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Vertical specialization and the quality of infrastructure

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VERTICAL SPECIALIZATION AND THE QUALITY OF INFRASTRUCTURE

Hildegunn Kyvik Nordås

Abstract

This paper explores the role of producer services and ICT on international outsourcing. The motivation for outsourcing is to focus on core business and improve efficiency and outsourcing companies usually outsource a number of functions and the efficiency gains depend on the ability for the suppliers to deliver the required quality at the right time. If only one is late or delivers a substandard product, it will delay the entire process or reduce the quality of the final product. The timeliness of delivery and the fulfilment of quality standards depend critically on the availability of producer services. Transport, communication and other logistics services are obvious in this respect, but also services such as testing and technical services contribute to enable suppliers in low-cost countries to enter the outsourcing market. I therefore argue that international outsourcing can best be understood within an analysis framework of many suppliers that are interdependent, and the O-ring theory of production is such a theory. The paper first presents and modifies this model and then explores its predictions in an empirical analysis of the determinants of international vertical specialization as defined by an index developed by Hummels et al. (2001). The index is calculated for a cross-section of 52 countries and 5 sectors and regressed on a number of variables affecting the timeliness of delivery. It is found that vertical specialization is sensitive to trade barriers and infrastructure quality and cost of infrastructural services. The relative importance of trade barriers and various indicators of infrastructure vary between sectors. Vertical specialization in the electronics sector appears to be most sensitive to trade barriers and the density of the telecommunication network. This is also the case for the motor vehicles sector, but the size of the parameters is somewhat lower. The chemicals sector is most sensitive to the restriction on maritime services, while for textiles and clothing the aggregated measure of infrastructure had the highest explanatory power. Only in the electronics sector did the wage level (GDP per capita was used as a proxy) matter for vertical specialization.

JEL classification: F12, F14

Keywords: O-ring theory of production, International trade, Vertical specialization.

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.

Many still associate manufacturing with the assembly line - and the assembly line with Charlie Chaplin's movie "Modern Times". Modern manufacturing has, however, changed a lot since Henry Ford's and Chaplin'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".[1]

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 an 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.

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

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 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. There are therefore reasons to believe that industries with a complex production technology involving many stages of production will tend to hire high-skilled workers, particularly those performing the tasks late in the production sequence. If inputs are purchased from outside suppliers, suppliers that have a reputation for high-quality products and reliability in terms of delivery will be preferred. 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. Thus, industries with a large number of sequential tasks tend to pay high wages and when tasks are outsourced to external suppliers, they tend to locate close to the customer or in a location where transport links are reliable and not too costly.

Industries differ in terms of technological separability of production stages. Even if production stages are technological separable, the need for coordination or synchronization may make them institutionally inseparable. Finally, the need for flawless components from

one stage to enter the next stage just in time may result in suppliers clustering around the lead firm in the supply chain. Thus, even if stages are technologically and institutionally separable, they may not be separable in space – distance may matter a lot.

This paper applies the so-called O-ring production function to a vertically specialized production network setting. It 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. A key feature of the o-ring theory is that quality of inputs cannot be substituted for quantity even when a lower quality has 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 focus on two dimensions of quality in this paper, 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.[2] The second part of the paper provides an empirical estimate of the determinants of vertical specialization in an international trade context. Here the focus is on the timeliness dimension of quality. 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 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

[2] 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.

production in different countries. In the empirical literature there is no consensus on exactly what vertical specialization is. Some authors define it as outsourcing of inputs to foreign firms, but it is not possible to identify such trade flows in international trade statistics. A narrower definition is provided by Hummels et al. (2001) who 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, including Ireland, Korea and Mexico. In addition Taiwan was included in the sample which covers 60 percent of world trade. A third 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. This measure does not capture US multinational firms' imports from their affiliates, nor does it capture intra-firm trade of foreign affiliates in the US. And obviously it does not measure vertical specialization that takes place through international outsourcing, which many argue has increased faster than intra-firm trade in intermediates (e.g. Antras and Helpman, 2003).[3] 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.

Turning to the driving forces of vertical specialization it has been argued that in modern manufacturing the production process is pulled from consumer demand, where consumers often make their own specifications of the product, all the way down the supply chain to the suppliers of raw materials. In contrast, traditional manufacturing was seen as the push of inputs through the production pipeline till the finished product reached the consumer. There has in other words been a shift from supply-push to demand-pull in the supply chain in a number of industries. The point of coordination of the supply chain has moved in the same direction. It is increasingly the companies that undertake activities closest to the consumers that organize and coordinate the supply chain. Reductions in transaction costs due to better

[3] See also Hanson et al. (2003) for a discussion of vertical production networks in multinational firms.

information and communication technology has made increased vertical specialization economically feasible. Thus, as transaction costs have come down, the number of transactions has increased.

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. 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 is 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.[4] 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.

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. 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

[4] See Milgrom and Roberts (1990) for a seminal article on modern manufacturing practices.

to operate smoothly. Furthermore, when the supply chain is organized as a lean network with just-in-time deliveries, delays at one stage can become very costly and delivery reliability may well be a more important competitive factor than the price of the input.

The importance of information and communication technology in modern manufacturing is also underscored in a recent study by Mun and Nadiri (2002). They estimated the spillover effect of investment in ICT in the U.S. economy during the period 1985-2000. Their focus is on how investment in ICT in one sector affects cost effectiveness in other sectors through backward and forward linkages. The results are interesting in a production networks perspective. First, they find that it is ICT investments in the services sectors that have the largest spillover effects on other sectors. Second, they find that ICT investments in one industry facilitate ICT investments in their supplier and customer industries as well. They further find that on average IT demand in an industry responds more strongly to IT investments in customer industries than in supplier industries. This is consistent with the existence of supply chains where technology choice is driven by firms high up in the supply chain. It is also consistent with a study of the Internet and US trade in services where US imports of business services is significantly correlated with suppliers' access to the Internet, while exports are not (Freund and Weinold, 2002).

The quality of transport services is obviously crucial for producers located at a distance from the lead firms in production networks to become part of the network. Transport services have been able to improve productivity and reduce costs substantially by utilizing ICT. Recent technology development, particularly electronic vehicle management systems (EVMS) have enabled carriers to know in real time where trucks and cargo are and can therefore better match supply and demand. A recent estimate from the U.S. finds that the installation of EVMS has increased capacity utilization by 13 per cent (Hubbard, 2003).

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 international outsourcing has gained in relative importance recently. The introduction of computer-assisted design and manufacturing and not least the possibility integrated 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 well 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:

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

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 10th 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 located at various distances from the lead firm in the production chain. 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 task if all tasks are performed to perfection. The price of an input or task is an increasing function of its quality. The profit maximizing lead firm chooses quality of the tasks performed according to the following maximization problem:[5]

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

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

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 *i*th task with respect to the quality of all the other tasks;

$$\frac{d^2Y}{dq_i d\left(\prod_{j\neq i} q_j\right)}=nB>0$$

is positive. This implies that the firm with the highest quality of the g -1 (g ≤ n) task will place the highest value of quality of the g-th task 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:

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

The total unit cost of production will then be nBq^n+nc, which equals the unit revenue if the constant term, *c*, is zero, which it will be 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).[6] The second element relates to the timeliness of delivery and is assumed to take an exponential form.

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

The parameter a represents the marginal cost of reducing faults and may reflect the skill level of those performing the task including 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, such that it takes a lot of effort for the supplier to be able to deliver on time. We notice that if the delivery time is zero and hence the task is performed on the spot, the cost of quality consists of the linear cost of reducing the number of faults only.

The performer of a particular task chooses quality level by maximizing profits as follows:

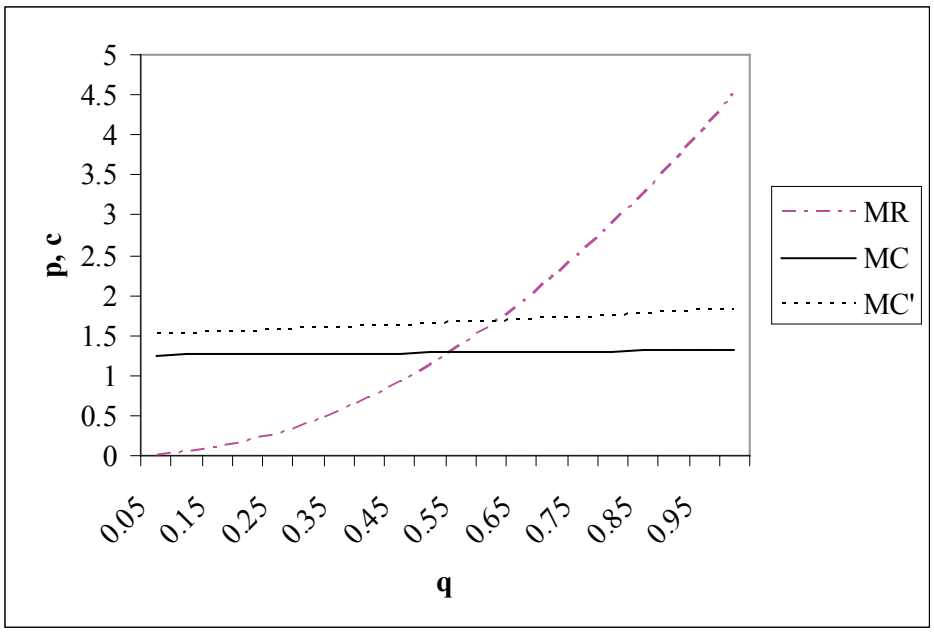
$\underset{q}{Max}\left[Bq^n - aq - e^{\beta q} + 1\right]$, which yields the first-order condition:

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

The condition is depicted in figure 1, where MR depicts the first term which is the marginal revenue earned by the supplier of the task in question, while MC represents his marginal cost, both as a function of quality. The figure compares two different values of β, the dotted line labelled MC' represents the highest value or the poorest infrastructure.

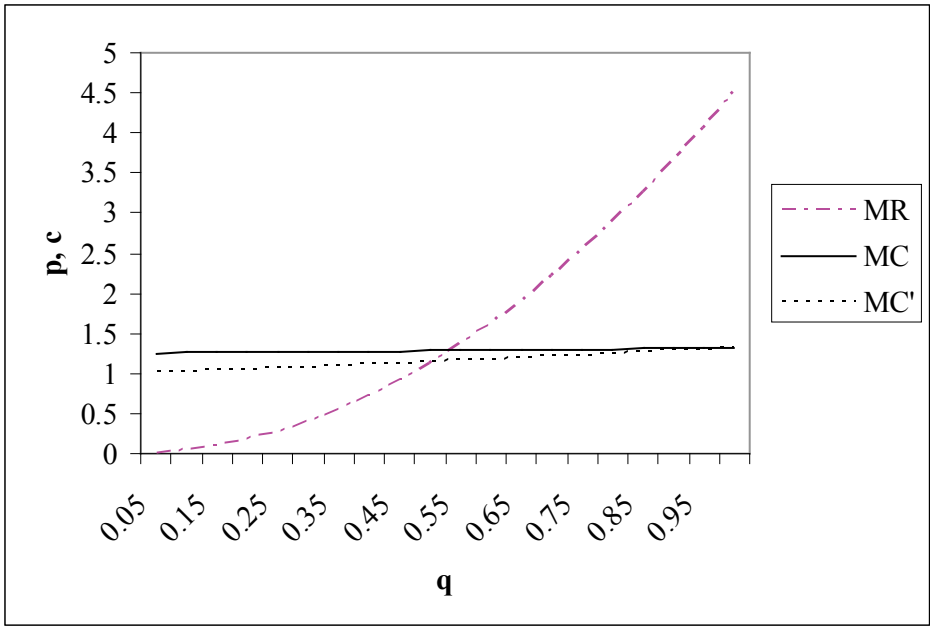
[6] Non-linearity renders the model impossible to solve analytical and there is not much loss of generality in imposing this restriction.

Figure 1. Market equilibrium, quality



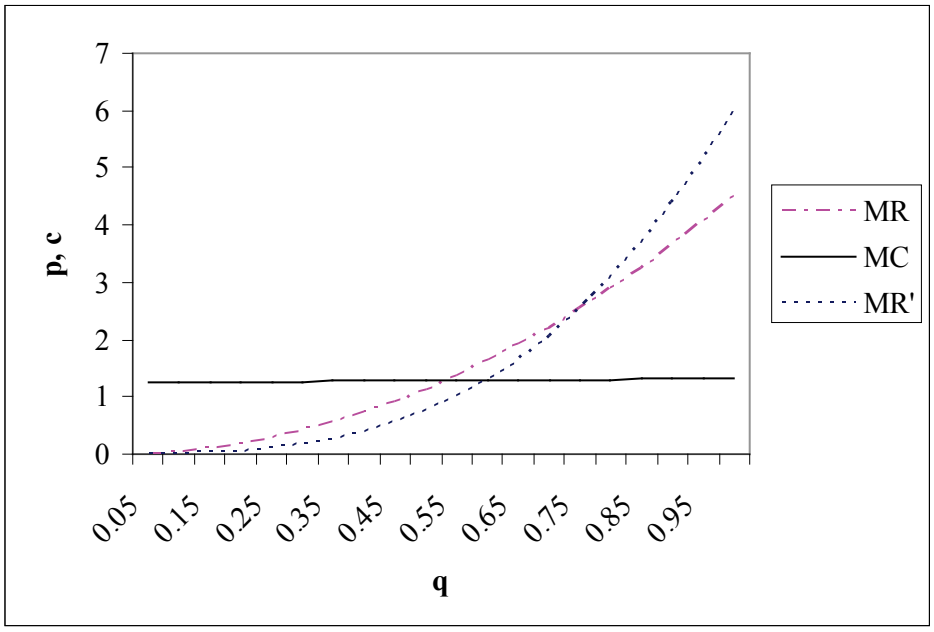
We notice that the suppliers located the closest to the lead firm has the lowest cost at all quality levels, while the suppliers located far from the lead firm would be able to break even only if the price for quality is relatively high. Thus, if a firm located close to the supplier has the same cost of production and the same cost of reducing the number of faults as a firm located further away, the firm close to the lead firm will be the preferred supplier for all levels of quality. However, as Figure 2 below shows, higher costs of delivering just in time can be compensated by lower cost of reducing faults, for example if the furthermost location has lower wages for a given skill level. In the figure the curves are drawn for $a = 2a'$ and $\beta = 0.5\beta'$.

Figure 2. Remoter supplier has lower wages



The remoter supplier now has a cost advantage for most levels of quality, except for the close to perfection quality. Having to incur higher costs of just in time delivery from further a field has to be compensated by lower cost of producing the required quality, which usually means lower wages. Turning to the demand side, an increase in the complexity of the production process (a higher n), would shift down the marginal revenue curve and make increase its curvature as illustrated by Figure 3

Figure 3. The impact of a more complex production



As the technology becomes complex, producers are willing to pay less for low quality, but more for high quality. Thus the reward for being able to meet high quality standards increases with the complexity of production in the lead firm. By the same token, those who are able to meet the delivery time requirements only of the firms that choose to enter the low-technology end will fetch a lower price for the same quality compared to the situation with a less complex technology.

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 where vertical specialization is found to be most prominent are electronics, motor vehicles, chemicals, and textiles and clothing. I estimated vertical specialization according to this definition 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 for suppliers to lead firms in vertical supply chains. Data on the rate of faults as a product leaves the factory gate can only be obtained at the firm level. However, if infrastructure is poor, storage facilities inadequate in terms of protecting the goods from damage the fault rate may increase between the supplier and the lead firm, 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 use the quality of infrastructure as a proxy for the parameters *a* and *β*.

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 $n = (n^h + n^f)$ where superscripts *h* and *f* respectively represent home and foreign and that $n^h/(n^h + n^f)$ is larger the larger the country. I therefore control for market size represented by the log of GDP.

There is little reason to expect that the vertical specialization index is systematically related to income levels. Although countries will 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. From table A.1 it appears that 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. Being landlocked does not necessarily impede vertical specialization either as cross-border outsourcing from neighbouring coastal countries appears to be common.[7] Botswana, for example, has a vertical specialization index of more than 70 per cent in both the textile and clothing sectors, and about 40 per cent in motor vehicles and chemicals, its major trading partner being South Africa. Finally, although industrial sectors differ in terms of technology and innovation, it appears that the technology aspects I am concerned with in this paper are applied in most industries. The technology relates to the way production is organized rather than the product innovations and it appears that better supply chain management is a concern in all industries. One should therefore expect that the model presented in section III applies to all sectors, although the parameter B probably varies between sectors.

The parameter β in the model represents the disadvantage of distance in terms of time to market. This disadvantage has at least three dimensions: transport of goods and services

[7] A landlocked dummy was introduced in the regression, but it was nowhere near significant.

from upstream suppliers to downstream customer takes more time and is more costly. Transfer of information in both directions may be less accurate as distance increases, particularly as the share of information transferred through direct communication declines. Finally transfer of payments for the goods and services being exchanged will be more time consuming if it involves cross border transactions, particularly when the currencies are different.[8] Data on the time it takes to transport goods between two points are not available and proxies need to be found. The costs I am interested in are probably more closely related to the quality and density of infrastructure than the price per ton kilometre of transport or the cost per minute of a telephone conversation. I therefore use an index of infrastructure quality as a proxy for timeliness. The index contains the density of roads, railways, airports and telephone lines, the quality or 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.[9] The cost of financial services is not included in this index and I therefore add the overhead costs in the banking sector as a proxy for this component of transaction costs in the regressions. In order to get an impression of the relative importance of the individual components in the infrastructure index, I also run the regression with each individual component of the index.

A proxy for the effectiveness of maritime transport services that turned out to be significant for some of the sectors is the trade restrictiveness index for maritime transport services as developed by Australian Productivity Commission and the National University of Australia.[10] The index takes values between 0 and 1 and is higher the more restrictions are imposed on international maritime services operations. Finally, tariffs are obviously a cost related to international trade. I include the average applied most favoured nation rate for each country and sector; the data are from the TRAINS database. This measure does not capture exemptions and preferential rates that may well be important for vertical specialization, but in the absence of data on bilateral trade flows, preferential rates cannot be utilized. International trade in the textiles and clothing sectors is subject to an intricate system of quotas (the Multi-

[8] In some industries, notably the textiles and clothing industry, downstream customers sometimes purchase the inputs to their upstream suppliers and the latter get net payments for the added value of their processing of these inputs.

[9] The index has been developed by Roberta Piermartini, WTO.

[10] The net interest margin of commercial banks and credit to private sector as a share of GDP were also tried as proxies for the cost and availability of financial services, but it turned out that the overhead costs of the commercial banks performed best in the regression in terms of significance of the parameter and the overall estimation.

Fibre Agreement), which is scheduled to be phased out by the end of 2004. I include a dummy taking the value of 0 if the country has no quotas under the MFA and 1 if it has with either USA, EU or both.[11]

I start with regressions on the entire sample, including a cross-section of observations of 52 countries and 5 sectors. Table 1 presents the result for the entire sample. As expected, market size as measured by (the log of) GDP is negatively related to international vertical specialization, and it turns out that this variable alone explains more than 50 per cent of the variation. The overhead costs in the banking sector also have the expected sign and are always significant. Tariffs take the expected sign, but are not significant. The first column presents the regression with the aggregated infrastructure index, while subsequent columns present the result of regression including one of the quality of infrastructure indices, as indicated by the column heading.

Table 1: Regression results, the entire sample

Variable	**Aggregate**	**Telecom**	**Roads**	**Maritime**
Constant	14.23***	13.3***	13.4***	13.5***
	(15.88)	(15.56)	(15.10)	(12.81)
Log GDP	-0.52***	-0.55***	-0.51***	-0.51***
	(-16.27)	(-16.18)	(-15.04)	(-12.44)
Tariffs	-0.004	-0.003	-0.0013	-0.003
	(-1.14)	(-0.94)	(-0.36)	(-0.70)
Finance	-0.07**	-0.08**	-0.12***	-0.09**
	(-2.01)	(-2.44)	(-2.97)	(-1.98)
Infrastr. index	-0.76***	0.18***	-0.0007	-0.75
	(-3.61)	(3.31)	(-0.39)	(-1.45)
n	225	220	205	255
Adjusted R^2	0.5887	0.5948	0.5984	0.5955

The infrastructure variable that turned out to yield the highest explanatory power in terms of adjusted R^2 and significance of individual parameters was the regression where aggregate infrastructure was replaced by the density of telecommunications. This underscores the importance of effective information flows for vertical specialization as indicated by the fact

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

that vertical specialization, international outsourcing and international production networks have gained prominence recently, following the rapid technological progress in the telecommunication sector. Roads and the restrictiveness on maritime services are not significant.

The five sectors are very different in terms of technology and international trade regime. I therefore turn to an analysis of each sector, starting with a regressions including tariffs (and quotas in the case of textiles and clothing), the aggregated infrastructure index and financial services. I next explore the impact of individual quality of infrastructure indices and report the cases where one individual index appears to explain most of the variation in vertical specialization. In the electronics sector it turned out that aggregate infrastructure was insignificant, but had the wrong sign in the regression. I hypothesize that outsourcing labour-intensive production stages to low-wage countries is a major driving force for this sector and include GDP per capita as a proxy for wage levels in this sector (ref).[12] The results are reported in table 2, panels A-E.

Table 2: Regression results by sector

Panel A: Textiles

	None	**Aggregate**
Constant	8.98***	9.91***
	(3.99)	(4.51)
Log GDP	-0.37***	-0.36***
	(-4.57)	(-4.79)
Tariffs	0.007	0.02
	(0.62)	(1.40)
Quotas	-0.79***	-0.27
	(-3.66)	(-0.75)
Finance		-0.04
		(-0.49)
Infrastr. Index		-1.43**
		(-2.23)
n	45	45
Adjusted R^2	0.4161	0.4755

[12] Including GDP per capita in the other regressions did not add to the explanatory power of the regression and it turned out to be insignificant and created problems of multicollinearity.

Panel B: Clothing

	None	Aggregate
Constant	11.33*** (5.56)	12.62*** (6.10)
Log GDP	-0.44*** (-6.02)	-0.42*** (-5.95)
Tariffs	-0.016* (-1.82)	-0.015 (-1.34)
Quotas	-0.95*** (-4.42)	-0.38 (-1.08)
Finance		-0.13* (-1.84)
Infrastr. Index		-1.52** (-2.48)
n	45	45
Adjusted R^2	0.4610	0.5622

Panel C: Chemicals

	Aggregate	Telecom	Maritime
Constant	11.47*** (10.54)	9.02*** (6.56)	9.36*** (5.78)
Log GDP	-0.42*** (-10.64)	-0.46*** (-8.74)	-0.36*** (-5.67)
Tariffs	0.044*** (3.98)	0.05*** (3.50)	0.04** (2.54)
Finance	-0.05 (-1.13)	-0.093* (-1.83)	-0.10 (-1.64)
Infrastr. Index	-1.92*** (-6.53)	0.33*** (3.34)	-2.39*** (-2.71)
n	45	44	32
Adjusted R^2	0.8183	0.7094	0.7287

Panel D: Motor vehicles

	Aggregate	**Telecom**
Constant	17.08***	17.35***
	(6.20)	(8.46)
Log GDP	-0.63***	-0.74***
	(-7.88)	(-9.37)
Tariffs	-0.006	-0.008**
	(-0.96)	(-1.98)
Finance	-0.17*	
	(-1.97)	
Infrastr. Index	-0.06	0.38**
	(-0.07)	(2.36)
n	45	45
Adjusted R^2	0.6187	0.6686

Panel E: Electronics

	None	**Aggregate**	**Aggregate**	**Telecom**
Constant	17.77***	18.21***	20.21***	19.41***
	(12.06)	(11.27)	(10.97)	(12.04)
Log GDP	-0.66***	-0.69***	-0.63***	-0.68***
	(-12.51)	(-11.47)	(-9.51)	(-11.22)
Tariffs	-0.04***	-0.05***	-0.05***	-0.05***
	(-3.54)	(-3.34)	(-3.45)	(-3.99)
Finance		0.06	0.096	0.08
		(0.82)	(1.27)	(1.10)
Infrastr. Index		0.098	-1.11	0.53
		(0.25)	(-1.57)	(1.54)
GDP per capita			-0.28**	-0.48*
			(-2.03)	(-1.88)
n	45	45	45	45
Adjusted R^2	0.7786	0.7725	0.7889	0.7944

The size of the market is significantly and negatively related to participation in international vertical specialization in all five sectors. The sectors where vertical specialization falls off most sharply with market size are electronics and motor vehicles, while local market size

appear to be less economically significant in the chemicals, textile and clothing sectors. This finding is consistent with previous empirical research suggesting that production networks in the automotive industry is more concentrated in space while textile and clothing production networks are more global in scope (Gereffin, 1999). Studies in the electronics sector suggest that also this sector tend to agglomerate in space.[13]

In the textiles and clothing sectors, quotas are negatively and significantly related to vertical specialization when included on its own in the regression. The quotas are allocated at a 6-digit HS level and are detailed, specific and allow little flexibility in terms of switching production between different materials and qualities, while flexibility is the linchpin of vertical specialization and production networks.[14] The impact of quotas loses its significance when infrastructure is included, however, suggesting that there is enough flexibility within the quota system to take part in vertical specialization if adequate infrastructure is in place. Both for textiles and clothing the aggregate infrastructure index best explains the extent to which the country participates in vertical specialization, while the financial sector is insignificant in the case of textiles, but takes the expected sign and is significant at a 10 per cent level in the clothing sector. None of the individual infrastructure variables are significant in the regression when included on their own together with tariffs, quotas and finance in the regression.

The chemicals sector differs from the other sectors in that tariffs take a significant and positive sign. It appears that protection of the industry go together with the participation in international vertical specialization. The aggregated infrastructure index together with finance has the highest explanatory power for this sector, but it is also the case that both telecommunications and the restrictiveness of regulation of maritime services take the expected sign and are significant at a one per cent level when included on their own together with tariffs and financial services. Furthermore, financial services become more significant in these regressions.

The infrastructure variable that seems to be the most important for being part of vertical specialization in the motor vehicle industry is the density of telephone lines. Information apparently plays a very important role in this sector, which has been the leading sector in

[13] A gravity model introducing distance between trading partners would shed more light on this issue, but bilateral data where trade in intermediates can be extracted are not readily available.

[14] HS refers to the Harmonized Commodities Description and Coding System Nomenclature.

terms of organizational innovations since the time of Henry Ford, and the sector that pioneered just in time supply management. It is therefore not surprising that the telecommunications take such a prominent role in explaining vertical specialization in this sector.

The electronics sector is the most sensitive to trade barriers in the form of tariffs in the sample. Tariffs significantly reduce the share of total exports that is driven by vertical specialization. Furthermore the size of the market alone explains almost 72 per cent of the variation in this sector. Infrastructure indicators are insignificant in all the regressions, and even entered with the wrong sign. Many of the production stages in the electronics sector are labour-intensive and it has been shown that outsourcing to low-cost countries is important in this sector (e.g. Lall and Albaledejo, 2003). I therefore controlled for GDP per capita as a proxy for wage costs in the electronics sector, and this turned out to restore the correct sign of the infrastructure parameters, although they are still not significant. GDP per capita is, however significant and negative, indicating that low-cost countries are more likely to participate in vertical specialization in this sector, given that they refrain from protecting the sector by imposing tariffs on imports of electronics. The finding that infrastructure is insignificant in this sector is somewhat surprising, but it could be the case that electronics processing plants are mainly located in export processing zones close to harbours or in special industrial development areas that are much better served as far as logistics and infrastructure is concerned than the average for the country in question.

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. In the case of inadequate infrastructure and logistics services, investments in quality may be destroyed on the 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.

I find a strong 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 the individual sectors, except electronics. In addition there are some sector-specific findings: The empirical estimates suggest that in order to participate in production networks in the electronics sector, trade barriers need to come down. In the chemicals sector telecommunications need to be improved and maritime services need to be less restrained by regulation. In order to host car parts producers, again the telecommunications infrastructure need to be improved.

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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:

Data sources:

GDP and GDP per capita: World Development Indicators; World Bank, CD-rom.
Overhead costs, banking sector: IMF
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