VERTICAL SPECIALIZATION AND THE QUALITY OF INFRASTRUCTURE

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Abstract

This paper explores the determinants of international outsourcing. The timeliness of delivery and the fulfilment of quality standards are important in vertical supply chains and depend critically on the availability, cost and quality of transport, communication and other logistics services, but also services such as testing and technical services contribute to enabling suppliers in low-cost countries to enter the outsourcing market. The determinants of international outsourcing are analyzed using the O-ring theory of production. Its predictions are next explored empirically by regressing vertical specialization on a number of variables affecting the timeliness of delivery and quality of the products. For this purpose the vertical specialization index developed by Hummels et al. (2001) is applied, estimated from input-output data where local and foreign sourcing of inputs is distinguished.

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I. INTRODUCTION

Once upon a time Henry Ford invented a way of producing cars that made them affordable for ordinary American families. Furthermore, the workers were paid sufficiently high wages to create a mass market for the mass produced cars. Ford's idea was to break up the production process in as small and standardized units as possible and organize the activities sequentially along an assembly line. He had built factories into which steel entered at the one end and finished, standardized cars rolled off at the other end. Henry Ford is also famously associated with the statement that the colour of the car does not matter as long as it is black.

Modern manufacturing has changed a lot since Henry Ford's days. The assembly line has been replaced by different forms of flexible production such as quality circles, just-in-time delivery and flexible automation. On the demand side, Mr. Ford would not get away with providing only one model and only black cars to the public. The modern consumer wants to have a choice. The idea of breaking up the production process in standardized units has, however, persisted. It has, moreover, seen a renaissance recently, but within a totally different organizational framework than the Fordist assembly line. The breaking up of production on standardized units today typically takes place both *between* companies and within companies. Thus, production becomes fragmented or decentralized to a number of specialized producers operating at different stages in the production process. The buzz-words of modern manufacturing are mass customization, outsourcing of non-core activities and supply chain management. The business literature is abound with books advising managers on how to manage the global supply chain.[†]

The international dimension of vertical specialization takes advantage of differences in comparative advantage between countries at a finer level of specialization than trade motivated by comparative advantage at the industry level. In a number of industries the vertical stages of production differ largely in their factor intensity. Some stages are labour-intensive, others are capital-intensive while yet others use skilled labour intensively. In the electrical machinery and electronics sectors, for example, product development is highly skills-intensive and could be located in a country rich in skilled and professional workers. Production of semiconductors and microprocessors, which constitute key components of most products in the electronics sectors (and other industries as well) is capital-intensive and could be located in a capital-rich country such as the US, Japan, EU or a middle-income Asian country that has had very high investment rates over the past few decades. Assemblage of the final products is labour-intensive and could be located in a labour-rich country such as China.

In a sequential production network or supply chain, production is undertaken by stages of production where one task follows after the other. Task 2 is thus performed by workers who process inputs delivered by workers that performed task 1; task 3 is performed by workers who process the output that resulted from task 2 and so on till task n is performed by workers using inputs from task n-1. Clearly, since every task adds value to the previous task, the value of the product increases with the stage it has reached. In such a sequential production process, the value added of all previous tasks will erode or come to nothing if the product is

[†] The process can be seen as one of branding final goods and commoditizing intermediate inputs.

damaged or destroyed at one stage of production. Therefore, in industries where the production process is complex and involves many stages, the cost of making an error can be large and the cost increases with the stage of production where the error occurs. Nevertheless, if raw materials are expensive relative to the value of the final product, there are cases where the cost of making faults are largest at a low stage of production. In the textiles and clothing sector, for example, errors in cutting the cloth are more costly than errors in stitching the apparel together. This is because errors in the sewing room can be corrected, while errors in the cutting room cannot. The same probably applies to a number of industries with assembly of high-technology products or big ticket items; mistakes at the assembly stage can be corrected relatively easily or they can be avoided by highly standardized processes. In either case industries with a complex production technology involving many stages of production will tend to carefully screen and monitor the quality of workers and suppliers.

When supply chain management involves the minimization of time to market within such a sequential production process, timeliness of delivery becomes crucial also at the early stages of production. If expensive machinery and high-skilled workers are made idle waiting for an input from suppliers performing an earlier task in the production chain, that would involve substantial losses. By the same token, garments sell for a substantial discount simply because it is late in the season. Clothing has been the entry level sector for many poor countries in their industrialization process. The delivery time of fashion garment is typically one week (Abertnathy et al., 1999) while in poor countries it may take as much as a month to get goods trough customs (Micco and Perez, 2002). Needless to say, poor infrastructure, corruption and ineffective border procedures may seriously impede poor countries in exploiting their comparative advantage for labour-intensive goods in an environment with increasingly time-sensitive vertical production networks.

A theoretical framework that captures the interdependence between production stages is the so-called O-ring production function developed by Kremer (1993). A key feature of the O-ring theory is that quality of inputs cannot be substituted for quantity even when a lower quality fetches a significantly lower price. If a firm has chosen high quality of n-1 stages in the production chain, it will also choose high quality of the *n-th* stage for reasons elaborated above. I therefore find this framework useful for exploring the relationship between relative production costs, the quality of infrastructure and institutions and trade in industries where vertical fragmentation has become important. To my knowledge this has not been done before.

The paper first presents the theoretical model as developed by Kremer (1993) and then makes some relevant adjustments in order to focus on the features of vertical specialization in an international context. I focus on two dimensions of quality, the fault rate of components and the timeliness of delivery. The Kremer model is simplified by abstracting from the use of capital in order to focus on the quality of inputs, and extended by including a supply function for quality.[‡] The second part of the paper provides an empirical estimate of the determinants of vertical specialization in an international trade context. A commonly used measure of the extent of vertical specialization in international trade is a vertical specialization index developed by Hummels et al. (2001). I regress this index on a number of variables which are likely to affect the extent to which firms engage in international vertical specialization using a

[‡] Kremer (1993) focuses on the quality of workers performing the tasks in the production chain and assumes that skills are distributed among workers according to an exogenous distribution function.

cross-section of data from 52 countries and 5 sectors. The rest of the paper is organized as follows: section II briefly discusses the nature and extent of vertical specialization. Section III presents the model, section IV presents the empirical findings while section V concludes.

II. THE NATURE AND IMPORTANCE OF VERTICAL SPECIALIZATION

A recent study by Yi (2003) finds that at least half of the observed increase in world trade since the 1960s can be explained by means of a model of world trade that incorporates vertical specialization. He developed a model that mimics a dynamic process where technological and organizational innovations have made it possible to slice up the production process, while lower trade barriers create economic incentives for locating different stages of production in different countries. In the empirical literature there is no consensus on exactly what vertical specialization is. Hummels et al. (2001) define vertical specialization as the import content of a country's exports (see section IV below for details). They find that the share of vertical specialization in exports was about 20 per cent in 1990, and that it had increased by 30 per cent since 1970, using data for 13 OECD countries plus Taiwan; a sample which covered 60 percent of world trade.

Another measure of vertical specialization is intra-firm trade in intermediate inputs. The U.S. Bureau of Economic Analysis compiles data on intra-firm trade of US multinational firms by intended use. Borga and Zeile (2003) finds that during the period 1966-1999, exports of intermediate inputs by US parents to their foreign affiliates increased forty-fold, and the share of intra-firm exports of intermediate products in US total merchandise exports increased from 8.5 to 14.7 per cent during the same period. Many argue that international outsourcing to external suppliers has increased faster than intra-firm trade in intermediates (e.g. Antras and Helpman, 2003). It is also worth noticing that while intra-firm trade as a share of world trade appears to have been fairly stable at about a third over the past two decades, intra-firm trade in intermediates has increased sharply, indicating that vertical multinational activity has increased relative to horizontal activity (Hanson et al., 2001; 2003).

These figures only cover trade in goods. In addition there is trade in services, where business services play an important role for vertical specialization providing logistics, matching suppliers and lead firms, assisting suppliers in meeting the quality standards of the lead firm among other important functions. Such services are probably mainly provided through commercial presence. According to UNCTAD (2003), the inward stock of foreign direct investment in business services increased nine-fold during the period 1990-2001 worldwide; about 5-fold in developed countries and almost a 100-fold in developing countries. Moreover, the share of business services in total inward stock increased from 6 to 17 per cent globally, and from less than 2 per cent to almost a quarter in developing countries during the same period.

The nature of the linkages between the firms in the supply chain differs between sectors and market segments. Close coordination of and frequent communication between suppliers and the lead firm are common features of all production networks. However, the nature of the communication and coordination varies from automated procurement to joint R&D. Automated procurement is common in supply chains that are driven by retailers. Sales data are gathered in real time at the sales point, transmitted to distribution centres, which in turn are electronically connected to the suppliers. Inventory management and procurement is often computerized and in some cases automated such that the entire sequence of activities from production of parts and components to after- sales services are coordinated by means of electronic networks. The technology supporting these networks are computers linked to the Internet or dedicated networks, the bar code and lasers that read the bar code.

Joint R&D and production planning are common in industries such as the car industry and the machinery sector. On the production technology side modern manufacturing equipment consists of flexible machine tools and production equipment that can be electronically programmed. Design and engineering are also computerized and can be fed directly into the programmable production equipment. This implies relatively small batch sizes, just-in-time delivery, quality control at source and consequently smaller inventories at all stages of production. Computer-assisted design (CAD) that feeds into computer-assisted manufacturing (CAM) is standard in many industries. Furthermore, the two (i.e. CAD and CAM) can be separated in space and between institutions through electronic transmission of design.[§] For example, even if manufacturing activities have relocated from Western Europe to emerging economies in Asia or more recently Eastern Europe, product development, product design and engineering activities have often remained in Western Europe either in specialized independent firms or as a main office function in multinationals.

Introducing modern, largely computerized technology at one stage in the production process often requires compatible technologies and computerization in the closest vertical stages as well in order for the system to operate smoothly. Suppliers in poor countries without access to electronic networks rely on logistics firms that also match suppliers and downstream customers and provide quality control.[**]

To summarize this section, trade driven by vertical specialization accounts for at least a fifth of total world trade and it has perhaps been the most important source of trade growth during the past decade. Intra-firm trade accounts for a large part of this, but there is growing evidence that sourcing from foreign outside suppliers has gained in relative importance recently. The introduction of computer-assisted design and manufacturing and not least the possibility of integrating the control of production and logistics using ICT have been crucial for the proliferation of international vertical specialization.

III. THE MODEL

A model that captures the features of vertical specialization is Kremer's (1993) O-ring theory of production. The basic idea is that production consists of a number of tasks, and the value of the resulting output depends on the successful performance of all tasks. The production chain is as strong as its weakest link with the logical consequence that producers will chose to have all links equally strong. Kremer's production function read:

$$Y = k^{\alpha}\left(\prod_{i=1}^{n} q_i\right)nB \tag{1}$$

[§] See Milgrom and Roberts (1990) for a seminal article on modern manufacturing practices, and Nordås (2004) for a case study.

[**] See Feenstra et al. (2002) for a discussion of role of Hong Kong logistic firms in mainland Chinese companies' trade performance.

Y is final output, n is the exogenous number of tasks needed to complete the production process and Kremer assumes that each task is performed by one worker where q is the quality of the worker's skills, interpreted as the ability of the worker to perform the task to perfection; $q \in (0, 1)$. B is the output per worker equipped with a single unit of capital if the worker performs his task to perfection. Thus, the maximum output if all task are performed to perfection is $Y = k^{\alpha} nB$. Assume that there are 10 tasks and all but one worker perform their task to perfection. If the lesser skilled worker's quality is 0.6, output will be reduced to $Y = 0.6 * k^{\alpha} nB$, or by the full 40 per cent lower ability of the 10^{th} worker.

In order to simplify the analysis and focus on the sequence of tasks undertaken in a vertically fragmented production chain, I set $\alpha = 0$ and open the possibility that tasks can be delivered from outside suppliers. The production function then reduces to:

$$Y = \left(\prod_{i=1}^{n} q_i \right) nB \tag{2}$$

The quality variable is now interpreted as the quality of input i measured relative to zero-faults and just-in-time arrival at the relevant production station, while B is a scalar that represents the output volume per unit of input if all inputs have zero faults and arrive on time. The price of an input is an increasing function of its quality. The profit maximizing lead firm chooses quality of the input according to the following maximization problem:[††]

$$\underset{q}{Max}\left[nB\left(\prod_{i}^{n} q_i \right) - \sum_{i=1}^{n} p(q_i) \right]$$

The first-order condition is

$$nB\left(\prod_{j \neq i}^{n} q_j \right) - p'(q_i) = 0 \tag{3}$$

The first term in this expression represent the marginal productivity of q_i . Following Kremer's argument, the derivative of the marginal product of the quality of the ith input with respect to the quality of all the other inputs;

$$\frac{d^2 Y}{dq_i d\left(\prod_{j \neq i} q_j \right)} = nB$$

is positive. This implies that the firm with the highest quality of the g -1 ($g \leq n$) input will place the highest value of quality of the *g-th* input and therefore be willing to pay the highest price for it. Thus, each firm will choose the same quality of all its inputs such that the first-order condition can be written as $p'(q) = nBq^{n-1}$. Assuming that the price of each input is a continuous function of its quality, we can find the relation between price and quality by integrating the first-order condition (3), which yields:

[††] Final output is the numeraire in the model.

$$p(q) = \int nBq^{n-1}dq = Bq^n + c \qquad (4)$$

The total unit cost of production will then be $nBq^n + nc$. The constant term, *c*, is zero if the lead firm operates in a competitive environment for its output, which is assumed. Equation (4) represents the price a producer of a particular task can obtain in the market as a function of the quality of the task. Providing quality is, however, costly and I assume that the performer of the task operate according to a cost function that has two elements; the cost of reducing the number of faults and the cost of delivering the inputs in time. The first element is assumed to be a linear function of $q \in (0, 1)$.[‡‡] The second element relates to the timeliness of delivery and is assumed to take an exponential form.

$$c(q) = aq + e^{\beta q} - 1 \qquad (5)$$

The parameter *a* represents the marginal cost of reducing faults and may reflect the skill level of workers and the quality of management and effectiveness of work organization. The parameter β is interpreted as a measure of the disadvantage of distance from the workstation in which the task will enter the production of the final good. I envisage the distance as measured in time units rather than in kilometres, since it is timeliness that matters. Furthermore, time to customer may vary substantially over similar distances depending on geographical characteristics, the quality of infrastructure and the efficiency and cost of communication, transport services and customs procedures when suppliers are foreign firms. A high β represents poor quality of infrastructure and services. We notice that if the delivery time is zero and hence the input is produced on the spot, the cost of quality consists of the linear cost of reducing the number of faults only.

The producer of a particular input chooses quality level by maximizing profits as follows:

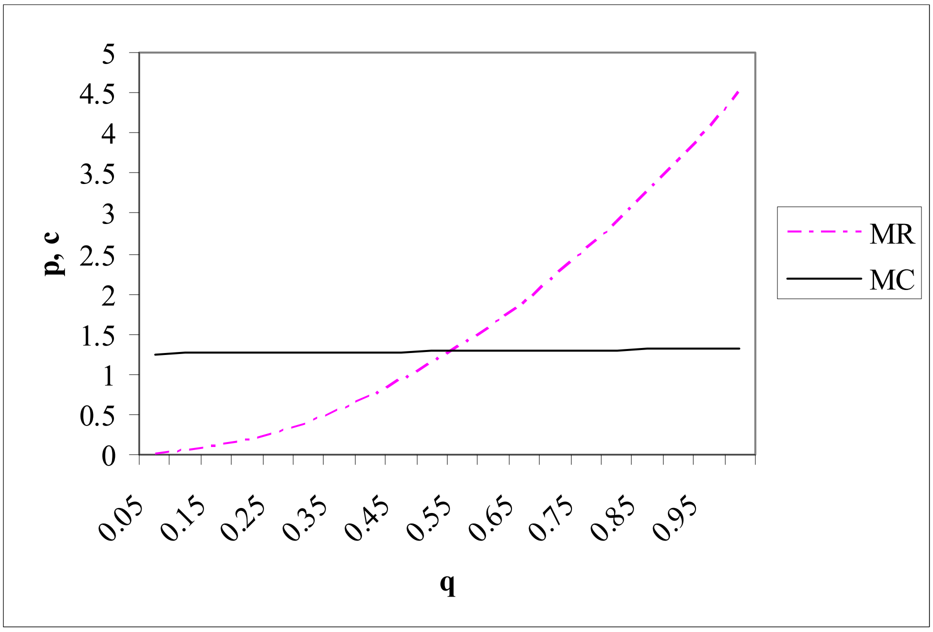
$\underset{q}{Max}\left[Bq^n - aq - e^{\beta q} + 1\right]$, which yields the first-order condition:

$$nBq^{n-1} - a - \beta e^{\beta q} = 0 \qquad (6)$$

The condition is depicted in Figure 1, where MR depicts the first term which is the marginal revenue earned by the supplier of the input in question, while MC represents his marginal cost, both as a function of quality. The marginal cost curve obviously intercepts the vertical axis at *a*.

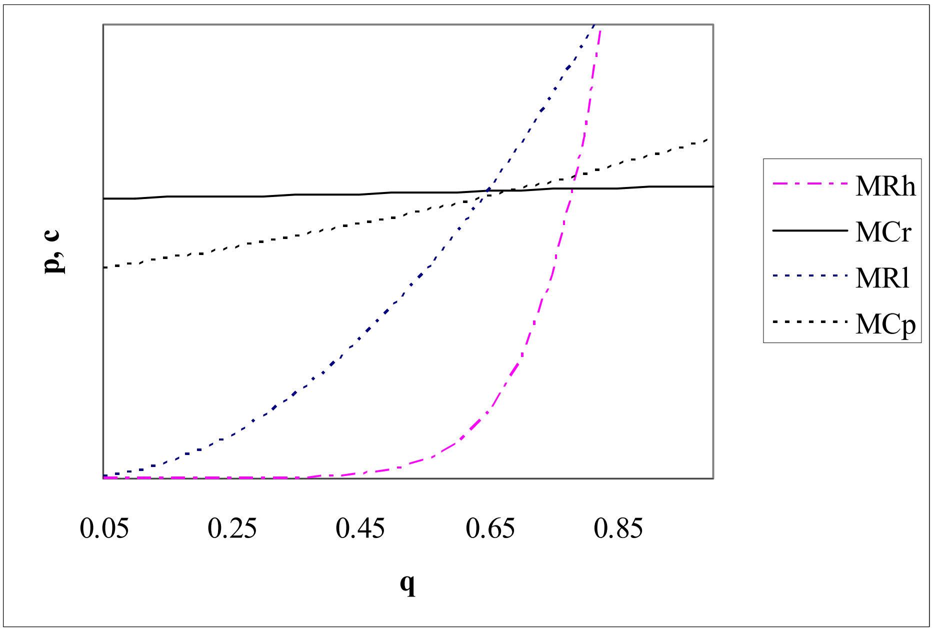
[‡‡] Non-linearity renders the model impossible to solve analytically and there is not much loss of generality in imposing this restriction.

Figure 1. Market equilibrium, quality



Consider two industries, high-technology and low-technology, where the two are distinguished by the number of inputs involved in producing the final output; $n_h > n_l$. Further, consider two different locations for the potential providers of the tasks; a high-wage location with good quality of infrastructure, indicated by subscript *r* and a low-wage location with poor infrastructure, indicated by subscript *p*; $\beta_p > \beta_r ; a_p < a_r$. Figure 2 depicts these two industries and the marginal cost of suppliers from the two locations. The poor location supplier has the lowest costs at low to medium quality levels, while the rich location supplier has the lowest cost at high quality levels. The marginal revenue curve is more convex the larger is *n*. The high-technology sector firms are not willing to pay much for low-quality inputs, while the low-technology sector firms have a positive demand also for low-quality inputs. The figure illustrates a case where the low-technology sector will source all inputs from the poor location, while the high-technology sector will source all inputs from the rich location.

Figure 2. Two industries, two regions



The O-ring theory in other words predicts that low-technology industries are likely to source inputs from low-cost countries while high-technology industries are likely to source inputs from firms close to the lead firm or from locations with good infrastructure. This prediction is further explored empirically in section IV below.

IV. EMPIRICAL ESTIMATES OF THE DETERMINANTS OF INTERNATIONAL VERTICAL SPECIALIZATION

In this section I provide some empirical evidence on the extent and determinants of international vertical specialization. I use the definition of vertical specialization suggested by Hummels et al. (2001) where vertical specialization in country *k*, sector *i* is given as:

$$VS_{ki} = \frac{\text{imported intermediates}_{\text{ki}}}{\text{gross output}_{\text{ki}}} \text{exports}_{\text{ki}}$$

The bracket expresses the intermediate imports share of total gross output. This is multiplied by total exports from sector *i* of country *k*. Vertical specialization can thus be seen as the import content of exports expressed in value terms. The sectors included in the analysis are electronics, motor vehicles, chemicals, and textiles and clothing. Electronics is the sector with the highest vertical specialization index among the manufacturing sectors included in the GTAP database. The motor vehicles industries is seen as a pioneer industry as far as management and industrial organization innovations are concerned and is included for that reason. Textiles and clothing are included for three reasons. First, they are often entry level industries for developing countries that are in the process of industrializing. Second, they are subject trade barriers that are unique for the sector through the Multi-Fibre Agreement that was replaced by the Agreement on Textiles and Clothing in 1995. Third, empirical studies have found this sector to develop in the direction of vertical specialization where timeliness is particularly important for the supply of inputs (Evans and Harrigan, 2003; 2004). The chemicals sector also has a high vertical specialization index and is interesting because of its capital intensity as a contrast to the clothing sector.[§§] I estimated vertical specialization according to the definition aabove for 52 countries using the GTAP database. This database includes an input-output matrix for each country and the matrix distinguishes between local and imported intermediates. The estimates are presented (as share of total exports in each sector for each country) in annex table A.1.

The model developed in the previous section identifies the rate of faults and the time of delivery as the most important factors of competitiveness in vertical supply chains. Data on the rate of faults when a product leaves the factory gate can only be obtained at the firm level. However, if infrastructure is poor, storage facilities inadequate for protecting the goods from damage, the fault rate may increase during transit, and the quality of infrastructure may be used as a proxy for the extent of such damage. Also the timeliness dimension is likely to be highly correlated with the quality of infrastructure and logistics services. I therefore expect the quality of infrastructure to be positively related to vertical specialization.

Assuming positive cost of producing a certain quality of each input, and assuming that β increases with distance, it is reasonable to believe that a larger part of the supply chain is located *within* the country in large countries compared to small countries; e.g. we would expect vertical specialization to constitute a larger share of Singapore's total exports than USA's total exports. In the context of the model, we could envisage that given $n = (n^h + n^f)$ where superscripts *h* and *f* respectively represent home and foreign $n^h / (n^h + n^f)$ is larger the larger the country. I therefore control for market size represented by the log of GDP, and I expect that it has a negative impact on vertical specialization. Table A.1 suggests that this is the case. Small countries, both rich and poor have a relatively high index. Vietnam, for example has an index of almost 70 per cent in the clothing industry and more than 50 per cent in the electronics industry, while Ireland has a vertical specialization index of close to 60 per cent in all the included industries except chemicals.

There is little reason to expect that the vertical specialization index is systematically related to income levels or wage levels. Although countries differ in terms of in which production stages they have a comparative advantage, it is not clear how the total amount of trade driven by vertical specialization may be affected by income levels, as indicated by Figure 2 above. Nevertheless, it is worth exploring the impact of the income level on vertical specialization, particularly whether the impact is different among sectors, and I include the log of GDP per capita to explore this.

The parameter β in the model represents the cost in terms of time, money and quality deterioration of transferring an input from the location it has been produced to the location of the next stage of processing. In the regressions I include three groups of variables as proxies for these costs. The first relates to geography, the second to policy and the third to infrastructure. Starting with geography, distance to major markets is one important element. A proxy for this variable is the log of the latitude of the capital of the country in question. Since wealth is concentrated in the temperate zone of the world, the latitude is correlated with distance to major markets.[***] Being landlocked or an island is found to have a negative

[§§] The pharmaceutical sector would have been even more interesting because of its R&D intensity, but the GTAP database does not present separate data for this sector.

[***] See Sala-i-Martin (1997) for a discussion of this variable.

impact on bilateral trade in a number of empirical studies applying the gravity model and I therefore include dummies for island and landlocked in the regression.[†††] I expect the landlocked and island dummies to be negatively related to vertical specialization, while latitude is expected to have a positive effect.

One policy variable of relevance to the timely and cost effective transfer of goods and services is trade policy represented by tariffs. The regressions include the log of the tariff factor (1+ t_{ki}) where t_{ki} is the average applied most favoured nation rate for country k and sector i; the data are from the TRAINS database. As already mentioned, international trade in the textiles and clothing sectors is subject to an intricate system of quotas which is scheduled to be phased out by 2005. I include two dummies taking the value of 0 if the country has no quotas under the MFA and 1 if it has a quota in the USA or EU respectively.[‡‡‡] Quotas are allocated at a very detailed level and quotas are subject to changes over time and across items. The system is rather bureaucratic and it is hypothesized that the lack of flexibility related to the system constitutes an impediment to vertical specialization. Finally, corruption has attracted much attention in recent years as an impediment to trade and growth. It is reasonable to assume that corruption, to the extent that it imposes an extra tax on transactions and in addition introduce uncertainty and delays, has a negative impact on vertical specialization. I therefore also include control of corruption in the regression. The control of corruption index is taken from Kaufman et al. (2002) and takes values between -2.5 and 2.5, the higher the value the better the control of corruption.

The parameter β is probably at least as much related to the quality and density of infrastructure than the price per ton kilometre of transport or the cost of exchanging information. I therefore use an index of infrastructure quality to capture the infrastructure impact on vertical specialization. The index contains the density of roads, railways, airports and telephone lines, the quality of roads (the share that has been paved) and the quality of ports (days of clearance and a port quality index). The lower the value of the index the better is the quality of infrastructure.[§§§] Telecommunications have been one of the driving forces for vertical specialization, so it is of interest to analyze the impact of this variable separately. I therefore include regressions where the aggregate infrastructure index is replaced by the cost of a 3 minute call to the US.

The expected sign on the infrastructure index is uncertain. On the one hand, better infrastructure lowers the cost of international transactions, contributing to more vertical specialization. On the other hand, good infrastructure also makes domestic transaction costs lower and could provide an incentive for both the lead firm and its suppliers to locate production in a country with good infrastructure. In addition many countries have established export processing zones (EPZ) with much better infrastructure and related services than average for the country in question. The quality of infrastructure for the country as a whole may therefore not always be a good proxy for the quality of infrastructure facing participants in international production networks.[****]

[†††] See Anderson and Wincoop (2003) for a review.

[‡‡‡] Information on quotas is from the customs department in the U.S. and from the SIGL in the EU.

[§§§] The index has been developed by Roberta Piermartini, WTO and is calculated by the same methodology as Limão and Venables (1999), but adds quality of ports, and density of airports.

[****] I am working on collecting data on this issue and will control for the existence of EPZ in the next draft of the paper.

Infrastructure, control of corruption and GDP per capita are highly correlated. Including all of them in the same regression may therefore imply problems of multicollinearity. As already noted, vertical specialization exploits comparative advantage at a finer level of specialization than the industry-level. Low-income countries may therefore engage in vertical specialization, specializing in the labour-intensive stages of production in industries that are classified as high-technology or capital-intensive. A significant impact of GDP per capita on vertical specialization, as I indeed find before controlling for infrastructure, may therefore capture the effect of infrastructure on vertical specialization. I therefore drop GDP per capita when introducing infrastructure in the regressions.

I start with regressions on the entire sample which is a cross-section of observations of 52 countries and 5 sectors. The left-hand side variable is vertical specialization as a share of total exports while the right-hand side variables are the logs of income, geography, policy and infrastructure variables and dummies for island and landlocked countries, quotas under the Mulit-Fibre Agreement and an index for control of corruption. With shares on the left-hand side and logs of absolute levels on the right-hand side the appropriate estimation technique is weighted least squares estimates. The analysis is conducted in three steps and Table 1 presents the results. I start by including measures of income and market size only, and it turns out that these variables alone explain more than 50 per cent of the variation. As expected, market size as measured by (the log of) GDP is negatively related to international vertical specialization. GDP per capita is positively related to vertical specialization, and thus rich countries are more likely to engage in vertical specialization than poor countries.

The next column adds the geography indicators. The two dummies have the expected negative sign and are significant. Latitude is significant at the one per cent level, but takes a negative sign, indicating that countries located close to the major markets participate less in international production networks when income and market size are controlled for. Latitude has a relatively low economic significance, however, indicated by the low parameter value. The elasticity of vertical specialization with respect to latitude is -0.16/30.2 = -0.005.[††††] One possible explanation is that producers in the rich, temperate zone are more likely to specialize in complex sectors where all inputs are high-quality and located close to the lead firm in the production chain. This is further explored by analyzing the sectors separately.

The next step is to include policy variables. Tariffs take the expected negative sign, and are significant at a 5 per cent level while the corruption index takes the expected positive sign and is significant at a one per cent level. The inclusion of the corruption index changes the sign of the coefficient on GDP per capita and renders it insignificant. The correlation coefficient between the two variables in the sample is 0.87, so it is likely that they capture much of the same sources of variation between countries. Having good institutions and good infrastructure are two aspects of having a high income level. Since I am primarily interested in these two aspects rather than the level of income *per se,* I drop GDP per capita in subsequent regressions.

I finally add measures of the quality of infrastructure. The first column in this section presents the regression with the aggregated infrastructure index. It has the expected sign but is not significant. Again there is the possibility that corruption and infrastructure capture the same sources of variation, since the correlation coefficient between the two is -0.75. I

[††††] The elasticity is calculated as the estimated parameter divided by the mean of the latitude variable in the sample.

therefore include a regressions in the next column where corruption is dropped, and notice that infrastructure then becomes significant. Furthermore, all variables included now take the expected signs and are significant at a 5 per cent level or better. The last two columns present regressions where aggregate infrastructure is replaced by the cost of telecommunications. The cost of telephone calls to the US has a significant and negative impact on vertical specialization.[‡‡‡‡]

Table 1. Regression results, the entire sample

				Infrastructure			
Variable	**Income only**	**Geography**	**Policy**	**Aggregate**	**Aggr. excl corrupt**	**Telecost**	**Telec excl. corrupt**
Log GDP	-0.56*** (-17.3)	-0.53*** (-15.49)	-0.54*** (-15.56)	-0.53*** (-15.3)	-0.53*** (-15.2)	-0.58*** (-13.97)	-0.58*** (-13.97)
Log gdp/capita	0.14*** (3.64)	0.18*** (4.63)	-0.04 (-0.52)				
log Latitude		-0.19*** (-3.91)	-0.16*** (-3.09)	-0.17*** (-3.32)	-0.14*** (-2.89)	-0.18*** (-3.56)	-0.18*** (-3.63)
Island		-1.28* (-1.78)	-1.54** (-2.17)	-1.48** (-2.09)	-1.52** (-2.14)	-1.44** (-2.11)	-1.44** (-2.10)
Landlocked		-0.40* (-1.90)	-0.44** (-2.09)	-0.45** (-2.13)	-0.44** (-2.10)	-0.30 (-1.47)	-0.33* (-1.63)
log Tariffs			-2.16* (-1.66)	-1.37 (-1.18)	-2.36** (-2.20)	-1.87* (-1.69)	-1.23 (-1.33)
Corruption			0.17*** (2.47)	0.12** (2.06)		-0.07 (-1.06)	
Log Infrastr.				-0.25 (-0.99)	-0.46** (-1.98)	-0.66*** (-4.80)	-0.56*** (-5.45)
n	255	255	240	240	240	220	220
Adjusted R^2	0.56	0.59	0.62	0.63	0.62	0.63	0.63

The five sectors included in the analysis are very different in terms of technology and international trade regime. I therefore turn to an analysis of each sector and apply the same three steps as for the entire sample. The results are reported in Tables 2-7.

[‡‡‡‡] The density of mobile plus fixed telephone lines also had a significant (at 10 per cent level) and positive impact when replacing the cost of telecommunications in the last regression (not reported).

Table 2. Regression results by sector: Textiles

				Infrastructure			
Variable	**Income only**	**Geography**	**Policy**	**Aggregate**	**Aggr. excl corrupt**	**Telecost**	**Telec excl. corrupt**
Log GDP	-0.35*** (-4.3)	-0.36*** (-4.02)	-0.40*** (-4.34)	-0.37*** (-4.01)	-0.37*** (-3.96)	-0.34*** (-3.01)	-0.35*** (-3.09)
Log gdp/capita	0.26*** (3.62)	0.21*** (2.60)	0.04 (0.22)				
log Latitude		0.18 (0.96)	0.10 (0.48)	0.01 (0.06)	0.01 (0.04)	0.05 (0.25)	0.03 (0.15)
Island		-0.61 (-0.49)	-1.13 (-0.93)	-1.07 (-0.92)	-1.08 (-0.90)	-1.12 (-0.90)	-1.21 (-0.98)
Landlocked		0.40 (0.80)	0.36 (0.73)	0.39 (0.82)	0.28 (0.58)	0.35 (0.67)	0.25 (0.49)
log Tariffs			-4.38 (-1.12)	-2.61 (-0.76)	-2.11 (-0.60)	-4.57 (-1.43)	-4.22 (-1.33)
Quota, US			-0.65* (-1.73)	-0.63* (-1.72)	-0.59 (-1.57)	-0.71* (-1.75)	-0.68* (-1.70)
Quota, EU			-0.26 (-0.55)	-0.27 (-0.59)	-0.01 (-0.02)	-0.25 (-0.51)	-0.18 (-0.37)
Corruption			-0.23 (-1.40)	-0.27* (-1.78)		-0.15 (-0.85)	
Log Infrastr.				-0.92 (-1.24)	-0.53 (-0.73)	0.14 (0.32)	0.35 (0.93)
n	51	51	48	48	48	44	44
Adjusted R^2	0.30	0.29	0.40	0.42	0.39	0.34	0.35

The size of the market and level of income per capita have the same effects for the textile sector as in the overall sample. The smaller the market and the higher the level of GDP per capita, the more vertical specialization. Geography appears to have no effect on vertical specialization in the textile sector, and including these variables actually reduces the explanatory power of the regression. The trade policy variables take the expected signs, but only quotas in the US market are significant. Adding policy variables nevertheless increases the overall explanatory power of the regression. GDP per capita becomes insignificant when corruption or infrastructure are included. Infrastructure appears to be unimportant for vertical specialization in the textile sector.

Table 3. Regression results by sector: Clothing

				Infrastructure			
Variable	**Income only**	**Geography**	**Policy**	**Aggregate**	**Aggr. excl corrupt**	**Telecost**	**Telec excl. corrupt**
Log GDP	-0.41*** (-6.43)	-0.41*** (-5.55)	-0.39*** (-5.01)	-0.34*** (-4.40)	-0.34*** (-4.27)	-0.40*** (-4.05)	-0.39*** (-3.72)
Log gdp/capita	0.25*** (4.34)	0.23*** (3.68)	-0.04 (-0.26)				
log Latitude		0.14 (0.80)	0.02 (0.13)	-0.06 (-0.36)	-0.03 (-0.17)	0.15 (0.83)	0.22 (1.16)
Island		0.45 (0.76)	0.26 (0.43)	0.26 (0.48)	0.08 (0.15)	0.36 (0.59)	0.39 (0.61)
Landlocked		0.21 (0.43)	0.18 (0.38)	0.19 (0.42)	0.16 (0.34)	0.08 (0.17)	0.26 (0.52)
log Tariffs			-0.76 (-0.39)	1.25 (0.74)	0.49 (0.29)	-1.35 (-0.84)	-2.52 (-1.57)
Corruption			0.42*** (2.47)	0.28* (1.75)		0.41** (2.22)	
Quota, US			-0.68** (-2.00)	-0.65** (-2.01)	-0.76** (-2.34)	-0.28 (-0.68)	-0.60 (-1.50)
Quota, EU			0.61 (1.51)	0.73* (1.94)	0.61 (1.62)	0.31 (0.66)	0.43 (0.86)
Log Infrastr.				-1.31* (-1.70)	-1.88** (-2.64)	0.16 (0.35)	-0.43 (-1.09)
n	51	51	48	48	48	44	44
Adjusted R^2	0.46	0.44	0.54	0.57	0.55	0.52	0.47

Also in the clothing sector income and market size alone explains almost half of total variation in the degree of vertical specialization, and the richer the country the larger the share of total exports is driven by vertical specialization. Otherwise vertical specialization appear to be largely driven by policy. The U.S. quota system appears to discourage vertical specialization, while the EU quota system have little significant effect, and if anything a positive effect. It also appears that the less corrupt the country, the more it is likely to engage in vertical specialization in the clothing sector. While the overall quality of infrastructure is positively and significantly related to vertical specialization in the clothing sector, the cost of telecommunications has no significant impact. I also aggregated textiles and clothing into one sector and ran the same regressions for the combined sector. The results were very similar to those of the clothing sector (not reported).

Table 4. Regression results by sector: Chemicals

				Infrastructure			
Variable	**Income only**	**Geography**	**Policy**	**Aggregate**	**Aggr. excl corrupt**	**Telecost**	**Telec excl. corrupt**
Log GDP	-0.49*** (-9.35)	-0.55*** (-10.36)	-0.56*** (-10.42)	-0.47*** (-11.35)	-0.47*** (-11.30)	-0.48*** (-7.15)	-0.48*** (-7.25)
Log gdp/capita	0.24*** (3.34)	0.25*** (3.41)	0.39*** (2.72)				
log Latitude		0.15 (1.59)	0.10 (0.97)	0.20*** (2.79)	0.17** (2.51)	0.17 (1.64)	0.18* (1.70)
Island		-1.27 (-1.09)	-1.13 (-0.97)	-0.89 (-1.02)	-0.92 (-1.04)	-1.33 (-1.03)	-1.32 (-1.04)
Landlocked		-0.64*** (-2.55)	-0.58** (-2.23)	-0.52*** (-2.65)	-0.53*** (-2.66)	-0.59** (-2.04)	-0.59** (-2.07)
log Tariffs			3.17 (0.91)	1.96 (0.94)	3.11 (1.64)	-3.47 (-1.24)	-3.64 (-1.48)
Corruption			-0.09 (-0.84)	-0.09 (-1.28)		0.02 (0.13)	
Log Infrastr.				-2.14*** (-6.59)	-2.01*** (-6.46)	-0.11 (-0.41)	-0.14 (-0.64)
n	51	51	48	48	48	44	44
Adjusted R^2	0.63	0.67	0.69	0.82	0.82	0.52	0.52

In the chemicals sector market size and income level alone explain as much as 63 per cent of the variation. Landlocked countries are less likely to engage in vertical specialization in the chemicals sector, although this effect disappears when road quality is taken into account (regression not reported). Thus, the disadvantage of being landlocked can obviously be compensated by good roads, which had a significant and positive impact on vertical specialization in the chemicals sector.[§§§§] Policy variables appear to be insignificant for vertical specialization in the chemicals sector, while the overall quality of infrastructure has a strong and positive effect. The elasticity of vertical specialization with respect to the quality of infrastructure index is -2.14/1.11 = -1.9, the highest among the sectors.

[§§§§] Also trade restriction on maritime services had a significant and negative impact on vertical specialization in the chemicals sector.

Table 5. Regression results by sector: Motor vehicles

				Infrastructure			
Variable	**Income only**	**Geography**	**Policy**	**Aggregate**	**Aggr. excl corrupt**	**Telecost**	**Telec excl. corrupt**
Log GDP	-0.69*** (-8.12)	-0.71*** (-7.42)	-0.72*** (-7.57)	-0.75*** (-8.58)	-0.75*** (-8.45)	-0.80*** (-9.65)	-0.83*** (-10.34)
Log gdp/capita	0.25* (1.73)	0.22 (1.03)	-0.27 (-0.92)				
log Latitude		0.15 (0.45)	0.09 (0.24)	0.01 (0.02)	0.23 (0.76)	0.62*** (2.54)	0.45** (2.11)
Island		-1.49 (-0.26)	-1.91 (-0.34)	-1.90 (-0.34)	-1.73 (-0.30)	-0.57 (-0.14)	-0.95 (-0.23)
Landlocked		-0.60 (-1.22)	-0.47 (-0.97)	-0.48 (-0.98)	-0.45 (-0.91)	-0.04 (-0.12)	-0.19 (-0.50)
log Tariffs			-4.65 (-1.14)	-3.08 (-0.87)	-6.04** (-2.18)	0.83 (0.32)	2.56 (1.11)
Corruption			0.28 (1.60)	0.23 (1.31)		-0.22 (-1.38)	
Log Infrastr.				0.35 (0.53)	0.50 (0.76)	-1.28*** (-5.54)	-1.08*** (-5.89)
n	51	51	48	48	48	44	44
Adjusted R^2	0.58	0.57	0.62	0.61	0.60	0.79	0.79

Vertical specialization in the car industry appears to be largely explained by market size and the cost of telecommunications. The elasticity of vertical specialization with respect to the cost of telecommunications is about 0.3. The costs of telecommunications are highly significant and including them in the regression improves the R square by as much as 20 percentage points. We also notice that latitude is significant and positive when cost of telecommunications are controlled for, indicating that vertical specialization is concentrated in the temperate zone with high density of wealth. These results are consistent with the observation that the motor vehicle supply chain is relatively information-intensive as suggested in several sector studies.

Table 6. Regression results by sector; electronics

				Infrastructure			
Variable	**Income only**	**Geography**	**Policy**	**Aggregate**	**Aggr. excl corrupt**	**Telecost**	**Telec excl. corrupt**
Log GDP	-0.61*** (-10.52)	-0.49*** (-7.64)	-0.48*** (-8.32)	-0.52*** (-8.36)	-0.52*** (-8.34)	-0.67*** (-9.81)	-0.65*** (-9.33)
Log gdp/capita	0.01 (0.13)	0.01 (0.21)	-0.39** (-2.50)				
log Latitude		-0.28*** (-3.61)	-0.24*** (-3.21)	-0.30*** (-3.87)	-0.28*** (-3.59)	-0.25*** (-3.81)	-0.25*** (-3.70)
Island		-1.08 (-0.36)	-1.45 (-0.54)	-1.26 (-0.44)	-1.24 (-0.43)	-1.14 (-0.50)	-1.23 (-0.53)
Landlocked		-0.18 (-0.31)	-0.20 (-0.41)	-0.23 (-0.43)	-0.24 (-0.45)	-0.25 (-0.58)	-0.31 (-0.69)
log Tariffs			-4.55 (-1.21)	0.83 (0.25)	-1.45 (-0.50)	0.15 (0.07)	3.11 (1.84)
Corruption			0.27** (2.31)	0.18 (1.47)		0.23* (-1.88)	
Log Infrastr.				0.41 (0.80)	0.17 (0.49)	-0.89*** (-4.09)	-0.61*** (-3.68)
n	51	51	48	48	48	44	44
Adjusted R^2	0.71	0.77	0.83	0.81	0.80	0.87	0.86

The electronic sector stands out from the others having a significant and negative sign on latitude in all regressions. Countries closer to the equator, which are mainly developing countries, engage relatively more often in vertical specialization in the electronics sector. Trade policy appears to have little effect, but corruption appears to affect vertical specialization negatively. Overall infrastructure is not significant, but the cost of telecommunications are highly significant and high costs reduce the extent of vertical specialization, with an elasticity of about -0.2.[*****] It appears thus that this is a sector where poor countries have an opportunity to enter a dynamic sector through participating in international production networks, provided that the flow of goods and services are not interrupted by activities related to corruption, and that they have a cost effective telecommunication system. We also notice the high R square in these regressions.

V. SUMMARY AND CONCLUSIONS

This study has first presented an analytical framework for studying the determinants of vertical specialization. The framework predicts that the more complex the production process, the more lead firms are willing to pay for high quality inputs and the less are they willing to pay for low-quality products. There are two aspects of quality that are relevant in this respect; the timeliness of delivery and the rate of faults of the inputs as they enter the production station. While the quality of the product as it leaves the factory gate is under the suppliers' control, the timeliness of delivery might not be. Furthermore, the quality of the product when it enter the premises of the customer may also be beyond the control of the supplier in countries with poor quality of infrastructure and related services. This represent a disincentive for producers in such locations to invest in quality if the quality is eroded on the

[*****] The mean of the cost of a 3 minute telephone call (peak rate) to the US was $4.38.

journey from factory gate to the customer, and the gains from investment in quality may come to nothing.

In order to assess the role of infrastructure and logistics, I regress a vertical specialization index on the quality of infrastructure and on the cost of telecommunications, controlling for market size, trade policy and geography. I find a positive correlation between the share of total exports that is driven by vertical specialization and the quality of infrastructure. This applies to the sample as a whole and for clothing and chemicals. In addition corruption appears to have a negative impact on participation in international production networks, and this problem appears to have the most serious consequences in the electronics and clothing sectors – sectors where the technological entry barrier to labour-intensive processing stages appear to be low also for poor countries. Electronics and clothing are also the sectors which appear to have the most geographically dispersed supply chain where altitude is either insignificant or significant and negative, further underscoring the opportunity for poor countries to enter these supply chains. The chemicals sector on the other hand appears to be more concentrated in rich countries and more sensitive to good infrastructure than any other sector. The sector that is found to be most sensitive to telecommunications costs is the motor vehicle industry.

The findings in this paper suggests that poor infrastructure and inefficient procedures related to the transfer of goods and services across international boundaries constitute a serious disincentive for local companies to invest in quality and thereby improve their ability to enter international production networks and improve productivity. Such implications are often overlooked in the trade and development debate. Trade facilitation, one and possibly the only so-called Singapore issue remaining on the agenda of the Doha development agenda under the auspices of the WTO, addresses these questions to some extent. A successful outcome of these negotiations and successful implementation of the results may prove a cost-effective way of easing some of the constraints facing entrepreneurs in poor countries with the potential to participate in vertical international specialization.

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Annex 1

Table A.1. Vertical specialization index

Country	Textiles	Clothing	Chemicals	Motor vehicles	Electronics
Argentina	4.5	2.1	11.4	26.4	36.7
Austalia	15.7	18.0	17.0	17.0	29.0
Austria	70.5	59.6	37.3	41.2	30.2
Bangladesh	16.2	23.8	18.1	12.3	10.1
Belgium	43.7	47.2	49.9	64.8	37.9
Botswana	71.6	72.8	40.1	39.6	28.8
Brazil	4.2	1.3	10.7	12.6	20.7
Canada	25.9	22.9	19.4	48.5	55.3
Chile	22.0	13.7	28.5	49.8	36.2
China	14.0	11.2	13.0	10.5	29.5
Columbia	11.8	9.4	11.7	28.8	11.5
Denmark	43.9	37.4	28.8	34.9	33.1
Finland	30.5	33.7	30.4	42.0	42.2
France	18.8	20.5	15.0	15.7	12.2
Germany	17.2	17.8	17.4	14.8	13.8
Greece	13.4	13.0	6.5	2.5	17.8
Hong Kong	9.2	28.8	27.4	21.6	56.1
Hungary	43.7	32.3	40.3	62.2	65.3
India	2.6	3.2	16.6	6.2	32.5
Indonesia	36.4	15.6	17.7	25.6	25.6
Irland	57.1	56.2	34.4	13.6	56.7
Italy	36.4	11.9	20.7	20.8	19.5
Japan	11.9	7.9	9.1	1.4	5.7
Korea	19.0	17.0	20.5	11.8	33.0
Malawi	4.1	4.1	13.6	66.7	52.4
Malaysia	33.1	13.1	27.2	34.0	62.5
Marocco	33.9	27.9	12.3	21.7	22.9
Mexico	5.5	4.5	28.5	34.4	47.0
Mozambique	12.6	15.0	17.6	69.2	54.2
Netherlands	58.7	57.3	40.5	44.8	33.7
New Zealand	8.3	16.8	18.1	35.0	27.3
Peru	5.9	0.3	20.7	11.3	19.4
Philippines	42.7	39.7	43.5	54.0	89.8
Poland	38.2	32.2	29.8	51.7	28.6
Portugal	21.5	17.3	18.4	29.8	30.3
Singarpore	21.0	65.7	43.9	50.8	78.7
Spain	28.4	26.9	28.9	32.9	23.9
Sri Lanka	38.4	48.6	33.8	36.6	65.5
Sweden	34.6	38.6	23.8	31.9	26.4
Switzerland	27.5	27.4	19.9	16.6	29.3
Taiwan	12.6	14.4	20.4	23.7	38.4
Tanzania	7.4	11.2	19.0	28.6	49.1
Thailand	15.6	4.2	7.3	31.3	26.8
Turkey	22.2	27.2	28.4	19.5	39.2
Uganda	5.8	8.9	57.1	24.0	40.9

UK	25.0	24.7	18.5	27.0	30.5
Uruguay	18.2	18.8	34.7	50.7	23.3
USA	8.7	13.2	5.5	12.1	15.2
Venezuela	10.2	9.9	14.8	38.9	51.0
Vietnam	60.8	68.5	44.5	54.1	52.5
Zambia	8.0	8.3	2.9	33.3	15.4
Zimbabwe	14.3	18.9	51.2	42.6	30.0

The vertical specialization index is the VS as presented in section IV above divided by total exports in the sector; i.e. the share of exports accounted for by vertical specialization.

Annex 2:

<u>*Data sources:*</u>

GDP and GDP per capita: World Development Indicators; World Bank, CD-rom.
Infrastructure index: WTO
Maritime services regulation index: Australian Productivity Commission and the National University of Australia;
Tariffs: the TRAINS database;
Textiles and clothing quotas: SIGL and the U.S. Customs Department