Input substitutability, trade costs and the product cycle

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Abstract

I exhibit a simple and realistic feature of technology and trade costs that influences the partition of manufacturing between the North and South depending on the degree of substitutability of internationally traded inputs in production. In the presence of higher wages in the North, when production of manufacturing goods requires tradeable, country-specific Ricardian inputs, goods with a low elasticity of substitution between inputs in production will have lower costs of manufacturing in the North and those with a high elasticity in the South.

JEL codes: D24, F12, O14, R30

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1 Introduction

In this note, I present a simple model of the product cycle where both the North and South share a common production technology and a legal environment, the inputs in production are tradeable (albeit at some cost) and there are higher wages in the North than in the South. By the virtue of the technology, the existence of trade costs and the trade in inputs, paradoxically a higher priced labor in the North may be a source of a comparative advantage in newly invented products no matter how big the wage gap is. The mechanism at play is different from those in the so far existing theories of the product cycle (for example Vernon 1966 or Antras 2005) or offshoring (for example Grossman and Rossi-Hansberg, 2008) that explain why a given product or task will be produced either in the North (high wage, high contract enforcement etc. environment) or in the South (the low-wage, low-contract enforcement location).

There are three important ingredients in our model. The first is an assumption that Ricardian inputs are equally distributed in the North and the South (so there is no asymmetry in the local input supply). The second assumption is that the technology in manufacturing final goods admits many inputs. For simplicity, I shall assume that each good admits in production one input from the North and the South, with different degrees of substitution between them. The third ingredient is that there are trade costs of moving goods between borders.\(^1\)

Given this environment, I show that for industries with technologies with a high degree of complementarity of internationally traded and country-specific inputs required for production, the presence of trade costs involved in the transportation of inputs causes that marginal costs of production are lowest in the location with the highest costs of local inputs (Section 2), i.e. the North with the highest wages. On the other hand, industries with production processes that have a high degree of substitution between inputs are going to have the lowest cost of production in countries with the lowest cost of local inputs as firms then can substitute for the costly (foreign) inputs. This feature may influence the location decisions of firms and the nature of the technology may determine the patterns of production specialization, a point that is made in a simple model of the product cycle in Section 3. More general distributions of inputs are considered in Section 4.

2 Input substitutability, trade costs and cost advantage

I begin with exposing the basic idea driving the model, developed further in the next section. Two countries, the North (denoted with a subscript \(n\)) and South (denoted with a subscript \(s\)), differ in wages with \(w_n > w_s\). Consider a final good produced under constant returns to scale. The production function is of the constant elasticity of substitution (CES) sort taking in all available inputs

\[
y = \left( \sum_i (z_i)^\rho \right)^{\frac{1}{\rho}} \tag{1}
\]

\(^1\)Anderson and van Wincoop (2004) estimate the size of trade costs being equivalent to a 170% ad-valorem tariff, including a 21% part in that estimate of just transport costs.
where \( y \) is the production, \( z_i \) is an intermediate variety input and \( \frac{1}{1-\rho} \) is the elasticity of substitution between inputs in production. The marginal cost of production \( \psi_j \) in country \( j \) is then

\[
\psi_j = \left( \sum_i (\xi_{ij})^{-\frac{\rho}{1-\rho}} \right)^{\frac{\rho-1}{\rho}}
\]

(2)

where \( \xi_{ij} \) is the price of input \( i \) in country \( j \).

All goods are tradeable. There are trade costs of the iceberg sort of order \( \tau \) on any internationally traded inputs.\(^2\)

In each country there is one input produced that can be used for the manufacture of the final good. These inputs can be thought of as being raw materials (equally distributed among countries), proprietary technology or Armingtonian (nationally differentiated) goods. The inputs are produced under constant returns to scale and perfect competition. We normalize the production technology so that one unit of labor is required to produce one unit of the input \( z = l \). Hence the domestic price of an input produced in country \( j \) is \( \xi_{jj} = w_j \). The price of this input in country \( k \) is then \( \xi_{jk} = \tau w_j \). The cost of moving inputs from the high wage location to the low cost one exceeds the cost of the opposite movement because of the iceberg trade cost.

**Lemma 1** Suppose that \( w_n > w_s \). Then the marginal cost of production is lower in the North if \( \rho < 0 \).

**Proof.** Compare directly the marginal costs of production in the North and in the South:

\[
\left( (w_n)^{-\frac{\rho}{1-\rho}} + (\tau w_s)^{-\frac{\rho}{1-\rho}} \right)^{\frac{\rho-1}{\rho}} < \left( (\tau w_n)^{-\frac{\rho}{1-\rho}} + (w_s)^{-\frac{\rho}{1-\rho}} \right)^{\frac{\rho-1}{\rho}}
\]

(3)

The above inequality is true for \( \rho < 0 \) when \( w_n > w_s \).\( \blacksquare \)

If the production technology has an elasticity of substitution between inputs lower than one so that inputs are complementary in the production process, one cannot avoid easily using the high cost location input which makes the cost of production in the South more costly. In the extreme Leontief case, it is clear that the marginal cost in the North \( \psi_n = w_n + \tau w_s < \tau w_n + w_s = \psi_s \). The opposite is true when \( \rho > 0 \) : all firms possessing such a technology for producing final goods will have lower marginal costs in the low wage location (the South) as they can easily substitute for the relatively more expensive inputs from abroad with local varieties. For a Cobb-Douglas technology \( (\rho = 0) \) the marginal costs in both locations are equal even though \( w_n > w_s \).

The observation holds regardless of the size of the trade cost in question. Moreover, even if the necessary input from the North would constitute a small proportion of the overall product costs when \( \rho < 0 \), firms may observe lower costs in the North given that the North-South wage gap would be high enough.

\(^2\)It does not matter that all trade costs are of the iceberg sort type, introduced by Samuelson (1954) and then widely used in the New Trade Theory models (I use them to get a simple model in Section 3). The result exhibited in Lemma 1 holds if there are per unit shipping costs which are constant between locations in addition to the iceberg costs. Finally, iceberg costs (i.e. the assumption that a fraction of the goods are lost in transit) are not necessary for Lemma 1 altogether; for example ad-valorem tariffs would do as well.
A crucial element here is that the trade costs in question indeed multiplicatively affect the costs of inputs (so for example are of the iceberg sort). There are many trade costs that are of this type: ad-valorem tariffs (which are not iceberg costs), freight costs, insurance, exchange-rate conversion costs, contract enforcement costs and these constitute the bulk of Anderson and van Wincoop’s (2004) estimates of trade barriers. Determining the value of \( \rho \) is an empirical issue; but, for example, in many industries such as aluminum, steel or refining the technologies do exhibit input complementarity.

The marginal cost differential in the production of the final good between the North and South cannot exceed the order of \( \tau \). Hence, in a world with constant returns to scale and equal trade costs for all categories of goods (including the final products) the above interplay between trade costs and technology cannot be a source of comparative advantage in trade between countries that trade inputs as the production within the boundaries of each country of such final goods would be cheaper than imports (though it would constitute a comparative advantage in third country markets). However, for models with increasing returns to scale in production, such a cost advantage could be exacerbated and play an important role in firm location decisions and in shaping comparative advantage of countries, to which we turn next.

3 A simple model of the product cycle

In this section, I develop a simple model of the product cycle incorporating the above implications of technology and trade costs. There are no barriers to technology transmission and new inventions (products) can be made either in the North or the South. Newly invented products (a "new" good) have technologies that initially admit only one method of production - this underscores their novelty. We assume that the new goods require complementary input usage that is not of a Vernonian sort (see Vernon 1966); i.e. it requires inputs that can be traded but are produced in different countries (you do not require a "thick" supplier market in either of the countries for producers to locate there). This newly invented product could be in principle produced in the South. As new technologies appear that allow for greater substitution of inputs to manufacture the product (as it "matures"), production would necessarily move to countries with low costs of local inputs that can be used to substitute for the costly foreign ones. We adapt now the standard general equilibrium monopolistic competition New Trade Theory model with homogenous firms (see Helpman and Krugman 1985) to study the location of the production and trade in such "new" and "mature" good sectors, in effect presenting a model of the product cycle.

3.1 Initial assumptions

There are two countries, North and South. Let subscripts \( n \) or \( s \) pertain the country and apply to the marginal cost \( \psi \), income \( I \) or the price level \( P \) while denote the prices charged by a firm producing in market \( i \) and selling in market \( j \) as \( p_{ij} \).

There are three final good sectors and one intermediate sector in each economy. Consumers have preferences of the Dixit-Stiglitz love-of-variety sort for the new and mature manufactures; services
also enter the utility function. Let their utility be described by the function

\[ U = \left( \sum_i x_{ni}^\sigma \right)^\frac{\gamma}{\sigma} \left( \sum_j x_{mj}^\sigma \right)^\frac{\gamma}{\sigma} \cdot (x_0)^{1-2\gamma} \]  

(4)

where there are respectively \( N \) and \( M \) varieties (firms) in the new and mature sectors, \( x_{ni} \) is the \( i \)-th new good variety while \( x_{mj} \) is the \( j \)-th mature good variety, \( x_0 \) is the quantity (hours) of services consumed and \( \gamma < \frac{1}{2} \). Consumers spend their entire income which they obtain through providing labor.

Labor is the primary factor of production.

A tradeable, perfectly competitive services sector produces services under constant returns to scale that can be traded across borders. The workers in the North are more productive in this industry, and to produce 1 hour of services \( a^{-1} \) hours of labor \( (a > 1) \) in the North and 1 hour in the South is required. There are no trade costs in the services sector and it allows to keep the trade balance at zero. The productivity in services thus sets the wages between the two countries, \( w_n = aw_s \). Normalize \( w_n = 1 \) so that \( w_s = a^{-1} \). Normalize the population and labor size to 1 in the North; to avoid any final good market size effects let the population of the South be \( a \). This way the income in the two countries is equal and \( I_n = w_n \times 1 = w_s \times a = I_s \).

There are two manufactured (differentiated) goods sectors that differ in the technology of production but are the same in terms of market organization (free entry after paying a sunk entry cost, monopolistic type of competition). As in Section 2, a nationally differentiated input is produced under constant returns to scale and perfect competition for the usage in the manufacturing industries. All differentiated goods and inputs are traded with an iceberg trade cost \( \tau \), equal across these sectors.

### 3.2 The "new" manufactured goods sector

New manufacturing goods producers have a technology where inputs coming from the North and South are complements so that the production function is as in eq. (1) \( y = \left( \sum_i z_i \right)^{\frac{1}{\rho}} \) and \( \rho < 0 \). Clearly \( \psi_n < \psi_s \) by the virtue of inequality (3).

There is free entry and interested firms sunk a cost (conduct R&D and build a production site) to obtain a patent to produce a good. In doing so, they choose one location to conduct production and they need to manufacture \( F \) units of the good as a sunk cost. Then, they can produce at a constant marginal cost, and there are increasing returns to scale from the point of view of the potential entrant. A firm that obtains a patent observes demand (that is derived from the utility function given by eq. 4) for its variety of \( \frac{I^*}{\psi} P^{1-\gamma} \) in a given market where \( \gamma \) is the fraction of income \( I \) that is spent on the new goods sector, \( P = \sum p^{-\frac{\gamma}{1-\gamma}} \) is the price level (aggregate) in the sector in the given market and \( p \) is the price that is charged by the firm. As is easily demonstrated, the optimal profit maximizing price charged by a firm in a market is then \( p^* = \frac{I^*}{\psi} \) where \( \psi \) is the income.

\[ \frac{I^*}{\psi} P^{1-\gamma} \]

Assuming two countries symmetric in population delivers the result for the "new" goods automatically by the virtue of the home market effect (Helpman and Krugman 1985). The North has then not only a lower marginal cost but also has a larger market for the new goods (as its income is higher).
marginal cost. When exporting, the iceberg trade cost increases the marginal cost of serving the foreign market to $p^* = \frac{\tau \psi}{\sigma}$.

Then, the zero profit condition of a firm that enters the sector in the North is

$$F_n = (1 - \sigma) \gamma \left[ \frac{I_n}{P_n} \frac{\sigma}{P_{nn}} + \frac{I_s}{P_s} \frac{\sigma}{P_{ss}} \right]$$

whereas that of the firm in the South is

$$F_s = (1 - \sigma) \gamma \left[ \frac{I_n}{P_n} \frac{\sigma}{P_{sn}} + \frac{I_s}{P_s} \frac{\sigma}{P_{ss}} \right]$$

This system is readily solved for the number of firms in the interior (that is if both North and South produce), and we are interested in the trade balance in these goods between the countries. The exports from the North to South are $N_n \frac{\tau \psi}{P_n} (\psi_n)^{-\frac{\sigma}{1 - \sigma}}$ whereas those from the South to North $N_s \frac{\tau \psi}{P_s} (\psi_s)^{-\frac{\sigma}{1 - \sigma}}$. Substituting for the number of firms, income and the price levels after standard calculations one can arrive at the condition for positive net exports of the new goods from North to South

$$I_s \left[ (\psi_s)^{-\frac{2}{1 - \sigma}} (\tau)^{-\frac{\sigma}{1 - \sigma}} - (\psi_s \psi_n)^{-\frac{1}{1 - \sigma}} \right] < I_n \left[ (\psi_n)^{-\frac{2}{1 - \sigma}} (\tau)^{-\frac{\sigma}{1 - \sigma}} - (\psi_s \psi_n)^{-\frac{1}{1 - \sigma}} \right]$$

This condition is readily verified as $I_s = I_n$ and $\psi_n < \psi_s$. We are not surprised that the result holds; the North has a cost advantage in the production of the new good and the market sizes are equal. It is not driven by the home market effect.

It can be easily verified that the wage in the South is low enough, then there is no production of the new goods there; the marginal cost of production in the North is much lower then and the Southern home market is too small so that any potential entrant cannot cover the sunk cost with the expected profits from locating in the South. This may seem surprising, but is a logical consequence of inequality (3) as lower wages and hence lower local input costs in the South do not help that country to obtain an advantage in the new good sector.

### 3.3 The ”mature” manufactured goods sector

The institutional setup of the mature goods is exactly the same as in the new goods manufacturing sector (firms sink costs to establish production facilities etc.) so that the zero profit conditions and the trade balance can be described as in (5) - (7). The difference is in the technology - the inputs are substitutes and the production function is $y = (\sum_i (z_i)^p)^{\frac{1}{p}}$ with $p > 0$. In this sector $\psi_s < \psi_n$ so the marginal costs are higher in the North. It is immediate from inspecting inequality (7) that the South will be the net exporter of the mature good due to its cost advantage. What is to note that if $w_s$ is low enough, then the South becomes the only country in which the production of the mature good takes place. This is because with such low wages locating and producing in the South while serving the market in the North is cheaper for any firm regardless of the Northern market size, a result emphasized by Davis (1998) in his critique of the New Trade Theory models with a homogenous good. Indeed, the mature good sector here is effectively similar (even though inputs
can be traded internationally) to the typical manufacturing sector studied in the New Trade Theory models (Helpman and Krugman 1985) when $\rho \rightarrow 1$.

### 3.4 Conclusions for the product cycle and the trade and wages debate

From the discussion above, it is clear that the North is the net exporter of the new good while the South is the net exporter of the mature good as long as $w_n > w_s$; the South and (to lesser extent) the North export also the inputs that are necessary for the industries in the other country and the service sector balances trade. If the North-South wage gap is wide enough, the North becomes the sole producer of the new good and the South of the mature good. The comparative advantage of the North is derived from the fact that the input cost there is lower than in the South. Note that by my assumptions on the size of the countries the home market effect is not at work.

The implication of the degree of input substitution and trade costs for the marginal cost of production provides an alternative to Vernon’s (1966) standardization of production arguments (lack of technology transfers to the South, larger domestic market) or the institutional-based explanation of Antras (2005) of the location of manufacturing during the product cycle. New products have technologies where the inputs are not substitutable between one another and hence will locate in the North. As the product matures and there are many production techniques that can be used to manufacture the same variety using different inputs, production will move to locations with cheapest inputs, in the South. The model encompasses the situation where the North has skilled labor that can be moved at a cost abroad while the South would be producing standardized tasks or raw materials; the model says that with equal per value trade costs and equal technological requirements in the production function the preferred location for final good production would be the North.

For the trade and wages debate (Krugman 2000; Acemoglu, 2003; Thoenig and Verdier, 2003; Epifani and Gancia, 2008), the fact that the North has higher wages does not mean that it will become deindustrialized; it will specialize in the production of final goods with technologies that require more complementary, internationally traded inputs that cannot be easily substituted away. If the North is able to perpetuate this situation through time through able new product development (that may look on the surface like the skill-biased technological progress as high skill labor is an input the North may have abundantly), a wage gap between the North and the South can persist.

The model offers another case when trade costs influence the comparative advantage of countries. Among other examples, Deardorff (2004) shows how trade costs may create local comparative advantage of countries that would not exist in a trade-cost free world. Assumptions on trade costs that segment markets play an important role for the location of firms and the existence of home market effects in the New Trade Theory. Anderson and Marcouiller (2005) show how trade costs created by lack of contract enforcement may create Ricardian comparative advantage.

### 4 More general technologies

The inputs in the example in Section 2 were country-specific as each of the countries was unable to produce the other production input. More generally, one can deliver examples of families of
technology distributions where the above insight holds. The requirement is that the two countries involved in trade need to have technologies dissimilar enough. Consider for example a production technology of the final good \( y = \left( \int_0^1 z(i) \, di \right)^{\frac{1}{\alpha}} \) and two countries with a Pareto distribution of the inverse of productivities (effectively a Pareto distribution of prices) over a continuum of inputs with the shape parameter \( \alpha > 0 \) and the maximum productivity equal to 1. Suppose that the distribution is ordered so that good zero gets the highest productivity draw in the North and good one gets the highest productivity draw in the South. The North then has a distribution of prices with a cumulative distribution function of \( 1 - \left( \frac{w_n}{\tau} \right)^{\alpha} \). The South, on the other hand, has the distribution of prices among the varieties that it offers on sale in the North of \( \left( \frac{w_s}{\tau} \right)^{\alpha} \). It has low productivity in inputs for which the North has a high productivity and vice versa. The maximum price of an input is then in the North \( p_{\text{max},n} = \left( (w_n)^{\alpha} + (\tau w_s)^{\alpha} \right)^{\frac{1}{\alpha}} \), whereas the minimum price of an input from the North is \( p_{\text{min},nn} = w_n \) and that from the South is \( p_{\text{min,sn}} = \tau w_s \). The cost of production of the final good in the North is then \( C_n = \left( \frac{\theta}{1 - \theta} \left( (w_n)^{\alpha} + (\tau w_s)^{\alpha} \right)^{\frac{\theta}{1 - \theta}} - (w_n^{\theta} + \tau^{\theta} w_s^{\theta}) \right) \). If \( \alpha < \frac{\theta}{2} \) one can show that the North (the country with the higher wage) will have a lower cost of final good production no matter what the transport cost \( \tau \) is.\(^4\) This means that countries need to be dissimilar in terms of technology and have a Ricardian productivity advantage over a set of goods that is large enough and/or the varieties have to be strongly complementary in the production process for the result to hold.

References


\(^4\) A closed-form solution and proof available upon request.


