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International Trade, Flexible Manufacturing and Outsourcing

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The aim of this annual workshop is to offer a forum for young researchers from the field of International Economics to present and to discuss their current topics of research with other experts. The workshop also provides the opportunity to gain an overview of recent developments, problems and methodological approaches in this field.

Detailed information on past workshops and the planning for the 2005 workshop are available at http://www.vwl.wiso.uni-goettingen.de/workshop. Do not hesitate to contact Dr. Carsten Eckel, *CeGE* (carsten.eckel@wiwi.uni-goettingen.de) for further questions.

International Trade, Flexible Manufacturing and Outsourcing

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Abstract

This study analyzes the impact of international trade on the diffusion of flexible manufacturing in a general equilibrium framework. Suppliers produce a flexible base product that can be adapted to the specific input requirements of a continuum of downstream industries. The vertical structure is determined by the trade-off between economies of scope in flexible manufacturing and product specificity of in-house production. In this framework, globalization can lead to alternating waves of insourcing and outsourcing, but once the world market reaches a threshold size, outsourcing prevails. We also derive a number of testable predictions with regard to firm size and productivity measures that are in line with recent empirical and casual evidence.

Keywords: International Trade, Flexible Manufacturing, Outsourcing, Vertical Integration, Globalization, General Equilibrium

JEL classification: F12, L11, L22

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1 Introduction

Modern manufacturing exhibits two prominent features: Manufacturing flexibility and outsourcing. Manufacturing flexibility describes the range of products that can be produced by a manufacturing system with only a minimum of intervention (US Office of Technology Assessment, 1984; Norman and Thisse, 1999). Today, many manufacturing firms use flexible manufacturing as a strategy to increase their market potential. As such, flexible manufacturing is an important determinant of a manufacturing firm's international competitiveness. Consequently, the diffusion of flexible manufacturing systems has increased significantly over the last decades (Gerwin, 1993; Mansfield, 1993; Norman and Thisse, 1999). In this paper we address the role of international trade in the diffusion of flexible manufacturing and study the accompanying market structure and welfare effects.

Flexible manufacturing can affect the vertical organization of industries by enabling upstream suppliers to provide inputs to a larger range of downstream producers. Many downstream firms use heterogeneous technologies that require specific inputs. From the viewpoint of these downstream firms, flexibility in upstream manufacturing increases the availability of inputs and raises the thickness in intermediate goods markets (McLaren, 2003). Through this channel, flexible manufacturing can affect the downstream firm's mode of procurement. If the range of available inputs rises, downstream firms are more likely to find suitable inputs in the market, so that an increase in market thickness can lead to outsourcing. In addition, the availability of inputs is an important determinant of the productivity of downstream firms, so that the diffusion of flexible manufacturing can also have implication for a country's welfare.

We introduce a simple framework that allows us to study the impact of international trade on flexible manufacturing and outsourcing. The vertical organization of industries is based on the trade-off between economies of scope in flexible manufacturing and product specificity of in-house production. We illustrate that international trade can affect the vertical equilibrium through changes in the number of suppliers (market thickness effect) and through changes in the range of industries serviced per supplier (market width effect). We will demonstrate how these two effects interact and how they can provide an explanation for alternating waves of insourcing and outsourcing (e.g., *Economist*, 1991; Marsh, 1998, 2003; Murphy, Winter and Mayne, 2003; *MSI Magazine*, 2003).

Our framework provides insights complementary to the popular Ethier framework. Ethier (1979, 1982) illustrated how international trade in intermediate goods can promote specialization and how an increase in specialization can lead to efficiency gains through external economies of scale (or "international economies of scale" in Ethier's terminology). Here, we emphasize the role of adjustments in the vertical organization of industries and provide an alternative explanation for productivity gains. In addition, we illustrate that adjustments in the market width of suppliers can lead to different predictions regarding the impact of international trade on the market structure in upstream industries.

This study is related to a number of earlier contributions. In our modeling of flexible manufacturing we build on Eaton and Schmitt (1994) and Norman and Thisse (1999) who provide models of flexible manufacturing systems based on the spatial model of product differentiation á la Hotelling (1929) and Salop (1979). However, both studies are confined to partial equilibrium in a consumer good industry and do not deal with issues of international trade or issues of vertical integration. In extending the analysis to general equilibrium we build on Grossman and Helpman (2002). They use Helpman's (1981) circle to model product differentiation in an intermediate good industry in general equilibrium and show how differences in certain industry characteristics can lead to different modes of organization. But, in contrast to our approach, they do not allow for flexible manufacturing.[1] This paper is also related to McLaren (2000) who illustrates how globalization can lead to a rise in outsourcing through an increase in market thickness. He emphasizes the role of international trade in facilitating arm's length trade between upstream and dowstream firms, but again, he does not address the role of flexible manufacturing, either.

2 Production Technologies

The starting point of our framework is a continuum of downstream industries all of which require the input of a specific intermediate good. Take computer chips for example. All electronic appliances and other goods with at least some electronic components require computer chips of one kind or another. So they are identical in their need of computer chips. But the exact types of chips needed are, of course, different and depend on the good produced.

In order to keep the analysis simple we assume that the intermediate good is the only input in the production of the final good and normalize units so that one unit of the specific input produces one unit of the final good. The production function of industry i can then be written as

$$X_i = \tilde{Q}_i, \tag{1}$$

where X_i is the output of industry i, and $\tilde{Q}_i$ is the input specific to industry i.

[1] Grossman and Helpman (2002) incorporate a notion of flexibility in an extension where upstream firms can choose the degree of specificity of their inputs. However, the flexibility is only important as an outside option. In equilibrium, each upstream firm produces only one variety with a single specification and sells to only one downstream firm.

All industries can be uniquely characterized by the specification of its input requirements. We adopt Helpman's (1981) modeling strategy and assume that all specifications can be represented by points on the circumference of a circle. The circumference represents the mass of industries and is denoted by Ω. Consequently, all final goods industries and their respective input requirements are indexed over the intervall $i \in [0, \Omega]$.

Assume that all final goods industries are perfectly competitive and that the assembly of the final good is costless. Then, the price of the final good p_i equals the price of the intermediate input $\tilde{q}_i$:

$$p_i = \tilde{q}_i. \tag{2}$$

There are two different technologies available for producing the intermediate input: a flexible manufacturing technology (section 2.1) and a specific technology (section 2.2).

2.1 Flexible Manufacturing

The flexible manufacturing technology is seperable into two stages. In the first stage, the manufacturer produces a base product taylored to a particular industry. In the second stage, this base products can be adapted to a number of different specifications. Both stages are costly.

The defining feature of flexible manufacturing is that a single intermediate producer services a range of industries. Thus, we have to distinguish between the location of a supplier and the locations of industries serviced. The specifications of a supplier's base product j indicate the address of this supplier on the circle. Hence, for industry $i = j$ no adaptation is necessary and no adaptation costs have to be incurred. But if this supplier services a different industry, the intermediate input has to be adjusted to the particular specifications of the final good and this adaptation is costly. In our one-dimensional representation of specifications, the deviation of an industry's specifications from the base product of a supplier can be described as the shortest arc distance δ_{ij} between the industry i's location on the circle and the address of supplier j. Adaptation costs a_{ij} from supplier j to industry i can then be described as a rising function of this distance:

$$a_{ij} = a\left(\delta_{ij}\right). \tag{3}$$

We assume that adaptation costs are symmetric, i.e. all industries are subject to the same adaptation function.

The adaptation function is convex and exhibits rising marginal adaptation costs ($a' > 0$ and $a'' > 0$). We assume that adaptation costs are similar in nature to iceberg transportation costs, i.e. when a final goods producer purchases an input at distance δ, only $\frac{1}{a}$ of this input can be employed in the production process of the final good:

$$\tilde{Q}_i = \frac{Q_{ij}}{a\left(\delta_{ij}\right)}, \tag{4}$$

where Q_{ij} describes the quantity shipped by supplier j for industry i and δ_{ij} describes the shortest arc distance between i and j. Hence, it is convenient to normalize adaptation costs so that $a\left(0\right) = 1$.

The assumption of iceberg adaption costs is convenient in a number of ways. First, it simplifies nicely the mathematical description of the process of adaptation by establishing a simple correspondence between the volume of production of any variant and the volume of production of the base product. Second, it provides a measure of productivity for intermediate goods. According to equations (1) and (4), the productivity of supplier j's base product in the production of industry i is given by $\frac{X_i}{Q_{ij}} = \frac{1}{a(\delta_{ij})}$.

In addition, the assumption of iceberg adaptation costs comes particularly handy in combination with free entry. If there are no barriers to entry and the delivery to any industry is essentially contestable, upstream firms cannot engage in price discrimination between industries with regard to the price of the base product.[2] Instead, they set a single price for their base product and add adaptation costs. Then, it is the effective prices paid by downstream firms in the various industries that differ. The effective price $\tilde{q}_{ij}$ paid by industry i to supplier j consists of the price for the base product q_j set by supplier j plus adaptation costs:

$$\tilde{q}_{ij} = a\left(\delta_{ij}\right) q_j. \tag{5}$$

The volume of production of the base product Q_j depends on the number of industries serviced and on the quantity sold to each industry. We refer to the range of industries serviced as a producer's market width and the quantities sold to each industry as the market depth. In the continuum case, the volume of production is given by the integral of output per industry over the entire market width:

$$Q_j = \int_0^{\delta_j^l} Q_{ij} di + \int_0^{\delta_j^r} Q_{ij} di, \tag{6}$$

where $\left(\delta_j^l, \delta_j^r\right)$ describes the range of industries serviced by supplier j to the left and to the right. Naturally, in equilibrium δ_j^l and δ_j^r are determined endogenously.

The production of the base product requires the input of labor. A flexible manufacturing

[2] We elaborate on this in section 3.3.

technology has both fixed and variable cost components. One can think of the fixed cost component as a cost for developing a versatile base product. Labor requirements l_j and the respective cost function C_j are given by

$$l_j = f + cQ_j, \tag{7}$$

$$C_j = wl_j = w\left(f + cQ_j\right), \tag{8}$$

where f and c denote fixed and marginal labor requirements and w is the (economy-wide) wage rate.

The description of the technology provides first insights into the economics of flexible manufacturing. On one hand, there are economies of scope in flexible manufacturing. Because of the product development cost f it is cheaper for one supplier to service a range of industries than for a range of suppliers to service individual industries $\left[C_j\left(\int Q_{ij}di\right) < \int C_{ij}\left(Q_{ij}\right)di\right]$.[3] On the other hand, supplying a larger range of industries also implies higher adaptation costs.

2.2 In-house Production

The specific technology is much simpler. It exhibity constant returns to scale where one unit of a specific intermediate input requires the input of $\frac{1}{m}$ units of labor:

$$\tilde{Q}_i = \frac{1}{m} l_i. \tag{9}$$

Assume that the specific technology is indivisibly linked with the assembly of the final product, so that this technology is only available to integrated consumer goods producers.[4] Hence, we will also refer to this technology as the in-house technology as opposed to outsourcing to a flexible manufacturer.

The cost function of industry i is then

$$C_i = wmX_i, \tag{10}$$

and marginal cost pricing yields

$$p_i = mw. \tag{11}$$

[3] Note that economies of scope in servicing industries and economies of scale in the production of the base product are isomorphic in this setup.

[4] Alternatively, we could assume that this technology is universally available, but independent firms have to incur an extra fixed costs g_i. In this case, outsourcing of the specific technology is technologically possible but economically unattractive $(g_i + m\tilde{Q}_i > m\tilde{Q}_i)$.

Note that (11) implies an internal transfer price for the input of

$$\tilde{q}_i = mw. \tag{12}$$

The advantage of the specific technology is clearly that each intermediate input is taylored to its final good. Hence, no adaptation costs arise. On the other hand, there are no economies of scale or scope, so that unit costs remain constant. Hence, the choice of technology is determined by the trade-off between economies of scope in flexible manufacturing and product specificity in in-house production.

3 Flexible Manufacturing and In-house Production in General Equilibrium

3.1 Market Width

The market width describes the range of industries serviced by a single supplier using flexible manufacturing. It is determined endogenously by a supplier's cost advantage over its immediate competitors. These competitors can be either other suppliers using flexible manufacturing or downstream firms with in-house production. Hence, there are two critical levels of δ. Let $\tilde{\delta}$ denote the range of industries for which a supplier has a cost advantage over its closest competitor using flexible manufacturing (both to the left and to the right) while $\bar{\delta}$ denotes the range of industries for which the supplier has a cost advantage over the specific in-house technology. The equilibrium market width is then determined by the minimum of these two. This is illustrated in figures 1.a and 1.b.

Figure 1 *Market width (a & b)*

Figure 1.a describes the determination of the market width when the supplier is competing primarily against in-house production. We will refer to this case as the IP regime. The horizontal axis is normalized so that the location of supplier j is at $\delta = 0$. At this point, the effective price $\tilde{q}$ for downstream firms is just equal to the price of the base product q. As supplier j starts selling to industries further away, adaptation costs increase and the effective price rises. The closest competitor using flexible manufacturing $(j+1)$ is located at distance d. Its effective price is also increasing in the distance to its base location. At $\tilde{\delta}_j$, the two effective price curves intersect. Supplier j has a cost advantage over supplier $j+1$ in the interval $\left(0, \tilde{\delta}_j\right)$ and a cost disadvantage in $\left(\tilde{\delta}_j, d\right)$. However, in the range $\left(\bar{\delta}_j, \bar{\delta}_{j+1}\right)$, the effective prices of both suppliers are larger than the costs of in-house production, mw.

Hence, the market width of supplier j is only $\left(0, \bar{\delta}_j\right)$ and the market width of supplier $j+1$ is $\left(\bar{\delta}_{j+1}, d\right)$. In the range $\left(\bar{\delta}_j, \bar{\delta}_{j+1}\right)$, downstream firms rely on in-house production. In this case, the market width is determined by the intersection of $\tilde{q}_j$ (and $\tilde{q}_{j+1}$) with mw.

Figure 1.b describes a scenario where in-house production is not feasible (FM regime). Here, the effective prices $\tilde{q}$ at $\tilde{\delta}$ are lower than the costs of in-house production. Hence, downstream firms purchase their inputs from supplier j in the range $\left(0, \tilde{\delta}_j\right)$ and from supplier $j+1$ in $\left(\tilde{\delta}_j, d\right)$. In this scenarion, the market width is determined by the intersection of the two $\tilde{q}$ curves.

Formally, the market width of supplier j to the left, δ_j^l, and to the right, δ_j^r, is determined by

$$q_j a\left(\delta_j^l\right) = \min\left\{mw; q_{j-1} a\left(d_{j-1} - \delta_j^l\right)\right\} \tag{13}$$

and

$$q_j a\left(\delta_j^r\right) = \min\left\{mw; q_{j+1} a\left(d_{j+1} - \delta_j^r\right)\right\}. \tag{14}$$

In general equilibrium, only the parameter m is exogenous. In partial equilibrium, individual suppliers also take the wage rate w and the prices of other suppliers as well as their locations as given. In this environment, a supplier maximizes its profits by simultaneously setting the price for its base product q_j and choosing its location on the circle, thereby determining d_{j-1} and d_{j+1} while $D = d_{j-1} + d_{j+1}$ remains constant. We limit the analysis to symmetric equilibria where $q_j = q_{j+1} = q$ and $\delta_j^l = \delta_j^r = \delta$ and we can omit indices.

Regarding the choice of location we can establish that if $mw \geq qa\left(\frac{D}{2}\right)$, so that $\delta = \tilde{\delta} \leq \bar{\delta}$ (FM regime), a symmetric equilibrium implies that $d_{j-1} = d_{j+1} = d = 2\tilde{\delta} = \frac{D}{2}$ (Helpman, 1981). If $mw < qa\left(\frac{D}{2}\right)$, so that $\delta = \bar{\delta} < \tilde{\delta}$ (IP regime), there exists an iso-profit section where supplier j is indifferent in its exact location. This iso-profit section is of length $D - 4\bar{\delta}$. The minimum distance to either side is $d^{\min} = 2\bar{\delta} < \frac{D}{2}$. Hence, due to this iso-profit section there exists a certain indeterminancy in the extact location choice. However, in a symmetric equilibrium, where $\delta_j^l = \delta_j^r$, this indeterminancy does not affect our principle results.

In a symmetric equilibrium, equations (13) and (14) can be summarized as

$$qa(\delta) = \begin{cases} qa(\delta) & (FM \text{ regime}) \\ mw & (IP \text{ regime}) \end{cases}. \tag{15}$$

3.2 Market Depth

The market depth is derived from the production of the various final goods. All final goods industries are perfectly competitive and demand is derived from a Cobb-Douglas utility function:

$$X_i = \alpha_i \frac{I}{p_i}. \tag{16}$$

Here, X_i is demand for final good i, I is income, and α_i is the (constant) share of income spent on good i.

The shares of income spent on consumer goods must add to one over the interval $[0, \Omega]$:

$$\int_0^{\Omega} \alpha_i di = 1. \tag{17}$$

We simplify further by assuming that the shares of income devoted to each good are identical across all goods ($\alpha_i = \alpha$). As a result, equation (17) implies $\alpha = \frac{1}{\Omega}$. The prices of final goods continue to differ between industries even in a symmetric equilibrium because different industries are subject to different adaptation costs.

Equations (1), (2), (6), and (16) now determine demand for Q:

$$Q = 2\delta \frac{\alpha I}{q}. \tag{18}$$

3.3 Free Entry Pricing and the Product Market Clearing Condition

We assume that there is free entry in all markets and market segments. This assumption has two dimensions. First, with free entry the number of suppliers is determined endogenously and each new entry can have an impact on the location of suppliers on the circle. We will refer to this dimension as the horizontal dimensions because it affects the degree of horizontal differentiation. This issue will be addressed later. The second dimension of the free entry assumption relates to the contestability of markets. Under free entry, no firm has exclusive control over the delivery to any industry, so that the markets for all base products are essentially contestable. A supplier is not only competing against other competitors to the left and to the right of its own location but also against potential competitors on the exact same location. We will refer to this dimension as the vertical dimension of the free entry assumption. As a consequence, all base products are priced at average costs $q = \frac{C}{Q}$:

$$q = w \left(\frac{f}{Q} + c \right). \tag{19}$$

The price-setting behavior as described in equations (5) and (19) implies that there is no cross-subsidizing between variants in order to increase the range of industries serviced. The reason for the absence of cross-subsidizing is that with free entry, cross-subsidizing is not a viable strategy. This is immediately obvious in the FM regime. If all firms pursue the same strategy in a symmetric equilibrium, cross-subsidizing cannot lead to an increase in the market width. However, in the IP regime, this is not so obvious. Figure 2 helps to illustrate the point.

Figure 2 *Cross-subsidizing in the IP regime*

In figure 2, $\tilde{q}$ denotes the effective price if no cross-subsidizing occurs (average cost pricing of the base product). In this case, the firm makes zero profits and services industries in the range $\left(0, \bar{\delta}\right)$. The curve $\tilde{q}'$ denotes a cross-subsidizing scheme where the respective firm charges a price above $\tilde{q}$ for industries in the range $(0, \delta_A)$ and a lower price in the range $\left(\delta_A, \bar{\delta}'\right)$. With this strategy, the firm is able to increase its market width to $\bar{\delta}'$. We assume that this strategy also leads to zero profits, i.e. that the additional profits captured in the range $(0, \delta_A)$ are just equal to the losses in the range $\left(\delta_A, \bar{\delta}'\right)$.[5] However, this firm can always be driven out of the market by a new competitor that locates on the exact same location and sets a price $\tilde{q}' - \epsilon$ in the range $\left(\delta_A, \bar{\delta}\right)$ and $\tilde{q}$ in the range beyond $\bar{\delta}$.[6] Since this firm does not have to cross-subsidize selling to industries in the range $\left(\bar{\delta}, \bar{\delta}'\right)$ it can therefore charge a lower price in the range $(0, \delta_A)$ and still make zero profits. Hence, this new firm captures the entire market width in the range $\left(0, \bar{\delta}\right)$ and the old supplier has to exit. This mechanism always works if a firm tries to increase its market width by cross-subsidizing. The only form of cross-subsidizing that is not ruled out by free entry is a form of cross-subsidzing that has no impact on profits and no impact on the market width. This is essentially a trivial cross-subsidizing, and we assume that it does not occur.

With free entry, all income is labor income, so that $I = wL$ (L denotes the economy's endowment with labor). Hence, (18) can be expressed as

$$f + cQ = 2\delta\alpha L. \tag{20}$$

Equation (20) ensures that the costs incurred in the production of the intermediate goods are covered by the expenditures of consumers. Therefore, we will refer to this condition as the product market clearing condition ($PMCC$).

[5] If cross-subsidizing leads to profits, it is always possible for a new entrant to undercut the indigenous firm and still make non-negative profits. Thus, profit-enhancing cross-subsidizing is never viable.

[6] The parameter ϵ denotes an infinitesimal small price reduction.

3.4 The Industry Equilibrium: Firm Size and Market Width

3.4.1 Industry Equilibrium in the IP Regime

In the IP regime, the industry equilibrium is determined by (15), (19) and (20). We combine (15) and (19) to

$$a(\delta)\left(\frac{f}{Q}+c\right)=m. \tag{21}$$

This equation describes the market width of a flexible supplier for a given output in the IP regime. We now have two equations (20 and 21) in Q and δ and the industry equilibrium can be illustrated graphically in a $Q-\delta$ diagram. This is illustrated in figure 3, where the curve based on equation (21) is indicated as $MW|_{IP}$ (Market Width IP). Clearly, the $PMCC$ is linear in Q and δ, and the δ-axis intercept is at $\delta|_{Q=0}=\frac{f}{2\alpha L}$. The shape of the $MW|_{IP}$ curve is determined by the shape of the adaptation function. If $a'(\delta), a''(\delta)>0$, then $\frac{\partial^2 Q}{\partial\delta^2}>0$, and the $MW|_{IP}$ curve is convex in δ. The Q-axis intercept is at $Q|_{\delta=0}=\frac{f}{(m-c)}$ (Note that $a(0)=1$). This implies that there exist three possible outcomes for the industry:

1. No solution if the $PMCC$ lies completely beneath the $MW|_{IP}$.
2. One single solution if the $PMCC$ lies tangent to the $MW|_{IP}$.
3. Two solutions if the $PMCC$ intersects the $MW|_{IP}$ from below.

Figure 3 *The industry equilibrium in the IP regime.*

Only the second intersection in case 3 provides a stable industry equilibrium. As the $PMCC$ determines demand for a given market width and the $MW|_{IP}$ provides the market width for a given output, a stable equilibrium requires that the slope of the $MW|_{IP}$ is steeper than the slope of the $PMCC$ in equilibrium. This is indicated by the arrows in figure 3. The slopes of the two curves are given by

$$\left.\frac{\partial Q}{\partial\delta}\frac{\delta}{Q}\right|_{PMCC}=\frac{f+cQ}{cQ}>0 \tag{22}$$

for the $PMCC$ and

$$\left.\frac{\partial Q}{\partial\delta}\frac{\delta}{Q}\right|_{MW}=\frac{\varepsilon(\delta)\,m}{m-a(\delta)\,c}>0 \tag{23}$$

for the $MW|_{IP}$, where $\varepsilon(\delta)=a'(\delta)\frac{\delta}{a(\delta)}>0$. Then, given (12), (15), (19) and (20), stability requires that $a(\delta)(\varepsilon(\delta)+1)\,c>m$. In addition, the IP regime can only lead to a meaningful solution if $m>c$.

3.4.2 Industry Equilibrium in the FM Regime

In the FM regime, equation (15) is redundant and plays no direct role in the determination of the industry equilibrium. In this case, the industry equilibrium is determined by the $PMCC$ (20), average cost pricing (19), and the first order condition (FOC) of profit maximization for firms. The FOC comes in because the market width of one firms depends on the pricing decisions of the adjacent firms.

Because intermediate goods producers compete in prices, the first order condition (FOC) of profit maximization implies that

$$q = \frac{\partial C}{\partial Q} \frac{\frac{\partial Q}{\partial q}\frac{q}{Q}}{\left(1 + \frac{\partial Q}{\partial q}\frac{q}{Q}\right)}. \tag{24}$$

Marginal costs can be derived from (8): $\frac{\partial C}{\partial Q} = wc$. For the price elasticity of demand, $\frac{\partial Q}{\partial q}\frac{q}{Q}$, we draw on (18):

$$\frac{\partial Q}{\partial q}\frac{q}{Q} = -1 + \frac{\partial \delta}{\partial q}\frac{q}{\delta}. \tag{25}$$

The first term on the right hand side refers to the intensive margin. It describes how the market depth adjusts to changes in the price of the intermediate good. With Cobb-Douglas preferences, this must be -1. The second term $\left(\frac{\partial \delta}{\partial q}\frac{q}{\delta}\right)$ on the right hand side describes adjustments of the extensive margin, i.e. changes in the market width. The size of this effect can be derived from the partial derivatives of either (13) or (14):

$$\frac{\partial \delta}{\partial q}\frac{q}{\delta} = -\frac{1}{2}\frac{1}{\varepsilon(\delta)}. \tag{26}$$

Clearly, the market width must fall when a supplier raises the price for the base product: $\frac{\partial \delta}{\partial q}\frac{q}{\delta} < 0$.

The FOC can then be written as

$$q = wc\left(1 + 2\varepsilon(\delta)\right). \tag{27}$$

The equilibrium is determined by equations (19), (20), and (27). The free entry first order condition as determined by (19) and (27) yields

$$Q = \frac{f}{2\varepsilon(\delta)\, c}. \tag{28}$$

The $PMCC$ (20) and the free entry FOC (28) determine the industry equilibrium in the FM regime. Again, the industry equilibrium can be illustrated graphically in a $Q - \delta$

diagram. This is illustrated in figure 4. The slopes of the $PMCC$ and the FOC are given by (22) and (29):

$$\left.\frac{\partial Q}{\partial \delta}\frac{\delta}{Q}\right|_{FOC} = -\eta\left(\delta\right), \tag{29}$$

where $\eta\left(\delta\right) = \varepsilon'\left(\delta\right)\frac{\delta}{\varepsilon(\delta)}$. We assume that $\varepsilon'\left(\delta\right) > 0$, so that $\eta\left(\delta\right) > 0$ and $\left.\frac{\partial Q}{\partial \delta}\frac{\delta}{Q}\right|_{FOC} < 0$.[7]

Figure 4 *The industry equilibrium in the FM regime*

The FM regime requires that the effective price paid by the marginal industry is below the unit costs of in-house production. Hence, the FM regime is only sustainable if $a\left(\delta\right)\left(1+2\varepsilon\left(\delta\right)\right)c < m$.

3.5 The Choice of Technology and the Vertical Equilibrium

Having described the industry equilibrium for alternative forms of vertical organization, we need to determine the vertical equilibrium now. The discussion above showed that a stable equilibrium in the IP regime requires that $a\left(\delta\right)\left(\varepsilon\left(\delta\right)+1\right)c > m$ and the FM regime is only sustainable if $a\left(\delta\right)\left(1+2\varepsilon\left(\delta\right)\right)c < m$. These conditions are illustrated in the upper part of figure 5. The IP regime requires that $\delta > \delta'$ and the FM regime requires that $\delta < \delta''$.

Figure 5 *The vertical equilibrium*

The lower part of figure 5 includes both figures 3 and 4. It illustrates that at δ' the $PMCC$ lies just tangent to the $MW|_{IP}$ if $L = L'$.[8] Furthermore, this figure shows that there is also a particular size of the economy L'' that corresponds to the critical level δ'' in the FM regime. Hence, the vertical structure of the economy depends on its size. We can differentiate between three cases:

1. If $L < L'$, then there is no flexible manufacturing and all downstream firms rely solely on in-house sourcing.

2. If $L' < L < L''$, then both forms of organization co-exist and the industry equilibrium is governed by the IP regime.

3. If $L'' < L$, then there is no in-house production and all downstream firms rely on external procurement and flexible manufacturing (FM regime).

[7] Take the following example: If $a = \left(1+\delta\right)^b$, where $b > 1$, then $\varepsilon = \frac{\delta}{1+\delta}b > 0$ and $\varepsilon' = \frac{b}{(1+\delta)^2} > 0$.

[8] It follows from (22) and (23) that if $m = ca\left(\delta\right)\left[\varepsilon\left(\delta\right)+1\right]$, then $\left.\frac{\partial Q}{\partial \delta}\frac{\delta}{Q}\right|_{PMCC} = \left.\frac{\partial Q}{\partial \delta}\frac{\delta}{Q}\right|_{MW}$.

3.6 The Labor Market Equilibrium and Firm Entry

Demand for labor consists of demand for flexible manufacturing and demand for in-house production. The final assembly is performed costlessly, so that downstream firms are best thought of as organization entities instead of actual production facilities. The labor market clears when $Nl_j + Ml_i = L$, where N is the number of flexible manufacturers, l_j denotes labor requirements for flexible manufacturing, M is the mass of industries relying on in-house production, and l_i denotes labor requirements for in-house production. As before, L stands for the endowment with labor. Using (1), (7), (9), (11), (16), (17), $I = wL$, and (20), the labor market clearing condition can be expressed as

$$N2\delta + M = \Omega. \tag{30}$$

In this form, the labor market clearing condition also expresses the fact that, in equilibrium, all industries (Ω) are either serviced by flexible manufacturers ($N2\delta$) or produce their inputs in-house (M).

The real wage can be calculated by using a price index for final goods. As the various downstream industries produce their goods with different technologies and productivities, prices of final goods differ, too. The price index for final goods is defined as

$$\tilde{p} = \frac{2\delta N\bar{p} + Mmw}{\Omega}, \tag{31}$$

where $\bar{p} = q\bar{a}(\delta)$ is the average price for inputs purchased from flexible manufacturers and $\bar{a}(\delta) = \frac{1}{\delta}\int_0^\delta a(i)\, di$ denotes the average adaptation costs for these inputs. With average cost pricing (19) and labor market clearing (30) we can express the inverse of the real wage as

$$\frac{\tilde{p}}{w} = \left(1 - \frac{M}{\Omega}\right)\bar{a}(\delta)\frac{q}{w} + \frac{M}{\Omega}m. \tag{32}$$

Equation (32) shows that the real wage is the inverse of a weighted average of two terms. The first term on the right hand side is the average unit labor requirement for downstream goods produced through flexible manufacturing and the second term is the unit labor requirement of in-house production. Both terms are weighed with the relative mass of industries applying the respective technology. In the FM regime, where $M = 0$, this expression is simply $\frac{\tilde{p}}{w} = \bar{a}(\delta)\frac{q}{w}$.

The number of flexible manufacturers N can be determined using the horizontal dimension of the free entry condition mentioned earlier. The circumference of the circle, Ω, can be interpretated as the entire market potential. Within this potential, each supplier tries to find its market niche. This niche is a segment on the circle where it can reach the equilibrium market width 2δ. New suppliers will enter as long as they are able to find their market niche.

As figure 5 illustrates there are two distinct equilibria. Therefore, we need to distinguish between entry in the FM regime and entry in the IP regime.

3.6.1 Entry in the FM regime

In the FM regime, flexible manufacturers compete directly against other flexible manufacturers. In a symmetric equilibrium, this means that there cannot be any industry relying on in-house production anywhere on the circle. Hence, $M = 0$. In this regime, entry occurs as long as the market potential for one more firm $\left(\frac{\Omega}{N+1}\right)$ is at least as large as the optimal market width $2\delta^{FM}$ necessary to break even. Then, a free entry equilibrium requires that

$$\frac{\Omega}{N} \leq 2\delta^{FM} < \frac{\Omega}{N+1}. \tag{33}$$

As the FM regime is only sustainable for small values of δ^{FM} $\left(\delta^{FM} \leq \delta'\right)$, and thus implies a large number of firms, the number of firms can be approximated by[9]

$$N = \frac{\Omega}{2\delta^{FM}}. \tag{34}$$

3.6.2 Entry in the IP regime

In the IP regime, the market width is given by $\delta = \delta^{IP}$. In this case, flexible manufacturers enter as long as the "unpenetrated market potential" (M) is at least as large as the optimal market width $2\delta^{IP}$. Here, a free entry equilibrium requires that

$$M < 2\delta^{IP} < \frac{\Omega}{N+1}. \tag{35}$$

The number of flexible manufacturers is then determined by

$$N = \text{integer}\left(\frac{\Omega}{2\delta^{IP}}\right) \tag{36}$$

and the level of in-house production by

$$M = \Omega - 2\delta^{IP}\,\text{integer}\left(\frac{\Omega}{2\delta^{IP}}\right). \tag{37}$$

[9] The true number of suppliers is determined by $N = \text{integer}\left(\frac{\Omega}{2\delta^{FM}}\right)$ and the true market width is $\delta = \varphi\delta^{FM}$, where $\varphi \in \left[1, \frac{\Omega}{\Omega - 2\delta^{FM}}\right)$. As δ^{FM} is small $\left(\delta^{FM} \leq \delta'\right)$, $\varphi \approx 1$, $\delta \approx \delta^{FM}$ and $N \approx \frac{\Omega}{2\delta^{FM}}$.

The integer constraint performs an important function in the determination of the level of in-house production because the IP regime is characterized by large market widths and small number of firms. Hence, the mass of industries relying on in-house production can be substantial. Therefore, we cannot disregard the integer constraint. According to (35), the mass of industries relying on in-house production lies in the range $M \in \left[0, 2\delta^{IP}\right)$.

Two parameters will be helpful in the characterization of the equilibrium. First, $\breve{M} = 2\delta^{IP}$ describes the upper bound of in-house production. Second, without further knowledge about the exact numerical solution of $\frac{\Omega}{2\delta^{IP}}$, all solutions within the interval $\left[0, 2\delta^{IP}\right)$ are equally probable *ex ante*. Hence, the "expected" mass of in-house production, denoted by $\tilde{M}$, is simpliy $\tilde{M} = \frac{1}{2}\breve{M} = \delta^{IP}$.

Note that the integer constraint has no impact on the vertical dimension of the free entry condition. No matter how many suppliers are competing side by side, all of them also compete against a potential competitor at their very own location. Hence, prices continue to be capped by average costs.

Both equations (34) and (36) illustrate that there is a negative relation between the flexibility in manufacturing and the number of suppliers in equilibrium. This is a well know result in the IO literature on flexible manufacturing (e.g., Norman and Thisse, 1999). The higher is the flexibility in manufacturing, the larger is the range of industries serviced by a single supplier, and the smaller is the number of supplier that can reach the equilibrium market width for a given mass of downstream industries.

4 International Trade

Suppose there are Ψ countries, which are identical in all respects except size to the country described above. Now assume that these countries switch from autarky to free trade with no trade costs. In the free trade equilibrium firms in all countries operate with identical technologies ($a(\cdot)$, c and f) in a larger, integrated market. Hence, the new equilibrium on the world market is characterized not only by symmetry within a country, but also by symmetry across countries. Suppliers in all trading countries are of equal size and market width.

International trade integrates product markets while national factor markets remain separated. Expenditures for final goods rise from $\alpha w^j L^j$ in country j to $\alpha \sum_{i=1}^{\Psi} w^i L^i$ in the world market. Similarily, the new product market clearing conditions for base products in country j are given by

$$w^j (f + cQ) = 2\delta\alpha \sum_{i=1}^{\Psi} w^i L^i, \tag{38}$$

First of all, equation (38) implies an equalization of wages because Q and $\sum_{i=1}^{\Psi} w^i L^i$ are identical for all countries. Then, equation (38) can be expressed as a single $PMCC$ for all countries:

$$(f + cQ) = 2\delta\alpha \sum_{i=1}^{\Psi} L^i. \tag{39}$$

International trade increases the size of the market for all countries $\left(\Delta L^j = \sum_{i=1}^{\Psi} L^i - L^j > 0\right)$. In our figures, international trade turns national $PMCC$s outwards around $\delta = 0$. This is our trade shock. We will now analyze the impact of trade on firm size, market width, form of vertical organization, firm entry and the real wage for the FM regime, the IP regime, and the case where international trade leads to a switch in regimes.

4.1 Trade in the FM regime

In the FM regime, all industries are serviced by flexible manufacturing. The industry equilibrium in the integrated market is determined by (28) and (39). International trade leads to an outward shift of the $PMCC$ in figure 4. This outward shift leads to an increase in firms size and reduces the equilibrium market width.

The comparative statics of an increase in L confirm these results:

$$\frac{\partial \delta}{\partial L}\frac{L}{\delta} = -\frac{f + cQ}{f + cQ\left(1 + \eta\left(\delta\right)\right)} < 0 \tag{40}$$

and

$$\frac{\partial Q}{\partial L}\frac{L}{Q} = \frac{\left(f + cQ\right)\eta\left(\delta\right)}{f + cQ\left(1 + \eta\left(\delta\right)\right)} > 0. \tag{41}$$

The impact on the number of suppliers is straightforward from equation (34). When δ falls, the number of suppliers N clearly rises:

$$\frac{\partial N}{\partial L}\frac{L}{N} = -\frac{\partial \delta}{\partial L}\frac{L}{\delta} > 0. \tag{42}$$

The impact on the real wage can be calculated from $\frac{\tilde{p}}{w} = \bar{a}\left(\delta\right)\frac{q}{w}$ and (27):

$$\frac{w}{\tilde{p}} = \left[\bar{a}\left(\delta\right)c\left(1 + 2\varepsilon\left(\delta\right)\right)\right]^{-1}, \tag{43}$$

so that

$$\frac{\partial\left(\frac{w}{\tilde{p}}\right)}{\partial L}\frac{L}{\left(\frac{w}{\tilde{p}}\right)} = -\left(\frac{a\left(\delta\right) - \bar{a}\left(\delta\right)}{\bar{a}\left(\delta\right)} + \frac{f\eta\left(\delta\right)}{f + cQ}\right)\frac{\partial \delta}{\partial L}\frac{L}{\delta} > 0. \tag{44}$$

Hence, a fall in δ leads unambiguously to an increase in the real wage $\frac{w}{\tilde{p}}$. This impact consist of two effects. The first effect, expressed by the first term in the parentheses on the right hand side of (44), indicates that as δ falls, average adaptation costs also fall. At the same time, the size of suppliers rises and they move down their average cost curves, so that the price of the base product also falls and $\frac{q}{w}$ decreases. This is the second effect in (44). Both effects tend to reduce the price index for downstream goods and increase derived demand for labor, so that the real wage rises.

Many of the results in this section are similar to the findings reported in Ethier (1982). The larger market in the integrated world supports a larger number of suppliers, but these new suppliers are now more specialized. However, specialization has a slightly different meaning in this setup. Here, suppliers are selling to a smaller range of industries compared to firms adding a smaller fraction to the value of downstream goods in Ethier's framework. In addition, international trade leads to an increase in (average) productivity in both frameworks. But whereas this increase is implicitly assumed in Ethier's production function, this framework provides a microeconomic explanation for the rise in productivity. Because the productivity of an input is inversely correlated with its adaptation costs, average productivity rises when average adaptation costs fall.

4.2 Trade in the IP regime

In the IP regime, the industry equilibrium is determined by (21) and (39). The outward shift of the $PMCC$ leads to an increase in firms size *and* equilibrium market width in figure 3.

The respective results of the comparative static analysis are

$$\frac{\partial Q}{\partial L}\frac{L}{Q} = \frac{\varepsilon(\delta)\,a(\delta)}{(\varepsilon(\delta)+1)\,a(\delta)\,c - m}\left(\frac{f+cQ}{Q}\right) > 0 \tag{45}$$

and

$$\frac{\partial \delta}{\partial L}\frac{L}{\delta} = \frac{a(\delta)\,(m - a(\delta)\,c)}{(\varepsilon(\delta)+1)\,a(\delta)\,c - m}\left(\frac{f+cQ}{mQ}\right) > 0. \tag{46}$$

The elasticities can be signed because $(\varepsilon(\delta)+1)\,a(\delta)\,c > m$.

The result with respect to the impact on the market width is fundamentally different from the impact in the FM regime. In the FM regime, the market width falls because the integrated market supports a larger number of suppliers. In the IP regime, however, suppliers are not competing against other suppliers but against in-house production. Hence, the market width is determined by the relative costs of flexible manufacturing vis-à-vis in-house production. International trade brings about an increase in the size of suppliers, so that average costs in the production of the base product fall. On the other hand, unit costs of in-house production are constant (m). Therefore, external procurement becomes more attractive to downstream industries at the margin and the market width of suppliers using flexible manufacturing rises.

The increase in δ implies that the upper bound of in-house production $\left(\breve{M} = 2\delta\right)$ and its "expected" mass $\left(\tilde{M} = \delta\right)$ clearly rise. But the impact of an incremental increase in L on the number of suppliers N and the exact mass of industries relying on in-house production M is not calculable because equations (36) and (37) are not continuous. However, we can derive some results regarding the absolute changes. First, we can show that the number of suppliers cannot rise. The free entry equilibrium (35) requires that $N + 1 < \frac{\Omega}{2\delta}$, and the right hand side of this inequality falls. Furthermore, from (30) we obtain $2\delta\frac{\Delta N}{\Delta L} + 2N\frac{\Delta\delta}{\Delta L} = -\frac{\Delta M}{\Delta L}$, where Δ denotes an absolute change. Hence, if $\frac{\Delta N}{\Delta L} = 0$, then $\frac{\Delta M}{\Delta L} = -2N\frac{\Delta\delta}{\Delta L} < 0$. If N remains constant, M clearly falls. However, since $M \geq 0$, this case is limited to $M + \frac{\Delta M}{\Delta L} \geq 0$, i.e. to $\frac{\Delta\delta}{\Delta L} \leq \frac{M}{2N}$. If $\frac{\Delta\delta}{\Delta L} > \frac{M}{2N}$, then N must fall $\left(\frac{\Delta N}{\Delta L} < 0\right)$. In this case, the change in M is ambiguous: $-\frac{\Delta M}{\Delta L} = \underbrace{2\delta\Delta N/\Delta L}_{-} + \underbrace{N2\Delta\delta/\Delta L}_{+}$.

The change in the mass of industries relying on in-house production is an important feature of this model. If M falls, this indicates that more downstream industries are sourcing their inputs through independent suppliers. We refer to this process as outsourcing. A fall in M also indicates an increase in the diffusion of flexible manufacturing. In contrast to outsourcing, an increase in M implies an increase in in-house production. This is referred to as insourcing. The ratio of M/N depends on two effects (see equation 30):

$$\frac{M}{N} = \left(\frac{N}{\Omega}\right)^{-1} - 2\delta. \tag{47}$$

The first term on the right hand side of (47) denotes the market thickness in the market for intermediate goods. In a spatial setup, an increase in N is not just an increase in competition, it provides downstream firms with a larger range of base product characteristics to choose from. *Ex ante*, downstream firms are then more likely to find a base product whose effective price is lower than the costs of in-house production.[10] Hence, an increase in market thickness tends to increase outsourcing. The second term on the right hand side of (47) is the market width of flexible manufacturing. If the market width rises, a single supplier can reach more industries. Therefore, an increase in the market width also tends to increase outsourcing.

Our results illustrate that within the IP regime, there is no clear answer to the question of whether international trade favors outsourcing or in-house production. On one hand,

[10] This definition of market thickness builds on McLaren (2000, 2003).

international trade leads to an increase in the market width of flexible suppliers. This "market width effect" tends to favor outsourcing. On the other hand, the increase in the market width can lead to a fall in the number of suppliers N (market thickness effect). This entry-deterring effect of flexible manufacturing can lower the market thickness and, thereby, favor in-house production.

The ambiguity in determining the impact on the number of upstream producers also affects the impact on the real wage. Using (17), the real wage as given by (32) can be written as $\frac{w}{\tilde{p}} = \left[(1-\alpha M)\,\bar{a}\left(\delta\right)\frac{q}{w} + \alpha M m\right]^{-1}$. The impact of international trade on the real wage can be divided into three effects. First, just like in the FM regime, $\frac{q}{w}$ falls as the size of upstream firms rises. The fall in average production costs for the base product clearly tends to increase the real wage. The second effect differs between the regimes. As δ rises in the IP regime, average adaptation costs rise, too. This tends to lower the real wage. And finally, since average costs of in-house production are higher than average costs in flexible manufacturing, the real wage is affected by the relative mass of industries relying on in-house procurement.

The first two effects can be summarized in the change in the effective unit labor requirements of flexible manufacturing. Using $\frac{\bar{p}}{w} = \bar{a}\left(\delta\right)\frac{q}{w}$ from (31), so that $\frac{\tilde{p}}{w} = (1-\alpha M)\frac{\bar{p}}{w} + \alpha M m$, the relative change in the real wage can be expressed as a weighed average of the impact on the effective unit labor requirements of flexible manufacturing and the relative change in the mass of industries using in-house production.

$$\frac{\partial\left(\frac{w}{\tilde{p}}\right)}{\partial L}\frac{L}{\frac{w}{\tilde{p}}} = -\lambda\frac{\partial\left(\frac{\bar{p}}{w}\right)}{\partial L}\frac{L}{\left(\frac{\bar{p}}{w}\right)} - (1-\lambda)\,\tilde{m}\frac{\partial M}{\partial L}\frac{L}{M}, \tag{48}$$

where $\lambda = \frac{(1-\alpha M)\bar{a}(\delta)\frac{q}{w}}{(1-\alpha M)\bar{a}(\delta)\frac{q}{w}+\alpha M m}$ and $\tilde{m} = \frac{m-\bar{a}(\delta)\frac{q}{w}}{m}$. The latter denotes the average cost disadvantage of in-house production relative to outsourcing.

The first effect can be signed unambiguously. As $\frac{q}{w} = \frac{m}{a(\delta)}$ from (12), we obtain

$$\frac{\partial\left(\frac{\bar{p}}{w}\right)}{\partial L}\frac{L}{\left(\frac{\bar{p}}{w}\right)} = \left[\bar{\varepsilon}\left(\delta\right) - \varepsilon\left(\delta\right)\right]\frac{\partial\delta}{\partial L}\frac{L}{\delta} < 0, \tag{49}$$

where $\bar{\varepsilon}\left(\delta\right) = \bar{a}'\left(\delta\right)\frac{\delta}{\bar{a}(\delta)} < \varepsilon\left(\delta\right)$. Hence, the fall in the average production costs for the base product clearly outweighs the increase in average adaptation costs in its impact on the real wage.

The last effect, the change in M, can be either positive or negative, depending on whether N changes. If the change in δ is too small to trigger adjustments in the number of suppliers N $\left(\Delta\delta \leq \frac{M}{2N}\right)$, then M clearly falls: $\frac{M}{N2\delta}\frac{\partial M}{\partial L}\frac{L}{M} = -\frac{\partial\delta}{\partial L}\frac{L}{\delta} < 0$. In this case, the real wage clearly rises: $\frac{\partial\left(\frac{w}{\tilde{p}}\right)}{\partial L}\frac{L}{\frac{w}{\tilde{p}}}>0$. But if N falls, this effect is ambiguous and we can only derive the impact on the "expected" mass of industries $\tilde{M}=\delta$. The "expected" mass of industries rises $\left(\frac{\partial\tilde{M}}{\partial L}\frac{L}{\tilde{M}}=\frac{\partial\delta}{\partial L}\frac{L}{\delta}>0\right)$, so that this effect tends to lower the "expected" real wage. Then, the impact of international trade on the "expected" real wage is ambiguous. An increase requires that

$$\varepsilon\left(\delta\right)-\bar{\varepsilon}\left(\delta\right)>\frac{\alpha M}{\left(1-\alpha M\right)}\tilde{m}. \tag{50}$$

The "expected" real wage rises if the adaptation function is strongly curved (high $\varepsilon\left(\delta\right)-\bar{\varepsilon}\left(\delta\right)$), if the relative mass of industries relying on in-house production is low (low $\alpha M/\left(1-\alpha M\right)$), and if the relative cost disadvantage of in-house production is small (low $\tilde{m}$).

4.3 Trade and a switch in regimes

International trade affects not only the equilibrium within a particular regime, it can also lead to a switch in regimes. The lower part of figure 5 clearly shows that the vertical organization of firms depends on the size of the economy. As international trade increases the size of the economy, it can also affect the vertical organization within an industry.

Let L^j denote the autarky size of the economy in country j and L^W the size of the world market. In the previous sections we covered the cases where both L^j and L^W fall in the same regimes: $L'<L^j,L^W<L''$ (IP regime) and $L''<L^j,L^W$ (FM regime). In this section we address first the case where $L^j<L'<L^W$ and then the case where $L'<L^j<L''<L^W$.

If $L^j<L'<L^W$, then the size of country j's economy in autarky is too small for flexible manufacturing. All industries rely on in-house sourcing. When this country opens up to trade with other countries, and the world market is large enough to support flexible manufacturing $\left(L'<L^W\right)$, then this country experiences a switch to the IP regime. As a consequence, some industries will switch from in-house procurement to outsourcing.

If $L'<L^j<L''<L^W$, then in autarky country j is governed by regime IP, and an opening up to trade will lead to a switch to the FM regime. In this case, international trade eliminates all in-house production and external procurement becomes the sole form of sourcing. The number of suppliers using flexible manufacturing (N) clearly rises. The market width of flexible suppliers will unambiguously fall, but the impact on the size of these firms is ambiguous. On one hand, the increase in demand brought about by the access to foreign markets tends to increase the output of firms, but on the other hand, the significant fall in the range of industries serviced works in the opposite direction.

The most important result of this section is that if international trade leads to a switch in regimes, it clearly favors outsourcing. Both a switch from no flexible manufacturing to the IP regime as well as a switch from the IP to the FM regime reduces the range of industries relying on in-house production and increases the diffusion of flexible manufacturing.

5 Discussion of Results

This framework provides a number of testable predictions with respect to the impact of international trade. First of all, the framework yields a clear prediction with respect to firm size:

Proposition 1 *International trade leads to an increase in the size of firms in the upstream industry.*

In both regimes, international trade leads to an increase in the size of firms in the upstream industry: $\frac{\partial Q}{\partial L}\frac{L}{Q} > 0$ [see equations (41) and (45)] This result differs from the predictions of the Ethier (1982) framework, and empirical evidence suggests that these size adjustments are indeed taking place (Tybout, 2003).

Second, in our framework we can decompose the impact of international trade on average productivity into the impact on the various components of productivity. Average productivity is given by $A = \frac{1}{\Omega L}\int_0^\Omega X_i di$. With average cost pricing, $A = \frac{w}{\tilde{p}}$. Then, given equations (31), (32) and (48), the relative change in A can be decomposed into three components:

$$\frac{\Delta A}{A} = -(1-\lambda)\,\tilde{m}\frac{\Delta M}{M} - \lambda\left(\frac{\Delta \bar{a}(\delta)}{\bar{a}(\delta)} + \frac{\Delta \frac{q}{w}}{\frac{q}{w}}\right). \tag{51}$$

Equation (51) shows that there are three sources of productivity gains. First, $-\left(\Delta\frac{q}{w}/\frac{q}{w}\right)$ captures gains from economies of scale and scope at the intermediate goods producer level. Second, $-\left(\tilde{m}\Delta M/M\right)$ captures productivity gains from an larger share of outsourcing. Since outsourcing is the more efficient mode of procurement, shifts toward outsourcing increase productivity. And finally, $-\left(\Delta\bar{a}(\delta)/\bar{a}(\delta)\right)$ captures gains from a better availability of intermediate inputs as measured by the fall in average adaptation costs. These three sources of productivity gains correspond to the *scale effect*, the *share effect* and the *residual (or technical efficiency) effect* in Tybout and Westbrook (1995) and Tybout (2003). Our findings yield the following predictions:

Proposition 2 *In the IP regime, the 'scale effect' is positive, the 'share effect' is ambiguous, and the 'residual effect' is negative. The size of the 'scale effect' outweighs the 'residual effect', so that the sum of both effects is positive. In the FM regime, there is no 'share effect'. Both the 'scale effect' and the 'residual effect' are positive.*

The result of a positive scale effect is well documented (Head and Ries, 1999; Tybout, 2003). In contrast to most theoretical studies that rely on a representative firm assumption (e.g. Ethier, 1982), our framework also yields a prediction with regard to the share effect. The discontinuities in the impact of trade on outsourcing imply an ambiguous relation. This theoretical ambiguity could explain some of the difficulties in finding evidence for the existence of a significant share effect in empirical studies (Tybout, 2003). The third effect, often referred to as the residual effect, can be pinpointed to savings in adaptation costs. This is equivalent to an increase in the productivity of inputs. Its sign is unambiguous within each regime, but switches between regimes.

As $A = \frac{w}{\bar{p}}$, the same results apply to the impact of international trade on the real wage. This has important welfare consequences. Our discussion of equations (48), (49) and (50) illustrates that international trade can potentially lead to a *fall* of the real wage through a thinning of upstream markets.

A central result of our study is that international trade can lead to a switch in regimes determining the industry equilibrium. The two regimes can be unambiguously identified by the impact of international trade on the market width of suppliers.

Proposition 3 *The two regimes governing the industry equilibrium can be distinguished by the impact of trade on the range of industries serviced by upstream firms. In the FM regime, the range of industries serviced falls with trade. In the IP regime, the range of industries serviced rises with trade.*

The switch in regimes indicates that globalization can have a more fundamental impact than just a larger trade volume. In our framework it can affect the primary competitors of a supplier. In the IP regime, a supplier using flexible manufacturing competes primarily against in-house production. Its market width is not limited by industries serviced by other flexible suppliers, but rather by industries using in-house production. In the FM regime, suppliers are competing directly against other suppliers.

A prominent feature of flexible manufacturing in spatial models is that the number of firms is related to their market width. Equations (34) and (36) illustrate that this feature holds in both regimes. Hence, the difference in the impact of trade on δ is mirrowed in the impact of trade on the number of firms:

Proposition 4 *In the FM regime, international trade increases the number of suppliers. Within the IP regime, international trade tends to reduce the number of suppliers.*

Our results with regard to the impact of international trade on outsourcing are summarized in proposition 5:

Proposition 5 *Outsourcing and the diffusion of flexible manufacturing rise, if (a) a switch in regimes occurs, or (b) the market width effect outweighs the market thickness effect. Insourcing and the diffusion of in-house production rise, if the market thickness effect outweighs the market width effect.*

First of all, our results show that the impact of international trade on outsourcing is a matter of the size of the trade shock. If opening up to trade leads to a switch in regimes, it unambiguously favors outsourcing. Furthermore, in the FM regime, international trade has no impact on the diffusion of flexible manufacturing. This result may appear as trivial, since flexible manufacturing and outsourcing are the sole form of organization in the FM regime, but this result also implies that once the economy is in the FM regime, international trade will not lead to a re-introduction of in-house production.

Within the IP regime, the impact of a small (marginal) trade shock has ambiguous effects regarding the vertical form of organization. The change in in-house production is $\frac{\Delta M}{\Delta L} = -\frac{2\delta N}{L}\left(\frac{\Delta N}{\Delta L}\frac{L}{N} + \frac{\Delta \delta}{\Delta L}\frac{L}{\delta}\right)$. As $\frac{\Delta N}{\Delta L}\frac{L}{N} \leq 0$ (the market thickness effect) and $\frac{\Delta \delta}{\Delta L}\frac{L}{\delta} > 0$ (the market width effect), the impact of trade on in-house production depends on whether $\left|\frac{\Delta N}{\Delta L}\frac{L}{N}\right| \gtreqless \left|\frac{\Delta \delta}{\Delta L}\frac{L}{\delta}\right|$.

Our results provide interesting insights into how international trade can affect the vertical organization of industries. It also provides an astonishing analogy to Ethier's (1979) paper. There, Ethier argued that scale economies resulting from an increased division of labor depend at an aggregate level upon the size of the world market rather than upon geographical concentration of the industry. Here, we see that the same is true for economies of scope and for the vertical organization of firms. The industry equilibrium is determined by the size of the world market rather than national markets.

Finally, our framework provides an interesting theory for waves of outsourcing and insourcing:

Corollary 1 *If globalization increases the size of the world market continuously, it will lead to waves of outsourcing and insourcing. The magnitude of these waves is increasing within the IP regime. These waves (as well as all in-house production) disappear when the world economy switches to the FM regime.*

Corollary 1 is based upon equation (37). This equation has points of discontinuity whenever $\frac{\Omega}{2\delta} \in \mathbb{N}^+$. In between these points of discontinuity, i.e. when $\frac{\Omega}{2\delta} \notin \mathbb{N}^+$, the impact of an increase in L on M is clearly negative $\frac{\partial M}{\partial L} = \frac{\partial M}{\partial \delta}\frac{\partial \delta}{\partial L} < 0$. At $\frac{\Omega}{2\delta} \in \mathbb{N}^+$, an increase in L leads to a fall in the equilibrium number of firms, so that there is a upward jump in the function $M(L)$. The magnitude of this jump is given by $\frac{\partial M}{\partial N} = 2\delta = \breve{M}$. Hence, the functional relation between M and L is given by a decreasing function in ranges where $\frac{\Omega}{2\delta} \notin \mathbb{N}^{+}$ and upward jumps whenever $\frac{\Omega}{2\delta} \in \mathbb{N}^{+}$. The magnitude of these upward jumps is clearly increasing in L $\left(\frac{\partial \check{M}}{\partial L} > 0\right)$.

Now assume that globalization leads to a series of incremental increases in the world market. This assumption is not meant as a dynamic interpretation of a static model. Instead, it is meant as a series of comparative static analyses, with no particular reference to time. Each upward shift can then be interpreted as a wave of insourcing (M rises as L increases) and the sections between these jumps can be interpreted as waves of outsourcing (M falls as L rises). In this sense, globalization can lead to alternating waves of outsourcing and insourcing. And as $\frac{\partial \check{M}}{\partial L} > 0$, the magnitude of these waves is increasing. However, in the long-run, outsourcing will prevail. These waves, as well as all in-house production, disappear when the economy switches to the FM regime.

6 Concluding Remarks

The present paper sets out to explain the impact of international trade on the diffusion of flexible manufacturing and the vertical equilibrium. The idea behind the framework is that an industry's mode of procuring inputs is determined by the trade-off between economies of scope in flexible manufacturing and the specificity of in-house production. In general equilibrium, this trade-off can be affected by international trade. We show that this framework yields a number of plausible and testable predictions which are in line with recent empirical and casual evidence.

The description of international trade in intermediate goods based on the spatial model of product differentiation provides insights complementary to the popular Ethier (1982) framework. The focus of the two approaches is different. The Ethier model is based on Dixit's and Stiglitz's (1977) "love of variety" approach and assumes that each supplier services only one industry. Consequently, the point of view is from the downstream firm and the analysis provides insights into how many suppliers are involved in the production of a single final good. In the spatial model each final goods assembler employs only one intermediate good. Hence, the point of view is from the upstream firm and our analysis puts an emphasis on the determination of the number of final goods industries serviced by a single supplier. Reality is somewhere in between these two worlds, and both models contribute to a better understanding of the whole picture.

7 Acknowledgments

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Figures

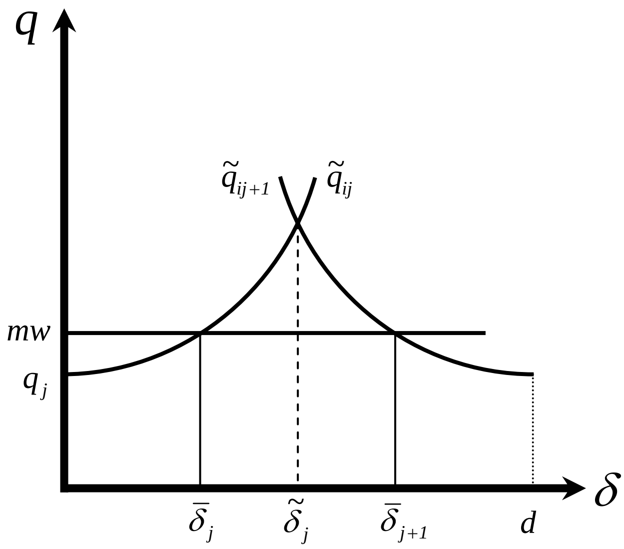

Figure 1.a:
Market width in the *IP* regime

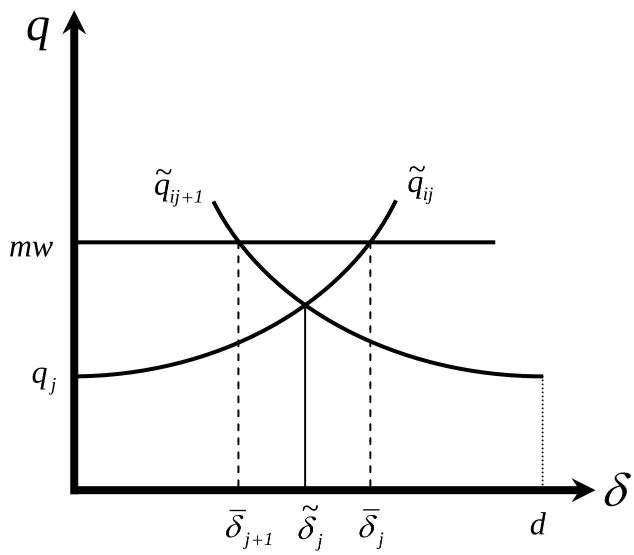

Figure 1.b:
Market width in the *FM* regime

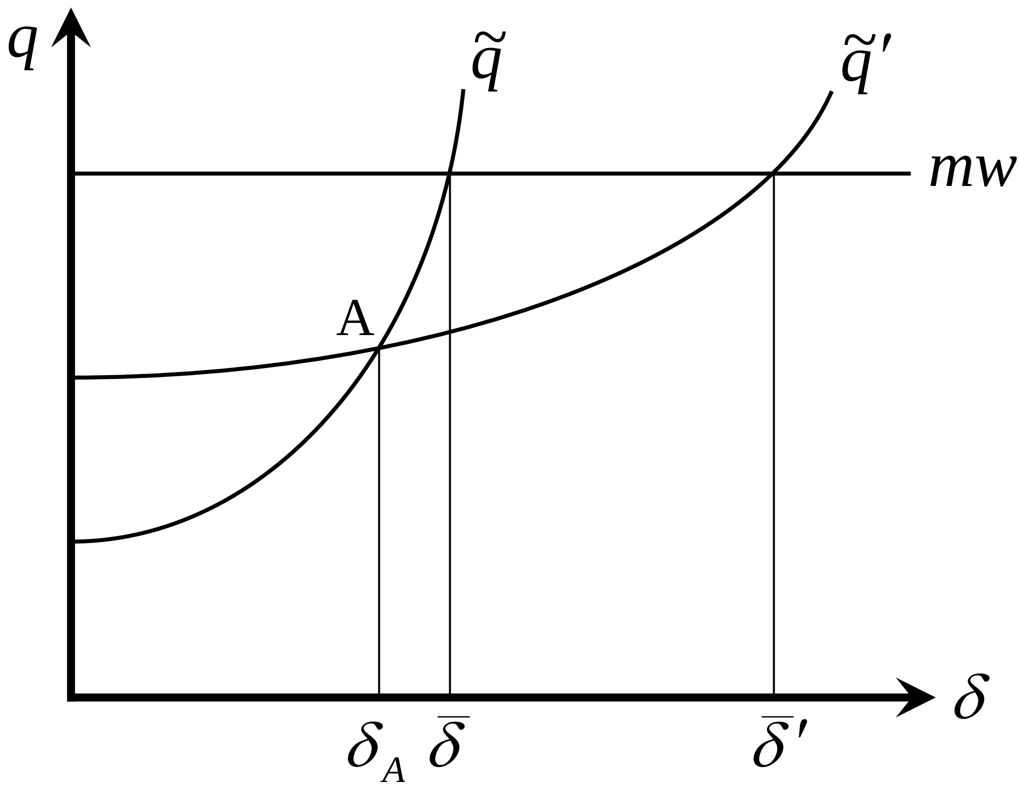

Figure 2: Cross-subsidizing in the *IP* regime

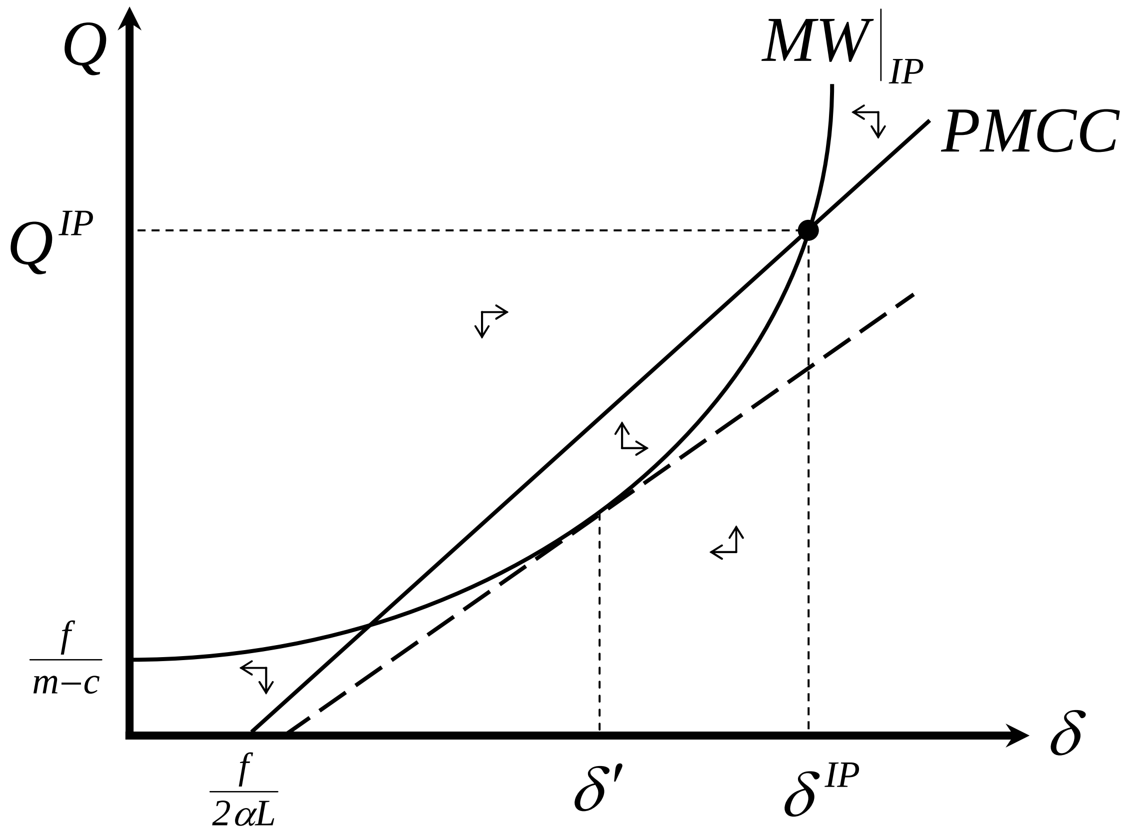

Figure 3: The industry equilibrium in the *IP* regime

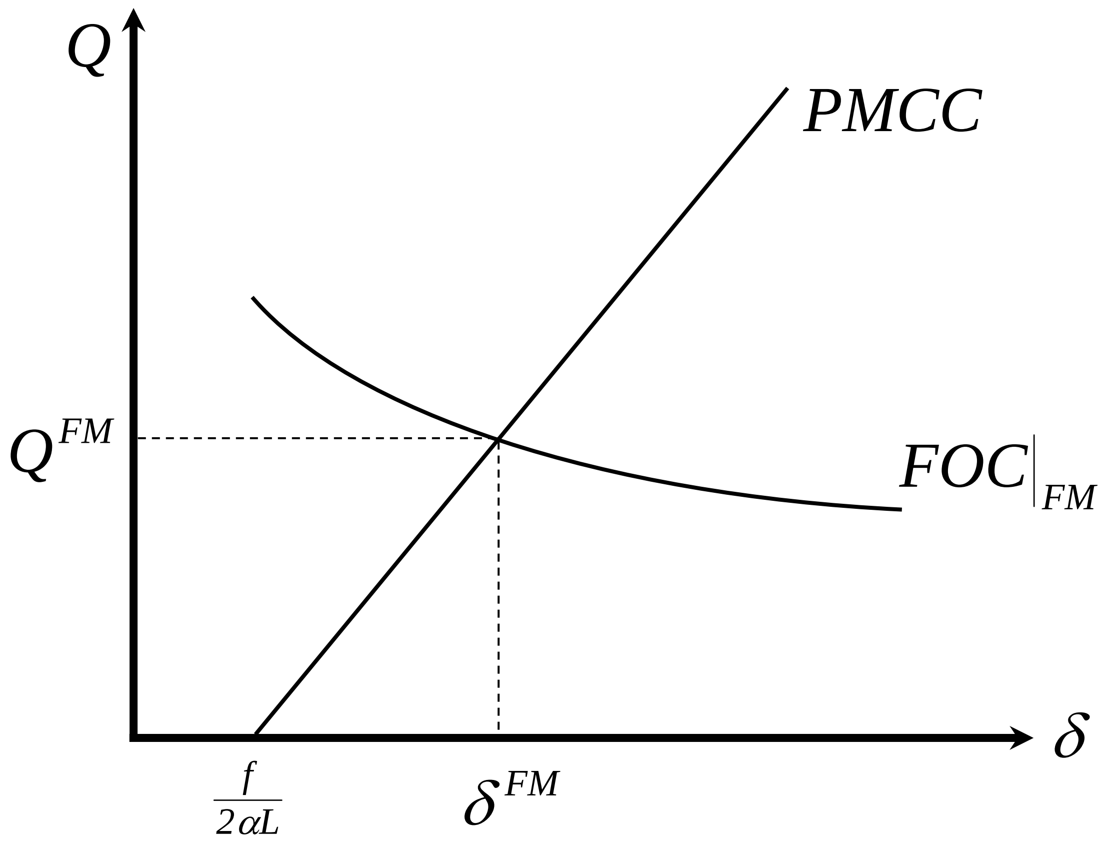

Figure 4: The industry equilibrium in the *FM* regime

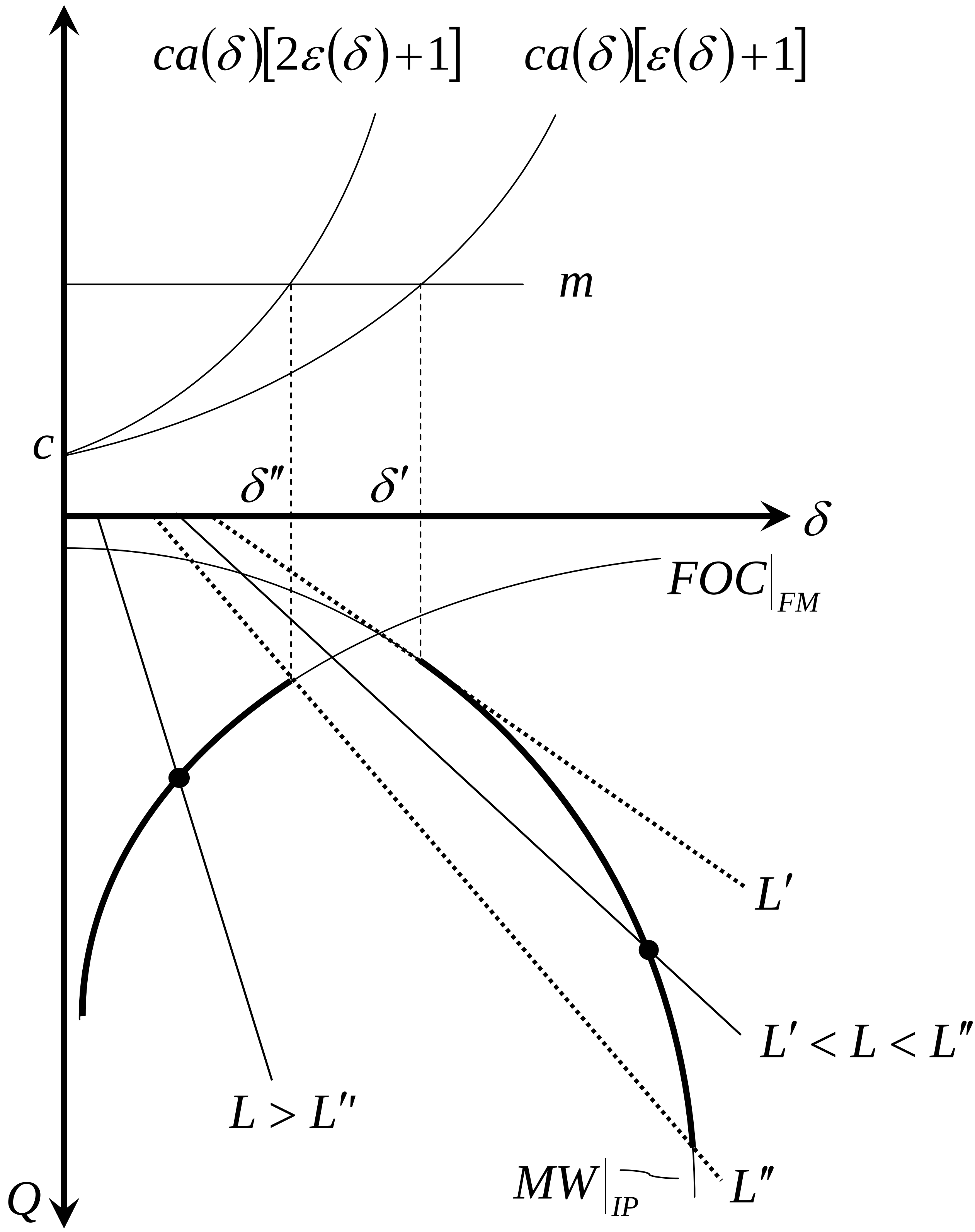

Figure 5: The vertical equilibrium

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