

# International Trade, Flexible Manufacturing and Outsourcing\*

Carsten Eckel<sup>†</sup>  
Department of Economics  
University of Göttingen

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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 variety 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. International trade increases the number of flexible suppliers but reduces the range of industries serviced so that the impact on the diffusion of flexible manufacturing is ambiguous. Globalization can lead to alternating waves of insourcing and outsourcing.

*Keywords:* International Trade, Flexible Manufacturing, Outsourcing, Globalization, General Equilibrium

*JEL classification:* F12, L11, L22

## 1 Introduction

International trade in intermediate goods is an important feature of globalization. Fragmentation and specialization both within countries as well as between countries are the driving forces behind the increase in trade flows of intermediate goods, parts, and components as well as the rise in cross-border business-to-business services. Not surprisingly, the causes and consequences of international trade in intermediate goods have received a lot of attention in the economics profession, and some of the studies have not only addressed questions of international trade, but also contributed to a better understanding of related issues of industrial organization, economic geography, or economic growth.

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<sup>†</sup>Department of Economics, University of Göttingen, D-37073 Göttingen, Germany, Phone: [+49] (551) 39-7298, Fax: [+49] (551) 39-2054, Email: carsten.eckel@wiwi.uni-goettingen.de

Today, our perception of the issues involved in the global division of labor are shaped to a large extent by Ethier's (1979, 1982) contributions. He 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). He provided a powerful tool in the form of a production function that exhibits increasing returns to scale in the number of intermediate goods suppliers. His framework has subsequently been applied to a number of related issues.<sup>1</sup>

But the Ethier framework disregards one important aspect of modern manufacturing: Manufacturing flexibility. 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 decade (Gerwin, 1993; Mansfield, 1993; Norman and Thisse, 1999).

Flexible manufacturing can also affect the vertical structure 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. 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 this paper we will introduce a simple framework that allows us to study the impact of international trade in intermediate goods on flexible manufacturing in upstream industries. Our model features the observed increase in the use of flexible manufacturing systems and shows that international trade can be a cause for their diffusion. We also show that there are two counteracting effects in the determination of the equilibrium industrial structure. On one hand, international trade increases the number of suppliers that use flexible manufacturing. On the other hand, the range of specifications offered by an individual supplier falls. 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).

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

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<sup>1</sup>Influential papers applying Ethier's (1982) framework to related fields include Romer (1987, 1990) in economic growth, Krugman and Venables (1995) in the area of economic geography, and Rodríguez-Clare (1996) in the field of economic development.

on the spatial model of product differentiation á la Hotelling (1929). However, both studies are confined to partial equilibrium in a consumer good industry and do not deal with issues of international trade or issue 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.<sup>2</sup> 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 downstream firms, but again, he does not address the role of flexible manufacturing, either.

In the next section we develop a model of flexible manufacturing in general equilibrium. In our benchmark case flexible manufacturing is the only mode of producing the input requirements for the downstream industry. This case provides general insights into how international trade can affect the structure of an industry characterized by flexible manufacturing. Then, we address the trade-off between flexible manufacturing and in-house procurement and show how international trade can affect the vertical equilibrium and facilitate the diffusion of flexible manufacturing.

## 2 Flexible Manufacturing in General Equilibrium

### 2.1 Production Technology

Flexible manufacturing in intermediate good industries can be characterized by three stylized facts (Gerwin, 1993; Mansfield, 1993; Norman and Thisse, 1999):

1. Final goods industries use heterogeneous technologies that require specific intermediate goods.
2. Standardized inputs can be adapted to a variety of specifications, but adaptation is costly.
3. Upstream firms use flexible manufacturing in order to increase their international competitiveness.

Hence, the starting point of our framework is a continuum of downstream industries all of which require the input of a certain intermediate good. In this respect all of these industries are identical. But each industry requires a particular specification of this intermediate good so that industries are different with respect to the specific type or variety of intermediate good they need. Take

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<sup>2</sup>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.

computer chips for example. All electronic appliances and all goods including 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

$$X_i = \tilde{Q}_i, \quad (1)$$

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

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  $\Omega$ . Consequently, all final goods industries and their respective input requirements are indexed over the interval  $i \in [0, \Omega]$ .

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  $\tilde{q}_i$ :

$$p_i = \tilde{q}_i. \quad (2)$$

We assume that the flexible manufacturing technology is separable into two stages. In the first stage, the manufacturer produces a base product tailored to a particular industry. In the second stage, it adapts this base product to a number of different specifications. Both stages are costly.

The production of the base product requires the input of labor. A flexible manufacturing technology has both fixed and variable cost components. Labor requirements  $l$  for a base product  $Q$  and the respective cost function  $C$  are given by

$$l_j = f + cQ_j, \quad (3)$$

$$C_j = wl_j = w(f + cQ_j), \quad (4)$$

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

Note that (3) and (4) use a new index  $j \in [0, \Omega]$ . The defining feature of flexible manufacturing is that a single intermediate producer services a range of industries. In our framework, a supplier chooses the specifications of its base product first and then adapts this base product to the specifications of other industries. Thus, we have to distinguish between the location of the supplier and the locations of industries serviced. In equation (3), the specifications of the base product  $j$  indicate the address of the supplier on the circle.

The base product is tailored to a particular industry. 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 from an industry's specifications from the base product of a supplier can be described as the shortest arc distance  $\delta$  between the industry's location on the circle and the address of the supplier. Adaptation costs  $a$  can then be described as a rising function of this distance:

$$a = a(\delta). \quad (5)$$

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 [ $a'(\delta) > 0$  and  $a''(\delta) > 0$ ]. 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  $\delta$ , only  $\frac{1}{a(\delta)}$  of this input can be employed in the production process of the final good:

$$\tilde{Q}_i = \frac{Q_{ij}}{a(\delta_{ij})}, \quad (6)$$

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

Similarly, the effective price  $\tilde{q}_i$  charged to industry  $i$  consists of the price for the base product  $q_j$  of supplier  $j$  plus adaptation costs:<sup>3</sup>

$$\tilde{q}_i = a(\delta_{ij}) q_j. \quad (7)$$

We assume that there are no barriers to entry at any stage in the production process. Hence, all prices will be equal to average costs. The price of the base product is then determined by average costs in the production of the base product:

$$q_j = \frac{C_j}{Q_j} = w \left( \frac{f}{Q_j} + c \right). \quad (8)$$

Equations (7) and (8) provide an expression for the effective labor requirements (including adaptation costs) per unit of the final good  $i$ :

$$\frac{\tilde{q}_i}{w} = a(\delta_{ij}) \left( \frac{f}{Q_j} + c \right). \quad (9)$$

The unit labor requirements provide first insights about the flexible manufacturing technology. On one hand, flexible manufacturing allows a supplier to realize economies of scope because unit labor requirements are decreasing in the quantity produced for all industries ( $\frac{\partial \tilde{q}_i}{\partial Q_j} < 0$ ). On the other hand, supplying a larger range of industries also implies higher adaptation costs ( $\frac{\partial \tilde{q}_i}{\partial \delta_{ij}} > 0$ ).

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<sup>3</sup>Note that suppliers are competing in prices, i.e. they set the price for their base product optimally and add adaptation costs. As a result, the base price is identical for all industries:  $q_{ij} = q_j \nabla i$ .

## 2.2 Firm Size and Market Width

The output of the base product of a flexible manufacturer 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 quantity demanded of the base product is given by the integral of individual demand per industry over the entire market width:

$$Q_j = \int_0^{\bar{\delta}_j^l} Q_{ij} di + \int_0^{\bar{\delta}_j^r} Q_{ij} di, \quad (10)$$

where  $(\bar{\delta}_j^l, \bar{\delta}_j^r)$  describes the range of industries serviced.

We can distinguish between a potential market width and an actual market width. The potential market width is determined by the cost advantage of a particular intermediate producer over his immediate competitors to the left and to the right on the circle. Clearly, a particular intermediate producer has a cost advantage for input specifications similar to the specifications of his base product. But as the supplier reaches out to industries located further away on the circle and closer to an adjacent competitor, his own adaptation costs rise while the competitor's adaptation costs fall. The potential market width of a supplier is then determined by the intersection of his own  $\tilde{q}_i$  curve with the  $\tilde{q}_i$  curves of his rivals, both to the right and to the left:

$$q_j a(\tilde{\delta}_j^l) = q_{j-1} a(d_{j-1} - \tilde{\delta}_j^l) \quad (11)$$

and

$$q_j a(\tilde{\delta}_j^r) = q_{j+1} a(d_{j+1} - \tilde{\delta}_j^r), \quad (12)$$

where  $(\tilde{\delta}_j^l, \tilde{\delta}_j^r)$  denotes the potential market width and  $d$  denotes the distance to the adjacent intermediate producers on the left ( $d_{j-1}$ ) and on the right ( $d_{j+1}$ ).<sup>4</sup> The potential market width includes all industries for which a particular supplier has a cost advantage over his competitors.

The actual market width, denoted by  $(\bar{\delta}_j^l, \bar{\delta}_j^r)$ , is then determined by the range of industries actually serviced. In our benchmark case, where flexible manufacturing is the only possible mode of procurement, the actual market width and the potential market width must be identical in equilibrium. Hence,  $\bar{\delta}_j^l = \tilde{\delta}_j^l$  and  $\bar{\delta}_j^r = \tilde{\delta}_j^r$ , and

$$(\bar{\delta}_j^l, \bar{\delta}_j^r) = (\tilde{\delta}_j^l, \tilde{\delta}_j^r). \quad (13)$$

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<sup>4</sup>Note the difference between  $d$  and  $\delta$ : While  $\delta$  measures the distance in specifications between an intermediate producer and a final goods producer,  $d$  denotes the distance between two adjacent intermediate producers. In a symmetric equilibrium, the distance between two adjacent intermediate producers is equal to their potential market width:  $d = 2\tilde{\delta}$ .

Demand per industry  $Q_{ij}$ , 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:

$$X_i = \alpha_i \frac{I}{p_i}. \quad (14)$$

Here,  $X_i$  is demand for final good  $i$ ,  $I$  is income, and  $\alpha_i$  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  $[0, \Omega]$ :

$$\int_0^\Omega \alpha_i di = 1. \quad (15)$$

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 (15) implies  $\alpha = \frac{1}{\Omega}$ .

Equations (1), (2), (10), and (14) now determine demand for  $Q_j$ :

$$Q_j = \frac{\alpha I}{q_j} (\bar{\delta}_j^l + \bar{\delta}_j^r). \quad (16)$$

Intermediate goods producers compete in prices. There are no barriers to market entry or exit, so that there are no profits in equilibrium ( $C_j = q_j Q_j$ ). The first order condition (FOC) of profit maximization with free entry implies

$$\frac{1}{\frac{\partial Q_j}{\partial q_j} \frac{q_j}{Q_j}} + 1 = \frac{\partial C_j}{\partial Q_j} \frac{Q_j}{C_j}. \quad (17)$$

The elasticity of the cost curve,  $\frac{\partial C_j}{\partial Q_j} \frac{Q_j}{C_j}$ , can be derived from (4). For the price elasticity of demand for  $Q_j$ ,  $\frac{\partial Q_j}{\partial q_j} \frac{q_j}{Q_j}$ , we draw on (16). Note that in a symmetric equilibrium  $\bar{\delta}_j^l = \bar{\delta}_j^r = \bar{\delta}_j$ . Hence,

$$\frac{\partial Q_j}{\partial q_j} \frac{q_j}{Q_j} = -1 + \frac{\partial \bar{\delta}_j}{\partial q_j} \frac{q_j}{\bar{\delta}_j}. \quad (18)$$

The first term on the right hand side ( $-1$ ) refers to the intensive margin. It describes how demand from existing customers adjusts to changes in the price of the intermediate good. The second term  $\left(\frac{\partial \bar{\delta}_j}{\partial q_j} \frac{q_j}{\bar{\delta}_j}\right)$  on the right hand side describes adjustments of the extensive margin, i.e. changes in the customer base.

The size of the effect on the extensive margin depends on who the intermediate producers competes with. In a symmetric equilibrium, the elasticity of the actual market width with respect to the price of the intermediate good can be derived from the partial derivatives of either (11) or (12):

$$\frac{\partial \bar{\delta}_j}{\partial q_j} \frac{q_j}{\bar{\delta}_j} = -\frac{1}{2} \frac{a(\bar{\delta}_j)}{\bar{\delta}_j a'(\bar{\delta}_j)} = -\frac{1}{2\varepsilon_{a,\delta}(\bar{\delta}_j)}, \quad (19)$$

where  $\varepsilon_{a,\delta}(\bar{\delta}_j) = a'(\bar{\delta}_j) \frac{\bar{\delta}_j}{a(\bar{\delta}_j)}$ . The FOC can thus be written as<sup>5</sup>

$$\varepsilon_{a,\delta}(\bar{\delta}) = \frac{1}{2} \frac{f}{cQ}. \quad (20)$$

With free entry, all income is labor income, so that  $I = wL$  ( $L$  denotes the economy's endowment with labor). In addition, free entry implies that  $q_j Q_j = w(f + cQ_j)$ . Hence, (16) can be expressed as

$$f + cQ = 2\alpha\bar{\delta}L. \quad (21)$$

Equation (21) 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).

The FOC in (20) and the PMCC in (21) simultaneously determine the size of suppliers ( $Q$ ) and their market width ( $\bar{\delta}$ ) for given  $f$ ,  $c$ ,  $a(\cdot)$ ,  $\alpha$  and  $L$ . For our analysis it will be helpful to illustrate the equilibrium graphically in a  $Q - \bar{\delta}$  space. The elasticity of the FOC is

$$\left. \frac{\partial Q}{\partial \bar{\delta}} \frac{\bar{\delta}}{Q} \right|_{FOC} = -\varepsilon'_{a,\delta}(\bar{\delta}) \frac{\bar{\delta}}{\varepsilon_{a,\delta}(\bar{\delta})}. \quad (22)$$

The elasticity of the PMCC is

$$\left. \frac{\partial Q}{\partial \bar{\delta}} \frac{\bar{\delta}}{Q} \right|_{PMCC} = \frac{f + cQ}{cQ} > 0. \quad (23)$$

Note that the slope of the FOC can be either positive, zero, or negative depending on whether  $\varepsilon'_{a,\delta}(\bar{\delta}) \leq 0$ . But even if the FOC is positive, i.e. if  $\varepsilon'_{a,\delta}(\bar{\delta}) < 0$ , it has to be flatter than the PMCC because the second order condition (SOC) requires that  $-\varepsilon'_{a,\delta}(\bar{\delta}_j) \frac{\bar{\delta}_j}{\varepsilon_{a,\delta}(\bar{\delta}_j)} < \frac{f+cQ}{cQ}$ . This point is illustrated in lemma 1:

**Lemma 1** *The second order condition requires that  $\left. \frac{\partial Q}{\partial \bar{\delta}} \frac{\bar{\delta}}{Q} \right|_{PMCC} > \left. \frac{\partial Q}{\partial \bar{\delta}} \frac{\bar{\delta}}{Q} \right|_{FOC}$ .*

**Proof.** Profits of supplier  $j$  are given by  $\Pi_j = q_j Q_j - w(f + cQ_j)$ . The FOC requires that  $\frac{\partial \Pi_j}{\partial q_j} = \frac{f Q_j}{(f + cQ_j)} \left( \frac{cQ_j}{f} + \frac{\partial \bar{\delta}_j}{\partial q_j} \frac{q_j}{\bar{\delta}_j} \right) = 0$ . The second derivative, evaluated at the optimum, is  $\frac{\partial^2 \Pi_j}{\partial q_j^2} = \frac{cQ_j}{(f + cQ_j)} \frac{\partial Q_j}{\partial q_j} \left( 1 + \left( \varepsilon'_{a,\delta}(\bar{\delta}_j) \frac{\bar{\delta}_j}{\varepsilon_{a,\delta}(\bar{\delta}_j)} \right) \frac{\partial \bar{\delta}_j}{\partial Q_j} \frac{Q_j}{\bar{\delta}_j} \right)$ , so that the SOC  $\frac{\partial^2 \Pi_j}{\partial q_j^2} < 0$  can be written as  $\left( \varepsilon'_{a,\delta}(\bar{\delta}_j) \frac{\bar{\delta}_j}{\varepsilon_{a,\delta}(\bar{\delta}_j)} \right) > -\frac{\partial Q_j}{\partial \bar{\delta}_j} \frac{\bar{\delta}_j}{Q_j}$ . Using equation (23) to solve for  $\frac{\partial Q_j}{\partial \bar{\delta}_j} \frac{\bar{\delta}_j}{Q_j}$ , the second order condition becomes  $-\varepsilon'_{a,\delta}(\bar{\delta}_j) \frac{\bar{\delta}_j}{\varepsilon_{a,\delta}(\bar{\delta}_j)} < \frac{f+cQ}{cQ}$ . ■

<sup>5</sup>We limit our analysis to symmetric equilibria, so that indices can be omitted.

For our analysis we assume that  $\varepsilon'_{a,\delta}(\bar{\delta}) > 0$ , so that  $\left. \frac{\partial Q}{\partial \delta} \frac{\delta}{Q} \right|_{FOC} < 0$ .<sup>6</sup> The equilibrium is then illustrated in figure 1.

**Figure 1** *Equilibrium output and market width*

### 2.3 Labor Market Equilibrium and Firm Entry

The supply of labor is inelastic and equal to the economy's endowment with labor  $L$ . A single supplier's demand for labor is given by (3). Let  $N$  denote the number of suppliers, then the labor market is in equilibrium if  $Nl = L$ . Substituting  $l = \frac{2\delta L}{\Omega}$  from (4), (21) and (15) yields

$$N2\bar{\delta} = \Omega. \quad (24)$$

The real wage in units of the base product can be derived from (8):

$$\frac{w}{q} = \frac{Q}{f + cQ} = \frac{Q}{l}. \quad (25)$$

It is equal to the average productivity of labor in the production of the base product.

It is easier to express the real wage in units of the base product because they all have the same price in a symmetric equilibrium. Prices of final goods differ due to the adaptation costs. The real wage in units of final goods can be calculated using the price index for final goods,  $\bar{p} = q\bar{a}(\bar{\delta})$ , the average adaptation costs  $\bar{a}(\bar{\delta}) = \int_0^{\bar{\delta}} \frac{a(\delta_i)}{\delta} di$ , the average output of final goods  $\bar{X} = \frac{\alpha L}{q\bar{a}(\bar{\delta})}$ , (15) and (21):

$$\frac{w}{\bar{p}} = \frac{1}{\bar{a}(\bar{\delta})} \frac{Q}{f + cQ} = \frac{\Omega \bar{X}}{L}. \quad (26)$$

Again, the real wage in units of consumer goods is equal to the average productivity in the production of consumer goods.

The labor market clearing condition (24) appears to determine the number of firms  $N$  as a function of the optimal zero profit market width  $\bar{\delta}$ :  $N = \frac{\Omega}{2\bar{\delta}}$ . This would indeed be the true solution for  $N$  if firms were freely divisible and  $N$  could be any nonnegative rational number ( $N \in \mathbb{Q}^+$ ). However, in reality firms are indivisible and  $N$  has to be a nonnegative natural number ( $N \in \mathbb{N}^+ \subset \mathbb{Q}^+$ ). Hence, the true solution for  $N$  is

$$N = \text{integer} \left( \frac{\Omega}{2\bar{\delta}} \right). \quad (27)$$

If  $\frac{\Omega}{2\bar{\delta}} \in \mathbb{N}^+$ , then there is no problem and (24) clearly determines the number of firms  $N$ . But if  $\frac{\Omega}{2\bar{\delta}} \notin \mathbb{N}^+$ , then there is a difference between integer  $\left( \frac{\Omega}{2\bar{\delta}} \right)$  and  $\frac{\Omega}{2\bar{\delta}}$

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<sup>6</sup>Take the following example: If  $a = (1 + \delta)^b$ , where  $b > 1$ , then  $\varepsilon_{a,\delta} = \frac{\delta}{1+\delta} b > 0$  and  $\varepsilon'_{a,\delta} = \frac{b}{(1+\delta)^2} > 0$ .

and (24) can only be an approximation to the true solution in (27). In this case, the actual market width in (24) must be larger than the optimal zero profit market width  $\bar{\delta}$  determined in (20) and (21), or else the labor market would not clear and some industries could not procure the necessary inputs at all.

As noted in (13), the actual market width must be equal to the potential market width  $2\tilde{\delta}$ . Therefore,  $2\tilde{\delta}$  is the true solution for the actual market width. Since  $2\tilde{\delta}$  is defined as the distance between the intersections of two  $\tilde{q}_i$  curves, the potential market width in a symmetric equilibrium is always given by

$$2\tilde{\delta} = \frac{\Omega}{N}, \quad (28)$$

where  $N = \text{integer}\left(\frac{\Omega}{2\bar{\delta}}\right)$ . If (28) holds as the true solution, it always guarantees that the labor market clears. Evidently, if  $\frac{\Omega}{2\bar{\delta}} \in \mathbb{N}^+$ , so that  $\text{integer}\left(\frac{\Omega}{2\bar{\delta}}\right) = \frac{\Omega}{2\bar{\delta}}$ , it holds that  $\tilde{\delta} = \bar{\delta}$ . On the other hand, if  $\frac{\Omega}{2\bar{\delta}} \notin \mathbb{N}^+$ , so that  $\text{integer}\left(\frac{\Omega}{2\bar{\delta}}\right) < \frac{\Omega}{2\bar{\delta}}$ ,  $\tilde{\delta} > \bar{\delta}$ .

The relative difference between the true solution  $\tilde{\delta}$  and the approximation  $\bar{\delta}$  can be expressed as

$$\frac{\tilde{\delta} - \bar{\delta}}{\bar{\delta}} = \frac{\epsilon}{N}, \quad (29)$$

where  $\epsilon = \frac{\Omega}{2\bar{\delta}} - \text{integer}\left(\frac{\Omega}{2\bar{\delta}}\right)$ . Obviously, the difference between the approximation and the true solution depends on  $\epsilon$ , i.e. on the difference between  $\frac{\Omega}{2\bar{\delta}}$  and the next lower natural number. But also note that  $\lim_{N \rightarrow \infty} \left(\frac{\tilde{\delta} - \bar{\delta}}{\bar{\delta}}\right) = 0$ . Hence,  $2\bar{\delta}$  is a good approximation for the true solution  $2\tilde{\delta}$  in large markets where  $\frac{1}{N}$  is close to zero.

In the Ethier (1982) framework, assuming that  $\frac{1}{N} \rightarrow 0$  is not trivial and relaxing this assumption makes a big difference to the results (Eckel, 2004). Here, however, assuming that  $N$  is small is less problematic even if the true solution deviates from the approximation.

In our framework, the free entry condition has two dimensions: A vertical dimension that refers to the threat of entry and potential competition at any particular location on the circle and a horizontal dimension that refers to new entry at different locations on the circle. The vertical dimension of free entry leads to the familiar average cost pricing rule. When a supplier raises his price above average costs, he makes profits that attract new entrants. These entrants will then locate at the same address on top of the incumbent supplier (hence the terminology) and steal his entire market share by undercutting his price for the base product. As a result, free entry implies that all suppliers charge average costs in order to prevent competition at their own location.

The horizontal dimension addresses the issue of where a new entrant chooses to locate. If incumbent suppliers charge prices equal to average costs, new suppliers search for their own market niche instead of challenging incumbent firms at their base locations. In this case it is of paramount importance in order to break even that they are able to find a market niche that allows them to

reach the optimal zero profit market width  $\bar{\delta}$  as determined in (20) and (21). The following lemma describes the entry condition:

**Lemma 2** *Entry occurs as long as*

$$\bar{\delta} \leq N \left( \tilde{\delta} - \bar{\delta} \right). \quad (30)$$

**Proof.** Equations (20) and (21) show that  $2\bar{\delta}$  is unaffected by changes in the number of suppliers  $N$ . However, it is constrained by the potential market width  $2\tilde{\delta} = \frac{\Omega}{N}$ . Hence, a new firm is able to reach  $2\bar{\delta}$  if  $2\bar{\delta} \leq 2\tilde{\delta}|_{N+1}$ . Substitute  $2\tilde{\delta}|_{N+1} = \frac{\Omega}{N+1}$  and  $\Omega = N2\tilde{\delta}$  to obtain  $\bar{\delta} \leq N \left( \tilde{\delta} - \bar{\delta} \right)$ . ■

The entry condition can be expanded to  $2\bar{\delta} \leq N \left( 2\tilde{\delta} - 2\bar{\delta} \right)$ . Then, the right hand side describes the degree to which the market potential exceeds the market width necessary to support  $N$  firms. This can be interpreted as the "excess market potential". The left hand side denotes the market width necessary to break even for a new firm. Hence, the entry condition expresses that entry occurs as long as the optimal zero profit market width is smaller than the "excess market potential". The equilibrium condition in (29) implies that no further entry occurs  $\left[ \bar{\delta} > N \left( \tilde{\delta} - \bar{\delta} \right) \right]$ .

Most importantly, however, a deviation of the approximation from the true solution has no impact on the vertical dimension of the free entry condition. The actual market width might be larger than the optimal zero profit market width, but this affects only the horizontal dimension. Even if the approximation deviates from the true solution, firms still have to charge prices equal to average costs. If they do not, there is always a competitor ready to move in on the exact same location and take away their entire market share. Therefore, even if  $N$  is small, the approximation has no impact on average costs pricing:

**Corollary 1** *Free entry implies average costs pricing even if  $N$  is small and the integer constraint is binding.*

Hence, we continue to work with the approximation where  $\tilde{\delta} = \bar{\delta}$  and assume that (24) holds with equality.

## 3 International Trade

### 3.1 Market Structure Effects

Suppose that there is a second (foreign) country, which is identical in all respects except size to the country described above (home). Now assume that the two countries switch from autarky to free trade with no trade costs. In the free trade equilibrium firms in both countries operate with identical technologies ( $a(\cdot)$ ,  $c$  and  $f$ ) in a larger, integrated market. Hence, the new equilibrium is characterized not only by symmetry within a country, but also by symmetry

across countries. Suppliers at home and abroad are of equal size ( $Q^d = Q^f = Q$ ) and market width ( $\bar{\delta}^d = \bar{\delta}^f = \bar{\delta}$ ).<sup>7</sup>

The domestic product market clearing conditions is now

$$w^d (f + cQ) = 2\alpha\bar{\delta} (w^d L^d + w^f L^f), \quad (31)$$

The respective PMCC abroad is

$$w^f (f + cQ) = 2\alpha\bar{\delta} (w^d L^d + w^f L^f). \quad (32)$$

Clearly, the two PMCCs imply an equalization of nominal wages,

$$w^d = w^f, \quad (33)$$

so that the product market clearing condition in the integrated market can be stated as one condition:

$$f + cQ = 2\alpha\bar{\delta} (L^d + L^f). \quad (34)$$

Labor continues to be an immobile factor. This implies that the two labor markets are still segmented and that the labor markets have to clear on a national level. The domestic labor market clearing condition changes to  $N^d 2\bar{\delta}\alpha (L^d + L^f) = L^d$  and the foreign labor market condition now becomes  $N^f 2\bar{\delta}\alpha (L^d + L^f) = L^f$ . Together, they provide two important information:

$$N^d + N^f = \frac{\Omega}{2\bar{\delta}} \quad (35)$$

and

$$\frac{N^d}{N^f} = \frac{L^d}{L^f}. \quad (36)$$

Equation (35) is the free trade equivalent to (24) in the autarky equilibrium. It shows that the scope of the market  $\Omega$  is now divided between domestic and foreign suppliers. Equation (36) states that the ratio of domestic suppliers to foreign suppliers is determined by the ratio of the labor endowments of the two countries. If the two countries are of equal size, they will also host the same number of firms in the free trade equilibrium. Otherwise, the larger country will host more suppliers.

The value of domestic exports is given by  $N^d 2\bar{\delta}\alpha w^f L^f$  and the value of domestic imports is  $N^f 2\bar{\delta}\alpha w^d L^d$ . Thus, equations (33) and (36) ensure that trade is balanced.

In our graphical analysis, international trade leads to an inward shift of the PMCC. The FOC, equation (20), is unaffected by the integration of the two markets. The new equilibrium yields a higher output and a smaller market width per firm. Figure 2 illustrates the new equilibrium.

## Figure 2 *International trade*

<sup>7</sup>A superscript  $d$  denotes domestic variables and a superscript  $f$  denotes foreign variables.

Equations (34) and (35) can also be solved for two key indicators of the market structure: (i) the ratio of workers per firm

$$\frac{L^d + L^f}{N^d + N^f} = f + cQ \quad (37)$$

and (ii) market thickness

$$\frac{N^d + N^f}{\Omega} = \frac{1}{2\bar{\delta}}. \quad (38)$$

The ratio of workers per firm is, naturally, linked to the size of firms. As  $Q$  rises as a consequence of trade integration, the number of firms can only rise by less than the size of the market. Thus, there is some consolidation in the intermediate goods industry:  $(N^d + N^f)|_{Trade} < N^d|_{Autarky} + N^f|_{Autarky}$ . At the same time,  $\bar{\delta}$  clearly falls, so that market thickness rises. Hence, the availability of intermediate goods increases:  $(N^d + N^f)|_{Trade} > \max \left\{ N^d|_{Autarky}; N^f|_{Autarky} \right\}$ .

Proposition 1 summarizes the results from this subsection:

**Proposition 1** *International trade leads to an increase in the size of the market for intermediate goods. Output of the base product rises and the number of final goods industries serviced (market width) falls. The market thickness increases in the market for intermediate goods.*

Note that if  $\varepsilon'_{a,\delta}(\bar{\delta})$  is negative, market thickness still rises. But in contrast to the case where  $\varepsilon'_{a,\delta}(\bar{\delta}) > 0$ , a reduction in market width increases the mark-up flexible suppliers can charge, so that optimal firm size falls. Hence, if  $0 > \varepsilon'_{a,\delta}(\bar{\delta}) > -\frac{f}{(cQ)^2}\alpha L$ ,<sup>8</sup> international trade still reduces the market width, but output per intermediate goods producer falls, too. As a consequence, the number of suppliers in the integrated market is larger even when compared to the sum of all firms in autarky.

### 3.2 Welfare Effects

The welfare effects can best be illustrated by the impact of international trade on the real wages in both countries. According to (26), the real wage in units of the downstream goods  $\frac{w}{p} = \frac{w/q}{\bar{a}(\bar{\delta})}$  is defined as the ratio of the real wage in units of the base product  $\left(\frac{w}{q}\right)$  and average adaptation costs  $\bar{a}(\bar{\delta})$ . Correspondingly, the welfare effects can be divided into a productivity effect and an availability effect.

The *productivity effect* measures the impact of international trade on the real wage in units of the base product. As  $\frac{w}{q} = \frac{Q}{l}$ , this effect emphasizes the impact on the productivity in the production of the base product. Since  $\frac{Q}{l} = \frac{Q}{f+cQ}$

<sup>8</sup>The SOC requires that  $\varepsilon'_{a,\delta}(\bar{\delta}) > -\frac{f}{(cQ)^2}\alpha L$ .

and  $\frac{\partial(Q/l)}{\partial Q} = \frac{f}{(f+cQ)^2} > 0$ , international trade increases the productivity in the production of the base products by increasing the output of the base product. Hence, the productivity effect is welfare enhancing.

The *availability effect* emphasizes the fact that international trade raises the market thickness in the market for intermediate goods. An increase in market thickness reduces the market widths of flexible suppliers and, thereby, reduces average adaptation costs, too:  $\frac{\partial \bar{a}(\bar{\delta})}{\partial \bar{\delta}} = \frac{1}{\bar{\delta}} [a(\bar{\delta}) - \bar{a}(\bar{\delta})] > 0$ . Hence, the availability effect is also welfare increasing.

Both effects apply to both countries so that international trade clearly enhances the welfare both at home and abroad. However, the size of the increase in welfare depends on the size of the economy in autarky. The larger the economy is in autarky, the larger is the real wage in autarky, and the smaller is the increase through international trade. Hence, both countries gain, but the smaller country gains more.

Proposition 2 summarizes the welfare effects of international trade:

**Proposition 2** *The impact of international trade on welfare can be divided into a productivity effect and an availability effect. Both effects are welfare enhancing, but the smaller country gains more than the larger country.*

This concludes our benchmark case. The study revealed interesting insights into how international trade can affect flexible manufacturing systems in general equilibrium. However, in this case flexible manufacturing was the only way to procure the necessary inputs. Hence, the benchmark case could not offer any insights into how international trade affects the *diffusion* of flexible manufacturing. For this we need an alternative technology which is introduced in the next section.

## 4 Flexible Manufacturing versus In-house Production

### 4.1 The Trade-off Between Product Specificity and Economies of Scope

Assume that aside from the flexible manufacturing technology there is also a specific technology. The specific technology exhibit constant returns to scale. One unit of a specific intermediate input requires the input of  $\frac{1}{m}$  units of labor:

$$\tilde{Q}_i = \frac{1}{m} l_i. \quad (39)$$

We 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.<sup>9</sup> Hence, we will also refer to this technology as the in-house technology.

The cost function of industry  $i$  is then

$$C_i = wmX_i, \quad (40)$$

and marginal cost pricing yields

$$p_i = mw. \quad (41)$$

Note that (41) implies an internal transfer price for the input of

$$\tilde{q}_i = mw. \quad (42)$$

In order to distinguish the price charged by a flexible manufacturer from the internal transfer price in the specific technology case we denote  $\tilde{q}_i$  in (42) by  $\tilde{q}_i^{ST}$  and  $\tilde{q}_i$  in (7) by  $\tilde{q}_i^{FM}$ .

The unit labor requirements of the two technologies are given by  $\frac{\tilde{q}_i^{ST}}{w} = m$  and  $\frac{\tilde{q}_i^{FM}}{w} = a(\delta_{ij})\left(\frac{f}{Q_j} + c\right)$ . They reveal the advantages and disadvantages of the two possible modes of procurement. The flexible manufacturing technology exhibits increasing returns to scope because it allows a supplier to sell a standardized base product to more than one industry. The more industries a flexible manufacturer can supply, the more unit labor requirements fall  $\left(\frac{\partial(\tilde{q}_i^{FM}/w)}{\partial Q_j} < 0\right)$ . On the other hand, supplying a larger range of industries also implies higher adaptation costs  $\left(\frac{\partial(\tilde{q}_i^{FM}/w)}{\partial \delta_{ij}} > 0\right)$ . The advantage of the specific in-house technology is that there are no adaptation costs when the intermediate inputs are tailored to the industry. But with the specific technology there are no economies of scope (or scale for that matter), so that unit costs do not fall with output  $\left(\frac{\partial(\tilde{q}_i^{ST}/w)}{\partial Q_i} = 0\right)$ . Hence, the trade-off between the specific in-house technology and the flexible manufacturing technology is a trade-off between product specificity and economies of scope.

The trade-off between product specificity and economies of scope has not yet been addressed in the literature. Related studies of market thickening have usually put an emphasis on governance costs on one side and on either transactions costs or search-theoretic conceptions on the other side. E.g., McLaren (2000) focuses on the trade-off between the hold-up problem of arm's length trade and the governance costs of integrated production. Grossman and Helpman (2002) emphasize the trade-off between the costs of running a larger and less specialized organization and costs that arise from search frictions and imperfect contracting.

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<sup>9</sup>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 ( $g_i + m\tilde{Q}_i > m\tilde{Q}_i$ ).

When downstream firms have a choice between two different ways of procuring their inputs, upstream firms have to compete not only against their immediate rivals but also against in-house production. Their market widths are now bounded by the minimum of their immediate rivals' effective prices  $\tilde{q}_i^{FM}$  and the price of producing the input in-house  $\tilde{q}_i^{ST}$ :

$$q_j a(\bar{\delta}_j^l) = \min \left\{ mw; q_{j-1} a(d_{j-1} - \bar{\delta}_j^l) \right\} \quad (43)$$

and

$$q_j a(\bar{\delta}_j^r) = \min \left\{ mw; q_{j+1} a(d_{j+1} - \bar{\delta}_j^r) \right\}. \quad (44)$$

In a symmetric equilibrium, the two conditions can be summarized by a single expression:  $qa(\bar{\delta}) = \min \{mw; qa(d - \bar{\delta})\}$ . If  $qa(d - \bar{\delta}) < mw$ , in-house production is not profitable for industries within the potential market width of a supplier. In this case the actual market width is identical with the potential market width  $\left[ (\bar{\delta}_j^l, \bar{\delta}_j^r) = (\tilde{\delta}_j^l, \tilde{\delta}_j^r) \right]$  and suppliers compete directly with their rivals for market shares ( $d = 2\bar{\delta}$ ). This is the case described in detail in the previous section. But if  $qa(d - \bar{\delta}) \geq mw$ , in-house production is profitable for at least some industries at the outer edge of the potential market width. In this case, suppliers are not directly competing with their rivals, but with in-house production ( $d > 2\bar{\delta}$ ), and the actual market width is only a subset of the potential market width  $\left[ (\bar{\delta}_j^l, \bar{\delta}_j^r) \subset (\tilde{\delta}_j^l, \tilde{\delta}_j^r) \right]$ .

In this latter case, where in-house production is profitable, an upstream firm's actual market width is determined by

$$q_j a(\bar{\delta}_j^l) = mw \quad (45)$$

and

$$q_j a(\bar{\delta}_j^r) = mw. \quad (46)$$

One immediate consequence of this change in the determination of the actual market width is that intermediate goods producers are not competing directly against other intermediate goods producers but primarily against in-house production. This makes the extensive margin more price elastic because the costs of in-house production are invariant to changes in distance. The price elasticity changes from  $\frac{\partial Q_j}{\partial q_j} \frac{q_j}{Q_j} = -1 - \frac{1}{2} \frac{1}{\varepsilon_{a,\delta}(\bar{\delta}_j)}$  in the previous section to  $\frac{\partial Q_j}{\partial q_j} \frac{q_j}{Q_j} = -1 - \frac{1}{\varepsilon_{a,\delta}(\bar{\delta}_j)}$  and the FOC becomes

$$\varepsilon_{a,\delta}(\bar{\delta}) = \frac{f}{cQ}. \quad (47)$$

Since demand is more price elastic when suppliers compete against in-house production, upstream firms charge a lower price for the base product in equilibrium. Hence, ceteris paribus, an upstream firm produces a larger output of the base product and sells to more industries. In a  $Q - \bar{\delta}$  space, the FOC is

located further outwards compared to the illustration in figure 1. The elasticity of the FOC, however, is unaffected by this change. It is still correctly described by (22).

The PMCC as described in (21) is not affected by the change in the price elasticity, either. Hence, the equilibrium  $Q - \bar{\delta}$  combination in the case where both technologies coexist is given by (21) and (47). Clearly, there is a switch in regimes determining the equilibrium between the case described in the previous section (flexible manufacturing only) and the case described here. Figure 3 illustrates how this switch occurs.

**Figure 3** *The equilibrium mode of procurement*

The upper diagram in figure 3 illustrates the effective unit labor requirements of the marginal industry  $\bar{\delta}$ , i.e. of the last industry serviced by a particular supplier. If both technologies coexist, the effective unit labor requirements of the marginal industry are determined by either (45) or (46):  $\frac{\tilde{q}^{ST}}{w} = m$ . If there is no in-house production and suppliers compete directly against each other, the effective unit labor requirements of the marginal industry depend on its distance to the location of the base product. The respective function can be calculated using (9) and (20):  $\frac{\tilde{q}^{FM}}{w} = \psi(\bar{\delta})$ , where  $\psi(\bar{\delta}) = ca(\bar{\delta})(2\varepsilon_{a,\bar{\delta}}(\bar{\delta}) + 1)$ . Clearly,  $\psi'(\bar{\delta}) > 0$  and  $\psi(0) = c$ . This part of the figure provides insights into the sustainability of the two regimes as a function of the actual market width  $\bar{\delta}$ . If  $\frac{\tilde{q}^{FM}}{w} < \frac{\tilde{q}^{ST}}{w}$  it also holds that  $a(\bar{\delta})\frac{q}{w} < m$ . In this case, even the marginal industry, i.e. the industry with the highest adaptation costs, finds it unattractive to produce the intermediate good in-house. Hence, no industry relies on in-house procurement and flexible manufacturing is the only mode of production. On the other hand, if  $\frac{\tilde{q}^{ST}}{w} < \frac{\tilde{q}^{FM}}{w}$ , the effective unit labor requirements of the marginal industry are larger than  $m$ , so that some industries at the outer edge of the market width switch to in-house procurement. The intersection of the two curves yields the critical  $\bar{\delta}^*$  where the marginal industry is just indifferent between in-house production and external procurement. This is where the switch in the two regimes occurs.

The lower part of figure 3 depicts the PMCC and the two FOCs corresponding to the two regimes determining the equilibrium in a  $Q - \bar{\delta}$  diagram. For each regime, the equilibrium is determined by the intersection of the PMCC with the respective FOC, either  $FOC|_{FM}$  for (20) or  $FOC|_{ST}$  for (47). The lower part of the diagram shows that there exists a critical size of the economy  $\tilde{L}$  that corresponds to  $\bar{\delta}^*$ . If  $L > \tilde{L}$ ,  $\bar{\delta} < \bar{\delta}^*$  so that  $\frac{\tilde{q}^{FM}}{w} < \frac{\tilde{q}^{ST}}{w}$ , and the equilibrium is determined by the intersection of  $PMCC$  and  $FOC|_{FM}$ . In this case, the in-house technology is not applied and all industries rely on external procurement. On the other hand, if  $L < \tilde{L}$  and  $\bar{\delta} > \bar{\delta}^*$  so that  $\frac{\tilde{q}^{FM}}{w} > \frac{\tilde{q}^{ST}}{w}$ , the equilibrium is determined by the intersection of  $PMCC$  and  $FOC|_{ST}$ . Then, some industries at the periphery of a supplier's market width find it more attractive to produce the inputs in-house and both technologies, in-house production and flexible manufacturing, coexist.

Clearly, the critical market size  $\tilde{L}$  depends on  $m$ . It can be calculated as the solution to the simultaneous equations  $\psi(\tilde{\delta}) = m$ , (20) and (21). If  $m$  rises,  $\tilde{\delta}^*$  also rises and  $\tilde{L}$  falls. Hence, we can define  $\tilde{L}$  as a declining function of  $m$ :

$$\tilde{L} = \Psi(m), \quad (48)$$

where  $\Psi'(m) < 0$ . Figure 3 also shows that  $\lim_{m \rightarrow c} \tilde{\delta}^* = 0$ . Hence, if  $m \leq c$ , flexible manufacturing is always more costly than in-house production because economies of scope in flexible manufacturing can never push unit labor requirements below marginal labor requirements:  $a(\delta_{ij}) \left( \frac{f}{Q_j} + c \right) > c \geq m$ .

Lemma 3 summarizes our insights into the equilibrium mode of procurement:

**Lemma 3** (i) If  $m \leq c$ , in-house production is the only mode of procurement. (ii) If  $m > c$ , the mode of procurement depends on the size of the market. There exists a critical market size  $\tilde{L}$ , so that if  $L > \tilde{L}$  in-house production is never profitable. If  $L < \tilde{L}$ , both forms of procurement coexist.

## 4.2 Labor Market Equilibrium and Firm Entry

In the case where both technologies are used labor is employed both by flexible manufacturers as well as by integrated downstream firms. Hence, demand for labor consists of  $Nl_j + Ml_i$ , where  $l_j$  denotes labor requirements in the production of flexible inputs from equation (3),  $l_i$  denotes labor requirements for in-house production from equation (39) and  $M$  denotes the mass of industries relying on in-house procurement. The labor market equilibrium now requires that  $Nl_j + Ml_i = L$ . Using the familiar identities, it can also be expressed as

$$N2\bar{\delta} + M = \Omega. \quad (49)$$

The labor market clearing condition also expresses the fact that in equilibrium, all industries ( $\Omega$ ) are either serviced by flexible manufacturers ( $N2\bar{\delta}$ ) or produce their inputs in-house ( $M$ ). Rearrange (49) to obtain

$$\frac{M}{N} = \left( \frac{N}{\Omega} \right)^{-1} - 2\bar{\delta}. \quad (50)$$

Equation (50) provides first insights into the relation between flexible manufacturing and specific in-house production. The ratio of in-house production to flexible manufacturing ( $\frac{M}{N}$ ) is determined by two forces: (i) The actual market width of flexible suppliers ( $2\bar{\delta}$ ) and (ii) the market thickness in the intermediate goods industry ( $\frac{N}{\Omega}$ ).

The relation between the actual market width of flexible suppliers ( $2\bar{\delta}$ ) and the relative diffusion of flexible manufacturing ( $\frac{M}{N}$ ) can best be illustrated by turning again to our concept of the potential market width. Given (28), the labor market clearing condition (49) can be rewritten as

$$\frac{M}{N} = 2 \left( \tilde{\delta} - \bar{\delta} \right). \quad (51)$$

Obviously, the relative level of in-house production is equal to the difference between potential and actual market width. It describes those industries on each end of the market width that a particular supplier has yet failed to reach. Equations (45) and (46) indicate that this difference depends on the degree of flexibility of production, i.e., technically, on the shape of the adaptation function  $a(\cdot)$ . Flexibility matters in the determination of in-house production. If flexibility is high, suppliers capture a larger portion of their potential market width so that their actual market width is larger. As a consequence, in-house production is relatively smaller.

The second force in (50), market thickness in the intermediate goods industry, is a measure for the availability of intermediate goods from flexible suppliers. Here, the thickness of the market is expressed as the ratio of the number of flexible suppliers ( $N$ ) to the mass of industries in the economy ( $\Omega$ ). The larger market thickness is, the easier it is for downstream firms to find intermediate goods with adequate specifications in the market. Hence, when market thickness rises, external procurement becomes cheaper on average and in-house production falls (and vice versa).

Naturally, the degree of market thickness depends on the entry conditions for new firms. Free entry means that new suppliers enter whenever they can manage to break at least even. As discussed above this implies that entry occurs as long as new firms are able to reach the optimal zero profit market width  $\bar{\delta}$  as determined by (21) and (47). By transferring our insights from lemma 2 to the dual technology case we can establish the following new entry condition:

**Lemma 4** *In the dual technology case entry occurs as long as  $M \geq 2\bar{\delta}$ .*

**Proof.** The new entry condition follows directly from substituting (51) into (30). ■

The entry condition in the dual technology case has a similar interpretation to the entry condition (30) in section 2. The mass of industries with in-house production  $M$  describes all industries that independent upstream firms with flexible manufacturing have failed to reach. It can be interpreted as the "unpenetrated market potential". Then, entry occurs as long as the actual market width of an entrant is not larger than the "unpenetrated market potential".

An equilibrium requires that further entry is not profitable:  $M < 2\bar{\delta}$ . Using (49), the no entry condition can also be expressed as  $N > \frac{\Omega}{2\bar{\delta}} - 1$ . Again, the number of firms has to be a natural number so that the equilibrium number of firms  $N$  is determined by the same condition as in (27):  $N = \text{integer}(\frac{\Omega}{2\bar{\delta}})$ . Our remarks concerning the vertical dimension of the free entry condition in corollary 1 continue to hold: This integer constraint has no impact on the validity of the average cost pricing rule.

Using equations (27) and (49) we can solve for the number of industries relying on in-house production:  $M = \Omega - 2\bar{\delta} \times \text{integer}(\frac{\Omega}{2\bar{\delta}})$ . Obviously, this cannot be solved without knowledge of the exact numerical solution of  $\frac{\Omega}{2\bar{\delta}}$ . However, we can derive an upper and lower bound of in-house production. Rewrite (27) as  $N = \frac{\Omega}{2\bar{\delta}} - \epsilon$ , where  $\epsilon = \frac{\Omega}{2\bar{\delta}} - \text{integer}(\frac{\Omega}{2\bar{\delta}}) \in [0, 1)$ . The upper bound of in-house

production is then given by

$$\check{M} = \lim_{\epsilon \rightarrow 1} \left( \Omega - 2\bar{\delta} \left( \frac{\Omega}{2\bar{\delta}} - \epsilon \right) \right) = 2\bar{\delta}. \quad (52)$$

The upper bound of in-house production is at the limit equal to the equilibrium actual market width of individual intermediate goods producers. This is intuitive because an equilibrium requires that  $M < 2\bar{\delta}$  so that in equilibrium  $M < \check{M}$ .

Naturally, the lower bound of in-house production is zero:

$$\check{M}' = \lim_{\epsilon \rightarrow 0} \left( \Omega - 2\bar{\delta} \left( \frac{\Omega}{2\bar{\delta}} - \epsilon \right) \right) = 0. \quad (53)$$

If the number of industries relying on in-house production is just equal to the actual market width ( $M = 2\bar{\delta}$ ), all industries will be serviced by independent suppliers when an additional intermediate goods producer enters. But note that at the margin of their market width, firms are charging prices (including adaptation costs) that are just equal to the costs of in-house production. Thus, an increase in the price of one intermediate good will only increase in-house production, but leave market widths of other suppliers unaffected. So even though in-house production is zero, a switch in regimes as described in figure 3 does not occur.

If  $M = \check{M}$ ,<sup>10</sup> equations (52) and (49) describe the upper bound of in-house production in an  $M - N$  diagram:

$$\check{M} = \frac{\Omega}{1 + N}. \quad (54)$$

Equations (27), (49) and (54) determine the equilibrium values of  $N$  and  $M$ .

**Figure 4** *The ratio of in-house production ( $M$ ) to flexible manufacturing ( $N$ )*

In figure 4, all natural numbers of  $N$  are indicated by straight vertical lines. The equilibrium values of  $M$  and  $N$  are determined by the intersection of the labor market clearing condition (49) with one of these straight vertical lines in the interval  $\left[0, \check{M}\right)$ .<sup>11</sup>

### 4.3 International Trade and the Diffusion of Flexible Manufacturing

We are now able to analyze how international trade affects the diffusion of flexible manufacturing. As indicated in equation (50), there are two forces that

<sup>10</sup>Note that only points *below* (54) can describe an equilibrium as the no entry condition requires that  $M < \check{M}$ .

<sup>11</sup>The way how the upper bound curve is derived ensures that there is only one natural number of  $N$  where the value of  $M$  corresponding to (49) lies in the range  $\left[0, \check{M}\right)$ .

determine the diffusion of flexible manufacturing: Market width effects and market thickness effects. International trade affects both, and we will show how the two effects interact in the diffusion of flexible manufacturing.

The lower part of figure 3 illustrates the impact of international trade if  $L^d, L^f < \tilde{L}$ .<sup>12</sup> As discussed in section 3, international trade increases the size of the market. This implies a downward turn of the PMCC which clearly reduces the equilibrium market width of flexible suppliers ( $\bar{\delta}$  falls). It also increases the size of firms as long as the integrated market is not larger than the critical market size:  $L^d + L^f < \tilde{L}$ . If  $L^d + L^f > \tilde{L}$  and  $L^d, L^f < \tilde{L}$ , the impact on the size of firms  $Q$  is ambiguous. The increase in the size of the market tends to raise the size of firms, but the switch in regimes reduces the price elasticity and this tends to reduce the size of the firms.<sup>13</sup>

The decline in the actual market width of suppliers is a general equilibrium effect which seems counterintuitive at first glance. If the size of the market grows, why should suppliers reduce the number of industries they service? In the single technology case discussed in section 2, the actual market width is determined by the potential market width ( $\bar{\delta} = \tilde{\delta} = \frac{Q}{2N}$ ). There, the decline in the actual market width was brought about by an increase in competition through new entry ( $N$  rises). But here, firms reduce their customer base even without new entry. The reason is that the increase in the size of the market leads to an increase in the demand for inputs per industry. But as suppliers increase production and hire more labor, the real wage in units of the base product rises. Consequently, in-house production becomes relatively cheaper and the marginal industries at the periphery of the market width switch from external to internal procurement. Therefore,  $\bar{\delta}$  falls and  $M$  rises.

The *market width effect* is illustrated in figure 5 by the movement from point  $P_1$  to  $P_2$ . As the figure shows, a reduction in  $\bar{\delta}$  implied in the increase in the size of the market leads to an outward turn of the labor market clearing condition (49). Note that the increase in the size of the market is too small to trigger new entry. Hence, the new equilibrium is characterized by the same number of suppliers using flexible manufacturing but by a larger number of industries relying on internal procurement. Hence, the ratio  $\frac{M}{N}$  clearly rises.

**Figure 5** *International trade and the diffusion of flexible manufacturing*

On the other hand, if the increase in the size of the market is large enough, new firms enter and market thickness ( $\frac{N}{\Omega}$ ) rises. The *market thickness effect* is illustrated in figure 5 by a move to point  $P_3$ . The new supplier services industries that previously relied on in-house production. Hence, new entry tends to lower the ratio  $\frac{M}{N}$ .

Obviously, the market width effect and the market thickness effect are counteracting in their impacts on the diffusion of flexible manufacturing. Thus, the overall impact on the diffusion of flexible manufacturing is ambiguous. However,

<sup>12</sup>The case where  $L > \tilde{L}$  is equivalent to the case discussed in the previous section.

<sup>13</sup>We limit our analysis here to  $\varepsilon'_{a,\delta} > 0$ .

the upper bound  $\check{M}$  falls as new firms enter. This is also illustrated in figure 5 where the level of in-house production at point  $P_2$  is larger than the upper bound  $\check{M}$  at  $P_3$ . In this example, the level of in-house production at  $P_2$  cannot be sustained in a market with more suppliers than in autarky. Hence,  $\frac{\check{M}}{N}$  clearly falls.

Proposition 3 summarizes our results:

**Proposition 3** *If  $L^d + L^f < \tilde{L}$ , international trade has an ambiguous impact on the diffusion of flexible manufacturing. The market width effect tends to reduce the diffusion of flexible manufacturing while the market thickness effect tends to increase it. The upper bound of in-house production clearly falls.*

If we think of globalization as an ongoing process of integrating national markets, we can model globalization in our framework as a continuous increase in the size of the world market  $L^w$ . In this case, we can describe how globalization affects the diffusion of flexible manufacturing in the integrated world economy (as opposed to the impact of a switch from autarky to free trade in a single country).

Figure 3 shows that a continuous increase in the size of the world market implies a continuous decrease in the actual market width. Then, figure 5 illustrates how a continuous decline in  $\bar{\delta}$  and the respective continuous outward movement of the labor market clearing condition (49) affects the ratio of  $M$  to  $N$  in the world economy. We see that, in this scenario, globalization can create alternating waves of outsourcing and insourcing. Here, outsourcing refers to a switch from in-house production to external procurement and insourcing refers to the reverse process.

In this scenario, it is the market thickness effect that leads to outsourcing because outsourcing occurs whenever the increase in the size of the world market leads to an increase in the number of suppliers. On the other hand, the market width effect leads to insourcing because insourcing occurs when in-house production becomes relatively cheaper so that the actual market width falls. These two effects are alternating, but the amplitudes of the waves are decreasing with  $\check{M}$ . Eventually, the size of the world market reaches the critical level  $\tilde{L}$  and the world economy switches to a regime without any in-house production.

**Corollary 2** *Globalization can create alternating waves of outsourcing and insourcing. In the long run, outsourcing prevails and in-house production ceases to exist.*

## 5 Concluding Remarks

The present paper sets out to explain the impact of international trade on the diffusion of flexible manufacturing. The idea behind the framework is that an industry's mode of procuring inputs is determined by the trade-off between economies of scope and the specificity of production and that in general equilibrium, this trade-off can be affected by international trade. We show that by

increasing the size of the economy, international trade triggers two responses: First, it reduces the actual market width of suppliers by raising real wages and lowering the relative costs of in-house production (market width effect) and, second, it increases the number of suppliers (market thickness effect). We also showed that if globalization is seen as a continuous increase in the size of the world economy, it can generate alternating waves of outsourcing and insourcing. But in the long run, outsourcing prevails and the economy switches to a regime where flexible manufacturing is the only mode of producing the inputs.

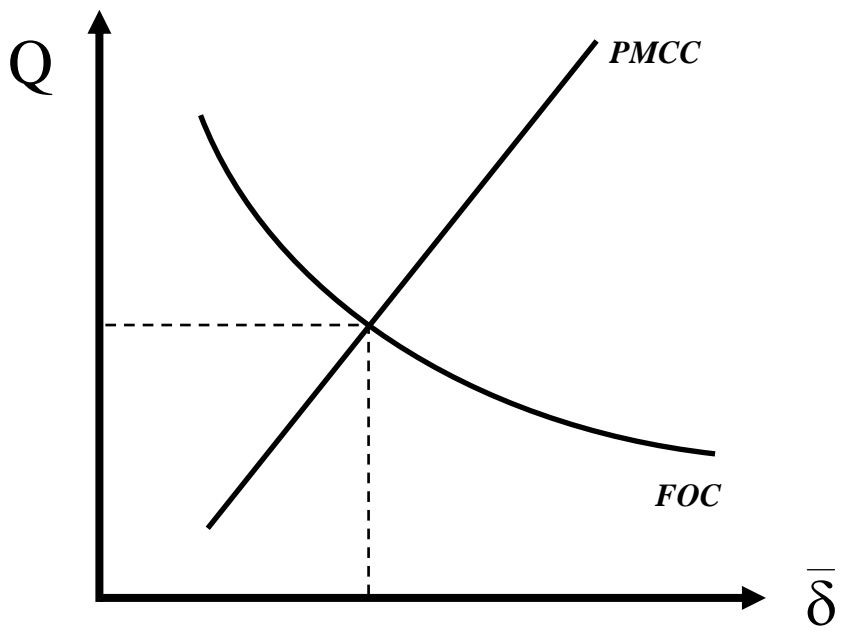
The description of international trade in intermediate goods based on the spatial model of product differentiation provides complementary insights to the popular Ethier (1982) framework. The focus of the two approaches is different. The Ethier model is based on Dixit's and Stiglitz's (1977) "love of 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.

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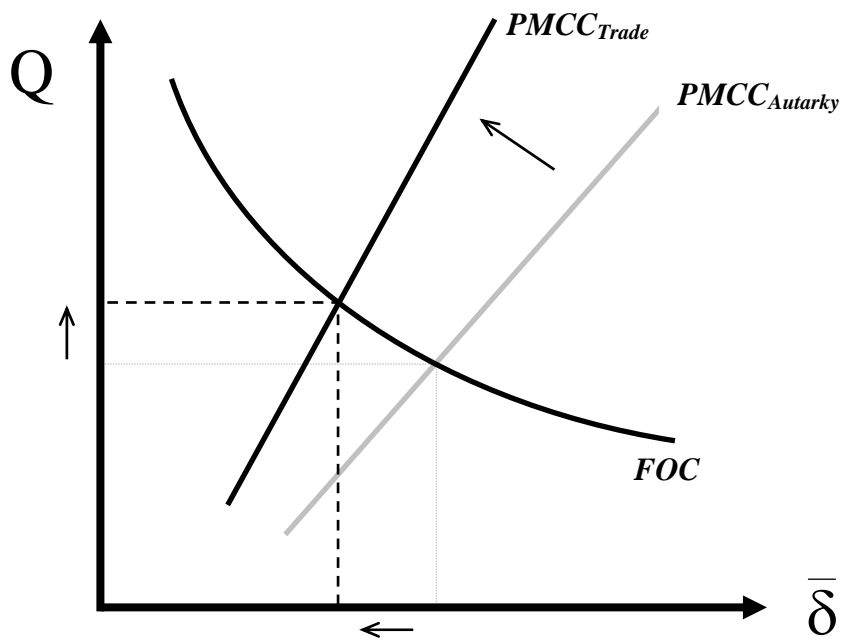
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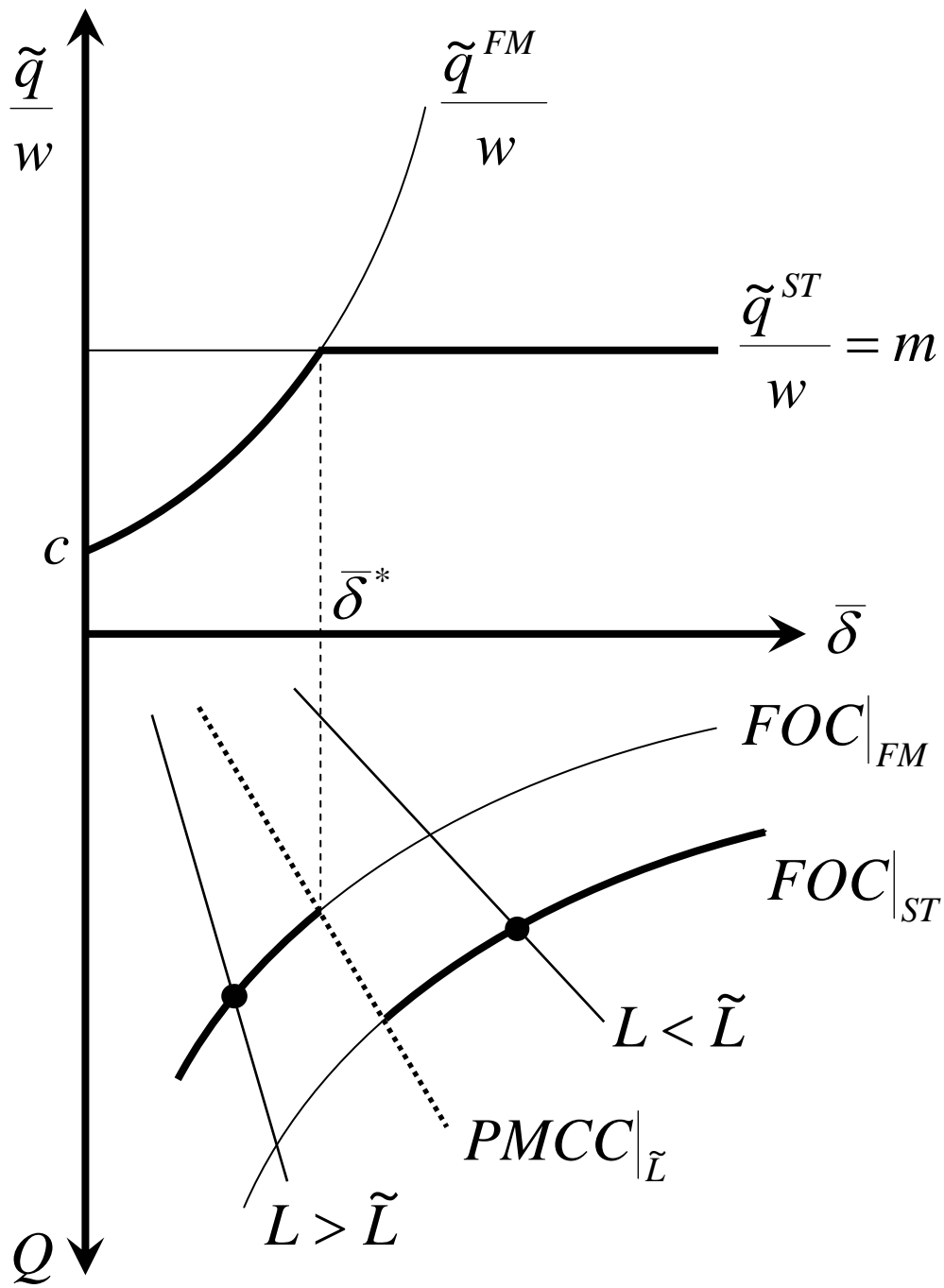
*Figures*



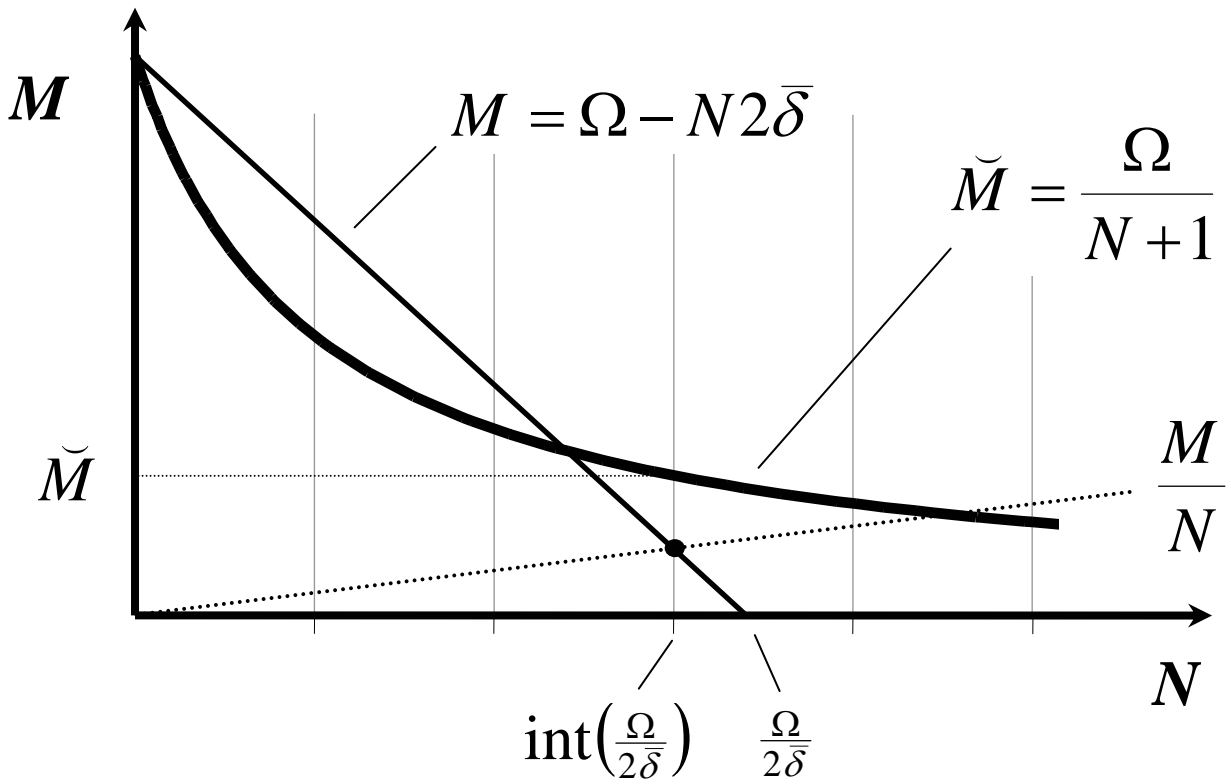
*Equilibrium output and market width*



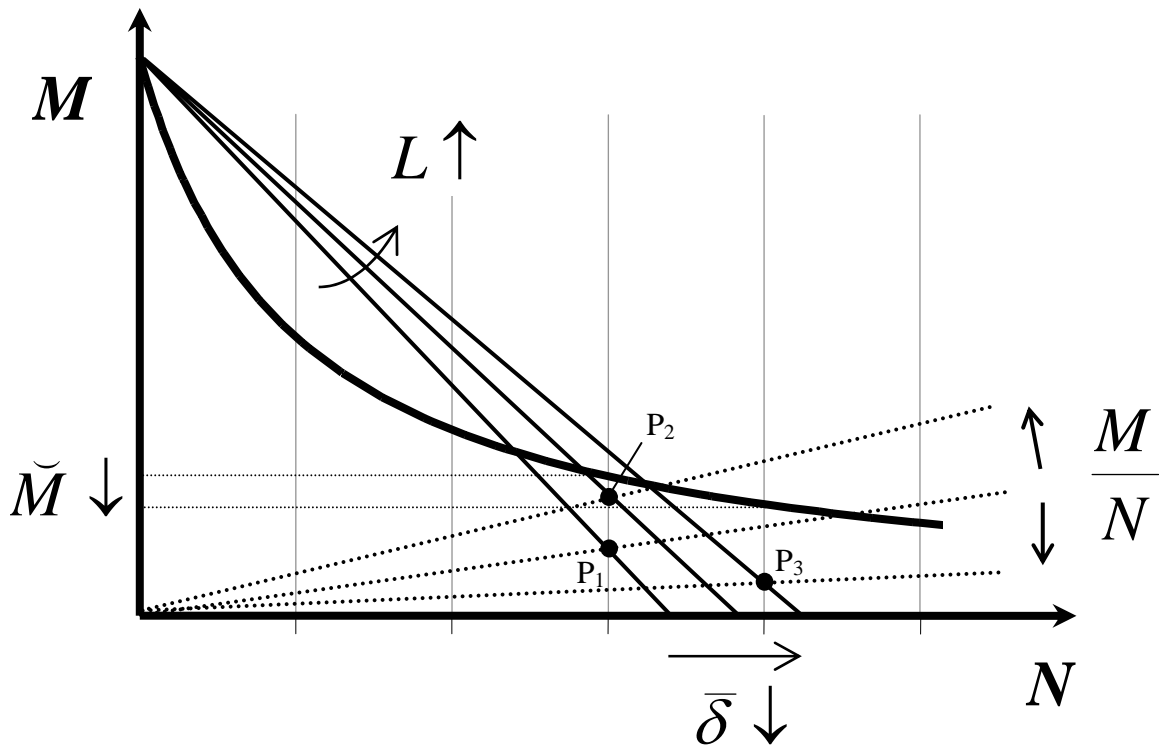
*International trade*



*The equilibrium mode of procurement*



The ratio of in-house production ( $M$ ) to flexible manufacturing ( $N$ )



International trade and the diffusion of flexible manufacturing