

Outsourcing Multiple Parts to Many Countries: An Application to the Automotive Industry

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Abstract

Existing models of outsourcing by and large assume that decisions are made for each product independently. Ignoring that manufacturers have to make joint decisions on multiple inputs will be inconsequential for many applications, but such a feature is likely to be important in the automotive industry. We extend the incomplete contracting model of the life cycle of a product (Antràs, 2005 *AER*) to a multi-component multi-country assembly process. Outsourcing decisions on components interact in two ways: (i) Marginal sourcing decisions towards low-wage countries reduce the cost of the final product, raising demand for all other parts and increasing the likelihood those will be sourced from low-wage countries as well. (ii) We also allow for the possibility that the loss (in relationship-specific investments) incurred when a relationship breaks down decreases with the past volume of parts production in a country. This captures in a reduced form way that the capacity for local institutions to deal with contractual disputes in a given sector increases with past investments. The evidence for U.S. automotive part imports, exploiting the price variation when a country starts exporting a new part, provides support for four predictions of the model.

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Executive Summary

Existing models of outsourcing by and large assume that decisions are made for each product independently. Ignoring that manufacturers have to make joint decisions on multiple inputs will be inconsequential for many applications, but such a feature is likely to be important in the automotive industry. To understand how offshoring of components is reshaping this industry a new model is needed.

We construct a model of incomplete contracting, where a firm has to make sourcing decisions on all components that enter a final vehicle. The production function and demand curve for the final good makes the sourcing decisions of all subcomponents are interrelated. As parts production moves from the high-wage North to low-wage South countries, the marginal cost of the final vehicle declines and the firm will move down its demand curve: increase production and raise its input demand for all components. We assume that parts become increasingly standardized over time, making production in low wage countries both feasible and more attractive. As parts made in low-wage countries mature further, local inputs rise in importance, lowering the parts' prices and hence the final product's marginal cost, starting the chain of events over again. In addition, we allow local institutions that deal with conflicts over specific investments to develop with past production experience.

The main prediction of the model is that taking multiple parts into account leads to accelerated offshoring over time. A first, direct effect comes from the demand for each individual part being linked to the cost of production of other parts through the production function of the final good. A second, indirect effect enters as past production reduces the problem of incomplete contracts, making the country a more attractive offshoring destination. We are able to derive four unique predictions from the theoretical model, most of which would not arise in more traditional trade models. Empirical evidence on U.S. automotive parts imports from 1989 to 2005 provides support for each prediction, but especially for (i) a positive relationship between the country-ordering of offshoring and the relative price at which the country enters the global production chain and (ii) a positive relationship between past production experience and relative export prices.

Finally, taking the model at face value we discuss six policy implications for the Canadian automotive industry that follow logically from the structure of the model. (1) Canadian policy will be unable to stop the entry of other countries into the global production chain. (2) Flexibility to take up production of new generations or focus on products that mature more slowly is of vital importance. (3) Technological prowess is important even within very narrowly defined products groups. (4) Policy interventions to improve the contracting environment are as important as those that aim at boosting productivity, and probably at least as effective. (5) Insisting on domestic control of production is likely to lead to production of less technologically intensive parts. (6) The extent to which complementarities are important makes it difficult to sustain a small and focused automotive industry.

1 Introduction

International trade, especially in manufactured products, has been growing rapidly over the past several decades. International fragmentation of production is often cited as an important factor, consistent with intermediate inputs being a growing share of world trade. For example, Hummels, Ishii, and Yi (2001) illustrate that the share of exports consisting of imported intermediates has increased by more than 30% from 1970 to 1990.^{1,2}

At the same time, transactions within firms but across country borders have steadily gained importance. Antràs (2003) finds that by 1994 roughly one third of international trade was intrafirm and that this fraction is increasing in the capital intensity of traded products. While foreign direct investment (FDI) can be a substitute for trade, as in Helpman, Melitz, and Yeaple (2004), with production sharing the effect can also go the other way: e.g. Blonigen (2001) finds evidence that FDI by Japanese automakers in the U.S. boosts imports of parts.³

Investment specificity has been the driving force in recent models that feature intrafirm trade, see Helpman (2006) for an overview. These models readily incorporate the fact that multinationals that outsource inputs overseas have the option to do so through subsidiaries or through arm's length transactions with independent firms. Existing models of outsourcing by and large assume that decisions are made for each product independently.⁴ Ignoring that manufacturers have to make joint decisions on multiple inputs will be inconsequential for many applications, but such a feature is likely to be important in the automotive industry, the focus of this study.

We extend the incomplete contracting model of the life cycle of a product (Antràs, 2005) to a multi-component assembly process. As contractual input intensity for each input declines over time, it generates a product-cycle. Initially, new products are only produced in the North; production shifts to integrated plants in the South when the production technology matures, and finally to independent South plants. In the model, outsourcing decisions on components interact in two ways. First, when an input previously sourced from the North moves to the low-wage South, the cost of the final product will fall discretely, raising demand for all other parts, and increasing the likelihood those will be sourced from low-wage countries as well. As parts made in low-wage countries mature

¹They base this conclusion on a sample of 14 countries that accounted for more than 80% of world manufacturing trade in 1990.

²Campa and Goldberg (1997) and Ng and Yeats (1999) explore the importance of global production sharing more generally. The latter find that “component trade now constitutes one-fifth of East Asian exports of manufactures” and that “(East Asian) global exports of components grew faster than any other major product group over 1984-1996.” Grossman and Helpman (2005) construct a general equilibrium model investigating what determines the location of subcontracted activities.

³Head, Reis, and Spencer (2004) similarly shows that U.S. exports of parts are higher to countries where U.S. firms have set up assembly plants.

⁴Examples are Antràs and Helpman (2004), Feenstra and Hanson (2005), and Bartel, Lach, and Sichernman (2005). The model in Spencer and Qiu (2002) and Head, Ries, and Spencer (2004) features multiple inputs, but outsourcing decisions are still made on each individually. They derive a threshold for the importance of specific investments and only products above the threshold will be customized.

further, local inputs rise in importance, lowering the parts' prices and hence the final product's marginal cost, starting the chain of events over again. Second, we also extend the model to a multi-country setting. Countries vary not only in their wages, but also in the protection of property rights they provide (Nunn, 2007). We allow for the possibility that the loss in relationship-specific investments that a multinational incurs when a relationship breaks down decreases with the past volume of parts production in a country. This captures in a reduced form way that the capacity for local institutions to deal with contractual disputes in a given sector increases with past investments—similar to the feedback between trade and institutions in Europe post 1500 in Acemoglu, Johnson, and Robinson (2005).

Specific investments are undoubtedly of primary importance in the automotive industry. The first empirical study supporting predictions of the transaction cost economics literature, Monteverde and Teece (1982), was on automotive components.⁵ Clark and Fujimoto (1991) illustrate that the automotive industry is the prototype example of 'integral design' where changes in one component have far-reaching impacts on the design of other. Also, Nunn (2007) finds that the automotive industry has the highest share of differentiated inputs, products not traded on exchanges, of all U.S. manufacturing sectors. As in Head, *et al.* (2004), we will allow for generic, i.e. uncustomized, inputs to limit the amount of rents that each individual input producer can appropriate. However, consumers value quality of the final product and that will be created by using customized components, which are initially produced intensively with labor inputs only the North possesses.

Several earlier papers explore the dispersion in unit value ratios that can be calculated from information on trade values and quantities. Such 'price' dispersion is often viewed as reflecting quality difference between the varieties produced in different countries, see Schott (2004), Hummels and Skiba (2004), and Hallak (2006). Rather than, or in addition to, specializing by industry as in traditional trade theory, countries also specialize vertically in varieties of different quality within industries. Generally, papers in this literature do not distinguish between final goods and intermediate inputs.⁶

The literatures on FDI and on quality dispersion in trade have developed almost entirely independently. Empirical work on FDI has relied mostly on FDI data and intrafirm transactions, while the literature that exploits the newly available detailed trade data tends to treat all commodities as final goods. However, as we have argued above, international trade, especially trade in intermediate inputs, and FDI are closely related. It seems only natural to make the distinction between intermediates and final goods explicit in the data; focusing on a single industry facilitates this.

Our first objective is to explore theoretically the linkages between outsourcing decisions of several intermediate inputs of the same final good using a model of incomplete contracts. We will incorporate each of the three issues highlighted in Helpman (2006): "(1) the impact of variations across industries

⁵The Fisher Body–GM integration is one of the original (and most controversial) case studies in asset specificity.

⁶Hallak (2006) makes the explicit assumption that demand for intermediate inputs is proportional to demand of final goods, thus avoiding having to model trade in intermediate inputs separately.

in intensity of inputs that suffer from agency problems; (2) Ricardian-type comparative advantage, that arises when legal systems of different quality interact with sectoral differences in contract dependency; (3) the impact of different degrees of contract incompleteness, which may vary across countries.” The importance of specific investments influences the location of production, which in turn influences costs through wage differences. As different inputs all go into one final product and demand is downward sloping, sourcing decisions on one input will influence the demand for, and hence also the sourcing decisions of, other inputs. The simplest way to link the different inputs, is to use a Leontief production function for the final good.

The second objective is to investigate empirically how well predictions from the model fit trade patterns for U.S. automotive part imports over the 1989–2005 period. The specific nature of our model yields a number of predictions that are unlikely to arise in more traditional trade models. For example, we predict that the likelihood one part will be outsourced is increased when other countries cross a sourcing threshold. For example, when the production of tires moves from the U.S. to Mexico, it lowers the outsourcing threshold for other parts, such as suspensions, that are still produced within the U.S. Moreover, in the multi-country version of the model, the probability that a component intensive in specific investments (e.g. suspension) is outsourced to an intermediate wage country (e.g. Mexico) increases if a more standardized component that goes into the same vehicle (e.g. tires) moves to a low-wage country (e.g. China).

We derive four detailed predictions from the model and present supporting evidence for each. First, the country-order in which goods are offshored by the U.S. is consistent with the relative price at which new countries enter the global production chain. Second, the price at which a component is first exported to the U.S. by a given country is higher for components which are offshored later, reflecting that outsourcing is accelerating with past outsourcing of different parts. Third, the entry price of new exports of one country is raised with the entry of third countries into the global production chain of automotive parts. This effect is particularly strong if we confine it to the entry of low-wage countries into mature parts. Fourth, past exports of automotive parts within a country are found to have a positive effect on the entry price of new exports, consistent with past production contributing to the development of dispute resolution institutions.

The remainder of the paper is organized as follows: In the next section, we give some background information on the North American automotive industry and its trading patterns. Then, we set up the model and describe the equilibrium in Section 3. The data and variable construction is discussed in Section 4. Results are in Section 5 and Section 6 concludes with the discussion of some policy implications.

2 Industry

It is well-known that the automotive industry is an important part of the Canadian economy, that it is a highly trade-intensive sector, and that new countries are rapidly being integrated in the global production chain. In this section, we give some background information on these three patterns to put the remainder of the paper into context.

The Industry Canada web site contains a wealth of statistics underscoring the importance of the sector for the Canadian economy.⁷ For example, it is the largest manufacturing sector accounting for 13% of manufacturing GDP and 27% of manufacturing trade. It employs 168,459 people in automotive assembly and component manufacturing, and another 333,888 in distribution and aftermarket sales and service. Total sales of light-duty passenger vehicle assembly alone stood at \$67.8 billion or 2.7 million vehicles. The automotive parts and components sector counts 914 establishments which produce original equipment and aftermarket auto parts; it employs 101,254 workers and has shipments of \$33.0 billion. Value added per worker as well as average wage rates are among the highest in the manufacturing sector. Overall, Canada has the 8th largest automotive industry in the world and, especially in final assembly, it is one of the most productive worldwide.

The industry in North America faces three major challenges, as discussed in detail in Van Biesebroeck (2005): model proliferation, flexible technology, and outsourcing. The catalyst for change is the seemingly interminable increase in the number of models that enter the marketplace. In 2004, more than 320 different models were sold in North America, 165 of which were produced regionally—a doubling since 1974. The accompanying loss in scale economies makes it difficult to maintain production efficiency, as the average assembly plant now manufactures approximately three different vehicles. Flexible technology was hailed as the solution, but flexible assembly lines lead to further losses in scale economies, large capital outlays, and pushed the bottlenecks to suppliers and dealers. Recently, firms started to pay more attention to their supply chain as a source of cost savings, especially offshore suppliers, but also as a partner in the design process, especially the largest (tier 1) suppliers. The sourcing process is undergoing profound changes and imports of parts in North America are increasing rapidly. To some extent this is driven by large tier 1 suppliers that supply several vehicle producers and by combining their output they reach the scale to develop production platforms in low-wage regions. Of course, rising production in East Asia for the local market also attracts producers and suppliers to the region and exporting is an obvious next step.

The Canadian industry has held up well internationally as Mexico integrated in NAFTA. As a whole, it runs a large surplus, which is a combination of a \$24.3b trade surplus in final vehicles and a \$16.3b deficit in parts. Both imports and exports are large, as 83% of the assembled vehicles are exported, compared to 58% of the value of parts production value. The final vehicle surplus is entirely with the United States, while net trade flows are negative with (in order) Japan, Mexico,

⁷Statistics mentioned in this section refer to 2005. See the portal web site for the Canadian Automotive industry for further information: <http://strategis.ic.gc.ca/epic/site/auto-auto.nsf/en/Home>.

South Korea, and Germany. In automotive parts, Canada runs a deficit with every important producer, but especially so with (in order) the United States, Mexico, Japan, and most recently also with China (from +\$202m in 2000 to -\$577m in 2005).⁸

Currently, Canada imposes a 6.1% tariff on non-NAFTA final vehicle imports and up to 8.5% on automotive parts imports. In the context of the Free Trade Agreement (FTA) negotiations with South Korea, the industry has lobbied fiercely for this trade protection to remain in place. However, Van Biesebroeck (2006) finds that the Canadian industry would only be mildly affected by the abolishment of the tariffs. It is unlikely that tariff-jumping FDI will materialize because of this low tariff, especially because the bulk of Canadian output is exported to the U.S., which only charges a 2.5% tariff. An FTA with South Korea is estimated to lower domestic output by only 0.5% and even a unilateral abolishment of the vehicle tariff would only lower output by 2.2%, again a consequence of the large share of domestic production not being sold in the domestic market. The impact on the parts sector is likely to be larger, but the export potential is also much higher, as foreign markets tend to have higher rates of protection.

An important pattern in the automotive parts import statistics is illustrated in Figure 1 (all volumes are normalized to 1 in 1992). For mature trading partners, the four countries in the top panel, the volume of imports rises steadily or remains constant with annual fluctuations depending on the type of vehicles produced. In sharp contrast, for the four countries depicted in the bottom panel, China, South Korea, Thailand, and Turkey, the import volumes rise exponentially. When countries initially enter the worldwide production chain of the automotive sector and imports to Canada are starting to take off, growth rates are accelerating over time. The same pattern is apparent for many more countries, not shown here due to space limitations.⁹

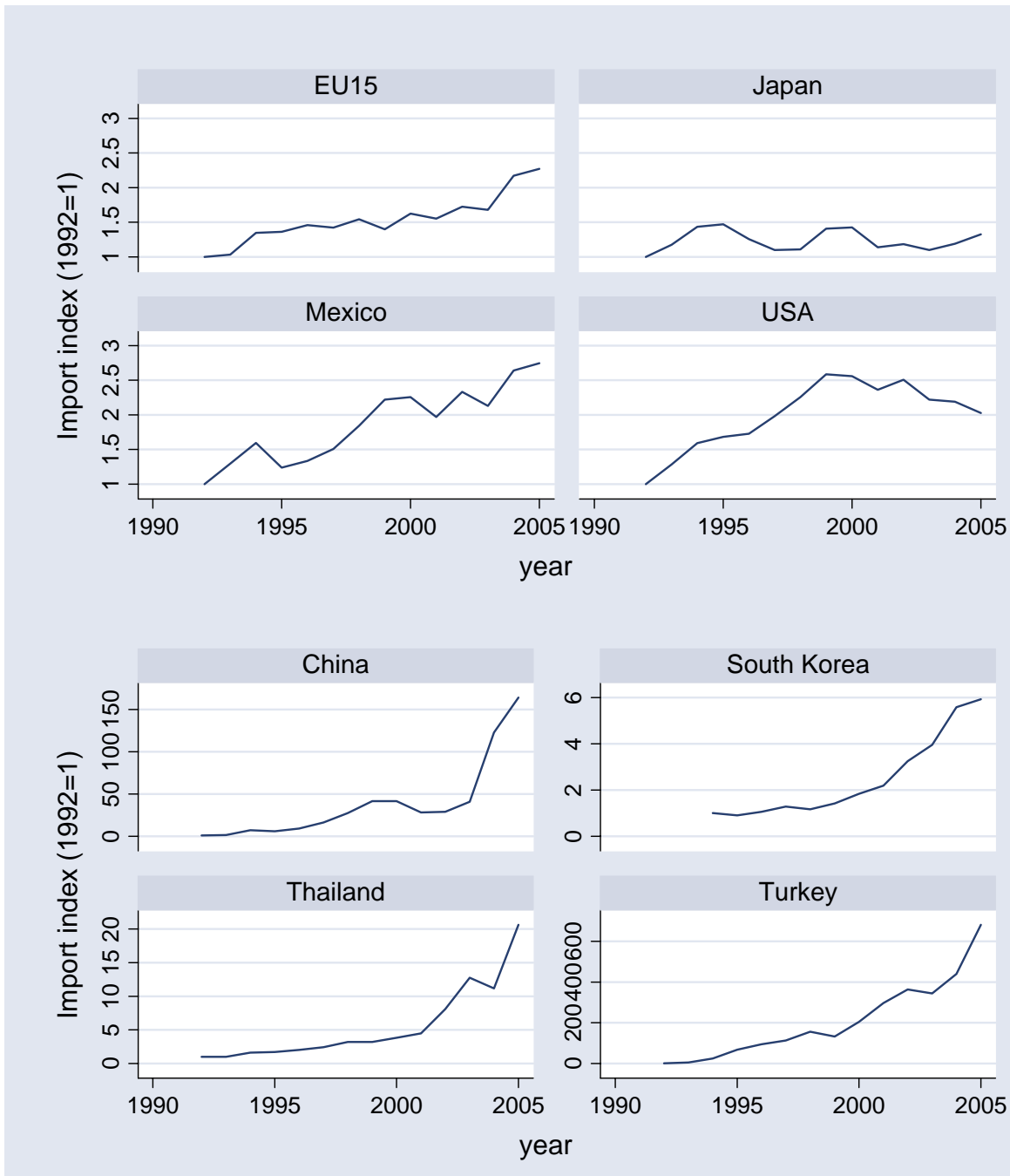
There are several reasons why one would expect offshoring to be accelerating over time. One explanation, advanced by Bartel, *et al.* (2005), relates to fixed costs associated with technology adoption. As technology progresses more rapidly or requires larger (fixed) investments to stay current, firms increasingly have an incentive to outsource the services that require the new technologies. This way, the dedicated service provider can spread the costs of new technologies over a larger client base and have greater incentives to stay up to date. As more firms outsource, the service provider will become better able to acquire the frontier-technology and will become more attractive to other firms as well.

A second reason for an acceleration in offshoring is more specific to the automotive industry and follows from the work on ‘integral design’ by Clark and Fujimoto (1991). Given that components in a vehicle interact in myriad ways, designers of different subsystems have to interact intensively.

⁸Between 2000 and 2005 the Canadian surplus with China in automotive parts briefly reached a maximum of +\$484m in 2003, but this was to a large extent due to the production of the Buick by GM in Shanghai, with Oshawa being the North American lead plant.

⁹Other countries that show exponential export growth when they initially start exporting to Canada are South Africa, Venezuela, Vietnam, Indonesia, and India.

Figure 1: Evolution of Canadian automotive parts imports from two sets of trading partners



Note: The industry is defined as NAICS 3363 ‘Motor Vehicle Parts Manufacturing’. The lines depicts the volume of Canadian imports normalized to 1 in 1992 (1994 for South Korea). The four countries at the top are traditional trading partners. The four countries at the bottom are emerging production sites for automotive parts and the vertical axis is rescaled for each of the bottom countries.

This provides an incentive to keep design in-house. Once one part is outsourced and the benefit of close coordination on site is lost anyway, it makes sense to move other parts offshore as well. On this dimension, motor vehicles are orthogonal to most electronics products, which are modular, i.e. different parts can be mixed and matched to produce a large variety of final products. The observation in Ng and Yeats (1999) that East Asia has become a powerhouse in electronics part production and assembly, but that automotive parts trade significantly lags European or North American volumes is thus not altogether surprising.

3 Model

The theoretical model is based on Antràs (2005), but augmented to incorporate many components which are combined to produce one final good. In addition to the product cycle results, as in Antràs (2005), the sourcing decisions for different parts interact and lead to more rapid offshoring of parts production.

3.1 Set-up

For our purpose, we limit attention to a partial equilibrium model of one industry. The model incorporates (i) a life cycle for products, i.e. declining importance of inputs that require skilled labor as products mature; (ii) contractual incompleteness in outsourcing relationships; (iii) traditional production cost comparative advantage. In order to discuss the linkage of outsourcing decisions among different parts of one final good, we will make specific assumption on the production function for the final good.

Assume there are $j = 1, 2, \dots, J$ firms in the industry. Each produces one variety of the differentiated final good. A representative consumer has a Dixit-Stiglitz utility function

$$U = \left[\sum_j (\theta_j y_j)^\alpha \right]^{\frac{1}{\alpha}},$$

where j denotes automobile varieties and θ_j is the quality shifter for variety j . Consumers are not only able to tell the different final goods apart, they have well-defined preferences over varieties. We introduce assumptions on the preference parameter (θ) later, but clearly, high quality leads to high demand.

Given a budget constraint for consumers, the demand for each variety of the final good is derived from the consumer's utility maximization problem and given by

$$\theta_j \cdot y_j = \lambda \left(\frac{p_j}{\theta_j} \right)^{-\frac{1}{1-\alpha}}. \tag{1}$$

$\lambda = E / \sum_j (p_j / \theta_j)^{-\frac{\alpha}{1-\alpha}}$ is the price index for the industry, which individual firm take as given, and E

is the fixed aggregate spending on all goods in this industry.¹⁰

Each variety of the final good requires exactly K intermediate inputs; for example, each car contains one engine, car body, set of tires, etc. To make one finished product, all K parts are combined, which is assumed to happen costlessly.¹¹ A representative firm producing variety j has the following Leontief production function

$$y_j = \min_{k=1,2,\dots,K} \{y_{jk}\},$$

where k indexes parts. Profit maximization behavior of the firm will set production of each part at the same quantity as the final good:

$$y_j^* = y_{jk}^*, \quad \forall k.$$

Production of each part requires two kinds of inputs: high-tech x_h and low-tech x_l . The production technology for each part is assumed to be Cobb-Douglas

$$y_{jk} = \varsigma_{jk} x_{jkh}^{1-z_{jk}} x_{jkl}^{z_{jk}} \quad (2)$$

where $\varsigma_{jk} = z_{jk}^{-z_{jk}} (1 - z_{jk})^{-(1-z_{jk})}$ and $z_{jk} \in (0, 1)$ is the technology index of part k of variety j . A low z implies that the part needs more skilled input, which we interpret as a younger and more advanced part. We further assume that consumers prefer newer goods, implying that $\theta_j = f(\mathbf{z}_j)$ will be decreasing in z_{jk} .

We consider two countries: North, also referred to as the home country, and South, also called foreign. Each country has a single type of labor input, with the wage in the North higher than in the South ($w_N > w_S$). Producing one unit of input requires one unit of labor, regardless of the production location. However, only North labor can produce high-quality x_h inputs, also with unit labor input. We assume inputs can be traded freely across borders. When production is finished, the final good is consumed in the North, without incurring trade cost.

We take all above parameters— J , K , z , θ , w_N , and w_S —as exogenous. Although some of these can be made endogenous in a general equilibrium setting, and such a model would be interesting to understand R&D activities for example, there won't be much gain from doing so for the purpose in this paper.

Since x_h can only be produced in the North country, we assume that each firm has a part center for each component in the North to produce x_h and to contract with a manufacturing plant for provision of the x_l inputs that go into the part. Each individual center takes on the same role of

¹⁰While a proportionate price increase of all varieties leaves market shares unchanged, an across-the-board price increase lowers demand for each variety, as the total expenditure in this industry is fixed (in partial equilibrium).

¹¹Alternatively, assembling all components can be included as a separate input in the Leontief production function.

the firms in the model of Antràs (2005)—they will contract and bargain with the manufacturer. In practice, these part centers can be owned by the producer of the final good or not; the crucial assumption is that they are located in the North.

To solve the contracting model, we have to specify the ‘appropriable quasi-rent’ that is at stake when the part center bargains with a supplier. Given the Leontief production technology, the entire value of the vehicle could be held-up by each supplier. Rather than adopting a multi-person bargaining game to split up the value of a vehicle, we continue to view the contracting process as a sequence of bilateral bargaining outcomes, but we give the firm the option to use a generic part if a relationship with a supplier breaks down. This, however, will lower the value and hence the consumers’ willingness to pay for the vehicle. Each part center’s budget is a share γ_{jk} of final revenue, where the fraction γ_{jk} is proportional to the utility gain from consuming the final good with a customized part k rather than a generic part. For example, if consumers value the j th variety of the final good with K specific parts at θ_j , a similar final good with a generic part k will be valued at $(1 - \gamma_{jk})\theta_j$.¹²

The time line of production is as follows: First, the firm will set the budget for each part center γ_{jk} , the total output y_j (which is also the output for each part y_{jk}), and the production mode for each part. Then, each part center will produce x_h and contract with a local or foreign supplier for x_l to produce y_{jk} of a customized part to maximize $\gamma_{jk}p_j y_{jk}$. Finally, costless final assembly takes place and the finished product is shipped to its consumption destination (in the North).

We solve the firm’s profit maximization problem backward, starting from the choices of the part center, which are conditional on γ_{jk} and y_j .

3.1.1 Behavior of Part Center

For part k going into final good j , the part center will contract, bargain and produce exactly as in Antràs (2005). There are three ways to produce the part: North production, South integration and South outsourcing.

North production (N)

If part k is produced in the North, there is no contracting problem and x_h and x_l are chosen directly to maximize profits:

$$\max_{x_l, x_h} \gamma_{jk} p_j y_j - w_l x_l - w_h x_h.$$

According to the first order condition with respect to x_h and x_l , the part center will produce at a

¹²It is straightforward to show that when utility is reduced to $(1 - \gamma_{jk})U$ the price will also be discounted to $(1 - \gamma_{jk})p_j$.

point so that $y_j = x_h/z = x_l/(1 - z)$ and

$$\gamma_{jk}^N \left(\frac{\partial p_j}{\partial y_j} y_j + p_j \right) = w_N. \quad (3)$$

The production cost per part will be

$$c_{jk}^N = w_N$$

and the implicit price per part that exhausts the part center's budget will be

$$p_{jk}^N \equiv \gamma_{jk} p_j = \frac{w_N}{\alpha}.$$

Vertical integration in South (I)

A second way to produce a part is in an integrated plant in the South. As the North firm owns the South facility, in case of a dispute the part center can always fire the manager of the South plant. We assume that in this case it will be able to realize only a share δ of the full potential revenue, because of tacit knowledge by the South manager or last minute customization that does not take place in case of a dispute. The outside option for the Southern integrated manufacturer is zero. Hence, the quasi-rent is $(1 - \delta)\gamma_{jk}p_j y_j$, which the two parties split 50-50 in bargaining. Both parties choose their input levels noncooperatively to maximize their own profit:

$$\begin{aligned} \text{South integrated manufacturer:} & \quad \max_{x_l} \frac{1 - \delta}{2} \gamma_{jk} p_j y_j - w_l x_l \\ \text{North part center:} & \quad \max_{x_h} \left(\frac{1 - \delta}{2} + \delta \right) \gamma_{jk} p_j y_j - w_h x_h \end{aligned}$$

Taking first order conditions and substituting the production function for the part, we find the following profit-maximizing condition:

$$\gamma_{jk}^I \left(\frac{\partial p_j}{\partial y_j} y_j + p_j \right) = 2 \left(\frac{w_S}{1 - \delta} \right)^{z_{jk}} \left(\frac{w_N}{1 + \delta} \right)^{1 - z_{jk}}. \quad (4)$$

Unit costs per part for the Northern part center, which incorporates the fact that the Southern partner receives half of the quasi-rent, amount to

$$c_{jk}^I = \left(\frac{w_S}{1 - \delta} \right)^{z_{jk}} \left(\frac{w_N}{1 + \delta} \right)^{1 - z_{jk}} (1 + \delta - 2\delta z_{jk})$$

and the price per part is

$$p_{jk}^I = \frac{2}{\alpha} \left(\frac{w_S}{1 - \delta} \right)^{z_{jk}} \left(\frac{w_N}{1 + \delta} \right)^{1 - z_{jk}}.$$

If a contract is entirely unenforceable ($\delta = 0$), both parties have the same bargaining position and production will be efficient, i.e. c_{jk}^I will be minimized. While a better contracting environment leads to less efficient production, as the South producer underinvests, this might lower the part center's outlay per part as its bargaining position is strengthened (p_{jk}^I falls).

Outsourcing in South (O)

The remaining method to produce the part is by outsourcing the production process of x_l to an independent South firm. In case of a dispute, both parties are now left with nothing as the part center cannot appropriate the input anymore and the supplier does not receive anything for an input customized for final good variety j . The quasi-rent in this relationship is the overall revenue.¹³ Both parties maximize their individual profits which are now entirely symmetric:

$$\begin{aligned} \text{South independent manufacturer:} & \quad \max_{x_l} \frac{1}{2} \gamma_{jk} p_j y_j - w_l x_l \\ \text{North part center:} & \quad \max_{x_h} \frac{1}{2} \gamma_{jk} p_j y_j - w_h x_h \end{aligned}$$

Similarly as before, independent profit maximization behavior leads to the following optimality condition

$$\gamma_{jk}^O \left(\frac{\partial p_j}{\partial y_j} y_j + p_j \right) = 2w_S^{z_{jk}} w_N^{1-z_{jk}}. \quad (5)$$

Costs to make a part in this production mode are

$$c_{jk}^O = w_S^{z_{jk}} w_N^{1-z_{jk}}$$

and the price will be

$$p_{jk}^O = \frac{2}{\alpha} w_S^{z_{jk}} w_N^{1-z_{jk}}.$$

3.1.2 Behavior of the firm

Now that we have derived the optimality conditions for the individual part centers and South partners, we can investigate which organizational forms a firm will choose when it takes decisions for all parts. The firm needs to (i) choose the quantity of output (y_j); (ii) assign the profit shares for each part center (γ_{jk}); and (iii) choose the mode of production for each part (N , I , or O).

We first determine quantity, conditioning on the modes of production. This implies that the relevant equations (3), (4) and (5), which capture each part center's profit maximizing behavior under the relevant organizational form, must be satisfied. With the constraint that $\sum_k \gamma_{jk} = 1$, we

¹³Alternatively, we could allow for a secondary market for customized x_h inputs, giving the supplier an outside option worth $\delta' < 1$ of the potential revenue. This would not materially change the conclusions, see Acemoglu, *et al.* (2005) for a related application.

can combine these conditions into one equation:

$$\underbrace{\frac{\partial p_j}{\partial y_j} y_j + p_j}_{= \alpha p_j} = \sum_n w_N + \sum_i 2 \left(\frac{w_S}{1-\delta} \right)^{z_{ji}} \left(\frac{w_N}{1+\delta} \right)^{1-z_{ji}} + \sum_o 2 w_S^{z_{jo}} w_N^{1-z_{jo}} = \underbrace{\alpha \sum_k p_{jk}^*}_{\equiv MC^*}. \quad (6)$$

n indicates the subset of the K parts that are made in the North, i parts are made in integrated plants in the South, and o indexes parts made in independent plant in the South. Equation (6) merely captures that the firm will set quantity such that marginal revenue from the finished vehicle, on the left-hand side, equals marginal cost for this vehicle. MC^* sums the marginal costs of all the parts, which can be thought of as the prices for components times α the (inverse) markup of the final vehicle. Note that when parts are produced in the South the actual marginal costs for the part center differs from the production costs, as the quasi-rent is split by bargaining. In addition, the markups on parts produced in the South will differ from α .

The optimal price for the final good price is given immediately by equation (6): $p_j^* = MC^*/\alpha$. Substituting this in the residual demand function, equation (1), allows us to calculate the optimal output level, which equals

$$y_j^* = y_{jk}^* = \lambda \left(\frac{\alpha \theta_j^\alpha}{MC^*} \right)^{\frac{1}{1-\alpha}}. \quad (7)$$

The share assigned to each part center follows immediate from the optimality conditions for each mode of production:

$$\begin{aligned} \gamma_{jk}^N &= w_N / MC^* \\ \gamma_{jk}^I &= 2 \left(\frac{w_S}{1-\delta} \right)^{z_{jk}} \left(\frac{w_N}{1+\delta} \right)^{1-z_{jk}} / MC^* \\ \gamma_{jk}^O &= 2 w_S^{z_{jk}} w_N^{1-z_{jk}} / MC^*. \end{aligned}$$

The profit for the firm will be

$$\begin{aligned} \pi^* &= p_j^* y_j^* - \sum_k c_{jk} y_j^* \\ &= y_j^* \left[\sum_k (p_{jk}^* - c_{jk}) \right] \\ &= y_j^* \cdot \left[\sum_n \left(\frac{1}{\alpha} - 1 \right) w_N + \sum_i \left(\frac{2}{\alpha} - (1 + \delta - 2\delta z_{ji}) \right) \left(\frac{w_S}{1-\delta} \right)^{z_{ji}} \left(\frac{w_N}{1+\delta} \right)^{1-z_{ji}} + \right. \\ &\quad \left. \sum_o \left(\frac{2}{\alpha} - 1 \right) w_S^{z_{jo}} w_N^{1-z_{jo}} \right] \end{aligned} \quad (8)$$

Note that $\left(\frac{1}{\alpha} - 1 \right) < \left(\frac{2}{\alpha} - (1 + \delta - 2\delta z_{ji}) \right) < \left(\frac{2}{\alpha} - 1 \right)$. It indicates that the equilibrium profit margin per part rises as the part moves from production in the North to an integrated South firm

and rises further if it is produced by an arms-length South firm.¹⁴

Finally, the firm chooses the production mode for each part by comparing profit in equation (8) under all three scenarios, while keeping the mode of production for all other parts fixed. Formally, profit for making part k in three different ways will be

$$\pi_k^N = \lambda \left(\alpha \theta_j^\alpha \right)^{\frac{1}{1-\alpha}} \left(\frac{1}{\alpha} MC_{-k}^* + \frac{1}{\alpha} w_N \right)^{-\frac{1}{1-\alpha}} \left(\Delta_{-k}^* + \left(\frac{1}{\alpha} - 1 \right) w_N \right) \quad (9)$$

$$\pi_k^I = \lambda \left(\alpha \theta_j^\alpha \right)^{\frac{1}{1-\alpha}} \left(\frac{1}{\alpha} MC_{-k}^* + \frac{2}{\alpha} \left(\frac{w_S}{1-\delta} \right)^{z_{jk}} \left(\frac{w_N}{1+\delta} \right)^{1-z_{jk}} \right)^{-\frac{1}{1-\alpha}} \cdot \left(\Delta_{-k}^* + \left(\frac{2}{\alpha} - (1 + \delta - 2\delta z_{jk}) \right) \left(\frac{w_S}{1-\delta} \right)^{z_{jk}} \left(\frac{w_N}{1+\delta} \right)^{1-z_{jk}} \right) \quad (10)$$

$$\pi_k^S = \lambda \left(\alpha \theta_j^\alpha \right)^{\frac{1}{1-\alpha}} \left(\frac{1}{\alpha} MC_{-k}^* + \frac{2}{\alpha} w_S^{z_{jk}} w_N^{1-z_{jk}} \right)^{-\frac{1}{1-\alpha}} \left(\Delta_{-k}^* + \left(\frac{2}{\alpha} - 1 \right) w_S^{z_{jk}} w_N^{1-z_{jk}} \right) \quad (11)$$

where $\frac{1}{\alpha} MC_{-k}^* = \sum_{m \neq k} p_{jm} = \sum_{n \neq k} w_N + \sum_{i \neq k} 2 \left(\frac{w_S}{1-\delta} \right)^{z_{ji}} \left(\frac{w_N}{1+\delta} \right)^{1-z_{ji}} + \sum_{o \neq k} 2 w_S^{z_{jo}} w_N^{1-z_{jo}}$ and $\Delta_{-k}^* = \sum_{m \neq k} (p_{jm} - c_{jm}) = \sum_{n \neq k} \left(\frac{1}{\alpha} - 1 \right) w_N + \sum_{i \neq k} \left(\frac{2}{\alpha} - (1 + \delta - 2\delta z_{ji}) \right) \left(\frac{w_S}{1-\delta} \right)^{z_{ji}} \left(\frac{w_N}{1+\delta} \right)^{1-z_{ji}} + \sum_{o \neq k} \left(\frac{2}{\alpha} - 1 \right) w_S^{z_{jo}} w_N^{1-z_{jo}}$. The firm will compare the above three equations for each part to choose the profit maximizing mode of production. It takes into account that both the vehicle quantity (through the part prices) and the profit per part are affected by the mode of production decision, which can be seen more clearly by rewriting the equations as

$$\pi_k^N = \lambda \left(\frac{\alpha \theta_j^\alpha}{\sum_{m \neq k} p_{im}^* + p_{jk}^N} \right)^{\frac{1}{1-\alpha}} \left(\sum_{m \neq k} (p_{jm}^* - c_{jm}) + (p_{jk}^N - c_{jk}^N) \right)$$

and similarly for I and O .

3.2 Equilibrium Choice

In this section, we will lay out the characteristics of the equilibrium for the above model.

3.2.1 Choice of production mode of individual parts

Consider a representative firm producing variety j . To choose the optimal output level, it has to first choose the optimal production mode for each part center. The choice described in equations (9), (10) and (11) is similar to the choice in Antràs (2005) and the same theorem also applies here.¹⁵

¹⁴Hence, the price/cost ratios in the previous section are not constant across the different production modes.

¹⁵We assume that the condition is satisfied for all three production modes to exist in equilibrium, instead of only North and independent South. For a detailed discussion about the existence of two valid cutoffs and for the proof of Proposition 1, see Antràs (2005).

Proposition 1 *There will be two unique cutoffs Z_{NI}^* and Z_{IO}^* so that when the technology to produce the part is relatively new, i.e. $z_{jk} < Z_{NI}^*$, part k will be produced in North completely; for an intermediate maturity, $Z_{NI}^* < z_{jk} < Z_{IO}^*$, x_{jkl} , the low-tech input for part k , will be produced in South, but the activity is undertaken within firm boundaries; and when finally the technology becomes standardized, $z_{jk} > Z_{IO}^*$, x_{jkl} will be outsourced to an independent South firm.*

Proposition 1 provides two windows on specialization: comparing across different components that enter the same final good and across successive varieties of final goods that use different generations of each part.

First, across different components, Proposition 1 tells us that for any variety j there will be two cutoffs. A firm will produce all parts with z value less than Z_{NI}^* in the North, parts with z value in between Z_{NI}^* and Z_{IO}^* in an integrated plant in South, and parts with z larger than Z_{IO}^* in an independent South plant. More sophisticated parts, i.e. those that require a lot of skilled labor input, will be more likely to be manufactured in the North. This captures that products differ in their skill content and that the skill-abundant North will focus on the production of high tech parts.

Second, across successive generations, there are also two cutoffs. In such a dynamic scenario, each new generation of a part initially starts out with a relatively low z value and will be produced in the North. As it matures over time, z rises, and when it crosses the Z_{NI} threshold, production will move from the North to an integrated plant in the South, and so forth. For each part, there will be such a product cycle, with the location of production shifting as parts mature. For parts that become standardized more rapidly, z will rise more quickly and production in the South will happen earlier. This captures that increasingly specialization happens within product categories, rather than between (see Schott (2004)), and the North tends to focus on higher quality product varieties.

3.2.2 Defining differences between generations

Proposition 1 does offer some insights into how firms will produce their parts, but additional assumptions are needed to structure the empirical work, as the trade data aggregates parts over different generations. Thus far we have only assumed that with each generation of the final good j , there is a set of K parts associated, each maturing at a rate of z_{jk} . We now impose two assumptions on the distribution of these z 's across both varieties j and parts k .¹⁶

Assumption 1 The order of technology intensity of parts will be same for any variety j , i.e.

$$z_{j1} < z_{j2} < z_{j3} \dots < z_{jK}, \quad \forall j.$$

¹⁶In principle, these assumptions could be derived from underlying assumptions on consumer preferences and on the link between R&D activities and maturity z . Profit maximizing R&D investment of the firm would then endogenize the life cycle of parts. We take the short-cut of specifying the z distributions directly.

Assumption 1 specifies that the relative maturity of different parts will be the same for all final good varieties. If part 2 is easier to make than part 1 in one variety, i.e. it can be produced with more low-skilled labor, it will be easier to make in any variety. For example, if making the suspension requires more high-tech inputs (x_h) than making bumpers in one kind of automobile, then it should be this way in any kind of automobile. Note that this does not preclude that the bumper of a high-end or modern automobile contains more high-tech inputs than the suspension of a simpler vehicle; the comparisons are within the same final good variety. As a result, we can order all parts by increasing z and this ordering will hold across vehicle generations.

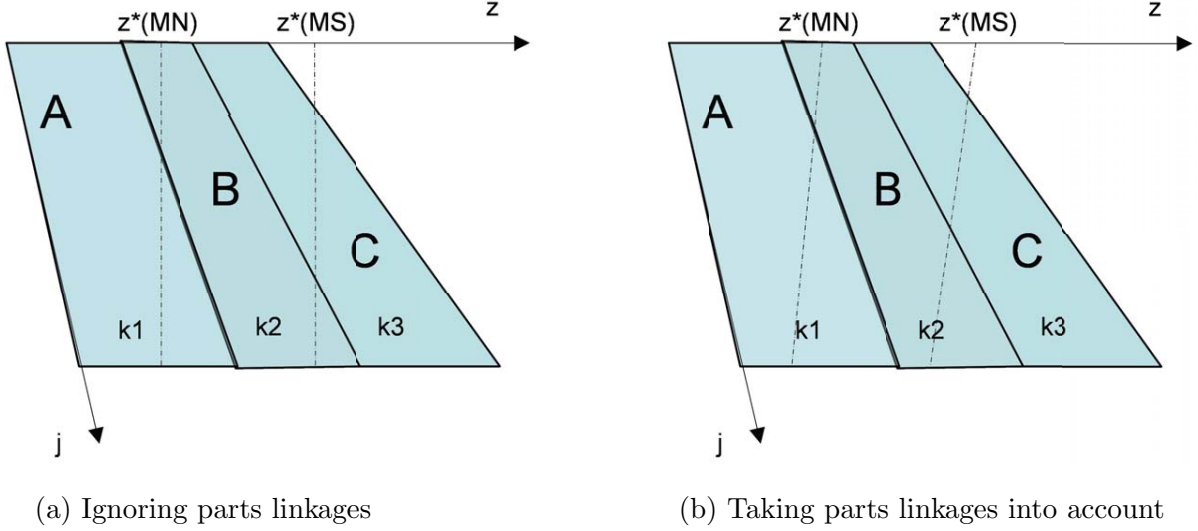
Assumption 2 If $\theta_1 > \theta_2$, $z_{1k} \leq z_{2k}$ for any k and $z_{2k'} - z_{1k'} \geq z_{2k} - z_{1k}$ for any $k' > k$

Assumption 2 puts restrictions on the $\theta = f(\mathbf{z})$ function that determines the quality of the final product. It says that if automobile 1 has higher quality than 2, it is because parts from 1 need (weakly) more high-tech inputs. Further, the difference between autos 2 and 1 in the technology content of their parts is non-decreasing in the index of parts. Parts that mature more quickly—which will be the same parts on each vehicle according to Assumption 1—will display a greater z difference between final product generations than parts that are still early in their life cycle.

With the above assumptions we can conclude that, if the cut-offs Z_{NI}^* and Z_{IO}^* are same across parts of different final good varieties, which is the prediction in Antràs (2005), low technology intensive parts that enter mature vehicles (high index of j and k) will be most likely to be produced in the South. Two extreme cases give straightforward predictions: (i) if the most advanced final good (highest θ_j) has sourced part k from the South, part k will be sourced from South completely; (ii) if the lowest-quality final good still make part k in the North, part k of all varieties of final goods will be produced in North. Other than these two extreme situations, there will not be complete specialization in production and trade. Instead, countries will specialize in some generations of some parts.

The benchmark equilibrium, for the moment ignoring the demand linkage between parts, is illustrated in the left panel of Figure 2. The horizontal axis represents the part index k and also the value of z_{jk} , as there is a one to one mapping according to Assumption 1. The vertical axis represents the final good index, with more recently introduced generations at the top. Holding the vehicle generation j constant, parts are ranked from less mature on the left to more mature to the right, i.e. drawing $k_1 < k_2 < k_3$ implies that for each vehicle $z_{j1} < z_{j2} < z_{j3}$. In area A, to the left first dashed threshold line (the line at $z^*(MN)$ represents Z_{NI}^* and $z^*(MS)$ represents Z_{IO}^*), parts will be produced in the North. In area B, in between the two dashed lines, production takes place in integrated South plants, and in area C in independent South plants. As a part goes through its life cycle, e.g. follow one of the solid lines from the left top to the right bottom, it will move from one area to the next. Eventually, once a vehicle matures sufficiently, all of its parts will be produced in the South. Assumption 2 implies that parts with more low-tech content (to the right) mature more quickly, i.e. the solid lines do not become steeper as we move to the right.

Figure 2: Production mode cutoffs with multiple vehicle generations (j) and parts (k)



3.2.3 Linkages between parts within each generation

Pure linkage through final good demand

Taking the linkages between parts into account, the Z_{NI} and Z_{IO} thresholds will not be the same anymore for different parts and final good varieties. The demand and production function for the final good directly link the demand for different parts entering the same final good. This is most apparent for the rigid Leontief production function, which implies that each part is needed in exactly the same quantity.¹⁷ The equilibrium production modes are affected in the following way:

Proposition 2 *The technology intensity parameter (z_{jk}) will not affect the cutoff values $Z^* = (Z_{NI}^*, Z_{IO}^*)$ as long as each part entering final good j is still produced in the North. However, as soon as the production of part k has moved to the South, the cutoff values Z^* for all other parts k' will decrease with z_{jk} .*

See proof in the Appendix.

The intuition is straightforward. As soon as a part is produced in the South, its output, but also its cost, will depend on its technology intensity z . Thus, when z rises, it does not only affect the part itself, it will affect the marginal cost, and hence also the optimal price and quantity, of the final good, and in this way the demand for all other parts. Moreover, an increase in z_{jk} might lead to part k crossing its threshold, which will affect its marginal cost and markup, which again affects the

¹⁷This demand-link will also be present for more flexible production functions, but allowing for substitution between parts complicates the derivations.

marginal cost of the final good and the demand for other parts. Given that the optimal thresholds for the mode of production depend crucially on the volume demanded, the pattern described in Proposition 2 ensues.

As in the previous section, we can use Proposition 2 to look at two dimensions of the model: across different parts of the same final good or across different generations of one part. First, for parts that enter the same final vehicle, if part $k' > k$ then $Z_{k'}^* \geq Z_k^*$. In other words, offshore production becomes gradually easier. A part that shifts its production to the South earlier (k') needs to overcome a relatively high offshore threshold. As most of the components of the vehicle are still made in the North, it is expensive and only sold in small quantities. Offshoring early is relatively difficult, i.e. the offshore threshold for this part is higher in z value than for parts that are offshored later.¹⁸ Production of part k will move to the South later in real time, but it actually does so at an earlier technology stage, i.e. for a lower z value.

Second, across different final good varieties, if $\theta_j > \theta_{j'}$, the cutoff point for each part k satisfies $Z_{jk}^* > Z_{j'k}^*$, except for the first part that moves to the South. In other words, parts offshoring is easier for final good varieties that are of lower quality and have production of some parts moved to the South earlier. High quality final goods, with parts that contain more of the high-skill inputs (according to Assumption 2), are more ‘conservative’ in offshoring: they shift production out of the North only when the technology is more standardized, i.e. when z_{jk} is higher. As a result, when part k entering vehicle j' has just moved production to the South, the corresponding part for vehicle j will still be made in the North.

This pattern corresponds to dynamics in the product cycle. If z is evolving at a constant rate for all pairs j and k , the above discussion tells us that the rate of offshoring, shifting production to the South, is increasing over time. Across parts, the cutoff for the first part to move South is higher than the cutoff for the second part. Across final good varieties, the offshore rate is faster in low quality final goods.

Combining the discussion across parts and across varieties, we need to adjust the predictions from the previous section as follows: if we write Z^* as a function of indices j and k , Z^* will be non-increasing over both arguments. It will be decreasing when j and k are sufficiently large, i.e. when some parts of j are produced in the South. Parts or final good varieties with a higher index tend to adopt production modes in the South more rapidly, i.e. at lower z . Holding j and k constant, the predictions still apply. Graphically, the only change in Figure 2 is that the dashed lines representing the Z^* thresholds are tilted to the left.

Complementarity in contracting

In the previous section, demand for parts was only linked through the production function of the

¹⁸Still, if $k' > k$, part k will use more skilled input at each point in time.

final good. As production costs for some parts declined, the optimal price for the final good declined, boosting demand for all parts and lowering all offshoring thresholds. We can introduce an additional link between the different parts through their impact on the contracting environment. In particular, we allow for the production of one part to create externalities for all subsequent part production. This is reminiscent of the effects in Acemoglu, *et al.* (2005), which presents evidence that the colonialism and Atlantic trade of Western Europe after 1500 gave rise to institutional change. This indirect effect strengthened property rights, lead to more trade, and ultimately to higher subsequent growth rates.

In a more micro-level application, Novak and Stern (2003) illustrates how outsourcing one automotive component can create externalities for other sourcing decisions. The source of the externality in their model is not the contracting environment, but the interdependency in coordination efforts or the need for disclosure of proprietary trade secrets. The result is that outsourcing of one component increases the likelihood that other components will be outsourced, i.e. not made in-house, as well.

In our model, we allow that initial production activities in integrated South plants improve the contract writing skills or the legal system of the host country. When automotive components are first produced in the South, the existing courts, lawyers, and dispute mediation mechanisms will be unfamiliar with the usual practices in the industry, for example with the high degree of specificity of investments. Over time, however, we expect experience in dealing with sourcing disputes in the automotive industry to grow with cumulative automotive parts production. As a result, past offshoring activities provide an externality on current offshoring decisions by improving the contracting environment, captured in our model by the δ parameter. Because the thresholds for the production modes depend on this contracting parameter, such effects will again change the equilibrium sourcing choices.¹⁹

Proposition 3 *Both cutoff points Z_{NI}^* and Z_{IO}^* are decreasing in δ .*

See proof in Appendix.

The basic intuition behind Proposition 3 is the following: firms want to move production from North to South (the first cutoff) to take advantage of the lower wage in the South. The incompleteness of contracts prevents it from happening right away. z first has to grow sufficiently large to overcome the wedge between the marginal cost of production and the price paid to the supplier under the South integrated mode. An improvement in the contracting environment, reduces the wedge, which will result in a shorter delay for offshore production: the threshold Z_{NI}^* is lowered. At the extreme, if $\delta = 1$ and $w_S < w_N$ nothing will ever be produced in the North.

The second cutoff reflects a trade-off between control over the output and production incentives. A larger value of δ gives North firms greater control over the output in the integrated production

¹⁹We assume that firms do not take these externalities into account when they make sourcing decisions. At each point in time, they take the contracting environment (δ) as given, ignoring that a decision to outsource today will improve the contracting environment for sourcing decisions tomorrow.

mode and will lead to lower input choices by the Southern partner. As a result, the production distortion under I relative to O is increasing in δ . The relative benefits of full outsourcing will be greater if δ is large and outsourcing will happen at an earlier stage (lower z), hence Z^*IO is lowered as well.

In sum, complementarities between outsourcing decisions—through improvements in the contracting environment—will lead to faster transitions in production modes. The effect on sourcing decisions is similar to the effect of the linkage through the demand and production function of the final good. In equilibrium, the Z^* thresholds will tilt even further to the left as automotive production experience accumulates over time (corresponding to higher j or k indices), reinforcing the difference between the left and right panels of Figure 2.

3.2.4 Introducing several Southern countries

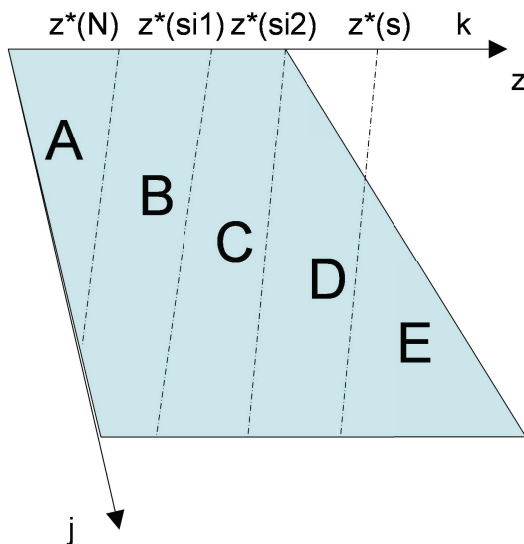
While the equilibrium sourcing structure was characterized in the previous sections, one crucial difference with the actual trade data is the existence of more than two countries. As we will use U.S. auto part imports from all countries in the empirical application, we first extend the model to a multi-country equilibrium.

Suppose there is a single North country and S South countries serving the North home market. Production in the North will be as before. We order the S South countries by their local wage rate w_s , where $s = 1, 2, \dots, S$ is the country index. In order for more than one South country to engage in offshore production, the contracting parameter δ also has to be country-specific. For all South countries that engage in offshore production, the value of δ_s has to be in the same order as w_s ; the other countries will be entirely skipped in the global production chain.

First, consider the choice of a South independent plant. Since the only thing that matters in this production mode is the wage, production by an independent South manufacturer will only happen in country S , which has the lowest wage of all active countries (and the worst contracting environment, but this will be irrelevant in outsourcing). Next, consider the choice of a multinational firm that produces in an integrated South plant. From the earlier discussion of cutoffs and production mode switching, it is obvious that production will first transition to the first South country—with the highest South wage and best contracting environment. At a later threshold, production will move up the s index until the last country. Then, the final threshold will mark the transition from integrated to outsourced production in country S .

In summary, the North will produce the parts with lowest z value, the first South country produces parts with a z value that is slightly higher and so on, till country S , which produces the most standardized parts in both integrated and independent plants. Such a multi-country organization could also be derived from the model in Antràs (2005). An additional wrinkle in our set-up is that the demand linkage of parts now connects events in different countries, even if they specialize in different parts. In addition, production of one part can have long-lasting effects in one

Figure 3: Cutoffs in a multi-country world with effects from related parts



country through its impact on the contractual environment, again affecting the demand for parts of another country. If the contracting environment in one country improves sufficiently, it can even lead to another country being skipped out of the value chain on the next generation of products.

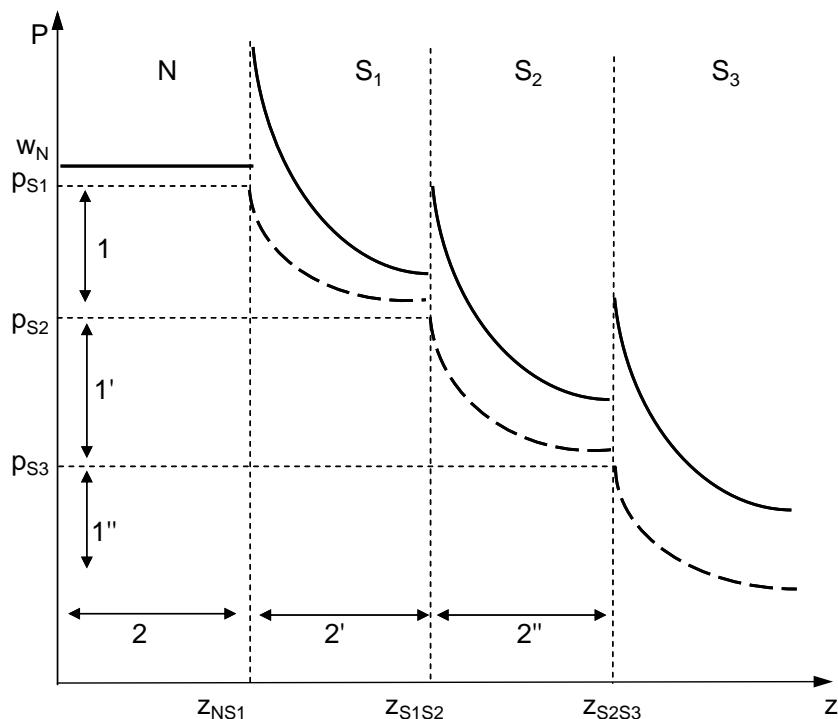
Figure 3 illustrates how to extend Figure 2 to our multi-country setup with one North and three South countries. The left-tilt in the dashed cutoffs for z reflect the linkage between parts, as before. Parts with z in Area A will be produced in the North, in area B in integrated plants in the first South country, in area C in the second country, and in area D in integrated plants in last South country. Eventually, a part's z index will reach area E and its production will move to independent plants in last South country, where it stays until the product is taken from the market.

3.3 Empirical model

In order to derive testable implications from the model, consider the predicted price evolution for a representative part in Figure 4. The dynamics over time come from the gradual increase in z_{jk} , leading new countries to take up production of the part. At first, only a few varieties of the final good are made and support of z_{jk} is only $(0, \bar{z})$, with \bar{z} a small number. All parts k are only produced in the North and the cost is w_N . Over time, the technology of the industry, characterized by the value of \bar{z} , matures and gradually more South countries start participating in the production chain.²⁰

²⁰Initially, for low \bar{z} , there are no “active” South countries, either due to country policy or maturity of the production technology. Only a few final good varieties will be made. Because producing any generation costs the same and consumers prefer the more advanced technology, as long as production does not move to the South, firms will tend to

Figure 4: Price and sourcing evolution for a representative part



When z_{jk} advances sufficiently and crosses the first Z_{NI}^* threshold, between the North and integrated plants in the first South country, production will move to S_1 . While the profits change smoothly when the threshold is crossed, prices and quantities will change discretely. Moreover, there will now be a gap between the total value created in production and the cost to the firm, because it will bargain with its supplier to divide the surplus. The solid line in Figure 4 represents the value created and this is sure to increase when parts transition from North to South. The dashed line is the cost to the North firm, which can be above or below w_N initially. On the graph, we have arbitrarily drawn p_{S_1} below w_N . Importantly, once production has moved to the South, the price is a combination of w_N and w_S and a further increase in z_{jk} will lower the price—hence the downward-sloping dashed line. Eventually p_{S_1} will certainly lie below w_N .

At subsequent thresholds between lower wage countries, indicated by $Z_{S_1S_2}$ and $Z_{S_2S_3}$ on Figure 4, the same pattern will be observed. The price to the Northern firm changes discretely when a new country is added to the production chain. Eventually, the good will be outsourced completely in the lowest wage country, but in the data we will not be able to distinguish this from production by integrated plants in the same country.

Subsequent South countries will enter to produce the part at the cutoff point, while existing

focus only on the best varieties.

producers might remain active as producers of newer generations of the same part. The basic result from Antrás (2005) still applies. If we assume that at each point in time only one variety switches location, the quantity at the threshold will be increasing in the country index ($s = 1, 2, \dots, S$), while the relative price *at entry* is gradually lower for later entrants. In Figure 4, we do expect to see $p_{S_1} \geq p_{S_2} \geq p_{S_3} \geq \dots$. This is the first prediction that we will take to the data:

Prediction 1: For a given component, a country’s entry price, when it exports the component for the first time, will be a decreasing function of its order in the sequence of countries that have subsequently taken up production of the part.

(The country-order $1, \dots, S_1, S_2, \dots, S$ reflects $w_1 \geq w_{S_1} \geq w_{S_2} \geq w_S$.)

If parts were not linked, the country-cutoffs should be identical for every part. A country’s wage advantage will overcome its contracting disadvantage when the part has become sufficiently standardized, i.e. when z_{jk} is sufficiently large and low-tech inputs are sufficiently important. This will translate into the same price decline relative to the previous producer, irrespective of the part, and as such we would expect each country to have only a single cutoff value: $Z_{S_1 S_2 k_1} = Z_{S_1 S_2 k_2} \forall k_1, k_2$. However, the effect from other parts, linked through the production function and demand for the final product, will modify this. For a part that is outsourced very early on (k'), most other parts that go into the same vehicle are still produced in the North or at South countries with relatively high wages. Hence, the threshold that $z_{jk'}$ has to cross before country s starts producing it will be high, because volumes are low. In comparison, a part that matures very slowly ($k < k'$) will be outsourced much later, at which point many other parts are already produced in the South. The higher volumes of the final product that this has lead to will make it advantageous to move production of k to country s at a lower level of z than was the case for part k' .

In Figure 4, the time it takes (measured by z) for production to transition from country S_1 to country S_2 will be longer for a part that is outsourced earlier (a high k index part). These maturity lengths are indicated on the graph by $2'$, $2''$, etc. As a result, the entry price decline we expect to see from p_{S_1} to p_{S_2} will be larger for goods that are outsourced early (k') than for more high-tech goods (k). Note that these lengths represent time for the technology to maturity. The correspondence with calendar time is likely to differ by part. Therefore, we will measure the lengths in percentage price reductions.

Prediction 2: For a given country, the part’s entry price, when it exports a component for the first time, will be an decreasing function of the part’s order in the offshoring sequence of parts.

(The part-order $1, \dots, k, k', \dots, K$ reflects $z_{j1} \leq z_{jk} \leq z_{jk'} \leq z_{jK} \quad \forall j$.)

The demand linkage of parts will have more far-reaching effects, linking production in one country to prices of other countries. For example, if a low-wage country starts producing a high-index part, it will boost demand for intermediate-index parts produced in intermediate-wage countries.

Interestingly, the model predicts that such entry will lead to higher demand for the final product and all its components and will spur intermediate countries to acquire production sooner (at higher entry prices) than in the absence of the demand linkage. The start of parts production in low-wage countries is often viewed as a negative factor for intermediate countries as they now face stronger competition. However, for parts that end up being installed in the same vehicle, the entry of low-wage countries could prove a boon. If countries can upgrade their production activities to more recent generations or to more high-tech components, they might benefit from the addition of low-wage countries to the production chain.

Prediction 3: The entry price in one country, when it exports a component for the first time, will be higher if there was immediately preceding entry of other countries into the production of any other part that enters the same generation of vehicles. This effect should be particularly strong for preceding entry of low-wage countries.

Predictions 2 and 3 capture the linkage between parts that works through the demand and production function of the final vehicle. In addition, Proposition 3 stated that the offshoring thresholds are decreasing in the δ parameter, which characterizes the contracting environment in a country. The extent to which the contracting environment is endogenous creates a dependency of entry prices on the past production experience of the country. This effect is in addition to the effect of the order in which parts are outsourced—which was captured by Prediction 2. Past production is predicted to lead to more rapid offshoring, i.e. when z has increased less and production in the South places a lower weight on the low-skilled input; therefore the entry price should be higher.

Prediction 4: For a given country, the entry price, when it exports a component for the first time, will be an increasing function of the past production volume of automotive parts in the country.

The four predictions can be investigated separately, focusing on one particular dimension of variation. For example, we can exploit cross-country variation by flexibly controlling for the other effects using a full set of component-time interaction effects (γ_{kt}). The following equations focus on the effects of each of the four predictions individually:

$$p_{ckt}^e = \beta_c c + \gamma_{kt} + \varepsilon_1 \quad (\text{P-1})$$

$$= \beta_k k + \gamma_c + \gamma_t + \varepsilon_2 \quad (\text{P-2})$$

$$= \beta_{-c} \text{entry}_{-ct} + \gamma_k + \varepsilon_3 \quad (\text{P-3})$$

$$= \beta_\delta \sum_{\kappa=1}^{k-1} \sum_{\tau=0}^{t-1} (p \cdot y)_{c\kappa\tau} + \gamma_{(k)t} + \varepsilon_4 \quad (\text{P-4})$$

The dependent variable throughout is the entry price when a South country c exports part k for the first time in year t . All prices are expressed relative to the North price for the part in that year.

The explanatory variables are the country index c , the part index k , the number of immediately preceding entry points by other countries, and the cumulative past export value across all parts in the same country. According to the predictions, we expect the following signs: $\beta_c, \beta_k \leq 0$, and $\beta_{-c}, \beta_\delta \geq 0$.

4 Data

We use data on U.S. automotive component imports from the rest of the world during the 1989–2005 period. Information for the first years, from 1989 to 2001, was compiled by Robert Feenstra and available through the NBER web site. Information for the later years, up to 2005, comes from the Global Trade Atlas, maintained by a private company, Global Trade Information Service.²¹ All trade statistics follow the Harmonized System (HS) 10-digit classification and are collected by U.S. Customs. Limited to automotive components, the original data set has 95,186 observations.²² There are an average of 303 HS categories with positive imports across all years, rising from 242 in 1989 to 335 in 2005, with a total of 364 unique 10-digit categories observed in total over the 17-year time period.

For each HS category, we observe in each year and for each exporting country the U.S. imports of auto parts in nominal values (U.S. dollar) and in quantity (units shipped or by weight). Given that the theoretical model defines the parts as being required in each vehicle, we aggregate them by combining detailed 10-digit HS categories that are close substitutes. For example, there are several categories that contain engines, while each vehicle will only need one. These could represent engines of different maturity (high versus low z), engines that will enter different generations of vehicles (different j), or the engine might serve to further differentiate final products of the same maturity and generation, e.g. diesel versus gasoline engines. What matters for our predictions is when a part made by one country will be replaced by the output of a second country. Therefore, we define categories by the functionality of the components in the vehicle: engines, brakes, tires, wheels, glass, etc.

All parts are grouped into 30 exhaustive, and mutually exclusive categories, which are listed in Table 1. Import values are aggregated by simple addition and deflated by the BLS Producer Price Index for Motor Vehicle Parts. Aggregation is more complicated for the prices. For each 10-digit HS category, we define a unit value ratio by dividing the real import value by the quantity, to obtain a proxy for price. We run into two aggregation problems. First, the quantity of different parts is measured in different units and prices will not be comparable. Second, most countries do not export

²¹The two web sites are <http://www.nber.org/data/> and <http://www.gtis.com/>

²²HS code 8708 contains the bulk of automotive components, but there are several other 4-digit categories solely comprised of automotive components. For example, HS 840820 contains ‘diesel engines for motor vehicles’, and HS 700721 contains ‘safety glass (laminated) for vehicles, aircraft, etc.’ The full list of included HS categories is available upon request.

in all the detailed HS sub-categories, which complicates weighting.

[Include Table 1 here]

We follow the method proposed by Hallak (2006) to obtain a price index that represents a weighted average of all the sub-category unit value ratios. The weights incorporate each country’s own trade volume and the number of categories it is active in. The index averages over J separate indices, where for each individual index one of J trading partners is used as reference country, using only that country’s exports in the aggregation. Dividing the aggregated trade values by the price indices gives a quantity index for each of the components and countries.

A common problem, faced by all researchers using unit value ratios on trade data sets, is the extremely large volatility in observed prices. Like them, we apply some very strict rules to trim the data and avoid the most extreme outliers, which can easily arise when a product in a detailed HS category is misclassified. In particular, any observation for which the log (de-meaned) price is larger than three in absolute value or for which the trade value amounts to less than 2% of the overall U.S. imports in that 10-digit HS category is discarded. Note that this data trimming is done before aggregating values and prices and will only marginally affect the coverage of the data set.

A second source of volatility stems from the annual nature of reporting. In the automotive industry, supply contracts tend to span several years. Individual shipments will aggregate to the agreed upon values and quantities, but there can be payment adjustments at the start or end of the contract. Such adjustments can cause a mismatch between prices and quantities in individual years that cover only a fraction of the contracting period, skewing unit value ratios. We often observe a relatively smooth year-on-year evolution for unit values, interspersed with adjacent positive and negative spikes. To allow for contract adjustments spilling into adjacent years, we construct a three-year moving averages of trade values and quantities, putting 30% weight on the previous and following year, and 40% on the current year.²³

Finally, we also reduce the country-dimensionality of the data set. First, because we do not observe domestic U.S. prices and quantities for the aggregated components, we need a proxy. In the theory, the crucial distinction between the North and the South is the wage rate that applies to low-skilled inputs. We aggregate trade volumes from a number of more developed countries that are likely to have similar wages as the U.S. into a composite ‘North’ country.²⁴ This North country averages a 36% share of U.S. automotive parts imports. Second, trade flows from countries that appear less than 150 times in the data set, once outliers are deleted, are combined into a composite ‘Other’ country. These countries are considered only casual or highly specialized participants in the automotive supply chain and not the focus of our application. The composite Other country

²³If no values are recorded in adjacent years, the weight is carried over to the current year.

²⁴This composite country is comprised of Japan and the important car-producing E.U. countries (Austria, Belgium, France, Germany, Italy, the Netherlands, Spain, Sweden and the United Kingdom).

averages 5% of U.S. automotive parts imports. The remaining eight countries are left untouched, except for the inclusion of Hong Kong imports with China. Table 2 lists all ten countries that make up the final data set.

[Include Table 2 here]

To summarize, these are the steps that get us from the original trade data to the final data set: 1) deflate import values by the U.S. PPI; 2) construct a moving average for values and quantities; 3) discard outliers; 4) aggregate countries; and 5) aggregate HS product categories. We end up with import values, and quantity and price indices for 2,859 observations. Each observation represents 1 of 30 composite automotive parts, 1 of 10 import countries (two of which are the composite North and Other country), and 1 of 17 years. Columns (1) and (2) in Table 2 show the frequency for each country in the original and final data sets.

5 Results

5.1 Ordering Countries and Parts

Before we can investigate the predictions of the model, we first have to construct the country and part indices c and k . One approach would be to use observable proxies for relevant characteristics in the model. For example, Hallak (2006) uses GDP per capita as a proxy for ‘taste for high quality products’ (country index) and Head, *et al.* (2004) use ‘engineering complexity’ to construct a part index that will be related to the ease of outsourcing.

In our case, the most important aspects of the model are difficult to observe: the skill-content and speed of standardization of the composite parts and the productivity-adjusted wage and contracting environment of the countries. Instead, we use the most basic prediction of the model, also contained in the model in Antràs, and use the observed order of outsourcing as a revealed ordering of the countries and commodities. Countries with a lower index (high wage and good contracting environment) and parts with a higher index (more low-skilled labor input) will enter the world production chain earlier.

For each country-component pair, we observe the entry point in the data set: the first year (after 1989) in which positive U.S. imports are recorded. Averaging the entry years across all 30 parts within each country gives the country index, see column (3) in Table 2. We have adjusted the average by assigning an entry year of 2006 (the first year past our sample period) to parts which are not exported yet. The index reflects comparative advantage and is influenced by the wage rate and contracting environment. Regressing the price index on the country index for the full sample produces a significantly negative coefficient (-1.36), consistent with our prior: more developed countries export goods with a higher price.

Similarly, we obtain an index for the 30 composite parts by averaging the entry year over all countries, results are in column (2) of Table 1. As we are using the North composite country as our proxy for domestic production, we average the difference in North versus South countries' entry years.²⁵ A high value indicates that, on average, South countries started exporting the part to the U.S. much later than North exports started. The gap is reported in column (3) of Table 1 and we have used this ranking to construct our preferred index, in column (1). For some parts, the index might be a surprise. For example, the engine ranks number 30, the first part exported by South countries, even though it is clearly not the most low-tech part on the list.

For both countries and parts we calculate indices based on the (inverse) GDP per capita rankings as a robustness check. For countries, these numbers are in column (6) of Table 2. For parts, we simply average the GDP per capita (weighted by quantity) over all observations in the data set. The average income of exporters for each part are reported in column (4) of Table 1; because differences in GDP are large, we also calculated the average country rank, in column (5).

5.2 Four Predictions

In this section, we report results for the four main predictions we derived from the model, as captured by the equations (P-1) to (P-4). The coefficient estimates are reported in the four panels of Table 3, following the ordering of the predictions. Throughout, we use the entry price, when a country exports a component for the first time, relative to the contemporaneous North price as dependent variable. We base our identification on the initial export price when a country enters the supply chain for a new part to avoid having to aggregate over different generations. This would severely complicate any analysis of prices and quantities in subsequent years as production of older generations shifts to low-wage countries, but high-wage countries remain active producers of newer generations.

[Include Table 3 here]

The first prediction, on the country ordering, is strongly supported in the data. Countries that enter the production chain at a later stage tend to charge lower prices. Each column in the top panel of Table 3 reports an estimate of equation (P-1), using different country indices as explanatory variable. All coefficient estimates are negative and highly significant. For example, the -0.089 coefficient in column (2)—using the average entry year adjusted for components that are not exported yet—indicates that for every year delay (on average) a country tends to charge 8.5% lower prices.²⁶

²⁵The vast majority of parts are already imported from the North country in 1989, but there are some exceptions. For example, air conditioner units only appear in the data set in 1995.

²⁶This statistic is calculated as follows: $\exp^{-0.089} - 1 = -0.085$.

The country index based on GDP per capita, in column (3), gives a qualitatively similar result: richer South countries tend to charge higher prices (relative to the contemporaneous North price). The point estimate indicates that every 10% decrease in GDP per capita is accompanied by a 1.9% decline in the relative export price. Even using the ordinal ranking of countries as explanatory variable changes very little. The result in column (4) is based on the same country-ranking as in column (2), but uses a linear scale from 1 to 10 instead of the average entry year. The point estimate is entirely unchanged, and the fit of the regression even increases.

Even stronger support for Prediction 1 is provided in the two panels of Figure 5. Both graphs report the results of a flexible regression with nine separate country dummies included as explanatory variables, instead of using the cardinality of the country-indices directly as in Table 3. In the top panel, the country-specific β_c coefficients are plotted against the indices used in columns (2) and (4): the average adjusted entry year (our preferred measure) at the top; and the GDP per capita at the bottom. Clearly the fit is quite good for either index. We can thus conclude that the ordering of countries, by entry year or income, is consistent with the relative prices they charge. Note that we are not merely saying that Chinese export prices are lower than Canadian. We find that when China first exports a part, its price discount relative to the current North imports of the same parts is larger than when Canada first exported the part, while we control for part-specific price changes over time.

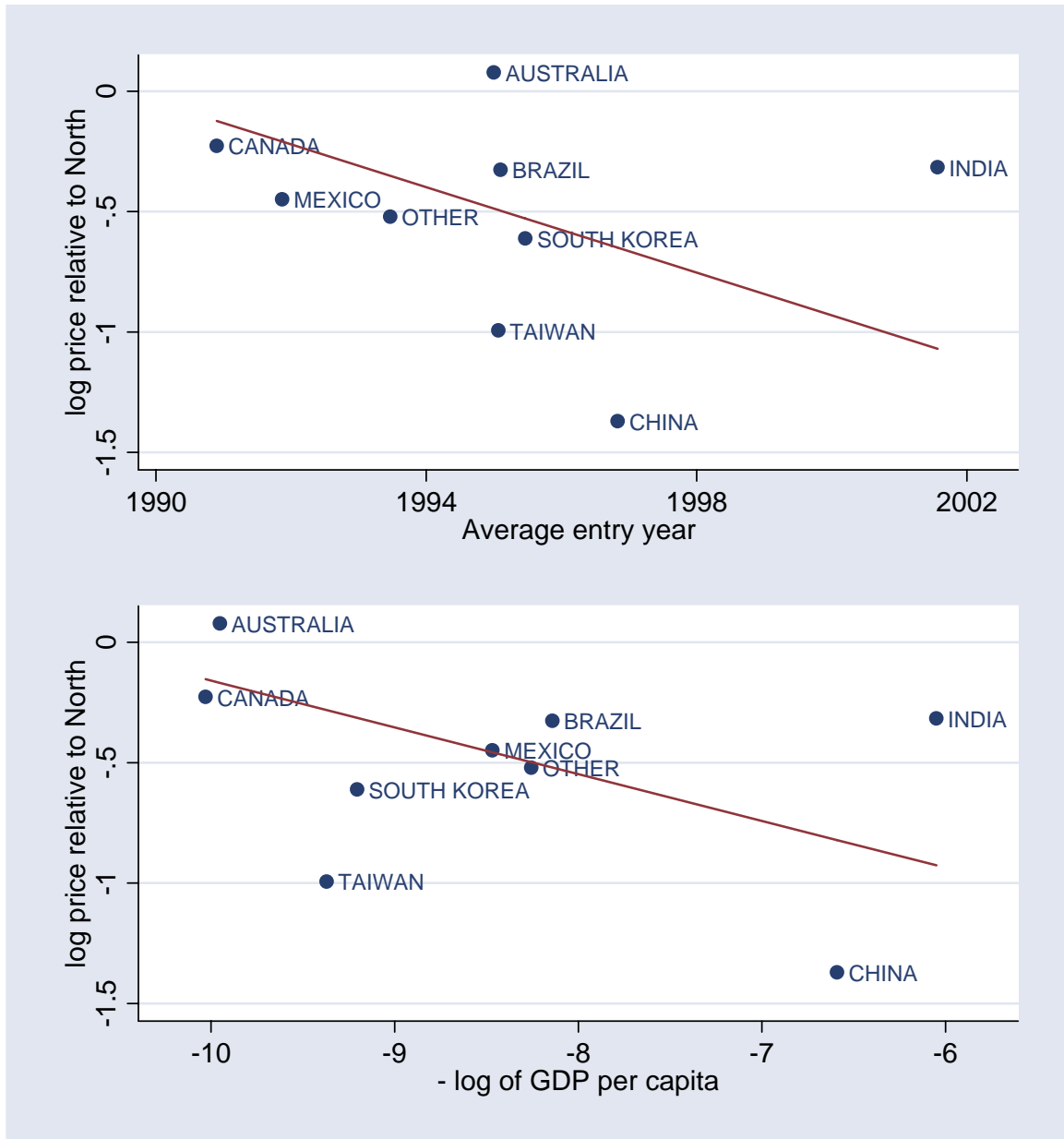
The second prediction is that the demand linkage between parts will cause the rate of offshoring to increase for later parts, those that mature more slowly. As a result a smaller price gap between the South and North upon entry is predicted for parts for which the average entry year of the South lags the North considerably (low index parts). While we predicted the estimation of equation (P-2) to yield negative coefficients, all results in the second panel of Table 3 are positive. Even though only the first coefficient is significantly different from zero, and only at the 10% level, the point estimates are suggestive that higher-tech parts, higher up in Table 1, tend to be sold at a lower relative price.

It (weakly) suggests that South countries face increasing hurdles as they take on more advanced components. The demand linkage, however, works in the other dimension, boosting quantity and shifting the maturity threshold forward. One explanation for the contradictory findings could be that quality becomes more important as countries move to more high-tech components, while our model only dealt with cost of production. Another explanation is that the ranking of parts differs by country because of idiosyncratic expertise and using the same index in all countries biases the results.

Figure 6 reports the results if we estimate equation (P-2) separately by country and also make the parts ranking country-specific.²⁷ The markers indicate the raw entry prices for each country-

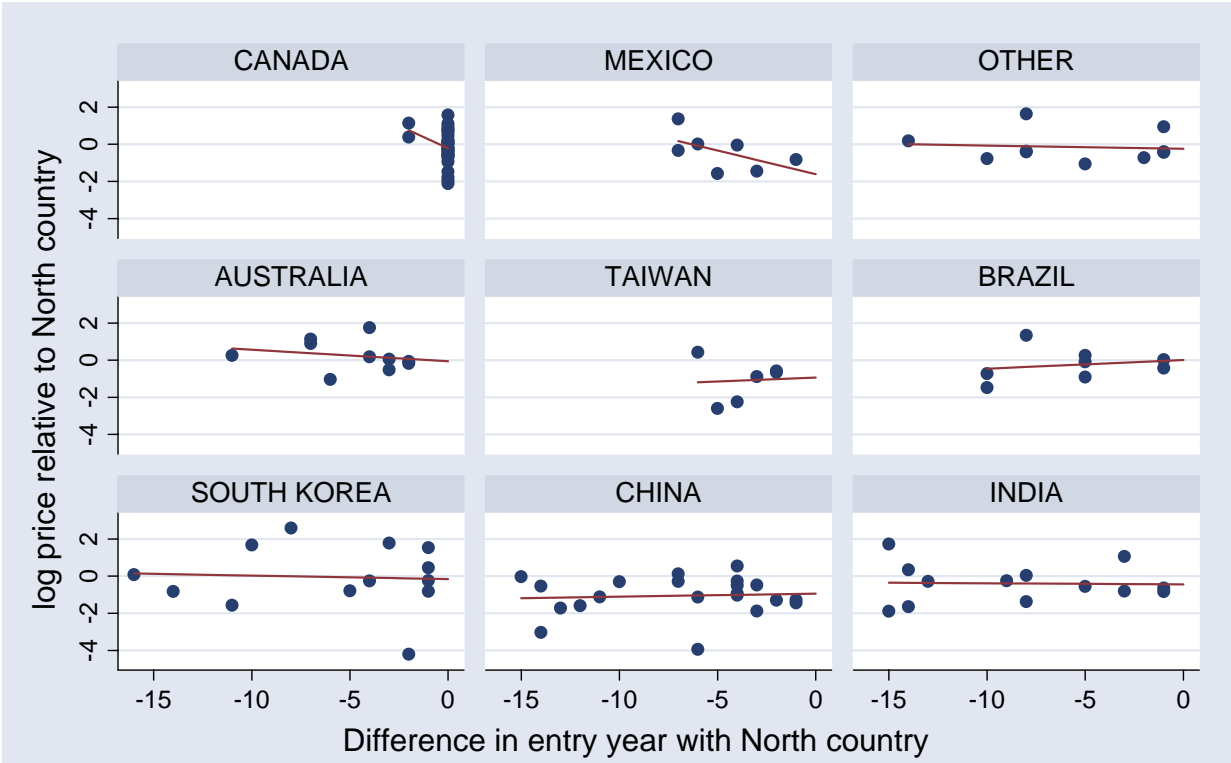
²⁷Note that we exclude parts with a South entry year in 1989, as the entry year for both the North and South are truncated. Only for Canada did we include parts with a zero gap, as we wouldn't have been able to estimate the coefficient otherwise.

Figure 5: Relative entry prices by country-rank



Note: Country-specific estimates for the β_c coefficient in equation (P-1) are plotted against two different country-indices (each index is higher if a country receives offshoring business later). The top panel uses the adjusted entry year, column (4) in Table 2, and the bottom panel the negative of log GDP per capita, column (5) in Table 2. The vertical axis measures the (log) entry price relative to the contemporaneous North price when a part is first exported by a country. The solid lines are least squares predictions characterizing the relationship; both slopes are significantly negative.

Figure 6: Relative entry prices by part-rank (estimated separately by country)



Note: The slope of the lines are the β_k coefficients in equation (P-2), estimated separately by country. Lines are negatively sloped for all countries except Brazil, Taiwan, and China. The observations are entry points for different components and the horizontal axis represent minus the number of years after North entry. Except for Canada, all zero gap observations are excluded.

component pair and the line is the fitted regression from (P-2), by country. The results are quite revealing in two ways. First, for six of the nine countries the line is now downward-sloping, consistent with Prediction 2. For only three countries, Brazil, Taiwan, and China, is the part-index still somewhat positively related to the relative price.²⁸ Second, while the fit is not very tight for several countries, the lines are steepest for countries that are likely to be least deterred by quality considerations: Canada, Australia, Mexico, and to a lesser extent South Korea.

The third prediction states that the addition of additional countries to the global production chain, will have beneficial effects for other South countries. In particular, it will accelerate the speed of offshoring for all other countries. To investigate it, we need to construct a proxy for other countries' taking up production of new parts. The most straightforward approach is to simply count the number of entry events across all other countries and parts: $entry_{-ct}$ in equation (P-3). We find that regressing the relative entry price on the lagged number of entry events by other countries

²⁸Moreover, for Brazil the result disappears if we normalize the relative prices by the average world price instead of the North price.

produces a positive coefficient, even controlling very flexibly for the type of part with a full set of part fixed effects. The point estimate, in column (1) of the third panel of Table 3, is only 0.001 and not significantly different from zero.

The effect is notably larger if we limit the sum in the construction of the $entry_{-ct}$ variable to include only parts with a higher rank, i.e. parts which are expected to be offshored earlier. The coefficient in column (2) is 0.003 and significant at the 10% level. Restricted to higher-ranked countries, implicitly countries with lower wages than the country under study, the effect of other countries' entry on price is even larger (0.006) and highly statistically significant, see results in column (3). Finally, limiting the sum to higher ranked parts and countries leads to the largest and most significant estimate, 0.008, in column (4). While these results are in line with the theoretical prediction, the absolute size of the effect is relatively small. Using the highest point estimate and the largest value for the entry variable, for Canada in 1990, we estimate a less than 1% increase in the relative price as a result of other countries taking up exports of new parts.

Results are similar if we use contemporaneous entry counts or take the sum of lagged and current entry events. If we omit the first year, when more than a third of all entry in the data set takes place, the coefficient estimates rise markedly, but the much smaller range of the explanatory variable leads to predicted effects on prices of a similar magnitude. While we can conclude that the effect of Prediction 3 is the expected direction, it is not very strong.

It is useful to point out that there are likely to be other forces, which we do not model, that are pulling in the other direction. A priori, one would have expected the entry of a low-wage country like China in the global production chain to exert downward pressure on Canadian parts export prices. In our partial equilibrium model, the absolute size of the Canadian parts industry—or at least the fraction of firms that engage in exporting—might shrink, but it will attract outsourcing business from the U.S. earlier. This is what the coefficient estimates in the third panel are picking up.

The fourth and last prediction states that past production will improve the contractual environment in a country and lead to accelerated offshoring for higher-tech components. To investigate this, we introduce the volume of past part exports as explanatory variable, still using the relative entry price as dependent variable. The coefficient estimate in column (1a) in the fourth panel of Table 3 is positive as predicted, albeit not significantly different from zero. The point estimate indicates that a doubling of past export volumes, raised the relative price by 2.7%, which is certainly not negligible. In column (2c), we estimate the same regression but use the number of parts that have been exported previously, instead of their cumulative export value, as explanatory variable. The coefficient estimate is again positive, but still insignificant. The size of the point estimate is quite large: doubling the number of parts exported raises the entry price by 1.1%. For the results in columns (2a) and (4a), the construction of the export experience variables is limited to only include parts that are taken up according to the parts-ordering in Table 1, following the average maturity or technological content. Both coefficients rise (especially for the number of parts measure), but

remain insignificant.

Thus far, we only used prices at initial export events (entry) into the analysis to avoid aggregation problems, but this is much less of a problem in the present case. Any increase in the contracting environment (as captured by the δ parameter), will raise a country's export price, both for existing parts exports and for new parts that are taken up because of the rise in δ . It also pushes a country towards a lower index in the country-ranking, obtaining offshoring business earlier. As such, the direct effect and any composition effects will work in the same direction and we can estimate equation (P-4) on the full sample of export transactions, not limited to entry events. The coefficient estimates are reported in the bottom panel of Table 3, using the same four measures of past export experience as explanatory variables. The increase in degrees of freedom now allow us to control much more generally for the type of part by including part-year interaction effects.

The pattern is similar to the results limited to entry years, but the effects are much stronger. All four coefficients are estimated positive and highly significant, even at the 1% level. All point estimates are much larger, most of them by a factor of two. Doubling past export volumes is now predicted to raise the relative export price by a full 6.0% (0.058 log points) and the 95% confidence bound is a tight interval: [5.0%, 6.9%]. Results for the number of parts exported are similarly strengthened and limiting export experience to the parts that follow the correct maturity order raises the coefficient estimates further. In all, this provides support for the existence of spillover effects from past export experience on current export prices.

6 Policy Implications

We developed a theoretical model of outsourcing that explicitly linked decisions on the production modes of individual parts. They are linked directly through the final demand and production function of the final good and indirectly through each part's impact on the local contracting environment. We derived four testable predictions that touched upon different dimensions of the model. Taking these to the data using information on automotive parts trade from one North country (U.S.), we found support for each of the four aspects of the model, although the evidence was stronger for some predictions (notable P-1 and P-4) than for others. The obvious question is now, 'What does this imply for the future of the Canadian auto industry?' and 'What policy implications can we derive from this analysis?'

Given the relative strong support for this model in this particular industry, it is instructive to take the model quite literally and see what policy conclusions logically flow from it. In the model, Canada is the first South country, the one that receives offshoring business first, but also has the greatest risk of losing it to higher-index countries. We will discuss implications for Canada from that point of view. Six corollaries jumped out to us.

1. As other countries reduce their unit wage cost, for example by increasing their productivity

level, or improve their contracting environment, they will enter the offshoring queue and take market share away from Canada. It seems unavoidable that rising capabilities in low-wage countries will have an impact on Canadian auto parts exports to the U.S. Any policy aimed at stopping it is bound to have only short-term impact and not be very effective. When U.S. firms are deciding to outsource production to Canada or to Mexico, any trade barrier that Canada erects (hypothetically) would disadvantage Canadian firms.

2. When mature products move down the chain to low-wage countries, this frees up resources in Canada. Canadian firms will be able to focus on less mature / more high-tech varieties of the products they used to make or move on to produce parts which are harder to offshore. Even more than in other trade models it is of the utmost importance to facilitate these transitions as they will be going on continuously. Comparative advantage at the product level is shifting continuously in this model. Given that lower wage countries will eventually become more attractive as products standardize, it is key for Canadian firms to enter the offshoring chain as early as possible. Greater flexibility to shift production between parts is a crucial asset in this world. Policy interventions that make transitions easier, e.g. subsidized training programs, accelerated depreciation of economically obsolete equipment, or organized information sharing between industry participants, would boost the long term viability of the industry in Canada.
3. At each point in time, new generations of the final product and all components are developed and introduced in production plants. At first, they are limited to firms in the North (U.S.), but they shift to the South (e.g. Canada) at varying speed. As these new generations materialize, they will often require new production skills. The first South country to acquire the necessary skills and achieve a sufficiently low productivity-adjusted wage to overcome its contracting disadvantage will be the first offshoring destination. To produce new products early, before they become standardized, investment in R&D and in modern capital equipment are indispensable. Hence, when Canadian firms are faced with increasing competition from low-wage countries, their optimal response will be to move up the quality chain—even within the same industry or even within the same product category. Eventually, new product innovation might even take place in the South, see Puga and Treffer (2005) for a model using the same specific investments framework. The relatively low R&D spending in the Canada automotive industry is clearly a handicap in this respect.²⁹
4. The attractiveness of a country is a combination of its unit wage cost and the contracting environment. Enhancing Canadian productivity would lower its unit wage cost, but this has been a priority area for many government departments over the last 20 years with relatively

²⁹Calculations on the ANBERD data set from the OECD indicate that in the U.S. more than \$17b was spent on R&D in the motor vehicle industry in 2003, while the Canadian R&D effort in this industry was a comparatively paltry \$400m. The Canadian share of innovation in North-America is much lower than its share of value added or employment.

limited results.³⁰ Policy is likely to be a more potent tool in enhancing the contracting environment than in boosting productivity levels. This would be especially beneficial for the automotive industry. Nunn (2007) demonstrates that automotive production requires the highest fraction of differentiated inputs of all manufacturing sectors. Moreover, Clark and Fujimoto (1991) stress the ‘integral’ nature of automotive design, which unavoidably requires a lot of specific investments. Promoting standards, providing easy access to the courts, developing a legal framework for less costly dispute resolution, guaranteeing equal treatment for foreign firms, etc. are only a few policy options that would promote the comparative advantage of the Canadian automotive industry.

5. The model predicts that eventually production will move to domestically controlled South firms. If Canada is concerned about control over production and wary of an excessive reliance on foreign-owned firms, accelerating the offshoring process is likely to yield more domestic control than obstructing it. The reason foreign firms often choose FDI over arms-length outsourcing is to maintain greater control and a better bargaining position over the surplus in the production of parts where North inputs are relatively important. The importance of FDI in Canadian manufacturing is reflective of the high-tech focus of our industry, compared to other offshoring destinations. More domestic control is likely to result in production of more mature products.
6. The model incorporates externalities in production through a positive effect on the contracting environment of past production and we found support for such an effect in the data. It implies that the industry should not be focused too narrowly on a few products for which Canada has a clear comparative advantage. Having an industry that is active in a whole range of automotive products provides experience with dispute resolution that boosts the comparative advantage across the board. In a world where new generations are introduced continuously and where parts mature at different speeds, South countries are continuously taking up production of new parts. Complementarities between the production of different parts facilitates the transfer of comparative advantage as production shifts.³¹ The policy implication is that the desirability of intervention in one sub-sector of the automotive industry should not be viewed in isolation from the rest of the industry. Government policy has certainly taken this view when subsidizing FDI in final assembly, as the effect on supplier plants was readily apparent. The model suggests that such linkages could be much more widespread. A small and focused automotive industry becomes less of a possibility if complementarities are strong.

³⁰While the relative productivity of Canadian assembly plants is slightly higher than U.S. plants, in automotive components Canadian firms are significantly less productive than their U.S. counterparts, mirroring the pattern for manufacturing as a whole.

³¹One can easily envision innovation capacity to play a similar role.

Appendix

- Proof for Proposition 2

The cutoff value Z^* is determined by the following function (use Z_{MN}^* as example)

$$\pi_{jk}^N = \pi_{jk}^{SI}, z_{jk} = Z_{MN}^*$$

So

$$\begin{aligned} LHS &= (A_{-k}^j + w_N)^{-\frac{1}{1-\alpha}} (B_{-k}^j + (1-\alpha)w_N) = \\ RHS &= \left(A_{-k}^j + 2\left(\frac{w_S}{1-\delta}\right)^{z_{jk}^*} \left(\frac{w_N}{1+\delta}\right)^{1-z_{jk}^*} \right)^{-\frac{1}{1-\alpha}} \cdot \\ &\quad \left(B_{-k}^j + (2-\alpha(1+\delta-2\delta z_{jk}^*)) \left(\frac{w_S}{1-\delta}\right)^{z_{jk}^*} \left(\frac{w_N}{1+\delta}\right)^{1-z_{jk}^*} \right) \end{aligned} \quad (13)$$

In other word Z_{jk}^{*MN} is a function defined by the above equality.

First any part that is produced in north will have no effect on both A and B , so Z_{jk}^{*MN} is independent of z_m , m indexes all parts that is still in the north. But any part that is produced in south will have impact on both A and B , so Z_{jk}^{*MN} is depend on z_q and z_r , q and r indexes parts in integrated south and outsourced in south.

Use part jR as an example. Taking derivatives on both sides of the above function yields

$$\frac{\partial LHS}{\partial z_{jR}} = \frac{\partial RHS}{\partial z_{jR}} + \frac{\partial RHS}{\partial z_{jk}^{*MN}} \cdot \frac{\partial z_{jk}^{*MN}}{\partial z_{jR}}$$

From the existence of cutoff Z_{jk}^{*MN}

$$\frac{\partial RHS}{\partial z_{jk}^{*MN}} > 0$$

To show

$$\frac{\partial z_{jk}^{*MN}}{\partial z_{jR}} < 0$$

we only need to show

$$\frac{\partial LHS}{\partial z_{jR}} - \frac{\partial RHS}{\partial z_{jR}} < 0$$

With derivatives with respect to z_{jR} from equation (13), it is equivalent to prove that

$$\begin{aligned} & \frac{2}{1-\alpha} \frac{B_{-k}^j + (2-\alpha(1+\delta-2\delta z_{jk}^{*MN})) \left(\frac{w_S}{1-\delta}\right)^{z_{jk}^{*MN}} \left(\frac{w_N}{1+\delta}\right)^{1-z_{jk}^{*MN}}}{A_{-k}^j + 2\left(\frac{w_S}{1-\delta}\right)^{z_{jk}^{*MN}} \left(\frac{w_N}{1+\delta}\right)^{1-z_{jk}^{*MN}}} \left(\frac{A_{-k}^j + 2\left(\frac{w_S}{1-\delta}\right)^{z_{jk}^{*MN}} \left(\frac{w_N}{1+\delta}\right)^{1-z_{jk}^{*MN}}}{A_{-k}^j + w_N} \right)^{-\frac{1}{1-\alpha}} \\ & < (2-\alpha) \left[\left(\frac{A_{-k}^j + 2\left(\frac{w_S}{1-\delta}\right)^{z_{jk}^{*MN}} \left(\frac{w_N}{1+\delta}\right)^{1-z_{jk}^{*MN}}}{A_{-k}^j + w_N} \right)^{-\frac{1}{1-\alpha}} - 1 \right] \end{aligned} \quad (14)$$

let $\Delta A \equiv 2\left(\frac{w_S}{1-\delta}\right)^{z_{jk}^{*MN}} \left(\frac{w_N}{1+\delta}\right)^{1-z_{jk}^{*MN}} - w_N > 0$, use Taylor expansion

$$\begin{aligned} \left(\frac{A_{-k}^j + 2\left(\frac{w_S}{1-\delta}\right)^{z_{jk}^{*MN}} \left(\frac{w_N}{1+\delta}\right)^{1-z_{jk}^{*MN}}}{A_{-k}^j + w_N} \right)^{\frac{1}{1-\alpha}} - 1 &= \left(1 + \frac{\Delta A}{A_{-k}^j + w_N} \right)^{\frac{1}{1-\alpha}} - 1 \\ &> \frac{1}{1-\alpha} \frac{\Delta A}{A_{-k}^j + w_N} \end{aligned}$$

so condition from (14) would be further transformed into a following sufficient condition

$$\frac{2}{1-\alpha} \frac{B_{-k}^j + \left(2 - \alpha(1 + \delta - 2\delta z_{jk}^{*MN})\right) \left(\frac{w_S}{1-\delta}\right)^{z_{jk}^{*MN}} \left(\frac{w_N}{1+\delta}\right)^{1-z_{jk}^{*MN}}}{A_{-k}^j + 2\left(\frac{w_S}{1-\delta}\right)^{z_{jk}^{*MN}} \left(\frac{w_N}{1+\delta}\right)^{1-z_{jk}^{*MN}}} \frac{\Delta A}{A_{-k}^j + w_N} < \frac{2-\alpha}{1-\alpha} \frac{\Delta A}{A_{-k}^j + w_N}$$

with the fact that

$$\frac{B_{-k}^j + \left(2 - \alpha(1 + \delta - 2\delta z_{jk}^{*MN})\right) \left(\frac{w_S}{1-\delta}\right)^{z_{jk}^{*MN}} \left(\frac{w_N}{1+\delta}\right)^{1-z_{jk}^{*MN}}}{A_{-k}^j + 2\left(\frac{w_S}{1-\delta}\right)^{z_{jk}^{*MN}} \left(\frac{w_N}{1+\delta}\right)^{1-z_{jk}^{*MN}}} < \frac{2-\alpha}{2}$$

inequality in (14) will be obvious. So

$$\frac{\partial z_{jk}^{*MN}}{\partial z_{jR}} < 0$$

Proof for $\frac{\partial z_{jk}^{*MS}}{\partial z_R} < 0$ is similar.

Now consider $\frac{\partial z_{jk}^{*MN}}{\partial z_q}$ and $\frac{\partial z_{jk}^{*MS}}{\partial z_q}$. Take part jQ and cutoff ∂z_{jk}^{*MN} as an example. Take derivatives from equation (13)

$$\frac{\partial LHS}{\partial z_{jQ}} = \frac{\partial RHS}{\partial z_{jQ}} + \frac{\partial RHS}{\partial z_{jk}^{*MN}} \cdot \frac{\partial z_{jk}^{*MN}}{\partial z_{jQ}}$$

Again if

$$\frac{\partial LHS}{\partial z_{jQ}} - \frac{\partial RHS}{\partial z_{jQ}} < 0$$

then

$$\frac{\partial z_{jk}^{*MN}}{\partial z_{jQ}} < 0$$

However similar approach shows a sufficient condition for $\frac{\partial LHS}{\partial z_{jQ}} - \frac{\partial RHS}{\partial z_{jQ}} < 0$ is

$$\frac{B_{-k}^j + \left(2 - \alpha(1 + \delta - 2\delta z_{jk}^{*MN})\right) \left(\frac{w_S}{1-\delta}\right)^{z_{jk}^{*MN}} \left(\frac{w_N}{1+\delta}\right)^{1-z_{jk}^{*MN}}}{A_{-k}^j + 2\left(\frac{w_S}{1-\delta}\right)^{z_{jk}^{*MN}} \left(\frac{w_N}{1+\delta}\right)^{1-z_{jk}^{*MN}}} < 1 - \frac{\alpha}{2}(1 + \delta - 2\delta z_{jQ}) - \frac{\alpha\delta}{\ln \frac{w_N(1-\delta)}{w_S(1+\delta)}}$$

the left-hand-side is the average mark-up for the whole system. In other words if the average markup is not too large, $\frac{\partial z_{jk}^{*MN}}{\partial z_{jQ}} < 0$

Proof for $\frac{\partial z_{jk}^{*MS}}{\partial z_{jQ}} < 0$ will be similar.

- Proof for Proposition 3

For simplification in both calculation and notation, the proof of this proposition is easier to do in a setting of continuous parts. Suppose for each variety j , there are many parts whose z value is from a distribution $f(z) > 0$ on support $(0, 1)$. Suppose there exist 3 countries: one north country with wage w_N and two south countries with wages $w_{S1} > w_{S2}$ and $\delta_1 > \delta_2$. Suppose all possible production modes exist: outsource in north, integrated in country $S1$, integrated in country $S2$ and outsource in country $S2$. This implies there are three cutoffs: Z_{MN}^* for cutoff between north production and integrated production in country $S1$, Z_{MM}^* for the cutoff between integrated production in $S1$ and integrated production in $S2$, and Z_{MS}^* for integrated production in $S2$ and outsourcing in $S2$. The profit function of the firm will be

$$\begin{aligned}\pi_j &= \lambda(\alpha\theta_j)^{\frac{\alpha}{1-\alpha}} \cdot \left(\int_0^{z_{MN}^*} w_N f(z) dz + \int_{z_{MN}^*}^{z_{MM}^*} 2\left(\frac{w_{S1}}{1-\delta_1}\right)^z \left(\frac{w_N}{1+\delta_1}\right)^{1-z} f(z) dz + \int_{z_{MM}^*}^{z_{MS}^*} 2\left(\frac{w_{S2}}{1-\delta_2}\right)^z \left(\frac{w_N}{1+\delta_2}\right)^{1-z} f(z) dz \right. \\ &\quad \left[\int_0^{z_{MN}^*} (1-\alpha)w_N f(z) dz + \int_{z_{MN}^*}^{z_{MM}^*} (2-\alpha(1+\delta_1-2\delta_1z)) \left(\frac{w_{S1}}{1-\delta_1}\right)^z \left(\frac{w_N}{1+\delta_1}\right)^{1-z} f(z) dz \right. \\ &\quad \left. \left. + \int_{z_{MM}^*}^{z_{MS}^*} (2-\alpha(1+\delta_2-2\delta_2z)) \left(\frac{w_{S2}}{1-\delta_2}\right)^z \left(\frac{w_N}{1+\delta_2}\right)^{1-z} f(z) dz + \int_{z_{MS}^*}^1 (2-\alpha)w_{S2}^z w_N^{1-z} f(z) dz \right] \right. \\ &= \lambda(\alpha\theta_j)^{\frac{\alpha}{1-\alpha}} \cdot A^{-\frac{1}{1-\alpha}} \cdot B\end{aligned}$$

where $A = \int_0^{z_{MN}^*} w_N f(z) dz + \int_{z_{MN}^*}^{z_{MM}^*} 2\left(\frac{w_{S1}}{1-\delta_1}\right)^z \left(\frac{w_N}{1+\delta_1}\right)^{1-z} f(z) dz + \int_{z_{MM}^*}^{z_{MS}^*} 2\left(\frac{w_{S2}}{1-\delta_2}\right)^z \left(\frac{w_N}{1+\delta_2}\right)^{1-z} f(z) dz + \int_{z_{MS}^*}^1 2w_{S2}^z w_N^{1-z} f(z) dz$ and $B = \int_0^{z_{MN}^*} (1-\alpha)w_N f(z) dz + \int_{z_{MN}^*}^{z_{MM}^*} (2-\alpha(1+\delta_1-2\delta_1z)) \left(\frac{w_{S1}}{1-\delta_1}\right)^z \left(\frac{w_N}{1+\delta_1}\right)^{1-z} f(z) dz + \int_{z_{MM}^*}^{z_{MS}^*} (2-\alpha(1+\delta_2-2\delta_2z)) \left(\frac{w_{S2}}{1-\delta_2}\right)^z \left(\frac{w_N}{1+\delta_2}\right)^{1-z} f(z) dz + \int_{z_{MS}^*}^1 (2-\alpha)w_{S2}^z w_N^{1-z} f(z) dz$

First consider the effect of δ_1 on Z_{MM}^* .

First order condition will be

$$\frac{\partial \pi_j}{\partial z_{MM}^*} = 0$$

while second order condition should also be satisfied (suppose internal solution)

$$\frac{\partial^2 \pi_j}{\partial z_{MM}^{*2}} < 0$$

First order condition will lead to the following equation

$$g \cdot f(Z_{MM}^*) \equiv -\frac{1}{1-\alpha} \frac{B}{A} \cdot \frac{\partial A}{\partial Z_{MM}^*} + \frac{\partial B}{\partial Z_{MM}^*} = 0 \quad (15)$$

to write it in detail

$$\frac{\frac{1}{1-\alpha} \frac{B}{A} - (1 - \frac{\alpha}{2}(1 + \delta_1 - 2\delta_1 Z_{MM}^*))}{\frac{1}{1-\alpha} \frac{B}{A} - (1 - \frac{\alpha}{2}(1 + \delta_2 - 2\delta_2 Z_{MM}^*))} = \frac{2\left(\frac{w_{S2}}{1-\delta_2}\right)^{Z_{MM}^*} \left(\frac{w_N}{1+\delta_2}\right)^{1-Z_{MM}^*}}{2\left(\frac{w_{S1}}{1-\delta_1}\right)^{Z_{MM}^*} \left(\frac{w_N}{1+\delta_1}\right)^{1-Z_{MM}^*}} \quad (16)$$

so

$$\frac{1}{1-\alpha} \frac{B}{A} = 1 - \frac{\alpha}{2} - \frac{\alpha}{2}(1 - 2Z_{MM}^*) \frac{\delta_2 W_2 - \delta_1 W_1}{W_2 - W_1} \quad (17)$$

where $W_1 = 2\left(\frac{w_{S1}}{1-\delta_1}\right)^{Z_{MM}^*} \left(\frac{w_N}{1+\delta_1}\right)^{1-Z_{MM}^*}$ and $W_2 = 2\left(\frac{w_{S2}}{1-\delta_2}\right)^{Z_{MM}^*} \left(\frac{w_N}{1+\delta_2}\right)^{1-Z_{MM}^*}$

And from second order condition

$$\frac{\partial g}{\partial Z_{MM}^*} < 0$$

Differentiate equation (15) with respect to δ_1

$$\frac{\partial g}{\partial Z_{MM}^*} \cdot \frac{\partial Z_{MM}^*}{\partial \delta_1} + \frac{\partial g}{\partial \delta_1} = 0$$

Because $\frac{\partial g}{\partial Z_{MM}^*} < 0$, we only need to know the sign of $\frac{\partial g}{\partial \delta_1}$ to sign $\frac{\partial Z_{MM}^*}{\partial \delta_1}$.

$$\begin{aligned} \frac{\partial g}{\partial \delta_1} &= \frac{1}{1-\alpha} \frac{B}{A} (W_2 - W_1) \cdot \frac{\partial B}{\partial \delta_1} \\ &\quad - \frac{\alpha}{2} (1 - 2Z_{MM}^*) W_1 - \left[\frac{1}{1-\alpha} \frac{B}{A} - \left(1 - \frac{\alpha}{2} (1 + \delta_1 - 2\delta_1 Z_{MM}^*) \right) \right] W_1 \frac{\delta_1 + 2Z_{MM}^* - 1}{1 - \delta_1^2} \end{aligned}$$

Note that in order to satisfy $w_{S1} > w_{S2}$ and $\delta_1 > \delta_2$, $\frac{\partial W_i}{\partial \delta_i} = W_i \frac{\delta_i + 2z - 1}{1 - \delta_i^2} < 0$ for $i = 1, 2$ and $z \in (Z_{MN}^*, Z_{MS}^*)$

$$\begin{aligned} \frac{\partial B}{\partial \delta_1} &= \frac{1}{A} \left(\frac{\partial B}{\partial \delta_1} - \frac{B}{A} \frac{\partial A}{\partial \delta_1} \right) \\ &= \frac{1}{A} \int_{z_{MN}^*}^{z_{MM}^*} \left[-\frac{\alpha}{2} (1 - 2z) - \frac{B}{A} \frac{\delta_1 + 2z - 1}{1 - \delta_1^2} + \left(1 - \frac{\alpha}{2} (1 + \delta_1 - 2\delta_1 z) \right) \frac{\delta_1 + 2z - 1}{1 - \delta_1^2} \right] 2 \left(\frac{w_{S1}}{1 - \delta_1} \right)^z \left(\frac{w_N}{1 + \delta_1} \right)^{1-z} f(z) dz \\ &= \frac{1}{A} \int_{z_{MN}^*}^{z_{MM}^*} \left[\left(1 - \frac{\alpha}{2} - \frac{B}{A} \right) \frac{\delta_1 + 2z - 1}{1 - \delta_1^2} - \frac{\alpha}{2} (1 - 2z) \frac{1 - \delta_1 (1 - 2z)}{1 - \delta_1^2} \right] f(z) dz \end{aligned}$$

as $\frac{B}{A} < 1 - \frac{\alpha}{2}$ and $\frac{\delta_1 + 2z - 1}{1 - \delta_1^2} < 0$

$$\frac{\partial B}{\partial \delta_1} < 0$$

With $W_2 - W_1 > 0$ (from equation (16)), $\frac{1}{1-\alpha} \frac{B}{A} (W_2 - W_1) \cdot \frac{\partial B}{\partial \delta_1} < 0$. A sufficient condition for $\frac{\partial g}{\partial \delta_1} < 0$ is

$$\frac{\alpha}{2} (1 - 2Z_{MM}^*) + \left[\frac{1}{1-\alpha} \frac{B}{A} - \left(1 - \frac{\alpha}{2} (1 + \delta_1 - 2\delta_1 Z_{MM}^*) \right) \right] \frac{\delta_1 + 2Z_{MM}^* - 1}{1 - \delta_1^2} > 0$$

The sufficient condition would be further written as

$$\frac{B}{A} < 1 - \alpha \left[1 - (1 - \alpha) \frac{2\delta_1 Z_{MM}^* (1 - Z_{MM}^*)}{1 - \delta_1 - 2Z_{MM}^*} \right]$$

We can also substitute $\frac{1}{1-\alpha} \frac{B}{A}$ from equation (17), it is easy to check that the sufficient condition will be

$$\begin{aligned} \frac{\alpha}{2} (1 - 2Z_{MM}^*) + \frac{\alpha}{2} (1 - 2Z_{MM}^*) \frac{(\delta_1 - \delta_2) W_2}{W_2 - W_1} \frac{\delta_1 + 2Z_{MM}^* - 1}{1 - \delta_1^2} &> 0 \\ \frac{W_2}{W_2 - W_1} &< \frac{1 - \delta_1^2}{(1 - \delta_1 - 2Z_{MM}^*) (\delta_1 - \delta_2)} \end{aligned}$$

$$\frac{W_1}{W_2} < \frac{1 + \delta_2}{1 + \delta_1} + \frac{2Z_{MM}^*(\delta_1 - \delta_2)}{1 - \delta_1^2}$$

As

$$\begin{aligned} \frac{W_1}{W_2} &= \left(\frac{w_1}{w_2}\right)^{Z_{MM}^*} \left(1 + \frac{2(\delta_1 - \delta_2)}{(1 - \delta_1)(1 + \delta_2)}\right)^{Z_{MM}^*} \frac{1 + \delta_2}{1 + \delta_1} \\ &\approx \left(\frac{w_1}{w_2}\right)^{Z_{MM}^*} \left(1 + \frac{2(\delta_1 - \delta_2)Z_{MM}^*}{(1 - \delta_1)(1 + \delta_2)}\right) \frac{1 + \delta_2}{1 + \delta_1} \\ &> \frac{1 + \delta_2}{1 + \delta_1} + \frac{2Z_{MM}^*(\delta_1 - \delta_2)}{1 - \delta_1^2} \end{aligned}$$

So only when the effect from $\frac{\partial B}{\partial \delta_1}$ is large enough, we can have

$$\frac{\partial g}{\partial \delta_1} < 0$$

Which leads to

$$\frac{\partial Z_{MM}^*}{\partial \delta_1} < 0$$

i.e. when δ_1 increases, country S_1 loses its right margin to country S_2 and parts are sourcing from country S_2 at an earlier technology stage.

Now consider the effect from δ_2 on Z_{MM}^* . Similarly, in order to prove

$$\frac{\partial Z_{MM}^*}{\partial \delta_2} < 0$$

we need to show

$$\frac{\partial g}{\partial \delta_2} < 0$$

$$\begin{aligned} \frac{\partial g}{\partial \delta_2} &= \frac{1}{1 - \alpha} \frac{B}{A} (W_2 - W_1) \cdot \frac{\partial B}{\partial \delta_2} \\ &\quad + \frac{\alpha}{2} (1 - 2Z_{MM}^*) W_2 + \left[\frac{1}{1 - \alpha} \frac{B}{A} - \left(1 - \frac{\alpha}{2} (1 + \delta_2 - 2\delta_2 Z_{MM}^*)\right) \right] W_2 \frac{\delta_2 + 2Z_{MM}^* - 1}{1 - \delta_2^2} \end{aligned}$$

It is easy to show that

$$\frac{\partial B}{\partial \delta_2} < 0$$

So the sufficient condition for $\frac{\partial g}{\partial \delta_2} < 0$ again is

$$\frac{\alpha}{2} (1 - 2Z_{MM}^*) W_2 + \left[\frac{1}{1 - \alpha} \frac{B}{A} - \left(1 - \frac{\alpha}{2} (1 + \delta_2 - 2\delta_2 Z_{MM}^*)\right) \right] W_2 \frac{\delta_2 + 2Z_{MM}^* - 1}{1 - \delta_2^2} < 0$$

Write this equation in the term of $\frac{B}{A}$

$$\frac{B}{A} > 1 - \alpha \left[1 - (1 - \alpha) \frac{2\delta_2 Z_{MM}^* (1 - Z_{MM}^*)}{1 - \delta_2 - 2Z_{MM}^*} \right]$$

Of course, we can also substitute $\frac{B}{A}$ from first order condition

$$\frac{\alpha}{2}(1 - 2Z_{MM}^*)W_2 + \left[\frac{(\delta_1 - \delta_2)W_1}{W_2 - W_1}\right]W_2 \frac{\delta_2 + 2Z_{MM}^* - 1}{1 - \delta_2^2} < 0$$

Similarly the condition can be written as the following form

$$\frac{W_2}{W_1} < \frac{1 + \delta_1}{1 + \delta_2} - \frac{2Z_{MM}^*(\delta_1 - \delta_2)}{1 - \delta_2^2}$$

As

$$\begin{aligned} \frac{W_2}{W_1} &= \left(\frac{w_2}{w_1}\right)^{Z_{MM}^*} \left(1 - \frac{2(\delta_1 - \delta_2)}{(1 + \delta_1)(1 - \delta_2)}\right)^{Z_{MM}^*} \frac{1 + \delta_1}{1 + \delta_2} \\ &\approx \left(\frac{w_2}{w_1}\right)^{Z_{MM}^*} \left(1 - \frac{2(\delta_1 - \delta_2)Z_{MM}^*}{(1 + \delta_1)(1 - \delta_2)}\right) \frac{1 + \delta_1}{1 + \delta_2} \\ &< \frac{1 + \delta_1}{1 + \delta_2} - \frac{2Z_{MM}^*(\delta_1 - \delta_2)}{1 - \delta_2^2} \end{aligned}$$

So for sure the sufficient condition is satisfied and

$$\frac{\partial g}{\partial \delta_2} < 0$$

Thus

$$\frac{\partial Z_{MM}^*}{\partial \delta_2} < 0$$

Now let's think about the other two cutoff Z_{MN}^* .

The first order condition, if we define g similar as above, can be written as

$$g \cdot f(Z_{MN}^*) \equiv -\frac{1}{1 - \alpha} \frac{B}{A} \cdot \frac{\partial A}{\partial Z_{MN}^*} + \frac{\partial B}{\partial Z_{MN}^*} = 0$$

Of course, first order condition can be further written as

$$\frac{\frac{1}{1 - \alpha} \frac{B}{A} - (1 - \frac{\alpha}{2}(1 + \delta_1 - 2\delta_1 Z_{MN}^*))}{\frac{1}{1 - \alpha} \frac{B}{A} - (1 - \alpha)} = \frac{w_N}{2(\frac{w_{S1}}{1 - \delta_1})^{Z_{MN}^*} (\frac{w_N}{1 + \delta_1})^{1 - Z_{MN}^*}}$$

so

$$\frac{1}{1 - \alpha} \frac{B}{A} = 1 - \frac{\alpha}{2} - \frac{\alpha w_N - \delta_1(1 - 2Z_{MN}^*)W_1}{2(w_N - W_1)}$$

where $W_1 = 2(\frac{w_{S1}}{1 - \delta_1})^{Z_{MN}^*} (\frac{w_N}{1 + \delta_1})^{1 - Z_{MN}^*}$

Second order condition implies

$$\frac{\partial g}{\partial Z_{MN}^*} < 0$$

First we look into the effect from δ_2 to Z_{MN}^* . So differentiate g with respect to δ_2

$$\frac{\partial g}{\partial Z_{MN}^*} \cdot \frac{\partial Z_{MN}^*}{\partial \delta_2} + \frac{\partial g}{\partial \delta_2} = 0$$

As

$$\frac{\partial g}{\partial \delta_2} = -\frac{1}{1-\alpha} \frac{B}{A} \cdot (w_N - W_1) \frac{\partial \frac{B}{A}}{\partial \delta_2}$$

We have shown that

$$\frac{\partial \frac{B}{A}}{\partial \delta_2} < 0$$

So

$$\frac{\partial g}{\partial \delta_2} < 0$$

Combined with second order condition,

$$\frac{\partial Z_{MN}^*}{\partial \delta_2} < 0$$

This is different from Antras model. In the original Antras model, each cutoff will only be dependent on the related countries. However, because some parts are produced in country 2, when contracting environment from country 2 improves, the inefficiency problem due to incomplete contract of the whole product system relieves and thus the cutoff point between north and south country 1 moves to a smaller z value.

Now consider the effect from δ_1 . Similarly, differentiate g with respect to δ_1

$$\frac{\partial g}{\partial Z_{MN}^*} \cdot \frac{\partial Z_{MN}^*}{\partial \delta_1} + \frac{\partial g}{\partial \delta_1} = 0$$

As

$$\frac{\partial g}{\partial \delta_2} = -\frac{1}{1-\alpha} \frac{B}{A} \cdot (w_N - W_1) \frac{\partial \frac{B}{A}}{\partial \delta_1} + \frac{\alpha}{2} (1 - 2Z_{MN}^*) W_1 + \left[\frac{1}{1-\alpha} \frac{B}{A} - \left(1 - \frac{\alpha}{2}\right) + \frac{\alpha}{2} \delta_1 (1 - 2Z_{MN}^*) \right] W_1 \frac{2Z_{MN}^* + \delta_1 - 1}{1 - \delta_1^2}$$

We have show

$$\frac{\partial \frac{B}{A}}{\partial \delta_1} < 0$$

So a sufficient condition for $\frac{\partial g}{\partial \delta_2} < 0$ is

$$\frac{\alpha}{2} (1 - 2Z_{MN}^*) W_1 + \left[\frac{1}{1-\alpha} \frac{B}{A} - \left(1 - \frac{\alpha}{2}\right) + \frac{\alpha}{2} \delta_1 (1 - 2Z_{MN}^*) \right] W_1 \frac{2Z_{MN}^* + \delta_1 - 1}{1 - \delta_1^2} < 0$$

Written in the term of $\frac{B}{A}$

$$\frac{B}{A} > 1 - \alpha \left[1 - (1 - \alpha) \frac{2\delta_1 Z_{MN}^* (1 - Z_{MN}^*)}{1 - \delta_1 - 2Z_{MN}^*} \right]$$

Of course, we can further substitute first order condition into the sufficient condition

$$\frac{w_N}{W_1 - w_N} > \frac{1 - Z_{MN}^*}{1 - \delta_1 - 2Z_{MN}^*} \cdot \frac{1 - \delta_1^2}{1 - \delta_1 (1 - 2Z_{MN}^*)}$$

Further write the above inequality as

$$\frac{w_N}{W_1} > \frac{(1 - Z_{MN}^*)(1 - \delta_1^2)}{(1 - \delta_1 - 2Z_{MN}^*)[1 - \delta_1(1 - 2Z_{MN}^*)] + (1 - Z_{MN}^*)(1 - \delta_1^2)}$$

As

$$\begin{aligned} \frac{w_N}{W_1} &= \frac{1}{2} \left(\frac{w_N}{w_1} \right)^{Z_{MN}^*} \left(\frac{1 - \delta_1}{1 + \delta_1} \right)^{Z_{MN}^*} (1 + \delta_1) \\ &\approx \frac{1}{2} \left(\frac{w_N}{w_1} \right)^{Z_{MN}^*} \left(1 - \frac{2\delta_1 Z_{MN}^*}{1 + \delta_1} \right) (1 + \delta_1) \\ &= \frac{1}{2} \left(\frac{w_N}{w_1} \right)^{Z_{MN}^*} (1 + \delta_1 - 2\delta_1 Z_{MN}^*) \end{aligned}$$

However

$$\frac{1 + \delta_1 - 2\delta_1 Z_{MN}^*}{2} < \frac{(1 - Z_{MN}^*)(1 - \delta_1^2)}{(1 - \delta_1 - 2Z_{MN}^*)[1 - \delta_1(1 - 2Z_{MN}^*)] + (1 - Z_{MN}^*)(1 - \delta_1^2)}$$

So we can not be sure if the sufficient condition would be satisfied or not.

At last, we look into the effect on Z_{MS}^*

First order condition, if define g similarly as above, will be

$$g \cdot f(Z_{MS}^*) \equiv -\frac{1}{1 - \alpha} \frac{B}{A} \cdot \frac{\partial A}{\partial Z_{MS}^*} + \frac{\partial B}{\partial Z_{MS}^*} = 0$$

Of course, it can be further written as

$$\frac{\frac{1}{1 - \alpha} \frac{B}{A} - (1 - \frac{\alpha}{2}(1 + \delta_2 - 2\delta_2 Z_{MS}^*))}{\frac{1}{1 - \alpha} \frac{B}{A} - (1 - \frac{\alpha}{2})} = \frac{2w_2^{Z_{MS}^*} w_N^{1 - Z_{MS}^*}}{2(\frac{w_2}{1 - \delta_2})^{Z_{MS}^*} (\frac{w_N}{1 + \delta_2})^{1 - Z_{MS}^*}}$$

so

$$\frac{1}{1 - \alpha} \frac{B}{A} = 1 - \frac{\alpha}{2} - \frac{\alpha \delta_2 (1 - 2Z_{MN}^*) W_2}{W_2 - W_S}$$

where $W_2 = 2(\frac{w_2}{1 - \delta_2})^{Z_{MS}^*} (\frac{w_N}{1 + \delta_2})^{1 - Z_{MS}^*}$ and $W_S = 2w_2^{Z_{MS}^*} w_N^{1 - Z_{MS}^*}$

It is easy to show that because

$$\begin{aligned} \frac{\partial \frac{B}{A}}{\partial \delta_1} &< 0 \\ \frac{\partial Z_{MS}^*}{\partial \delta_1} &< 0 \end{aligned}$$

The effect is just the same as δ_2 on Z_{MN}^* : although condition from country 1, δ_1 , has no direct effect on the cutoff Z_{MS}^* , when contracting environment in country 1 get better, the overall incompleteness in the contracting of the whole product system is relieved, and Z_{MS}^* is able to move to a smaller z value.

Now we consider the effect from δ_2 . In order to have

$$\frac{\partial Z_{MS}^*}{\partial \delta_2} < 0$$

We need to show that

$$\frac{\partial g}{\partial \delta_2} < 0$$

Similarly

$$\frac{\partial g}{\partial \delta_2} = -\frac{1}{1-\alpha} \frac{B}{A} \cdot (W_2 - W_S) \frac{\partial \frac{B}{A}}{\partial \delta_2} - \frac{\alpha}{2} (1 - 2Z_{MS}^*) W_2 - \left[\frac{1}{1-\alpha} \frac{B}{A} - \left(1 - \frac{\alpha}{2}\right) + \frac{\alpha}{2} \delta_1 (1 - 2Z_{MS}^*) \right] W_2 \frac{2Z_{MS}^* + \delta_2 - 1}{1 - \delta_2^2}$$

As before

$$-\frac{1}{1-\alpha} \frac{B}{A} \cdot (W_2 - W_S) \frac{\partial \frac{B}{A}}{\partial \delta_2} < 0$$

the sufficient condition for $\frac{\partial Z_{MS}^*}{\partial \delta_2} < 0$ thus becomes

$$-\frac{\alpha}{2} (1 - 2Z_{MS}^*) - \left[\frac{1}{1-\alpha} \frac{B}{A} - \left(1 - \frac{\alpha}{2}\right) + \frac{\alpha}{2} \delta_1 (1 - 2Z_{MS}^*) \right] \frac{2Z_{MS}^* + \delta_2 - 1}{1 - \delta_2^2} < 0$$

Substitute first order condition into the inequality and re-arrange it, we will get

$$\frac{W_2}{W_S} < \frac{1 - \delta_2 + 2\delta_2 Z_{MS}^*}{1 - \delta_2^2}$$

As

$$\begin{aligned} \frac{W_2}{W_S} &= (1 + \delta_2)^{-1} \left(\frac{1 + \delta_2}{1 - \delta_2} \right)^{Z_{MS}^*} \\ &\approx (1 + \delta_2)^{-1} \left[1 + \frac{2\delta_2 Z_{MS}^*}{1 - \delta_2} - Z_{MS}^* (1 - Z_{MS}^*) \left(\frac{2\delta_2}{1 - \delta_2} \right)^2 \right] \\ &< \frac{1 - \delta_2 + 2\delta_2 Z_{MS}^*}{1 - \delta_2^2} \end{aligned}$$

So the sufficient condition is satisfied and

$$\frac{\partial Z_{MS}^*}{\partial \delta_2} < 0$$

Table 1: Parts Index

Component	Component index (1)	Entry year (average) (2)	Entry gap (North-South) (3)	Average exporter GDP/capita (4)	rank (5)
Lighting system	1	2003.0		4,746	6.8
Non-drive axles	2	1996.6	8.5	20,429	2.9
Body parts	3	1996.3	7.1	22,075	2.2
Suspension	4	1995.1	6.8	21,574	2.7
Seat belts	5	1992.5	4.7	7,893	5.3
Drive axles	6	1992.5	4.0	24,518	1.9
Seats	7	1992.3	4.0	16,180	4.0
Chassis fitted with engine	8	1992.3	3.7	15,089	3.8
Mufflers & exhaust pipes	9	1997.1	3.6	22,740	2.3
Radiator	10	1991.9	3.3	11,327	4.9
Inner tube	11	1991.8	3.1	8,811	5.5
Brakes	12	1991.7	3.0	20,314	2.9
Mounted brake linings	13	1996.3	2.6	23,452	2.0
Panel clocks	14	1991.3	2.6	21,011	3.0
Bodies	15	1991.1	2.5	22,666	2.1
Steering modules	16	1996.0	2.4	14,681	3.9
Clutches	17	1996.1	2.4	23,089	2.3
Bumpers	18	1995.9	2.2	21,278	2.3
Safety glass	19	1990.8	2.0	12,631	4.4
Wheels	20	1990.8	2.0	13,853	4.5
Other parts	21	1990.4	1.6	21,742	2.5
Gear boxes	22	1990.2	1.5	26,970	1.3
Rear view mirror	23	1990.3	1.4	8,204	6.2
Mountings	24	1993.9	1.0	14,139	4.4
Battery	25	1989.8	0.9	10,031	5.0
Air conditioner	26	1996.6	0.8	13,285	4.2
Locks	27	1989.7	0.8	7,530	6.0
Tires	28	1989.4	0.5	19,595	3.1
Radio	29	1989.1	0.1	7,545	6.1
Engine	30	1989.1	0.1	20,868	2.7

Notes: Details on the aggregation of the 10-digit HS products are in the text. Column (2) averages across all countries the first year a component is exported to the U.S. Column (3) performs the same calculation, but subtracts the year the component was first exported by the North. Columns (4) and (5) average exporter characteristics in each year positive exports to the U.S. are recorded. Components are ranked according to column (3), which yields the part-index in column (1).

Table 2: Country Index

Country	Frequency in data set		country index	Average entry year		GDP/capita (USD)
	original (1)	final (2)		unadjusted (4)	adjusted (5)	
North	4000	446	1	1990.3	1990.8	28,662
Canada	2515	431	2	1990.9	1990.9	22,678
Mexico	1967	409	3	1991.9	1991.9	4,758
Other	1371	341	4	1992.6	1993.5	3,852
Australia*	303	95	5	1993.6	2000.2	20,986
Taiwan	1379	268	6	1991.7	1995.1	11,740
Brazil	789	229	7	1991.8	1995.1	3,432
South Korea	839	264	8	1993.8	1995.5	9,938
China	1563	261	9	1995.8	1996.8	728
India	356	115	10	1997.7	2001.6	424

Notes: Columns (4) and (5) average across all components and for each country the year each component was first exported to the U.S. If a good was not exported by 2005, it receives a missing value in column (4) and a value of 2006 in column (5). Components are ordered by column (4), which yields the country index in column (3). For the 'North' and 'Other' composite countries, GDP/capita for individual countries is weighted by their frequency in the data set.

* REMARK: The 'adjustment average entry year' for Australia needs to be recalculated.

Table 3: Regression results testing the four predictions

Dependent variable: p_{ck}^e (log) entry price for each country-part pair relative to North				
	(1)	(2)	(3)	(4)
Country index c	-0.129 (.041) ^{***}	-0.089 (.028) ^{***}	-0.194 (.058) ^{***}	-0.089 (.024) ^{***}
R ²	0.068	0.072	0.078	0.095

Notes: All regressions are for 240 observations and include part-year fixed effects. Each column uses a different country-index: (1) Unadjusted entry year; (2) Adjusted entry year; (3) – log of GDP/capita; (4) ordinal rank corresponding to (2). Standard errors are in brackets. *** Indicates significant at the 1% level, ** at the 5% level, and * at the 10%.

	(1)	(2)	(3)	(4)
Part index k	0.073 (.041) [*]	0.023 (.037)	0.120 (.183)	0.039 (.052)
R ²	0.165	0.152	0.152	0.153

Notes: All regressions are for 212 observations (North country is excluded) and include additive country and year fixed effects. Each column uses a different part-index: (1) Average entry year for a part across the sample; (2) Average gap with entry year of North country; (3) – log of average GDP/capital of exporter; (4) Average country-rank of exporter.

	(1)	(2)	(3)	(4)
Other countries' entry	0.001 (.002)	0.003 (.002) [*]	0.006 (.002) ^{***}	0.008 (.003) ^{***}
R ²	0.237	0.268	0.240	0.260

Notes: All regressions are for 241 observations and include part fixed effects; The explanatory variable is sum of entry events by other countries in the previous period. The sum is over (1) all countries and parts; (2) only higher ranked parts; (4) only higher ranked countries; (2) only higher ranked countries and parts.

	(1a)	(2a)	(3a)	(4a)
Cumulative past output	0.027 (.055)	0.033 (.058)	0.011 (.016)	0.034 (.057)
R ²	0.167	0.168	0.168	0.168

Dependent variable: p_{ckt} Any (log) price for each country-part pair relative to North				
	(1b)	(2b)	(3b)	(4b)
Cumulative past output	0.058 (.009) ^{***}	0.060 (.009) ^{***}	0.022 (.003) ^{***}	0.032 (.008) ^{***}
R ²	0.308	0.309	0.313	0.299

Notes: First set of regressions is for 241 observations and include year fixed effects; second set is for 2840 observations and include part-year interaction effects. Columns use different measures of past output: (1) Value of all previous parts exports (in logs); (2) same as in (1), but limited to parts that follow the correct order (i.e. reverse of column (1) in Table 2); (3) same as (1), but number of products (instead of value); (4) same as (2), but numbers again.

References

- [1] Acemoglu, D., Aghion, P., Griffith, R., and Zilibotti, F. “Vertical Integration and Technology: Theory and Evidence,” Working Paper, August 2005.
- [2] Acemoglu, D., Johnson, S., and Robinson, J. “The Rise of Europe: Atlantic Trade, Institutional Change and Growth,” *American Economic Review* 95(3), June 2005, 546–579.
- [3] Antràs, P., “Firms, Contracts, and Trade Structure,” *Quarterly Journal of Economics*, 118(4), November, pp. 1375–1418.
- [4] Antràs, P., “Incomplete Contracts and the Product Cycle,” *American Economic Journal*, 2005
- [5] Antràs, P. and Helpman, E., “Global Sourcing,” *Journal of Political Economy* 112(3), 2004, 552–850.
- [6] Bartel, A., Lach S., and Sicherman N., “Outsourcing and Technological Change,” *NBER Working Paper No. 11158*, February 2005.
- [7] Campa, J. and Goldberg, L., “The Evolving External Orientation of Manufacturing Industries: Evidence from Four Countries,” *Federal Reserve Bank of New York Economic Policy Review*, 4, pp. 7999.
- [8] Clark, K. B., and Fujimoto, T., *Product Development Performance: Strategy, Organization, and Management in the World Auto Industry*, Harvard Business School Press, 1991.
- [9] Feenstra, R. C. and Hanson, G. H., “Ownership and Control in Outsourcing to China: Estimating the Property-rights Theory of the Firm,” *Quarterly Journal of Economics*, May 2005, 729–761.
- [10] Grossman, G. M. and Helpman, E., “Outsourcing in a Global Economy,” *Review of Economic Studies* 72(1), January, pp. 135–159.
- [11] Hallak, J. C., “Product Quality and the Direction of Trade,” *Journal of International Economics*, 2006
- [12] Head, K., Ries, J. and Spencer, B. J., “Vertical Networks and U.S. Auto Parts Exports: Is Japan Different?,” *Journal of Economics and Management Strategy*, 2004
- [13] Helpman, E., “Trade, FDI, and the Organization of Firms,” *Journal of Economic Literature* 44, September 2006, pp. 589–630.
- [14] Helpman, E., Melitz, M. J., and Yeaple, S.R., “Export versus FDI with heterogeneous firms,” *American Economic Review* 94, 2004
- [15] Hummels, D., Ishii, J. and Yi, K. M., “The Nature and Growth of Vertical Specialization in World Trade,” *Journal of International Economics*, 2001
- [16] Hummels, D. and Klenow, P.J., “The Variety and Quality of a Nation’s Exports,” *American Economic Review*, 2005

- [17] Hummels, D. and Skiba, A., “Shipping the Good Apples Out? An Empirical Confirmation of Alchian-Allen Conjecture,” *Journal of Political Economy*, 2004
- [18] Monteverde, K. and Teece, D. J., “Supplier Switching Costs and Vertical Integration in the Automobile Industry,” *The Bell Journal of Economics* 13, 1982, 206–213.
- [19] Ng, F. and Yeats, A., “Production Sharing in East Asia: Who Does What for Whom and Why?,” 1999
- [20] Novak, S. and Stern, S. “Complementarity Among Vertical Integration Decisions: Evidence from Automobile Product Development,” Working Paper, Kellogg School of Management, November 2003.
- [21] Nunn, N. “Relationship-Specificity, Incomplete Contracts, and the Pattern of Trade,” *Quarterly Journal of Economics* 122(2), May 2007.
- [22] Puga, D. and Trefler, D., “Wake Up and Smell the Ginseng: The Rise of Incremental Innovation in Low-Wage Countries,” NBER Working Paper No. 11571, August 2005.
- [23] Schott, P. K., “Across-Product Versus Within-Product Specialization in International Trade,” *Quarterly Journal of Economics*, 2004
- [24] Spencer, B. J. and Qiu, L. D., “Keiretsu and Relationship-Specific Investments: Implications for Market-Opening Policy,” *International Economic Review* 42(4), 2002, 871–901.
- [25] Van Biesebroeck, J., “Trends and Complementarities in the Canadian Automobile Industry,” (forthcoming) in Z. Chen and M. Duhamel, *Industrial Economics and Performance in Canada*, Ottawa: Industry Canada, January 2005.
- [26] Van Biesebroeck, J., “The Canadian Automotive Market,” Report for the Department of Foreign Affairs and International Trade, 2006, <http://www.dfait-maeci.gc.ca/tna-nac/RB/camen.asp>