**Working Paper No 34/03**

# Fragmented production – a curb on China's export growth?

**by**

**Hildegunn Kyvik Nordås**

SNF project no 1302
Political and economic structural changes in Asia

The project is financed by the Norwegian Shipowners' Association and the Research Council of Norway

SIØS - Centre for International Economics and Shipping

INSTITUTE FOR RESEARCH IN ECONOMICS AND BUSINESS ADMINISTRATION
BERGEN, AUGUST 2003
ISSN 1503-2140

*SIØS - CENTRE FOR INTERNATIONAL ECONOMICS AND SHIPPING*

SIØS – Centre for international economics and shipping – is a joint centre for The Norwegian School of Economics and Business Administration (NHH) and The Foundation for Research in Economics and Business Administration (SNF). The centre is responsible for research and teaching within the fields of international trade and shipping.

*International Trade*

The centre works with all types of issues related to international trade and shipping, and has particular expertise in the areas of international real economics (trade, factor mobility, economic integration and industrial policy), international macroeconomics and international tax policy. Research at the centre has in general been dominated by projects aiming to provide increased insight into global, structural issues and the effect of regional economic integration. However, the researchers at the centre also participate actively in projects relating to public economics, industrial policy and competition policy.

*International Transport*

International transport is another central area of research at the centre. Within this field, studies of the competition between different modes of transport in Europe and the possibilities of increasing sea transport with a view to easing the pressure on the land based transport network on the Continent have been central.

*Maritime Research*

One of the main tasks of the centre is to act as a link between the maritime industry and the research environment at SNF and NHH. A series of projects that are financed by the Norwegian Shipowners Association and aimed directly at shipowning firms and other maritime companies have been conducted at the centre. These projects include studies of Norwegian shipowners' multinational activities, shipbuilding in Northern Europe and the competition in the ferry markets.

**Human Resources**

The centre's human resources include researchers at SNF and affiliated professors at NHH as well as leading international economists who are affiliated to the centre through long-term relations. During the last few years the centre has produced five PhDs within international economics and shipping.

**Networks**

The centre is involved in several major EU projects and collaborates with central research and educational institutions all over Europe. There is particularly close contact with London School of Economics, University of Glasgow, The Graduate Institute of International Studies in Geneva and The Research Institute of Industrial Economics (IUI) in Stockholm. The staff members participate in international research networks, including Centre for Economic Policy Research (CEPR), London and International Association of Maritime Economists (IAME).

**FRAGMENTED PRODUCTION – A CURB ON CHINA'S EXPORT GROWTH?**

Hildegunn Kyvik Nordås

**Abstract**

*This paper explores the impact of vertical specialization on world trade within the framework of the O-ring theory of production. Within such a framework there is little scope for substituting quantity for quality or for gaining market shares by undercutting established suppliers purely on cost. Furthermore, quality requirements will increase as lead firms in the supply chain invest in technology that reduces inventory and speeds up the production process. It is shown that potential suppliers in low-cost countries will only have an incentive to upgrade quality if adequately efficient infrastructure, logistics and customs procedures are in place. Changing trade patterns between USA and Mexico and China suggests that proximity and low trade barriers are important determinants of the extent and nature of vertical specialization. Thus, a larger share of Mexico's trade with USA is driven by vertical specialization than China's trade with USA. Nevertheless, China has caught up with Mexico as far as share in US total imports is concerned, and the market share gap has narrowed even in electronics, the sector in which vertical specialization is most prominent. It appears that vertical specialization adds to total world trade rather than replacing traditional trade flows.*

JEL classification: F12, F14

Keywords: Vertical specialization, China, Mexico, Electronics, Motor vehicles.

# FRAGMENTED PRODUCTION – A CURB ON CHINA'S EXPORT GROWTH?

## I. INTRODUCTION

During the past few decades, world trade has been growing faster than world GDP, which implies that an increasing share of world output crosses international borders. During the same period, trade barriers have declined substantially as a result of successive trade negotiation rounds under the auspices of the GATT/WTO, unilateral trade liberalization and regional trade agreements. A closer look at the figures reveals that since the early 1960s, average worldwide most favoured nation tariffs on manufactured products have declined by 11 percentage points, while world manufacturing exports' share of gross domestic product has increased by a factor of 3.4. The largest decline in tariff rates came early in the period, while the largest increases in trade relative to GDP growth came late in the period (Yi, 2003). It therefore seems like the reductions in trade barriers alone cannot explain the accelerating growth in world trade, at least not within the analytical framework of the well established models of comparative advantage or the models of intra-industry trade. Thus, an estimate of the elasticity of exports with respect to tariffs yields an elasticity of 7 in the period 1962-85, and 50 in the period 1986-99 (Yi, 2003). Obviously, these elasticities are far above reasonable levels, and there must be additional explanations for the expansion in world trade.

A recent study by Yi (2003) finds that at least half of the observed increase in world trade 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 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. When trade barriers are low, there are incentives to locate the labour-intensive production stages in relatively labour-abundant countries, the capital-intensive stages in relatively capital-abundant countries and the skills-intensive stages in relatively skills-abundant countries. In the electrical machinery and electronics sectors, for example, product development is highly skills-intensive and would 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 would 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 would be located in a labour-rich country such as China.

Vertical specialization in other words allows a finer division of labour between countries and allows a country to exploit its comparative advantage, say for labour-intensive manufacturing, even in industries where only some activities or stages of production are labour-intensive. International vertical division of labour implies that a product or components thereof cross international borders several times during the production process and tariffs and other trade costs may have a multiplicative effect on the total cost of producing and marketing the final product. Therefore, vertical specialization will not take place until tariff rates and other trade costs have come sufficiently down. By the same token, when trade costs have come down to a critical level, firms will start to slice up the production process and exploit different locations' comparative advantage. The result is a non-linear relationship between trade costs and the volume of trade.[1]

Empirical evidence from studies of US multinationals find that the industries in which vertical production networks are most common are transportation equipment, including motor vehicles, machinery, electronics, metals and chemicals. A study by Hanson et al. (2003) found that trade costs are an important determinant of such trade and that small changes in trade costs can lead to large changes in trade flows. They estimated the elasticity of trade relative to changes in trade costs to -3.28, meaning that a one per cent decline in trade costs, whether these are tariffs or transport costs, results in a 3.28 per cent increase in imports of intermediates. This study analyzed firm-level data on intra-firm trade of US multinationals. The elasticity is much smaller than in the Yi (2003) study, and the difference could probably be explained by two factors. First, the Yi study does not take declines in transport costs into account and this omission could bias the elasticity estimate upwards. Second, the Hanson et al. study does not capture the possibility that lower trade barriers *induce* vertical specialization since it analyses a cross-section (from 1994) of firms that already engage in vertical specialization. This study may thus underestimate the elasticity.

This paper studies the choice of suppliers in vertical production networks and focuses on the quality dimension of a supply network. This is an aspect that is at the core of supply chain management analysis in the business literature, reflecting the complementarities between the production stages or activities and focusing on the fact that "time is money". In the economics literature, the so-called O-ring theory of production captures important aspects of vertical production networks. Nevertheless, to my knowledge it has not been applied to the analysis of vertical supply chains and this paper aims to do so. The most important property of the O-ring model is that quality cannot be substituted for quantity. The event that inspired and gave name to the theory was the accident with the Challenger space shuttle. It turned out that the reason why it exploded was that some O-rings could not withstand the heat during launch. Because of defects in these simple components, lives were lost and huge investments in sophisticated equipment were eroded. Another example from the world of arts: a performance by a top-ranking symphonic orchestra would be completely destroyed if it had engaged a mediocre trombonist who might blow the horn in a big way while slightly out of tune or out of step. In such cases two mediocre musicians could certainly not replace one excellent; not even if they were willing to play for free. Other less disastrous but still costly examples are garments that sell for a substantial discount because of almost invisible mistakes or simply because the season is running late.

A supply chain or vertical production network is in other words as strong as its weakest link, and one malfunctioning component may destroy the value of all other components. Therefore, the lead firm in a supply chain will be very cautious in the choice of suppliers if it has entered a market where quality is a strategic variable. The same would be the case if the firm has chosen a production technology in which there is very little slack in terms of timing and in which very little resources are devoted to rooting out deficiencies, as suppliers are expected to deliver close to zero deficiencies.

[1] One could also envisage that as trade barriers have come down from high to low, specialization according to comparative advantage dominated at a high trade cost level, intra-industry trade was phased in at a lower trade cost level and vertical specialization at still lower trade costs.

The rest of the paper is organized as follows: Section 2 provides a brief review of recent literature on the relations between international production networks and trade costs. The O-ring model is presented and extended in section 3 where the implications of the O-ring theory for the choice of suppliers and the incentives for potential suppliers to provide the required quality in a vertical production network are explored. The predictions of the model are next applied to the study of China and Mexico's trade with the US in section 4. It compares China and Mexico's trade with the US in the sectors in which vertical specialization is most common. Policy implications are discussed in section 5 which also concludes. More rigorous theory development and econometrics are left for future research, but the analysis here provides a relatively simple analytical framework and a flavour of the empirical relevance of the theory.

## II. RELATIONS TO PREVIOUS RESEARCH

The paper builds on insights from two seminal papers – Milgrom and Roberts (1990) and Kremer (1993). Milgrom and Roberts describe the features of modern manufacturing and suggest a production function that formalises the observations they make. Modern manufacturing is above all characterized by flexibility. Modern machine tools are programmable, they can perform many tasks and it is possible to switch between batches quickly and smoothly. Scale apparently does not matter as much as it used to at the fabrication level, although scale might matter even more than it used to in product development (R&D) and marketing. Production cycles have been shortened, allowing firms to respond more quickly to demand fluctuations. Once the product cycle and the time to market have become shorter, the entire production process from raw materials to after sales services must speed up, and better coordination between the production stages might be necessary. Lead firms in many industries therefore tend to develop closer relations to their suppliers, often including joint production planning.[2] Milgrom and Roberts (1990) emphasized the complementarities between the various technologies employed in manufacturing. In order to capture the full benefit from investments in automation, organizational changes may be necessary, relations to suppliers may need to be reorganized and complementary investments in modification of buildings, skills upgrading and equipment may be necessary. Otherwise bottlenecks will be created causing costly stoppages. A similar observation is made more recently by Bresnahan et al. (2002) who find that investments in information technology does not achieve its full potential unless changes are made to the organization and the workforce is properly trained. The cost of the latter two elements can be much higher than the investment in the computers in the first place.

Milgrom and Roberts (1990) formalized their observations in a profit function where demand shrinks with time to market and costs involve expected reworking costs, the cost of back-orders, the cost of inventory holdings, which in turn depends on the number of set-ups and demand conditions. They show the complementarity between these elements and they provide a tool for analysing the impact of changes in exogenous variables such as technological changes and changes in transaction costs. Clearly, if such flexible production involves several companies located in different countries, the cost and effectiveness with

[2] See for example UNCTAD's World Investment Report 2001 for a discussion of vertical linkages and supplier relations in a development context.

which the inputs can be handled and transported between the various locations are highly relevant.

Kremer (1993) takes the idea of complementarities one step further and introduces a production function where final output is a function of a multiple of tasks. The production function exhibits the property that quality cannot be substituted for quantity. The tasks may take place sequentially or in parallel. Studies of production networks usually assume a sequential order of tasks, but I will argue that assemblage of a number of components or modules produced in parallel is equally relevant. A combination where a number of modules are produced in parallel, but where production of each module is characterized by a sequence of tasks is also a possibility. In either case, an error made in the performance of one task (such as the mediocre musician or the O-ring) can erode the value of all the other tasks being performed.

Kremer (1993) focuses on skills and discusses firms' employment strategy, arguing that once a firm has chosen a high-quality strategy it will employ highly skilled workers in all the tasks performed by the firm. Consequences of shortages of skills can be severe. If a firm that chooses a high-quality technology cannot find highly skilled workers or suppliers to perform all the tasks it plans to undertake in a certain location, it will not locate there. Kremer (1993) argues that this is an important reason why many developing countries continue to produce mainly raw materials in spite of having low-cost labour and access to manufacturing technology and access to markets. In this paper the model is adapted to an analysis of a firm's choice of suppliers in the context of vertical production networks.[3] With such an interpretation the conclusions are that high-quality firms will select suppliers that have a reputation for high-quality products and reliability. When supply chain management involves the minimization of time to market within 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. Thus, industries with a large number of sequential tasks tend to be willing to pay for quality and reliability. In the next section I present a simplified version of Kremer's model where I also endogenize the quality parameter and discuss how changes in trade costs and technology may affect international vertical specialization.[4]

## III. THE MODEL

I take as a starting point Kremer's (1993) O-ring theory of economic development and adapt it to a partial equilibrium framework determining the market equilibrium for intermediate inputs in a production network. 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. The O-ring production function reads:

[3] An extension of the model would be to determine endogenously which tasks are performed in-house and which components are purchased from the market. Here I focus on the quality demanded from outside suppliers and the willingness of suppliers to provide the required quality.

[4] Quality is assumed to be a continuum with an exogenously given distribution in Kremer's (1993) paper, but in the last section worker's skills are determined by education which is imperfectly transformed into observed skills in a stochastic way.

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

Y is final output, *n* is the exogenous number of tasks needed to complete the production process, *q* is the quality of input *i* $q \in (0, 1)$ and can be interpreted as the probability that the input *i* will have the required quality and arrive at the right production station at the right time. B is a scalar that represents the output volume if all tasks are performed to perfection. The parameter $\alpha \in (0 < \alpha < 1)$ represents returns to quality. If $0 < \alpha < 1/n$, there are diminishing returns to quality, and if $1/n < \alpha < 1$, there is increasing returns. The profit maximizing manufacturer chooses quality according to the following maximization problem:

$$\underset{q}{Max}\, nB\left(\prod_{i}^{n} q_i\right)^{\alpha} - \sum_{i=1}^{n} p(q_i) \qquad p'(q) > 0; p''(q) < 0 .$$

The first-order condition is

$$\alpha nB\left(\prod_{i=1}^{n} q_i\right)^{\alpha-1} \prod_{j \neq i}^{n} q_j - p'(q_i) = 0$$

Kremer (1993) has shown that a firm will choose the same quality of all its inputs such that the first-order condition can be written as $p'(q) = nq^{\alpha n - 1}$. 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 both sides of the first-order condition, which yields:

$$p(q) = \int nq^{\alpha n - 1} dq = Bq^{\alpha n} + c \quad (2)$$

The constant term, *c*, in the integration must be zero if the firm operates in a competitive environment, which is assumed. We notice that the price increases in *q*. In the following I will assume that the tasks involved in production of the final good Y are performed by outside suppliers which face a demand for quality represented by (2). The suppliers' cost of producing quality *q* is given by:

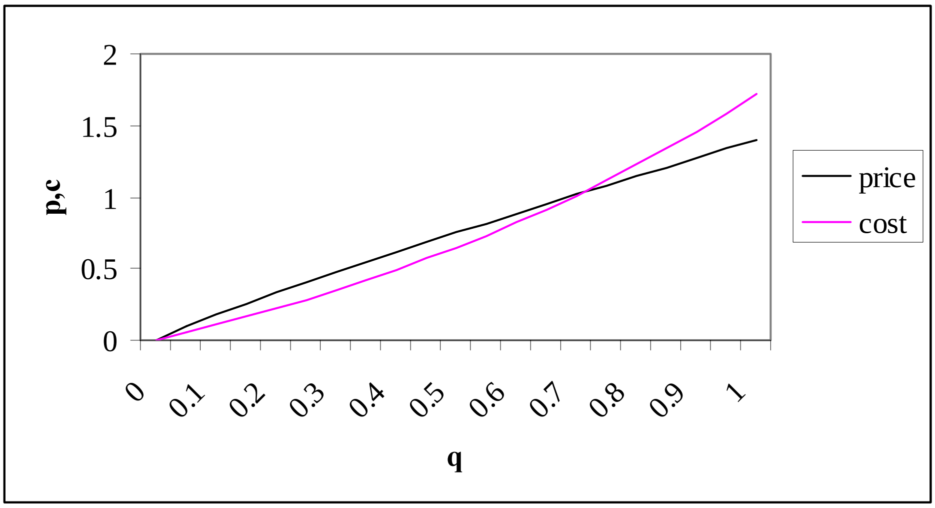
$$c(q) = e^{\beta q} - 1 \quad (3)$$

The cost function has the desirable property that the cost of producing zero quality (i.e. the probability of delivering the right quality at the right time is zero), and that the cost rises exponentially with quality. The parameter $\beta$ represents the impact of exogenous variables on the cost function. One could for example envisage that the quality of transport services, ports, customs procedures and infrastructure affects the firms' cost of delivering the demanded quality at the appropriate time to the customer.[5] There would for example be no incentives for a producer in a developing country to invest in quality if the goods in question are stored for a considerable time in a port warehouse where they are subject to humidity and a number of hazards that would diminish the quality and delay its delivery to an extent that the customer would not be willing to pay for the quality enhancement that took place in the

[5] Exporters typically deliver the goods on a free on board basis and thus cover the cost of domestic transport and port handling.

factory. A high $\beta$ represents low quality of relevant services and infrastructure. The concavity of the price schedule combined with the convexity of the cost function ensures that there exists a market equilibrium for reasonable parameter values. The cost and the price functions are depicted in figure 1.

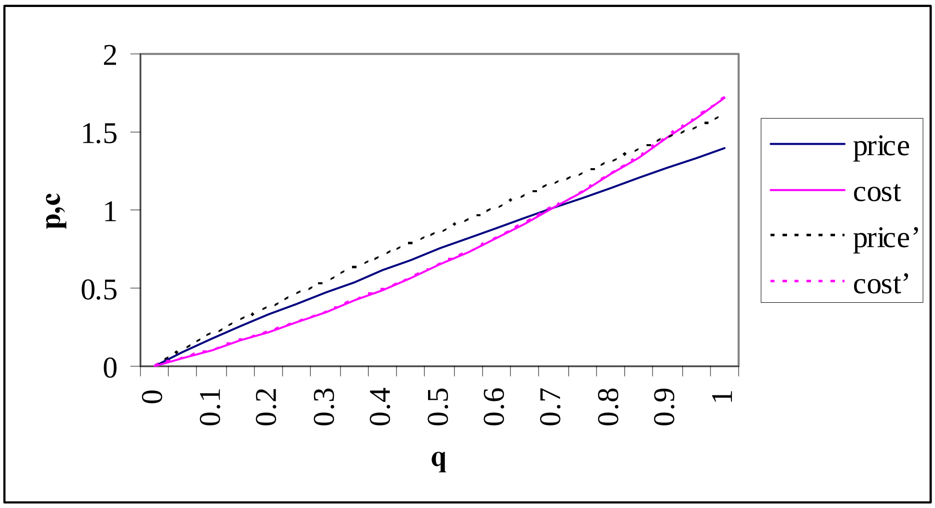
**Figure 1. Unit cost and unit price of input**




The supplier of the input in question would break even at the quality level represented by the intersection of the two curves. An exogenous change in B would rotate the price curve around the origin, counter-clockwise for an increase in B, and thus shift the break-even quality to the right (see figure 1a). The parameter B could for example represent the firm's stock of technology embodied in its capital or the skills of its workers.[6] The impact of changes in B on the demand for quality illustrates the complementarities stressed by Milgrom and Roberts (1990). An increase in B, say due to investments in new technology, would raise the demand for higher quality inputs, and this would as we have seen affect all input producers. In a production network context, investment in more flexible production technologies with lean inventory management would increase demand for zero-deficiency components delivered on a timely basis, and suppliers unable to satisfy these requirements would be replaced.

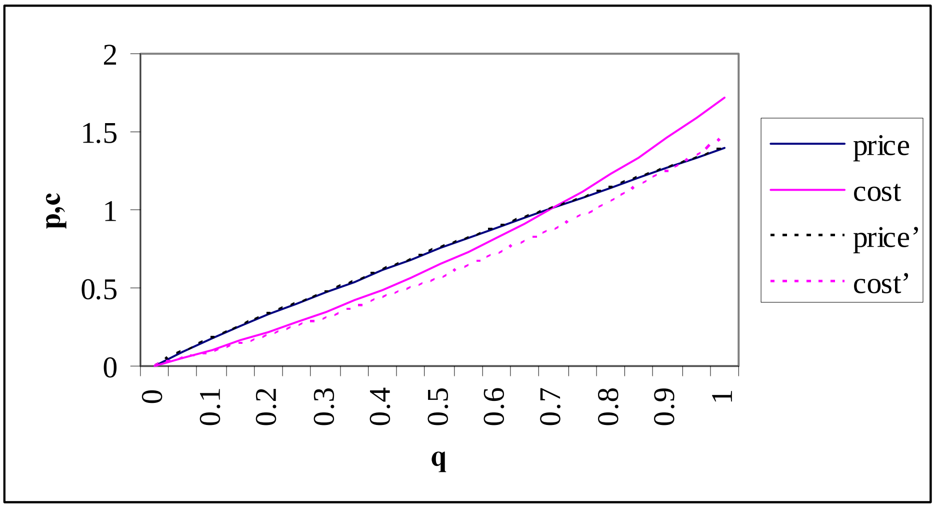
[6] A general equilibrium version of the model would endogenize investment in capital and skills and allocates skills among firms and industries.

**Figure 1a. The impact of an increase in B**




Turning to the supply side, a decline in $\beta$ would rotate the cost function clock-wise around the origin, again shifting the break-even quality to the right (see figure 1b). In a development context, improvement in port handling, customs procedures and the quality of domestic transport and logistics services could improve developing country suppliers' ability to deliver the required quality at a competitive price and thus participate in vertical production networks.

**Figure 1b. The impact of a reduction of $\beta$**



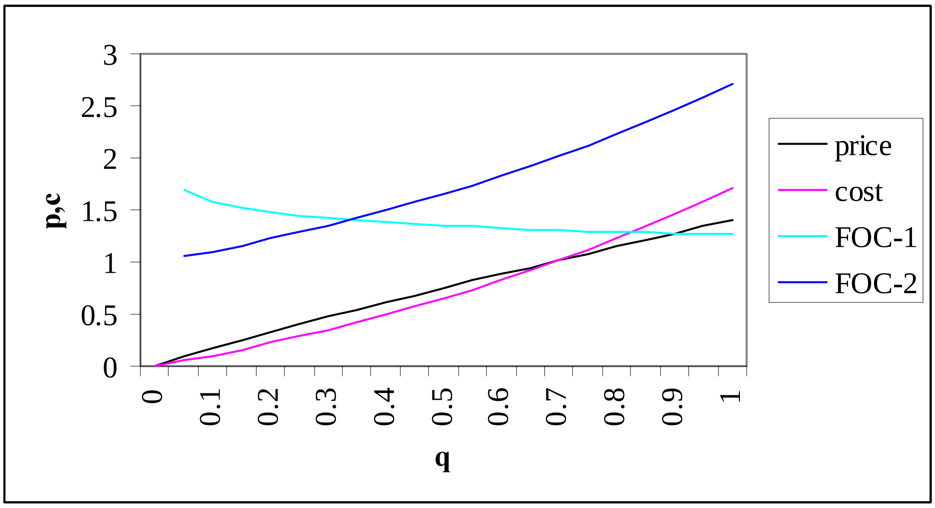

The supplier will provide a quality level that maximizes his profits as follows:

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

$$\alpha nBq^{\alpha-1} - \beta e^{\beta q} = 0 \qquad (4)$$

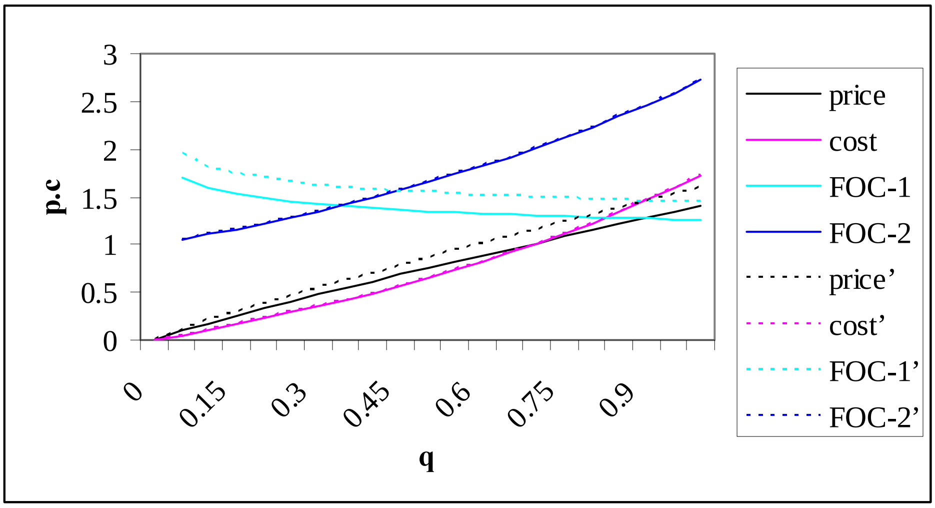
The condition is depicted in figure 2, and shows that the optimal level of quality investment for the supplier is as usual the point where the vertical distance between price and cost is the largest.

**Figure 2. Market equilibrium, quality**




FOC-1 and FOC-2 represent the first and second term in the first order condition respectively. The first term is downward sloping in $q$ if $\alpha n < 1$ (i.e. equation 1 exhibits diminishing returns to quality), and upward sloping in $q$ if $\alpha n > 1$. The second term is always upward sloping in $q$. Whether the first term is upward or downward sloping there exists a market equilibrium for reasonable parameter values. An increase in the productivity of the downstream firm (i.e. an increase in B) affects the first term in condition (4); (FOC-1) depicted in figure 2a. The rotation of the price schedule is the same as depicted in figure 1a. In addition the FOC-1 shifts upward and in the new equilibrium the quality is higher and the supplier is compensated through a higher price.

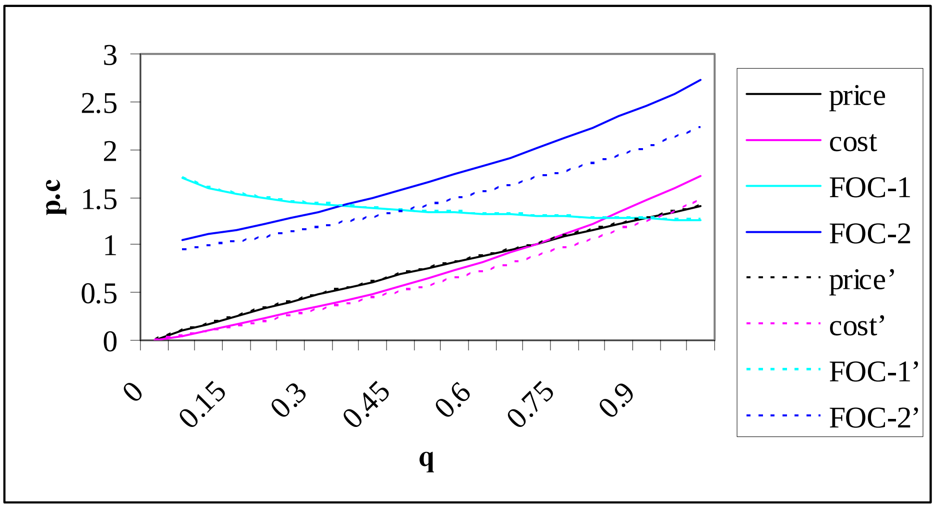
**Figure 2a. Impact of increase in B**




At the optimal profit-maximizing quality level, the supplier will earn a positive profit, and would thus have an incentive to invest in quality as long as $\beta$ is sufficiently low for a market equilibrium to exist.

A decline in $\beta$ will rotate the second term (FOC-2) graph clockwise, as demonstrated in figure 2b. This time the new equilibrium yields a higher quality at a lower cost.

**Figure 2b. The impact of a decline in $\beta$**




Improvements in local port handling, customs procedures, logistics and transport would in other words encourage local producers to invest in quality. A high value of $\beta$ in contrast would be reflected in steeper cost and FOC-2 curves, and the suppliers would only be able to participate in production networks with a low quality requirements, or if $\beta$ is sufficiently high, they would not be able to participate at all. If extended to a multi-country framework where the suppliers of intermediates in one country competed with suppliers from other countries, a decline in $\beta$ in one country would improve that country's firms' relative competitiveness.

The number of tasks undertaken by a production network is indicated by the parameter $n$ and indicates the complexity of the production process. An exogenous increase in the number of tasks would shift down the quality-price schedule because the firm cannot increase its total costs as long as the price of its final product is fixed. It is, however, likely that the complexity of the technology is a choice variable on the part of the firm. Moreover it is often a strategic variable reflecting the market niche that the firm would target. I therefore extend the model to endogenize the number of tasks. Let B = B($n$) = $n^{\rho}$, $0 < \rho < 1$. The production function is modified to read:[7]

$$Y = n^{\rho+1}\left(\prod_{i=1}^{n} q_i\right)^{\alpha} = n^{\rho+1}q^{\alpha n} \qquad (5)$$

The firm maximizes profits subject to $q$ and $n$ as follows:

$$\max_{q,n} n^{\rho+1}q^{\alpha n} - np(q)$$

[7] Recall that the firm will choose the same quality of all inputs in equilibrium.

The first-order condition with respect to $q$ will be the same as before; $p'(q) = \alpha n^{\rho+1} q^{\alpha n-1}$, which integrating both sides yields $p(q) = n^{\rho} q^{\alpha n}$. The first-order condition with respect to $n$ reads:

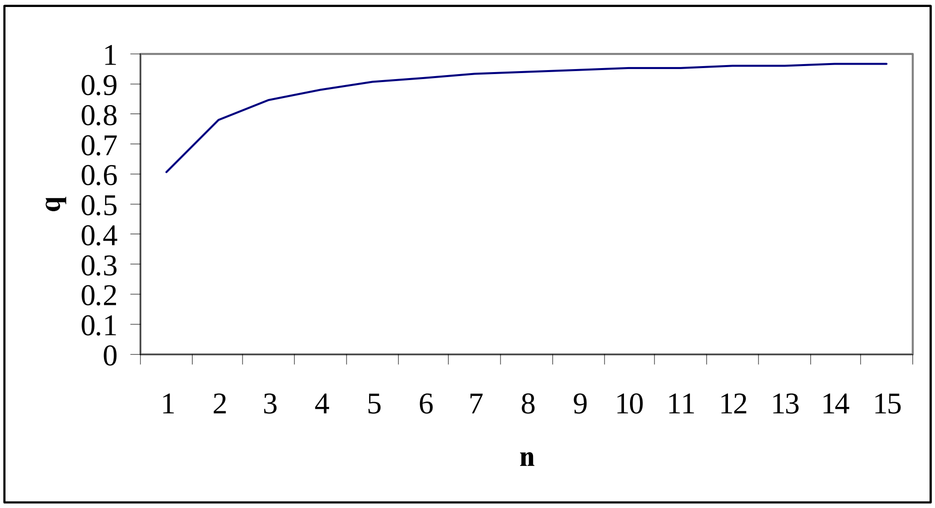
$$\frac{\delta\pi}{\delta n} = (\rho+1)n^{\rho} q^{\alpha n} + \alpha n^{\rho+1} q^{\alpha n} \ln q - p(q) = 0$$

Substituting for $p(q)$ yields:

$$\ln(q) = -\rho/n \text{ or } q = e^{-\rho/n} \qquad (6)$$

The relationship between $q$ and $n$ is depicted in figure 3.[8] We notice that the quality requirement increases steeply with the number of tasks and approaches unity asymptotically. In other words as the technology becomes complex, suppliers will have to satisfy strict quality requirements such as close to zero-deficiency and there is very little room for delays in delivery times. Therefore, firms with complex technologies tend to be located in countries with a well developed supplier base, good infrastructure and a sufficient pool of skills.

**Figure 3. Relation between quality of inputs and complexity of production**




To summarize this section, the production network interpretation of the model indicates that investment in flexible production technology or an upgrading to a more complex production technology (an increase in B or $n$), increases demand for quality inputs. Two important dimensions of quality relevant to the supply chain discussion are the deficiency rate when the input arrives at the factory gate and the timeliness of its arrival at the factory gate. The tolerance for slack and errors declines sharply with the complexity of the technology and low costs will not compensate for low quality in these markets – although in reality far from all markets will choose the high quality, complex technology. On the input supply side we notice that producers in environments of poor infrastructure and inefficient ports and customs procedures will have little or no incentives to invest in quality and enter high-quality production networks because the value of their investments will be eroded before the products reach the customer. One would also expect industries characterized by production

[8] The figure is drawn for $\rho = 0.5$.

networks to be more geographically clustered than other industries, even in rich countries because of the timeliness requirement. In the next section I adopt the insights from the O-ring theory to Mexico and China's bilateral trade with USA.

## IV. CHINA AND MEXICO'S TRADE WITH USA

Mexico and China were the third and fifth largest sources of imports to the United States respectively in 2001, while Mexico was the third most important destination of US exports and China the sixth.[9] China's GDP is about twice that of Mexico, measured at current USD while Mexico's GDP per capita is more than four times China's, measured at constant 1995 USD (World Bank, 2002). Relative GDP per capita is a rough indicator of relative stocks of human and physical capital per worker, and Mexico therefore appears to have a comparative advantage relative to China in more capital and human capital intensive stages of production. In the context of the model developed in the previous section, Mexican producers have a higher value of B than Chinese producers, while US firms would have a much higher value of B still.

Mexico has a common border with USA and together with Canada the two countries established a free trade area in 1994 (NAFTA). China has enjoyed most favoured nation access to the American market since 1980 and the country became a member of WTO in late 2001. Mexico is probably at an advantage relative to China in terms of transport costs, but according to the TRAINS database on applied tariffs, China and Mexico face about the same tariff levels on the US market.[10] However, China has much lower labour costs, and it has therefore a comparative advantage in labour-intensive industries.[11] Since transaction costs presumably affect the cost of providing quality and transaction costs vary between sectors, we would expect that China has a higher value of $\beta$ than Mexico in some sectors and lower $\beta$ in others, depending on trade barriers and how sensitive quality is to timeliness. Location within the two countries is also relevant due to much better infrastructure and a larger pool of skills and producer services suppliers in the coastal areas and free trade zones in China and in the border region in Mexico.

Hong Kong has played an important role in providing the services that enhance quality and improve the competitiveness of Chinese firms in international markets where quality and time to market are important. These are services that add value to the product through quality testing (including sorting out deficient products), packaging and transport such that the timeliness and close to zero deficiency requirements can be met even if the Chinese producer is unable to fulfil the quality requirements. A study by Feenstra et al. (2002) finds that intermediaries in Hong Kong indeed not only contributed to bridging the gap between outside

[9] EU is considered one trading partner in this ranking and it is the US's largest trading partner (WTO, 2002).

[10] The simple average applied tariff rate in 2001 in electronics (HS 85) was 1.95 for both China and Mexico, and in the motor vehicle industry the simple average applied rate was 2.27 for China and 2.68 for Mexico (TRAINS database).

[11] A rough calculation using ILO (2003) data on labour costs indicates that labour costs are about 6 times higher in Mexico than in China. The problem with the calculation is that labour costs are given at pesos per hour in Mexico (49.3) and in Yuan per year in China (14622), both figures from 2001. Using the IMF data on exchange rates and assuming that the Chinese work about 2000 hours per year, yields relative labour costs Mexico/China at about 6.

markets' quality requirements and mainland Chinese manufacturers' capabilities, but also helped match Chinese suppliers and foreign customers. The value added by these intermediaries was estimated to on average 16 per cent of the value of exports that went through Hong Kong intermediaries (excluding re-exports).

The O-ring theory predicts that (Canada and) Mexico would be the source of inputs to production networks led by US firms which have chosen a high-quality strategy, while Chinese suppliers would participate in networks led by Japanese firms and US firms where time to market is not of critical importance. According to a director of a Mexican electronics firm it is perfectly possible for his firm to compete with China on quality, but not on price. The director further explains that before China made its entry into the US electronics market, production in Mexico was all about bringing in raw materials and sending them out.[12] Now he finds that Mexican firms need to do more design, and thus compete in higher quality markets (Authers and Silver, 2003). I will in the following analyse the data and assess the extent and nature of vertical specialization among the US, China and Mexico.

Within a vertical specialization framework, there are several possible trade patterns. One possibility is sequential stages of production where raw materials constitute the first stage and subsequent stages add value through further processing until the final stage assembles the components and market the final product. It is often assumed that the lower stages are less capital and skills-intensive than the late stages. In that case the lower stages would be produced in low-cost countries that are relative abundant in labour, while intermediate stages would be located in middle-income countries with relatively low costs, but reasonably well endowed with skills. The final stages would be produced in a country relative abundant in skills, which also tends to be a relative rich country with a significant market for the final goods. Within a sequential production network we would therefore expect that Mexico would import intermediate goods from China and other poorer countries; process the intermediates and then export the output to the United States for final processing or final consumption.

A second possibility is "radial" production networks with a coordinating firm, e.g. a multinational enterprise with headquarters in the US at the centre. The coordinating firm will typically own a trademark, it will provide product design, engineering and often it will provide key inputs produced to its specifications, in-house or by external suppliers locally or abroad. Production of intermediate products is then distributed on a number of producers which may be located in several countries and may or may not have lower tier subcontractors locally or in yet other countries. The production of inputs is coordinated and ideally synchronized by the coordinating firm, which eventually assembles the inputs and market the final goods for the local market and exports. The role of the coordinating firm may entail manufacturing and/or assembly, or it may be limited to R&D, design and marketing. Within a radial pattern of vertical specialization, we would expect that Mexico and China would import key intermediate products and services from the US and Japan respectively and that the output is then exported back to the US or Japan. There would be only limited trade between China and Mexico within such supply networks.

In order to assess to what extent Mexico and China participate in international production networks and the impact of the proliferation of such networks on their trade with USA, I estimate an index of vertical specialization for the two countries and analyse the trade

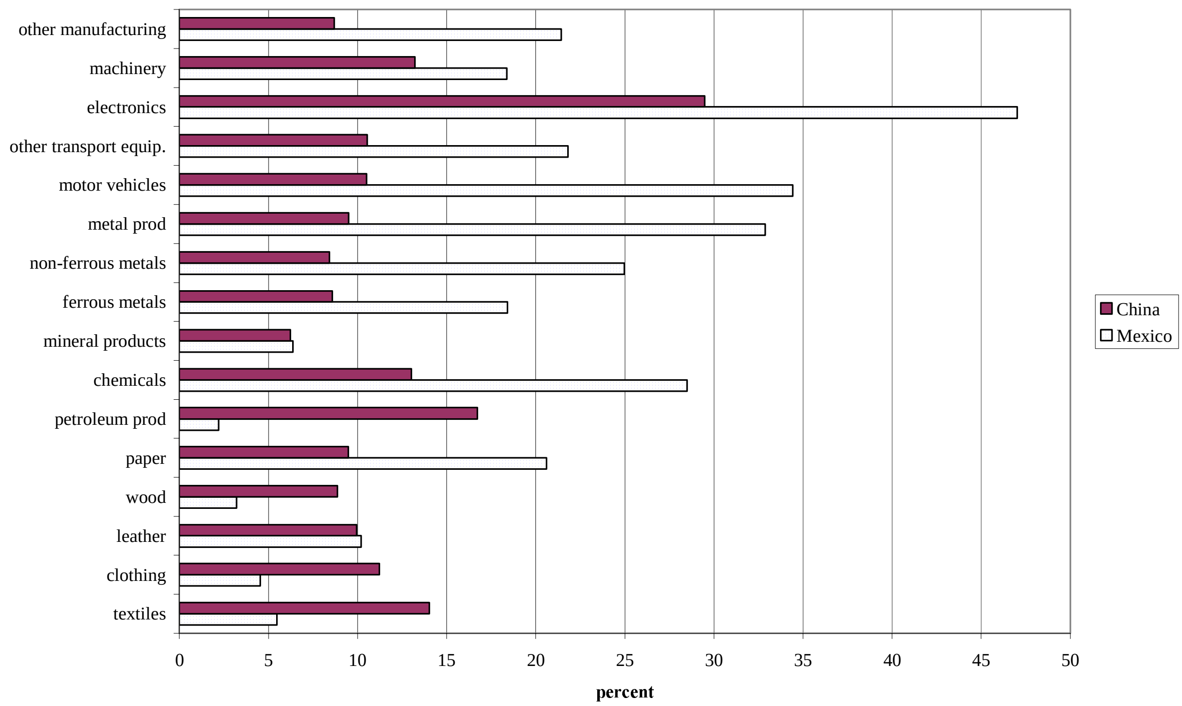
[12] After processing them, it must be presumed.

patterns for the sectors in which vertical specialization is the most important. Hummels et al. (2001) have developed an index that measures the extent of international vertical specialization. It is defined as a production structure where a good is produced in two or more sequential stages, two or more countries provide value added during the production of the good and at least one country must use imported inputs in its stage of the production process, and some of the resulting output must be exported. A country's trade that results from vertical specialization can formally be presented as:

$$VS_{ki} = \frac{MI_i}{GO_i} X_i$$

VS is vertical specialization in country *k* and sector *i,* MI is imported intermediates, GO is gross output while X is exports. I used the GTAP database to estimate the VS for China and Mexico. The share of total exports by sector accounted for by VS is presented in figure 4.

**Figure 4. Vertical specialization as share of total exports, China and Mexico, 1997**




We see that in most sectors the extent of vertical specialization is greater in Mexico than in China. The exception is clothing, textiles, petroleum products and wood; relatively low-technology products. We also notice that in both countries electronics is the industry that by far has the largest share of vertical specialization-driven exports and in both countries chemicals, motor vehicles and other transport equipment, machinery and metal products are also industries where a relatively large share of trade is driven by vertical specialization. Finally, clothing and textiles are found in the literature to be structured as vertical production networks.[13] In these sectors the vertical specialization index is relatively large in China, while it is not in Mexico. Yet, a recent study (Evans and Harrigan, 2003) finds that Mexico has gained market share from China in the US market for clothing precisely because of the

[13] See for example Gereffi (1999).

importance of timely delivery as retailers introduce better supply chain management technology and replenish their stocks more often.[14] These two findings can be reconciled if both inputs and final goods production is located on the Mexican side of the border, while the US firms' inputs are mainly in the design and marketing stages. Flows of these services are not recorded in merchandise trade statistics.

I choose to take a closer look at the two industries for which production networks are found to be most predominant in the literature, electronics and motor vehicles. These are also the two sectors with the highest index in Mexico. Although China has a low index in the motor vehicles sector, the analysis could indicate the likely future development in the sector as China liberalizes its trade and industrial policy. The cost structure of the two sectors in terms of primary inputs is presented in table 1. The figures are given at USD million and the factor shares are given in parentheses.

**Table 1: Cost structure, primary inputs (1997)**

| | Unskilled labour | Skilled labour | Capital |
|---|---|---|---|
| **Mexico** | | | |
| Electronics | 1481.7 (29%) | 420.4 (8%) | 3122.5 (62%) |
| Motor vehicles | 1962.4 (24%) | 451.4 (5%) | 5902.4 (71%) |
| **China** | | | |
| Electronics | 4936.2 (37%) | 1011.0 (8%) | 7276.0 (55%) |
| Motor vehicles | 2481.5 (39%) | 441.4 (7%) | 3505.3 (55%) |

Source: GTAP

We first notice that total value added in both sectors is larger in China than in Mexico. Second, in both countries both sectors use a relatively capital-intensive technology, but Mexico has the most capital-intensive technologies in both sectors. This could indicate that Mexico indeed specializes in intermediates higher up in the value chain than China, but more information is needed to draw firm conclusions on this. We also notice that the factor share of skilled labour is small in both countries, particularly in the motor vehicle industry in Mexico. The cost share of primary factors in total gross output (i.e. value added) is relatively low and smaller in China than in Mexico (about 20 percent in both sectors in China, about 29 percent in the motor vehicle industry and about 26 percent in the electronics sector in Mexico). This is lower than the manufacturing average, which is about a third, and shows that intermediate inputs feature more prominently in the cost functions of these sectors than the average for manufacturing. The factor shares indicate that in both countries both industries are characterized by large-scale, probably highly automated plants that process intermediate inputs and/or prepare such inputs for further processing, where the tasks being performed do not require much formal skills.

Ideally, a study of vertical specialization should be able to follow a product from raw materials to final product, including the border crossings. International trade statistics does not allow for such a detailed analysis. I therefore analyse the available data in three steps. First, I use the GTAP data to analyse the input-output structure of the motor vehicles and electronics industries. Second, I analyse the patterns of trade in the products that are most intensively used in the production process.

[14] The study used data from the period 1990-98. There has, however been a reversal in market shares since 1998 where China has regained market share. China's market share was about 19 percent in 1993, declining to 13.2 in 1999 and then rising to 15 percent in 2002 (calculated from the COMTRADE database).

The cost structures of intermediate inputs are presented in table 2. The figures are given at millions USD, the import share refers to the share of each category of inputs that is imported, while the input-output coefficient (I-O) is defined as $x_{ij} / Y_j$; the value of inputs from sector *i* needed to produce one unit of output in sector *j*.

**Table 2. Cost structure of intermediate inputs, motor vehicles**

| | Mexico | | | China | | |
|---|---|---|---|---|---|---|
| Input | Value | % imports | I-O coeff. | Value | % imports | I-O coeff. |
| Forestry | 0 | - | - | 22 | 6.4 | 0.1 |
| Food | 2.2 | 13.6 | 0.0 | 0 | - | 0.0 |
| Coal | 0 | - | - | 32.9 | 0.0 | 0.1 |
| Oil | 0 | - | - | 0.1 | 0.0 | 0.0 |
| Gas | 0 | - | - | 1.0 | 0.0 | 0.0 |
| Other minerals | 9.8 | 12.2 | 0.0 | 45.4 | 18.7 | 0.1 |
| Textiles | 210.3 | 64.6 | 0.7 | 393.1 | 19.9 | 1.2 |
| Clothing | 32.0 | 76.9 | 0.1 | 58 | 9.3 | 0.2 |
| Leather | 0.7 | 42.9 | 0.0 | 111.6 | 15.0 | 0.3 |
| Wood | 87.5 | 51.2 | 0.3 | 102.2 | 10.1 | 0.3 |
| Paper | 536.4 | 34.4 | 1.8 | 136.9 | 17.8 | 0.4 |
| Petroleum prod. | 48.0 | 41.9 | 0.2 | 62.0 | 13.4 | 0.2 |
| Chemicals | 1893.7 | 46.2 | 6.5 | 2290.5 | 16.2 | 7.1 |
| Non-mineral met.prod | 400.8 | 32.7 | 1.4 | 522.9 | 12.5 | 1.6 |
| Ferrous metals. | 1666.6 | 18.9 | 5.7 | 2575.1 | 11.7 | 8.0 |
| Non-ferrous metals | 486.0 | 38.0 | 1.7 | 486.2 | 19.4 | 1.5 |
| Metal products | 540.2 | 46.6 | 1.9 | 398.9 | 6.6 | 1.2 |
| Motor vehicles | 9007.2 | 71.7 | 31.1 | 12506.3 | 12.9 | 38.8 |
| Electronics | 263.7 | 96.5 | 0.9 | 114.5 | 42.4 | 0.4 |
| Other transp. equip. | 14.6 | 67.1 | 0.1 | 31.9 | 0.9 | 0.1 |
| Machinery | 477.4 | 89.2 | 1.6 | 2918.6 | 22.4 | 9.1 |
| Other manufacturing. | 1.7 | 64.7 | 0.0 | 286.7 | 8.3 | 0.9 |
| Services | 5011.6 | 13.4 | 17.3 | 2719.5 | 1.7 | 8.4 |
| Total | 2069.4 | 48.3 | | 25816.3 | 13.1 | |

Source: GTAP database

The cost structures of the motor vehicle industry in the two countries are similar, but there are three notable differences. Fist, the import share is much larger in Mexico, indicating that the Mexican industry is more integrated into international production networks than the Chinese industry. In fact, motor vehicles are one of the major so-called maquiladora industries which are dominated by foreign, mainly US companies processing inputs for exports back to USA (Hanson, 2003). In contrast only about 13 percent of intermediate inputs are imported in the Chinese motor vehicle industry. The other major difference is the share of services in intermediate inputs. The input-output coefficient is more than twice as high in Mexico, and about 13 percent of the services are imported. This probably reflects a tendency of Chinese firms to produce services in-house as the producer services market is less developed there. Finally, machinery constitutes a relatively large share of total inputs in China, while it does not in Mexico, indicating that the Mexican industry produce more up-market vehicles and more parts.[15] In both countries the major input comes from the motor vehicles sector itself, and we can therefore focus on the origin of these inputs to assess the geographical dimension of vertical specialization (see figures 5 and 6 below). Table 3 presents the cost structure of the electronics industry in the two countries.

[15] The more features that are added to the car, the less will the relative cost of the machinery be.

**Table 3. Cost structure intermediate inputs, electronics**

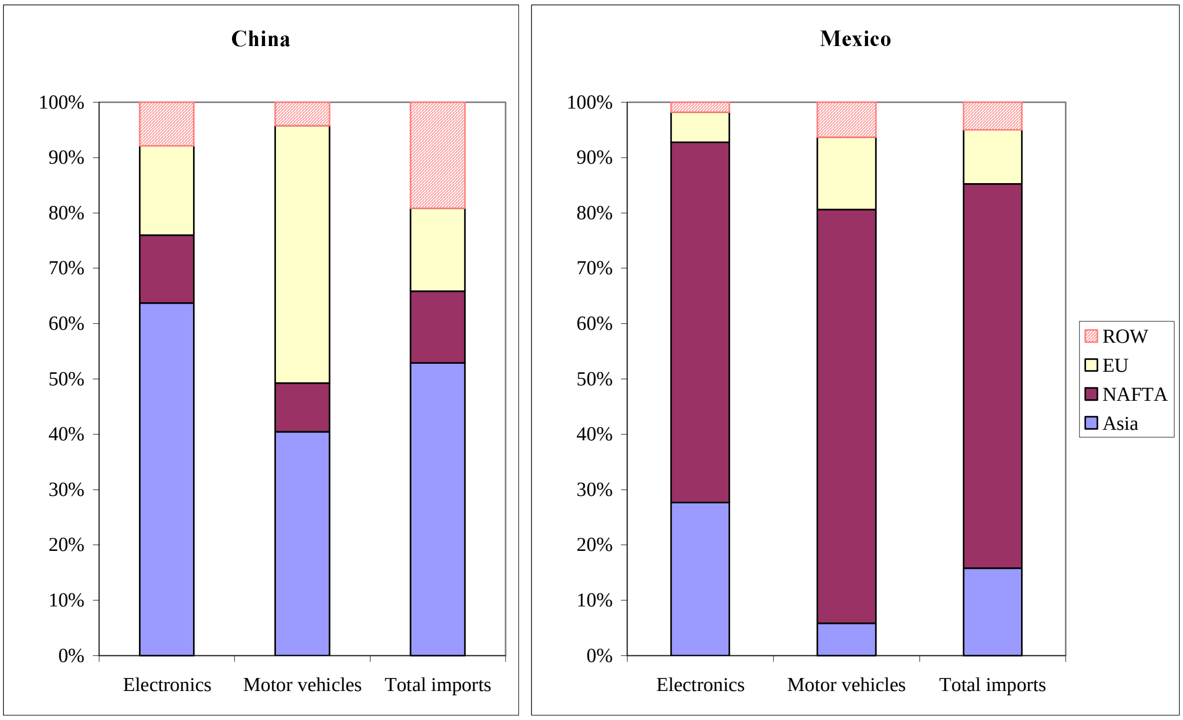
| | Mexico | | | China | | |
|---|---|---|---|---|---|---|
| Input | Value | % imports | I-O coeff. | Value | % imports | I-O coeff. |
| Forestry | 0 | - | - | 2.8 | 14.3 | 0.0 |
| Coal | 0 | - | - | 8.0 | 1.3 | 0.0 |
| Gas | 0 | - | - | 3.8 | 0 | 0.0 |
| Other minerals | 2.2 | 18.2 | 0.0 | 50.7 | 6.5 | 0.1 |
| Textiles | 20.2 | 61.4 | 0.1 | 144.1 | 28.9 | 0.2 |
| Clothing | 11.1 | 91.0 | 0.1 | 39.4 | 9.4 | 0.1 |
| Leather | 1.4 | 50.0 | 0.0 | 13.7 | 15.3 | 0.0 |
| Wood | 343.2 | 77.6 | 1.8 | 85.7 | 10.4 | 0.1 |
| Paper | 222.3 | 27.3 | 1.2 | 767.1 | 17.5 | 1.1 |
| Petroleum products | 1.1 | 36.4 | 0.0 | 26.4 | 14.0 | 0.0 |
| Chemicals | 625.2 | 26.9 | 3.3 | 5592.1 | 26.6 | 8.3 |
| Non-mineral met. prod | 86.1 | 36.4 | 0.4 | 2781.8 | 18.8 | 4.1 |
| Ferrous metals | 216.9 | 31.7 | 1.1 | 347.3 | 12.6 | 0.5 |
| Non-ferrous metals | 283.7 | 22.6 | 1.5 | 648.2 | 23.8 | 1.0 |
| Metal products | 325.4 | 56.9 | 1.7 | 1387.5 | 6.6 | 2.1 |
| Motor vehicles | 263.9 | 88.4 | 1.4 | 123.2 | 13.1 | 0.2 |
| Electronics | 3856.7 | 95.0 | 20.1 | 30908.0 | 52.5 | 45.9 |
| Other transp. equip. | 1.3 | 76.9 | 0.0 | 2.7 | 0.0 | 0.0 |
| Machinery | 4232.6 | 89.0 | 22.1 | 5806.9 | 16.4 | 8.6 |
| Other manufacturing | 7.1 | 67.6 | 0.0 | 428.7 | 7.6 | 0.6 |
| Services | 3654.1 | 10.4 | 19.1 | 4939.4 | 2.3 | 7.3 |
| Total | 14154.5 | 63.0 | | 54107.5 | 36.7 | |

Source: GTAP

Also in the electronics industry, import content is much higher in Mexico than in China. Another significant difference in the structure of costs is the distribution of costs on electronics and other machinery. In Mexico the two have a similar weight in total costs, while in China electronics dominates total costs. See below for a more detailed analysis of the electronics sector.

According to the GTAP data from 1997, 99 percent of imports of motor vehicles were used for production (capital and intermediate use) in China and 91 per cent in Mexico, while the corresponding figures were 93 and 73 percent in the electronics sector for China and Mexico respectively. The sources of total imports of these goods should therefore give a fairly good picture of the sources of imported inputs in the diagonal cells in the input-output table. Imports by country of origin in the two sectors and total imports are presented in figure 5.

**Figure 5. Sources of imports, 2001**



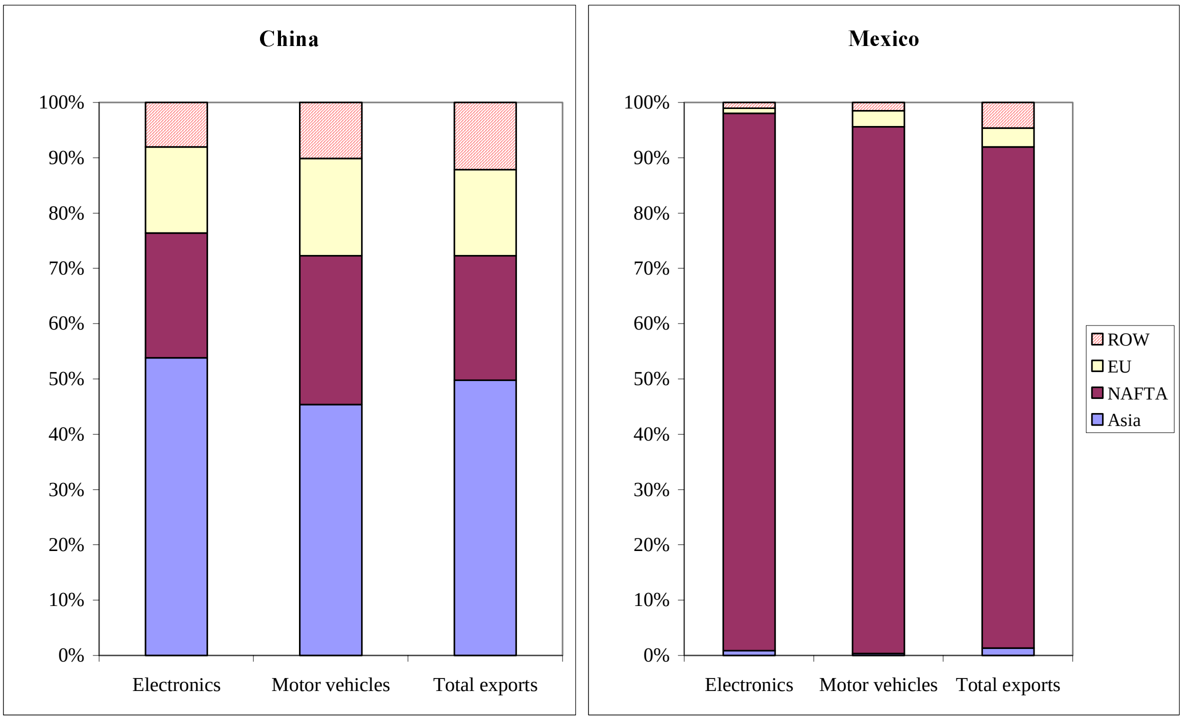

Source: COMTRAD database

Comparing the sources of imports of the two countries, there is clearly a regional dimension to trade. However, imports from neighbouring countries are not systematically larger in the electronics and motor vehicles industries than the average for total imports. Asia has a higher market share in electronics than it has for total imports to China, but that is also the case for Asia's trade with Mexico, reflecting Asia's comparative advantage in this sector. Japan was the second largest source of imports of electronics to Mexico followed by Taiwan, Korea and China. In China Japan was the largest source of imports, followed by Taiwan, USA and Korea. China's market share in Mexico was less than 3 percent, while Japan's was about 10 percent. This indicates that Mexico imports higher value added electronics from the newly industrialized countries in Asia rather than low-value added components from low-income countries in Latin America and Asia, including China. There is thus little evidence of the sequential value chain in the electronics sector.

In the motor vehicles industry, the regional dimension is very strong in Mexico, while China is more oriented towards Europe for inputs. Recall, however, that China has a very low import share in the motor vehicle industry, indicating that the vertical supply chain largely consists of domestic suppliers. The Chinese motor vehicle industry is moreover found to be highly inefficient, fragmented and dominated by state-owned enterprises (Liu and Woo, 2001). In recent years China has attracted numerous foreign investors in the motor vehicle industry and the industry is likely to restructure completely following deregulation and trade liberalization in the sector (Nordås, 2002). It might follow a similar pattern as the Mexican motor vehicle industry, although it is unclear whether the regional giant in car manufacturing, Japan, would adopt a similar sourcing policy as the American industry (Qui and Spencer, 2002), European manufacturers are probably too far away to pursue such a strategy, as the motor vehicle supply chains are found to be highly regional in scope (Gereffi, 1999). The most likely outcome is therefore that foreign investors choose a low-quality (low $n$) strategy, given relatively high transaction costs, relative scarcity of skills, relatively small pool of high-quality suppliers of goods and services, probably particularly the latter (high $\beta$). Foreign investors as well as local firms are therefore likely to focus on the fast-growing domestic mass market.

Turning to exports, figure 5 depicts the destination of China and Mexico's exports in 2001. We see that Mexico's exports are extremely concentrated on the NAFTA market, where USA accounts for about 98 percent of total NAFTA exports. China's exports are more diversified. Its largest export markets in electronics are Hong Kong followed by USA and Japan.

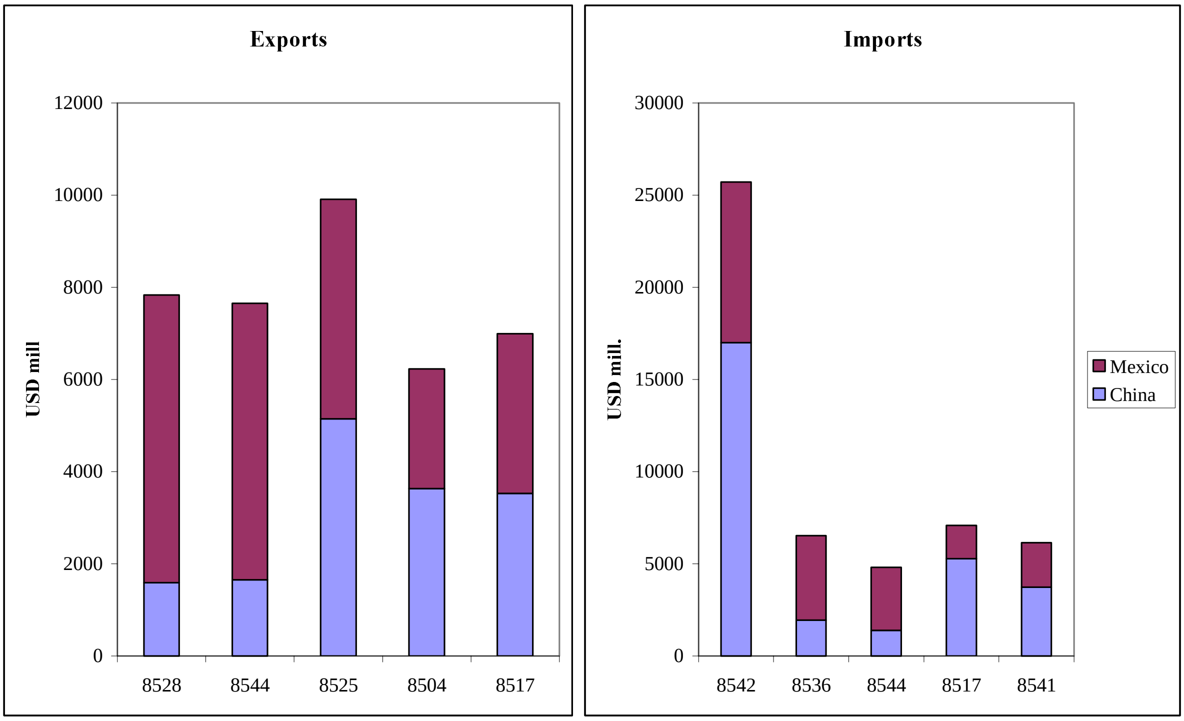
**Figure 5. Destination of exports, 2001**




Source: COMTRAD database

Both Mexico and China are net importers in the electronics sector. Since the sector contains everything from insulated copper wires to integrated circuits and other advanced components and products, it is useful to also compare the structure of imports and exports within the electronics sector. Figure 6 presents the three major exports and imports at a 4-digt (HS 1996) level.

**Figure 6. The three largest exports and import categories in electronics, 4-digit HS 1996 level, 2001**




Source: COMTRAD

In both countries the largest imports is HS code 8542, integrated circuits and micro-assemblers, accounting for about 30 percent of total imports in electronics in China and 17 percent in Mexico in 2001.[16] The second and third largest imports in China are electrical apparatus for line telephony or telegraphy (HS 8517) and diodes, transistors and semiconductor devises (HS 8541).[17] The corresponding figures in Mexico are electrical apparatus for switching of protecting electrical circuits (HS 8536) and insulated cables, wire and optical fibres (HS 8544).[18] In Mexico the imports are more concentrated on intermediate inputs than in China. China actually has a much larger trade deficit in final goods than in parts and components in the electronics sector (Lall and Albaledejo, 2003). The five largest sources of imports of integrated circuits are presented in table 4. Values are in USD mill. and percentages represent the country in question's market share on the Chinese and Mexican markets for integrated circuits.

[16] HS category 8542 faced an applied average tariff rate of 6.16 per cent in China and 0.79 per cent in Mexico in 2001 (TRAINS database).

[17] HS category 8517 faced a tariff rate of 12.62 per cent and HS 8541 10 per cent in China in 2001 (TRAINS database).

[18] The tariff rates in Mexico in 2001 for HS 8536 were 15.72 per cent and for HS 8544 16.94 per cent.

**Table 4. The five largest sources of imports of integrated circuits, 2001**

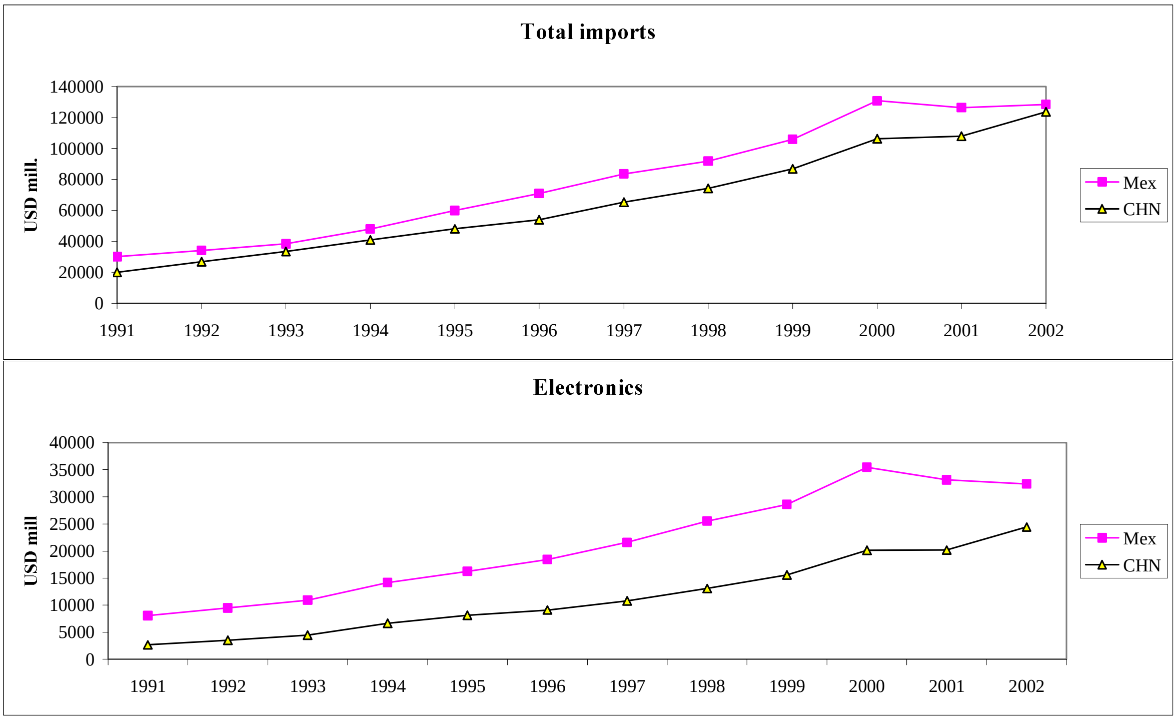
| | China | | | Mexico | |
|---|---|---|---|---|---|
| **Supplier** | **Value** | **Percent** | **Supplier** | **Value** | **Percent** |
| Japan | 3999 | 23.5 | USA | 4786 | 55.0 |
| Taiwan | 3074 | 18.1 | Japan | 1114 | 12.8 |
| Malaysia | 1691 | 9.9 | Taiwan | 572 | 6.6 |
| USA | 1557 | 9.2 | Philippines | 517 | 5.9 |
| Korea | 1422 | 8.3 | Malaysia | 485 | 5.8 |

Source: COMTRAD

China is less dependent on one supplier than is Mexico, and there is a clear regional bias in the sourcing of inputs. Interestingly, the Philippines have made it to the top 5 exporters of integrated circuits to Mexico, while China has not. Turning to exports, both countries have transmission apparatus for radio and broadcasting among the top three (first for China, third for Mexico; HS code 8525). Mexico's largest exports in the electronics sector are TV sets (HS 8528) and insulated cables including fiberoptics (HS 8544). China's second and third largest exports within the electronics sector are electric transformers, static converters and inductors; and telephones for line telephony - both relatively low-technology products. The more detailed study of electronics appears to be consistent with vertical specialization of the radial type where China is integrated in Asian supply networks and Mexico mainly in American networks. China appears to provide low-technology intermediates and assemble final goods, while Mexico's electronics sector is somewhat more capital-intensive (see table 1) and more technologically sophisticated. China's world market share in more technologically advanced electronics industries is, however, rapidly increasing (Lall and Albaledejo, 2003).

It would be interesting to see if this trade pattern is reflected also in the two countries' relative market share on the US market and how market shares have developed over time. Figure 6 depicts US total imports and US imports in the electronics sector from China and Mexico.

**Figure 6. China and Mexico's exports to USA, 2001**




Source: COMTRAD database

Apparently, China has not only been able to sustain its market share in the US market following the introduction of NAFTA, it has also increased its market share and caught up with Mexico as far as total trade is concerned and the gap has narrowed also in the electronics sector, particularly after the 2000/01 recession in the US and China's membership in the WTO in late 2001. China and Mexico both accounted for about 11 percent of US total imports in 2002. In the electronics sector Mexico accounted for about 21 percent of USA's imports, while China accounted for about 16 percent. China's exports of motor vehicles and parts to USA are, however, insignificant.

To conclude this section, the observed trade pattern is compatible with vertical specialization of the radial type. Mexico imports high-quality components from USA, mainly from parent companies of foreign invested companies. It also imports some inputs from other countries, notably in Asia, including high-technology inputs. The imported intermediaries are then processed in Mexico and sold back to USA. China's trade pattern in the electronics sector is compatible with being a major producer of the "commoditized" part of the industry – relatively low-technology consumer electronics (i.e. final goods) and standardized components. The components appear to be further processed in Asia rather than Mexico, while the finished products appear to be exported all over the world. A linear sequential pattern of vertical specialization is less compatible with this trade pattern as this would be reflected in higher import share in Mexico from lower cost countries in Asia or Latin America and the Caribbean. Latin America and the Caribbean are included in ROW, which has lost market share in Mexico over time in the electronics industry, but gained in the motor vehicles industry since 1997. Another observation pointing in the direction of radial production networks is the fact that developed countries have a larger market share in electronics *components* than in electronics final products on the world market (Lall and Albaledejo, 2003).

## V. POLICY IMPLICATIONS AND CONCLUSIONS

This paper has explored the implication of vertical specialization on international trade, using a simple version of the O-ring theory of production and technology and applying the insights to Mexico and China's trade with USA. The main insights from the O-ring theory is that quantity cannot be substituted for quality and once a high-quality technology is chosen, a firm tend to purchase all its inputs from high-quality suppliers. The important empirical questions are: What are the relevant dimensions of quality? How widespread are vertical production networks? And what proportion of trade within production networks is in the high-quality segment?

The business literature points to timeliness of delivery and close to zero deficiency rates as two important dimensions of quality, as modern manufacturing enterprises have increasingly focused on managing the entire supply chain in a more efficient way. The O-ring theory predicts that the more such investments take place, the more likely it is that the enterprises will choose high-quality suppliers. Turning to the supply side I argue that the less efficient the infrastructure, port handling services and customs procedures, the less incentives will a potential exporter of intermediate products have to upgrade its quality to the required maximum deficiency ratios. For developing countries there are probably large potential gains from participating in vertical production networks. In particular technology transfer and access to market networks for their exports are important benefits. An important policy implication of the O-ring theory is that improved port handling services and logistics and improved customs procedures can make the difference whether or not local firms have the incentives to upgrade quality and link up to vertical production networks beyond the commodity stage.

Turing to the second question, recent research has found that vertical fragmentation accounts for about 30 percent of world trade and that its share probably is increasing (Hummels et al., 2001). There are, however, large differences between countries and industries. In both Mexico and China vertical specialization account for a lower share of total trade in manufactures than the world average 30 percent (about 26 percent in Mexico and 14 percent in China), indicating that vertical fragmentation is more common between developed countries than between developing and developed countries.[19] These data are, however, from 1997, and there are reasons to believe that the vertical production networks have become more widespread since then. Although one should be careful about drawing conclusions from the relatively brief analysis of Mexico and China, it appears that although it is Mexico that is in the better position to participate in vertical specialization networks due to its common border and free trade agreement with USA, China has gained market shares on the US market even in the electronics sector, where closely knit vertical production networks are most prominent, indicating that vertical specialization adds to rather than replaces traditional trade flows.

[19] Author's calculation based on the GTAP database. See also Hummels et. al. (2001).

To conclude, we have seen that if the infrastructure and logistics services are adequate such that investments in quality is not destroyed on the journey from factory gate to customer, the gains from investment in quality can be substantial. By the same token, poor infrastructure, long delays in ports and customs, and poorly developed transport and logistics services can block producers in distant or poor markets from participating in markets where they previously were competitive due to low production costs. With the proliferation of production networks, therefore, governments need to focus on trade facilitation and logistics in addition to tariffs and non-tariff barriers.

## References


Authers, J. and S. Silver, 2003, "Mexico's lost decade: as investment switches to China, the opportunities created by Nafta are under threat", Financial Times 01.07.2003.

Bresnahan, T.F, Brynjolfsson, E. and Hitt, L.M. (2002). 'Information technology, workplace organization and demand for skilled labour', *The Quarterly Journal of Economics* **117**, 339-76.

COMTRAD database, www.wits.worldbank.org

Evans, C.L. and J. Harrigan, 2003, "Distance, time and specialization", NBER working paper no. 9729, May.

Feenstra, R.F, G.H. Hanson, S. Lin, 2002, "The value of information in international trade: gains to outsourcing through Hong Kong", NBER Working Paper no 9328, November.

Gereffi, G., 1999, "International trade and industrial upgrading in the apparel commodity chain" *Journal of International Economics,* vol. 48, 37-70.

GTAP database, Purdue University, CD-rom.

Hanson, G.H., 2003, "What has happened to wages in Mexico since NAFTA? Implications for hemispheric free trade", NBER Working Paper no. 9563, March.

Hanson, G.H., R.J. Mataloni Jr. and M.J. Slaughter, 2003, "Vertical production networks in multinational firms", NBER working paper no 9763 May.

Hummels, D., J. Ishii and K.M. Yi, 2001, "The nature and growth of vertical specialization in world trade", *Journal of International Economics* vol. 54, no 1. pp. 75-96.

ILO, 2003, LABORSTA, http://laborsta.ilo.org/

IMF, 2003, International Financial Statistics, CD-rom.

Ianchovichina, E. and W. Martin, 2001, “Trade liberalization and China’s accession to the World Trade Organization”, *Journal of Economic Integration* vol 16 no 4, pp 421-444.

Kremer, M., 1993, "The O-ring theory of economic development", *The Quarterly Journal of Economics* Vol 118, no. 3, pp. 551-575.

Lall, S. and M. Albaladejo, 2003, "China's manufactured export surge: the competitive implications for East Asia", World Bank mimeo, June.

Liu, G.S. and W.T. Woo, 2001, “How will ownership in China’s industrial sector evolve with WTO accession?” *China Economic Review,* vol. 12, pp. 137-161.

Nordås, H.K., 2002, "Direction of trade following China's entry into the WTO" SNF working paper no 04/02.

Qui, L.D. and B.J. Spencer, 2002, "Kereitsu and relation-specific investment: implications for market-opening trade policy", Journal of International Economics, 58, 49-79.

TRAINS database, www.wits.worldbank.org

UNCTAD, 2001, “World Investment Report 2001: Promoting linkages”, United Nations: Geneva.

Venables, A.J., "Geography and international inequalities: the impact of new technologies", Paper presented at the World Bank Annual Conference on Development Economics, Washington May 2001.

World Bank, 2002, World Development Indicators, CD-rom.

WTO, 2002, "International Trade Statistics 2002", Geneva: World Trade Organization.

Yi, K-M, 2003, "Can vertical specialization explain the growth of world trade?", *The Journal of Political Economy,* vol. 111, no 1, pp. 52-102.