^*]}\right) = \beta^*\, p_I^*\,. \tag{26}$$

Utility maximization for foreign consumers leads to

(27) $$\int_0^1 p_m^* c_m^* d\varpi = \gamma w^*,$$

(28) $$p_a c_a^* = (1-\gamma) w^*.$$

Optimal choice of the inputs by a foreign firm producing the composite input leads to

(29) $$\frac{(1-\mu) z^*}{\mu L_m^*} = \frac{w^*}{p_m^*}.$$

For a foreign firm producing the composite input, free entry and exit leads to zero profit:

(30) $$p_I^* L_m^{*\,1-\mu} [\int_0^1 z^{*\,\frac{\sigma-1}{\sigma}} d\varpi]^{\frac{\mu\sigma}{\sigma-1}} - w^* L_m^* - \int_0^1 p_m^* z^* d\varpi = 0.$$

For a foreign firm producing a manufactured good, free entry and exit leads to zero profit:

(31) $$p_m^* x^* - (f^* + \beta^* x^*) p_I^* = 0.$$

The foreign country produces the agricultural good for both domestic and foreign consumption. Total demand for the agricultural good is the sum of demand from the home country Lc_a and demand from the foreign country $L^* c_a^*$. Thus, total demand for the agricultural good is $Lc_a + L^* c_a^*$. Total supply of the agricultural good is L_a^*. The clearance of the market for the agricultural good requires that

(32) $$Lc_a + L^* c_a^* = L_a^*.$$

In the foreign country, total demand for labor is the sum of demand from the agricultural sector L_a^* and demand for the production of the composite input L_m^*. Thus, total demand for labor is $L_a^* + L_m^*$. Total supply of labor in the foreign country is L^*. Labor market equilibrium in the foreign country requires that

(33) $$L_a^* + L_m^* = L^*.$$

The clearance of the market for the composite input in the foreign country requires that

(34) $$\int_0^1 n^* (f^* + \beta^* x^*) d\varpi = L_m^{*\,1-\mu} [\int_0^1 (z^*)^{\frac{\sigma-1}{\sigma}} d\varpi]^{\frac{\mu\sigma}{\sigma-1}}.$$

With international trade, equations (3), (4), (6), (7), (9), and (14) are still valid. Those equations, equations (21)-(23), and equations (25)-(34) form a system of 19 equations defining a system of 19 endogenous variables p_m, p_m^*, p_a, p_I, p_I^*, L_a^*, L_m^*, x, x^*, n, n^*, w, c_a, c_a^*,

c_m, c_m*, z, $z*$, and E as functions of exogenous parameters. An equilibrium with international trade is a tuple (p_m, p_m*, p_a, p_I, p_I*, L_a^*, L_m^*, x, $x*$, n, $n*$, w, c_a, c_a^*, c_m, c_m^*, z, $z*$, E) satisfying those 19 equations.

3.2. Properties of an equilibrium with international trade

To study the properties of this equilibrium with international trade, we now reduce the system of nineteen equations for international trade to a smaller number of equations. From equations (29) and (30), the price of the composite input in the foreign country is equal to

(35) $$p_I^* = \frac{1}{\mu^\mu (1-\mu)^{1-\mu}} (p_m^*)^\mu .$$

A comparison of equation (18) with equation (35) shows that the price of the composite input in the foreign country may not necessarily be higher than that in the home country. The reason is that though the prices of manufactured goods in the foreign country are higher, the wage rate in the foreign country is lower. If the wage rate in the foreign country is sufficiently low, the price of the composite input in the foreign country will be lower than that in the home country.

In this model, $nx + (1+t)n*x*$ can be interpreted as the world "effective" supply of a manufactured good. Plugging the value of z from equation (6) and the value of $z*$ from equation (29) into equation (24) leads to the following equation with an interpretation similar to that of equation (17):

(36) $$(1-\mu) p_m [nx + (1+t)n*x*] = \gamma (wL + L*) .$$

Define the ratio of the domestic wage rate to the price of a manufactured good as $w_m \equiv w / p_m$. The system of nineteen equations with international trade is reduced to the following system of three equations defining three endogenous variables w_m, x, and w as functions of exogenous parameters:[13]

(37a) $$\Gamma_1 \equiv (f + \beta x) w_m^{1-\mu} - \mu^\mu (1-\mu)^{1-\mu} x = 0 ,$$

[13] Equations (37a)-(37c) are derived as follows. Plugging the value of p_I from equation (18) into equation (9) yields equation (37a). Plugging the value of p_I from equation (18) and the value of $nx + (1+t)n*x*$ from equation (36) into equation (25) and replacing p_m by using equation (37a) yield equation (37b). Plugging the value of $x*$ from equation (31), the value of p_I^* from equation (35), and the value of $nx + (1+t)n*x*$ from equation (36) into equation (26), replacing p_m by using equation (37a), and replacing $wL + L*$ by using equation (37b) yield equation (37c).

(37b) $$\Gamma_2 \equiv \sigma \gamma f(wL + L^*) - \mu^{\frac{\mu}{\mu-1}} w x^{\frac{\mu}{\mu-1}} (f + \beta x)^{\frac{2-\mu}{1-\mu}} = 0,$$

(37c) $$\Gamma_3 \equiv \left[(1+t)^{1-\mu}(f + \beta x)w^{1-\mu} - \beta^* x\right]^2 - (1+t)^{2-\mu} f^* f w^{1-\mu} = 0.$$

Partial differentiation of equations (37a)-(37c) with respect to w_m, x, w, L, σ, and t leads to

(38) $$\begin{pmatrix} \frac{\partial \Gamma_1}{\partial w_m} & \frac{\partial \Gamma_1}{\partial x} & 0 \\ 0 & \frac{\partial \Gamma_2}{\partial x} & \frac{\partial \Gamma_2}{\partial w} \\ 0 & \frac{\partial \Gamma_3}{\partial x} & \frac{\partial \Gamma_3}{\partial w} \end{pmatrix} \begin{pmatrix} dw_m \\ dx \\ dw \end{pmatrix} = -\begin{pmatrix} 0 \\ \partial \Gamma_2 / \partial L \\ 0 \end{pmatrix} dL - \begin{pmatrix} 0 \\ \partial \Gamma_2 / \partial \sigma \\ 0 \end{pmatrix} d\sigma - \begin{pmatrix} 0 \\ 0 \\ \partial \Gamma_3 / \partial t \end{pmatrix} dt.$$

Let Δ_Γ denote the determinant of the coefficient matrix of (38). Stability of the system requires that $\Delta_\Gamma < 0$. The following proposition studies the impact of a change of the size of the domestic population on domestic welfare.

Proposition 2: When the size of the domestic population increases, (i) the ratio of the wage rate to the price of a manufactured good in the home country increases; (ii) the level of output for a manufacturing firm in the home country increases; (iii) the wage rate in the home country decreases.

Proof: An application of Cramer's rule to the system (38) leads to

$$\frac{dw_m}{dL} = \left(\frac{\partial \Gamma_1}{\partial x}\frac{\partial \Gamma_2}{\partial L}\frac{\partial \Gamma_3}{\partial w}\right)/\Delta_\Gamma,$$

$$\frac{dx}{dL} = -\left(\frac{\partial \Gamma_1}{\partial w_m}\frac{\partial \Gamma_2}{\partial L}\frac{\partial \Gamma_3}{\partial w}\right)/\Delta_\Gamma,$$

$$\frac{dw}{dL} = \left(\frac{\partial \Gamma_1}{\partial w_m}\frac{\partial \Gamma_2}{\partial L}\frac{\partial \Gamma_3}{\partial x}\right)/\Delta_\Gamma.$$

It can be shown that $\frac{\partial \Gamma_1}{\partial w_m} > 0$, $\frac{\partial \Gamma_2}{\partial L} > 0$, and $\frac{\partial \Gamma_3}{\partial w} > 0$. Thus $\frac{dw_m}{dL} > 0$, $\frac{dx}{dL} > 0$, and $\frac{dw}{dL} < 0$. ■

In this model, a given percentage of income is spent on each type of good. As an increase in the size of the population leads to the ratio of the wage rate to the price of a manufactured good in the home country to increase, an increase in the size of the domestic population increases a domestic consumer's consumption of manufactured goods. As an increase in the size of population leads to the wage rate in the home country to decrease and the price of the agricultural good is normalized to one, an increase in the size of the population decreases a domestic consumer's consumption of the agricultural good. To understand Proposition 2, an increase in the size of the domestic population increases the size of the market. Thus, the output of a manufacturing firm increases. The ratio of the wage rate to the price of manufactured goods in the home country increases because a larger market leads to a lower level of markup. Since the wage rate in the foreign country is fixed at one, the price of a manufactured good in the foreign country decreases. Through equation (21), this means that the price of a manufactured good in the home country also decreases and it leads to a lower wage rate in the home country.

The result that the ratio of wage rate to the price of manufactured goods increases with the size of the population is roughly consistent with the industrialization experience of countries such as the United Kingdom. Maddison [1982] records that population growth accompanies the process of industrialization. As the real wage rate increased during the process of industrialization, the size of the population increased at the same time.

What is the impact of a change in the size of the foreign population on the welfare of the foreign country? Similar to the system of equations (37a)-(37c), from the equilibrium conditions with international trade, we can derive the following system of equations:

(39a) $$\Phi_1 \equiv (f^* + \beta^* x^*) - \mu^{\mu}(1-\mu)^{1-\mu} x^* p_m^{*\,1-\mu} = 0,$$

(39b) $$\Phi_2 \equiv \sigma\gamma f^*(wL + L^*) - \mu^{\frac{\mu}{\mu-1}} x^{*\frac{\mu}{\mu-1}} (f^* + \beta^* x^*)^{\frac{2-\mu}{1-\mu}} = 0,$$

(39c) $$\Phi_3 \equiv \left[(1+t)^{\mu-1}(f^* + \beta^* x^*) - \beta w^{1-\mu} x^*\right]^2 - (1+t)^{\mu-2} f w^{1-\mu} f^* = 0.$$

A comparison of equations (39a)-(39c) with equations (37a)-(37c) reveals that the impact of a change of L^* on variables related to the foreign country is symmetric to a change of L on variables related to the home country. Thus, the impact of a change in the size of the foreign population on foreign welfare is similar to that of a change in the size of the domestic population on domestic welfare. More importantly, a comparison of equations (39a)-(39c) with equations (37a)-(37c) shows that the impact of a change of a parameter is likely to affect the welfare of the two countries in a similar way. For example, if a change in the size of the domestic population increases domestic wage rate, it will also increase the foreign wage rate. Thus, the core and the periphery may not have divergent interests when a parameter changes.

What is the impact of a change of the elasticity of demand in an open economy? An application of Cramer's rule to the system (38) leads to $dw_m / d\sigma < 0$, $dx / d\sigma > 0$, and $dw / d\sigma < 0$. That is, in an open economy, an increase of the elasticity of demand leads to a lower price of a manufactured good, a higher level of output for a manufacturing firm, and a lower wage rate in the home country. Thus, the impact of a change of the elasticity of demand on the price and the output of a manufacturing firm is similar to that in a closed economy. This means that the impact of a change of the elasticity of demand is robust to whether the economy is closed or open.

The following proposition shows that the impact of a change of the level of transportation costs on endogenous variables is sensitive to the level of linkage effects. When the level of linkage effects is close to zero, an increase of the level of transport costs increases the level of output for a firm in the home country, increases the ratio of the domestic wage rate to the price of a manufactured good, and decreases the domestic wage rate. When the level of linkage effects is close to one and the marginal cost in the two countries are sufficiently close, an increase of the level of transport costs decreases the level of output for a firm in the home country, decreases the ratio of the domestic wage rate to the price of a manufactured good, and decreases the domestic wage rate.

Proposition 3: When $\mu \to 0$, $\frac{dw_m}{dt} > 0$, $\frac{dx}{dt} > 0$, $\frac{dw}{dt} < 0$. When $\mu \to 1$ and $\beta \to \beta^*$, $\frac{dw_m}{dt} < 0$, $\frac{dx}{dt} < 0$, $\frac{dw}{dt} < 0$.

Proof: Partial differentiation of equations (37b) and (37c) leads to

$$\frac{\partial \Gamma_2}{\partial x} = \frac{\mu^{\mu/(\mu-1)} w x^{1/(\mu-1)} (f + \beta x)^{1/(1-\mu)}}{1-\mu} (\mu f - 2\mu \beta x),$$

$$\frac{\partial \Gamma_3}{\partial t} = \frac{(1+t)^{1-\mu}(f+\beta x)w^{1-\mu} - \beta^* x}{1+t}\left[(2-\mu)\beta^* x - \mu(1+t)^{1-\mu}(f+\beta x)w^{1-\mu}\right].$$

When $\mu \to 0$, $\frac{\partial \Gamma_2}{\partial x} < 0$, $\frac{\partial \Gamma_3}{\partial t} > 0$. When $\mu \to 1$, $\frac{\partial \Gamma_2}{\partial x} > 0$, $\frac{\partial \Gamma_3}{\partial t} < 0$ if the marginal cost in the two countries are sufficiently close.

An application of Cramer's rule leads to

$$\frac{dw_m}{dt} = -\left(\frac{\partial \Gamma_1}{\partial x}\frac{\partial \Gamma_2}{\partial w}\frac{\partial \Gamma_3}{\partial t}\right)/\Delta_\Gamma,$$

$$\frac{dx}{dt} = \left(\frac{\partial \Gamma_1}{\partial w_m}\frac{\partial \Gamma_2}{\partial w}\frac{\partial \Gamma_3}{\partial t}\right)/\Delta_\Gamma,$$

$$\frac{dw}{dt} = -\left(\frac{\partial \Gamma_1}{\partial w_m}\frac{\partial \Gamma_1}{\partial x}\frac{\partial \Gamma_2}{\partial t}\right)/\Delta_\Gamma.$$

When $\mu \to 0$, $\frac{dw_m}{dt} > 0$, $\frac{dx}{dt} > 0$, $\frac{dw}{dt} < 0$. When $\mu \to 1$ and $\beta \to \beta^*$, $\frac{dw_m}{dt} < 0$, $\frac{dx}{dt} < 0$, $\frac{dw}{dt} < 0$. ■

Since the price of the agricultural good is one, domestic welfare is determined by the domestic wage rate (the level of consumption of the agricultural good) and the ratio of the domestic wage rate to the price of a manufactured good (the level of consumption of manufactured goods). Proposition 3 shows that when the level of linkage effects is low, the impact of a change of the level of transportation costs on domestic welfare is ambiguous because the domestic wage rate and the ratio of the domestic wage rate to the price of a manufactured good move in opposite directions. When the level of linkage effects is high, a decrease of the level of transportation costs always increases domestic welfare.

In this model, when the level of linkage effects is sufficiently high, a decrease of the level of transportation costs will never decrease the welfare of the core country (domestic welfare). This aspect is different from Krugman and Venables [1995]. Through simulation, they show that a decrease of the level of transportation costs may be harmful for the developed country in terms of the consumption of manufactured goods. In their model, firms producing manufactured goods engage in monopolistic competition. Each manufactured good is produced by only one firm in the world. If a manufacturing firm moves from a developed country to a developing country, the developed country has to incur transportation costs to import this manufactured good. This leads to a *discrete* change of the price of a manufactured good and the price of this manufactured good in the developed country may *jump* upward. In this model, each manufactured good may be produced in both countries. A change of transportation cost will not lead to a discrete change in the price of a manufactured good.

4. CONCLUSION

In this paper, we have studied the impact of international trade in a general equilibrium model in which firms producing manufactured goods engage in oligopolistic competition and linkage effects are present. We have derived the following results analytically. First, a country with a larger population has a comparative advantage in the production of manufactured goods. Second, when countries have the same production technologies and the same labor endowment, core-periphery pattern arises only if the transportation costs are sufficiently low. Finally, an increase in the size of the domestic population increases a domestic consumer's consumption of manufactured goods, but decreases a domestic consumer's consumption of the agricultural good. The impact of a change of the level of transportation costs on endogenous variables is sensitive to the level of linkage effects. When the level of linkage effects is sufficiently high, a decrease of the level of transportation costs will never decrease the welfare of the core country.

Appendix A: Both countries produce both types of goods

In this appendix, we study the pattern of trade when both countries produce both agricultural and manufactured goods. When both countries produce the agricultural good, the wage rate in the two countries will be the same: $w = w^* = 1$.

Total demand of the agricultural good is the sum of demand from the home country Lc_a and demand from the foreign country $L^* c_a^*$. Thus the total demand of the agricultural good is $Lc_a + L^* c_a^*$. When both countries produce the agricultural good, the total supply of the agricultural good is $L_a + L_a^*$. The clearance of the market for the agricultural good requires that world quantity demanded equals world quantity supplied:

(A1) $$Lc_a + L^* c_a^* = L_a + L_a^*.$$

When both countries produce both types of goods, equations (3), (4), (6), (7), (9)-(11), and (14) are still valid. Those equations and equations (21)-(23), (25)-(31), (33)-(34), and (A1) form a system of 21 equations defining a system of 21 endogenous variables p_m, p_m^*, p_a, p_I, p_I^*, L_a, L_a^*, L_m, L_m^*, x, x^*, n, n^*, w, c_a, c_a^*, c_m, c_m^*, z, z^*, and E as functions of exogenous parameters. For this system of equations to be consistent, it can be shown that the exogenous parameters need to satisfy the following equation:

$$\text{(A2)}\qquad \mu^{\frac{\mu}{\mu-1}}\left[\frac{(1+t)^{\frac{2-\mu}{2}} f^{\frac{1}{2}} f^{*\frac{1}{2}} - (1+t)^{1-\mu} f}{(1+t)^{1-\mu}\beta - \beta^*}\right]\left[f + \frac{(1+t)^{\frac{2-\mu}{2}} \beta f^{\frac{1}{2}} f^{*\frac{1}{2}} - (1+t)^{1-\mu}\beta f}{(1+t)^{1-\mu}\beta - \beta^*}\right]^{\frac{2-\mu}{1-\mu}} - \sigma\gamma f(L+L^*) = 0\,.$$

There are ten parameters μ, t, f, f^*, β, β^*, σ, γ, L, and L^* in equation (A2). If nine of the parameters are exogenously determined, the value of the remaining parameter can be solved by (A2). If all ten parameters are exogenously given, the measure that the combination of exogenous parameters satisfies (A2) is zero in the space spanned by the ten parameters. That is, the probability that both countries produce both types of goods is zero. Thus, the scenario that both countries produce both types of goods is less likely to appear than the scenario that one country produces the manufactured good and the other country produces both types of goods. This is the reason why we address the scenario that both countries produce both types of goods in this Appendix rather than in the main text. If the combination of ten exogenous parameters happens to satisfy (A2), the system of equations defining the equilibrium for both countries to produce both types of goods can be reduced to equations (37a)-(37c). However, comparative statics in Proposition 2 following equations (38)-(40) may not apply because a change of the size of the domestic population may make (A2) invalid and thus the scenario that both countries produce both types of goods will not be an equilibrium anymore.

Appendix B: Both countries specialize in the production of one type of goods

In this appendix, we study the equilibrium in which the home country specializes in the production of manufactured goods and the foreign country specializes in the production of the agricultural good.

Total demand for a manufactured good in the foreign country is $L^* c_m^*$. The supply of a manufactured good in the foreign country is the amount of arrived import $E/(1+t)$. The clearance of market for a manufactured good in the foreign country requires that

(A3) $$L^* c_m^* = \frac{E}{1+t}.$$

When both countries specialize, equation (3), (4), (6)-(9), (11), (14), (21), (22), (27), (28), and (32) are still valid. Those equations and equation (A3) form a system of 14 equations defining a system of 14 endogenous variables p_m, p_m^*, p_a, p_I, x, n, w, w^*, c_a, c_a^*, c_m, c_m^*, z, and E as functions of exogenous parameters.

From the above system of equations, the wage rate in the home country is $w = \frac{\gamma L^*}{(1-\gamma)L}$. The wage rate in the foreign country is one. For the wage rate in the home country to be higher than that in the foreign country, we need $\gamma L^* > (1-\gamma)L$. The validity of this inequality is necessary for the home country to specialize in the production of manufactured goods and the foreign country to specialize in the production of the agricultural good.

Also, from the above system of equations, the output of a domestic firm can be expressed as $x = \frac{f}{\mu^\mu \left[\frac{(1-\mu)(1-\gamma)Lp_m}{\gamma L^*}\right]^{1-\mu} - \beta}$. In this equation, p_m is defined implicitly by

$$\mu^\mu \left[\frac{(1-\mu)(1-\gamma)Lp_m}{\gamma L^*}\right]^{1-\mu} - \beta$$

$$- \frac{p_m f(1-\mu)(1-\gamma)\mu^\mu \left[\frac{(1-\mu)(1-\gamma)Lp_m}{\gamma L^*}\right]^{1-\mu}}{\sigma \gamma L^* \left[\mu^\mu \left[\frac{(1-\mu)(1-\gamma)Lp_m}{\gamma L^*}\right]^{1-\mu} - \beta\right]} = 0.$$

If the values of exogenous parameters are provided, p_m can be calculated from the above equation. Then other variables can be calculated.

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