The Impact of Market Scale on Standardization and Specialization

Waka Cheung
School of Economics, Jinan University, Guangzhou, China.

Yew-Kwang Ng
Department of Economics, Monash University, Clayton, Vic 3800, Australia
Email: kwang.ng@monash.edu

Abstract

A Hotelling long-run equilibrium model based on the microeconomics of optimization is developed to analyze the impact of market scale on specialization and standardization. Among our conclusions is that, the degree of vertical division of labor and the number of varieties produced in a production line increase, via a rise in the extent of market with population, average income and market transaction efficiency; however, the opposite effects also result from a rise in average income via the preference for individualized products. The net effect of average income varies in different cases. Using these conclusions we explain some phenomena in the garment and auto industries.

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1. Introduction

In the process of industrialization, standardization and specialization are two significant and closely related characteristics. According to Fraser (1983, p526-7), for example, although the sewing machine was invented in America in 1846, handwork for custom-made clothing continued to predominate until the Civil War (1861-1865). The demand for uniforms made mass production, a production mode with the characteristics of higher degree of vertical division of labor within a firm and intensively using machines to produce standardized products, predominant in the industry. The question is, as the sewing machine had been invented, why did mass production not prevail until the production of uniforms fifteen years later?

Another interesting phenomenon is the huge difference in the degree of vertical division of labor between two kinds of clothing firms which coexisted after the Civil War, the “small shop” (Fraser 1983 p526) which usually produced custom-made clothing and the clothing firm which usually specialized in producing one kind of clothing, such as shirts, coats, etc. In contrast to the homework for custom-made clothing, the degree of division of labor in the production of standardized goods was high. In Chicago in 1900’s, for example, not counting the production of raw materials and machines, it took sixty workers to produce a coat, fifty to make a pair of pants, twenty a vest, and eighty to eighty-five to produce a single
The purpose of this paper is to develop a model to analyze the phenomena above. Our basic idea is that, the vertical division of labor requires workers in the production line to spend time to coordinate. Changing from producing one variety to another, say from jean to skirt, the division of labor has to be reorganized. Thus, the more varieties a firm produces, the more coordination time each worker has to spend. In addition, the more workers vertically specializing in a production line, the more coordination time each worker spends. Therefore, a firm which produces more varieties prefers less degree of vertical division of labor within a firm. That is why the vertical division of labor in a “small shop” is less than that in a specialized firm.

Next, the function of clothing standardization in Fraser’s case is to enlarge the production scale which makes the vertical division of labor worthy. Before the introduction of standardized clothing, a specialized firm can only satisfy a small part of the market demand, the demand of those consumers who prefer the products the firm produces. On the other hand, after the introduction of standardized clothing, a specialized firm which produces standardized clothing can satisfy a larger section of market demand, which makes a firm easier to bring into play the advantage of vertical division of labor. In addition, uniforms production provides an opportunity from which mass production is improved and standardized clothing is gradually accepted. That is why mass production began with the production of uniforms.

Besides the phenomena in the clothing industry, our model can also be used to analyze the tendency of standardization and specialization in the process of the industrialization in the automobile industry. It is divided into three periods characterized respectively by craft production for customization, mass production for standardized consumption, and flexible specialization for individualized consumption (Gartman 2004, Womack et al. 1990, Rubenstein 2001), where flexible specialization is thought of “as the manufacture of a wide and changing array of customized products using flexible, general purpose machinery and skilled, adapted labor” (Hirst and Zeitlin 1991).

Until recently the literature on the relationship between standardization and vertical division of labor consists mainly of a large numbers of case studies (e.g. as cited in Footnote 1), but it has received little emphasis in formal analysis. Although not directly related to the vertical division of labor, the models mentioned below study the correlation between product individualization and production modes, similar phenomena are explained in this paper but different factors are emphasized.

Mobius and Schoenele (2006) show that the number of varieties in a market is determined by the trade-off between the marginal utility of a higher degree of customized products and the relevant loss in a lower production scale, with increasing returns to scale due to the fixed cost/price of the machine. As a consequence, the number of varieties declines as the production mode changes from artisan to mechanical production. In addition, more varieties are produced as technology improves (the price of machine declines).

Milgrom and Roberts (1990) analyze the tendency of flexible multi-product firms in the late twentieth century. In their optimizing model, product improvement increases the market sale on the one hand, but increases the fixed costs associated with machines setups, product redesign, and the purchase of capital equipment on the other. Therefore, the usage of flexible machines and programmable, multitask production equipments allow a firm to produce a variety of products efficiently in very small quantities.

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1 Besides Fraser’s, the case studies by Egle (1938), Simmons and Kalantaridis (1994), Taplin (1989 and 1995), Hiebert (1990), Green (1997), Huys et al. (1999), Collins (2001), Waddell 2004 and others are related to the investigation on the correlation between product standardization and vertical division of labor through comparing the production modes in the clothing industry.

2 Since the publication of Chamberlin (1933) and Robinson (1933), many papers have studied product differentiation in a variety of contexts [Matsuyama (1995)]. On the other hand, there are many papers studying the division of labor. To our knowledge, however, the relationship between product differentiation and vertical division of labor has not been formally explored.
Compared with the models discussed above, our analysis shows the effects of the extent of a market on the vertical division of labor within a firm and the use of machines. Our idea is that, the extension of the internal vertical division of labor increases the static efficiency and the economies of scale but at the expense of flexibility (more coordination time is needed in multi-variety production) of a firm. It also needs a minimum extent of the market to bring about economies of specialization. In the early stage, with the application of specialized machines, internal vertical degree of division of labor increases. Product standardization is a supplemental means to increase the demand facing a firm when the extent of the market is not large enough. Today, adapting for the tendency of market individualization, production becomes more flexible. It implies that, as machines become technologically more flexible, the internal vertical division of labor tends to decline.

This paper is organized as follows. Section 2 presents the basic assumptions of this paper. Section 3 provides an equilibrium analysis based on the microeconomics of optimization, and applications and discussions are undertaken in Section 4. This paper concludes in section 5, and the proofs of all propositions are in section 6.

2. The basic assumptions

2.1 Market demand

Assume that there are two types of people (e.g. females and males) distributing evenly and alternately on a circle with unit perimeter. Each group has $0.5M$ people. The person in group one consumes only goods $X$ but not goods $Y$, while the person in group two consumes only goods $Y$ but not goods $X$. In this model, the price a consumer pays equals the price of a goods plus the transportation cost. Thus the individual demand function of type one [two] is assumed as $(2.1a)$ $(2.1b)$.

$$x = \frac{I}{(p_x + \delta rp_x)\theta}, \quad \theta > 1$$

$$(2.1a)$$

$$y = \frac{I}{(p_y + \delta rp_y)\theta}, \quad \theta > 1$$

$$(2.1b)$$

where $x$ ($y$) is the quantity demanded and $p_x$ ($p_y$) is the price of $X$ ($Y$), $I$ is the individual income, $\delta$ is the arc distance between the point the consumer lives and the point the firm locates, $r$ is the rate of transport price for each unit of distance relative to the price of the good, $\theta$ is the absolute elasticity of market demand, and $\theta>1$ insures that the total revenue increases with the output level.

There is a standardized good $Z$ which is a replacement good for either $X$ or $Y$. We also assume that a unit of $Z$ is indifferent to $k$ ($0\leq k<1$) units of $X$ or $Y$. Here $k<1$ means that the utility from consuming a unit of $Z$ is less than that from consuming a unit of $X$ ($Y$).

For solving the demand function of $Z$, imagine that $X$ is a bag of candies with one kilogram and $Z$ is a bag with $k$ kilograms. The demand for candies does not vary with how many candies are packed in a bag. It means that if the price of $Z$ satisfies $p_z=kp_x$, the quantity demand for $Z$ will satisfy $z=x/k$. Since the individual demand function for $X$ is $(2.1a)$, thus the individual demand function for $Z$ is:

$$z = \frac{Ik^{\theta-1}}{(p_z + \delta rp_z)\theta}, \quad \theta > 1$$

$$(2.2)$$

where we assume that $Z$ and $X$ ($Y$) do not simultaneously exist.

2.2 The vertical chain of production

We assume that products $X$, $Y$ and $Z$ have the same production function. In the later part of this paper,
we will only present the production of \(X\). The production of \(Y\) and \(Z\) is similar.

We use the interval \((0, 1]\) to denote the infinitely divisible vertical chain in the production process of the final good \(X\). For example, \(X_{(s', s]}\) denotes the production process from an intermediate good \(s'\) to another intermediate good \(s\), where \(0<s<s'<1\); \(X_{(0, s]}\) denotes the production process from the beginning to the intermediate good \(s'\) where \(s'<1\), or to the final good where \(s'=1\); and \(X_{(s, 1]}\) denotes the production process from the intermediate good \(s\) to the final good, where \(0<s<1\). For convenience we use \(X_s\) to denote \(X_{(0, s]}\), where \(0<s<1\), and use \(X\) to denote \(X_{(0, 1]}\).

Vertical division of labor within a firm means that the interval \((0, 1]\) is divided into some independent intervals, and a worker just works in parts of the intervals but no one covers the whole interval \((0, 1]\). If a worker works in some intervals, we would say the worker specializes in these intervals.

### 2.3 Production functions

Three kinds of inputs are required in production. The first is labor, we assume that workers are identical, and each is endowed with one unit of time for production. The second is machines, we assume that one final good consists symmetrically of two components, component one and component two. Since one unit of effective production time can produce \(A(l-b)\) amount of output is produced. Moreover, we assume that there is a symmetric structure in the production process of \(X\) which implies the following two points.

First, since the production of \(X\) requires an amount of entry cost \(b\), under the condition that there is no economies (or diseconomies) of scope, we need only \((s'-s)b\) as the entry cost in the production process of \(X_{(s, s']}\), and hence \(l-(s'-s)b\) is the effective production time.

Second, assume that one final good consists symmetrically of two components, component one and component two. Since one unit of effective production time can produce \(A\) amount of final goods, one unit of effective production time can produce \(2A\) amount of component one or component two. It means that as the scope of the production decreases, the productivity level increases accordingly. From (2.3) we know that one unit effective production time can produce \(A\) units of \(X_{(0, 1]}\). As the production interval is changed from \((0, 1]\) to \((s, s']\), from symmetry, one unit of effective production time can produce \(A/(s'-s)\) units of \(X_{(s, s']}\). Thus, with effective production time \(l-(s'-s)b\), one worker can potentially produce
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\[ X_{(s,t)} = \frac{A[l - (s' - s)b]}{s' - s} \]  

Thus, as a Leontief production function, the intermediate goods and the labor contribution will satisfy (2.3).

Now consider the arrangement of division of labor for output maximization. Suppose that there are \( n \) workers in a firm with production technique (2.3), where each worker uses one machine with productivity \( A \) and devotes \( l \) units of working time in production.

**Lemma 1** The arrangement for output maximization is that \((0, 1]\) is evenly divided into \( n \) independent subintervals, where each worker produces in one subinterval. The firm’s maximum output level is

\[ X = A(nl - b) \]  

(2.6)

Lemma 1 shows that the production exhibits the economies of vertical specialization (i.e. the level of productive efficiency under division of labor is higher than that without division of labor). In the case of no division of labor, all people do the same task. According (2.3), the output is

\[ X = na(l - b) \]  

(2.7)

Comparing (2.6) with (2.7), the production line with vertical division of labor has a higher productivity due to the fact that each worker needs to pay less entry cost. The workers just need to learn the skill in a sector in the production line instead of learning the skill of the whole product.

2.4 Putty-clay technology

There is a trade-off between productivity and flexibility. As shown in Lemma 1, the vertical division of labor in a production line will increase the productivity by reducing each worker’s entry cost. However, it needs the workers in the production line to spend time to coordinate. The more workers vertically specializing in a production line, the more coordination time each worker spends. Besides, switching from the production of one goods to another, say from jean to skirt, they need to reorganize the division of labor. Thus, the more goods/varieties they produce, the more coordination time each worker needs to spend. Therefore, the firm which produces a smaller number of varieties prefers a higher degree of vertical division of labor within the firm.

Besides the number of varieties and the degree of vertical division of labor within a firm, the coordination time also correlates with the usage of machines in production. In the process of industrialization, machines are divided into three categories, simple machines (tool), specialized machines and flexible machines (Faunce 1965). Among them the simple machine is the most flexible in multi-varietiy production (with least coordination time in multi-varietiy production). In contrast, the specialized machine is the least flexible, where productivity is greatly increased at the expense of flexibility. Between them is the flexible machine. Due to the application of automatic and digital technology, the flexible machine retains the productivity of the specialized machine but improves the flexibility significantly.

It cannot be concluded that a firm will always prefer to specialize in producing one variety. This is because a firm with a higher degree of vertical division of labor needs a larger extent of the market to bring to play the advantage of specialization. If the extent of the market is not large enough, a firm will earn a larger profit in multi-varietiy or standardized production.

According to the idea mentioned above, in a firm which produces \( m \) \((m = 1, 2)\) varieties of goods in a production line with \( n \) vertically specialized workers, we assume that each worker needs to pay \( c_mnl \) units of coordination time in production, where \( c_2 > c_1 \). It reveals that the coordination time is positively correlated with the number of varieties and the degree of vertical division of labor\(^3\). In addition, it should be assumed

\(^3\) Becker and Murphy (1992) develop a model to study the vertical division of labor in a cooperative team. Vertical division of labor increases productivity on the one hand but coordination costs on the other. The
that coordination time \( c_2 \) is different if different machines are used.

Since \( X \), \( Y \) and \( Z \) are the different varieties of the same product, for simplicity we assume that they share the same entry cost. That means that, if a worker specializes in subinterval \((s, s')\), according to production function (2.3), she just needs to pay entry cost \((s'-s)b\), no matter which varieties she produces. This assumption is consistent with the situation in the clothing industry. It requires almost the same knowledge in a specialized function, such as cutting, sewing, buttonhole making, or pressing, no matter which variety is produced.

### 2.5 Management cost

For represent the management cost of the firm, we assume that each worker have to pay \( cm \) units of time as the average coordination cost of the whole firm, where \( c \) is the cost coefficient and \( m \) is the number of workers in the firm. It means the average management cost increases with the size of the firm.

### 3. The model

As a standard assumption of long-run equilibrium, we assume that the firms in the model are free to enter or exit any industry. It implies that the maximum profit a firm earns is zero.

Since specialization and standardization are considered, the firms in this model have several strategy-variables:

1. The strategies of horizontal specialization and standardization. The firm may specialize in producing \( X \), \( Y \) or the standardized good \( Z \), or generalize in producing both \( X \) and \( Y \) in a production line or in respective production lines.
2. The numbers of workers and machines \((n)\) in a production line.
3. The degree of vertical division of labor in a production line; according to Lemma 1, the even division of the interval \((0, 1]\) where each worker produces in one subinterval is optimal for maximum output.
4. The location point in the circle.

For convenience, we assume that \( n \) is a continuous variable. But the strategies in (1) are discrete. Thus we divide the analysis into four structures, and then compare the maximum profits in these structures.

### 3.1 Structure 1

In this structure all firms will specialize in producing \( Z \), the standardized product of \( X \) and \( Y \). Denote \( d \) as the largest distance between a firm and her customers. From (2.2) her demand functions for \( Z \) is:

\[
Z = \int_0^d \frac{MI}{(p_z + \delta p_z)} d \delta = \frac{Bk^{\theta-1}}{p_z^{\theta}}
\]  

(3.1)

where

\[
B = \frac{MI}{(\theta-1)r \left[1 - \frac{1}{(1 + dr)^{\theta-1}} \right]}
\]  

(3.2)

Assume that the firm has \( n \) workers. When production chain \((0, 1]\) is divided evenly into \( n \) pieces of subintervals, each worker has to pay the entry cost \((b/n)\), the coordination time for the vertical division of labor in the production line \((c/n)\), and the average management cost for the operation of the firm \((cn)\). Thus her effective production time is \([1-(c_1+c)n-b/n]\). According to Lemma 1, the firm’s output is \( z = A[n-(c_1+c)n^2-b] \). Since \( n \) workers are hired and each worker is equipped with one machine, the firm has to pay wages and the prices of machines amounting to \( wn \) and \( tn \) respectively. Thus the profit maximization of the firm is represented as:

optimal division of labor is decided by the trade-off between the marginal productivity and the marginal coordination costs. But their model does not relate to multi-variety production and the usage of machines.
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\[
\max \{B^{1/\theta} (kA)^{(\theta-1)/\theta} \left[ n - (c_i + c) n^2 - b \right]^{(\theta-1)/\theta} - (w + \tau) n \}
\]
\[
st : n > 0
\]
(3.3)

Since the objective function in (3.3) is a concave function respected to \( n \), the optimal \( n \) should satisfy the first-order condition:

\[
\frac{(\theta-1)B^{1/\theta} (kA)^{(\theta-1)/\theta} [1 - 2(c_i + c)n]}{\theta [n - (c_i + c) n^2 - b]^{1/\theta}} = w + \tau
\]
(3.4)

Furthermore, in long-run equilibrium a firm has zero maximum profit, thus

\[
B^{1/\theta} (kA)^{(\theta-1)/\theta} [n - (c_i + c)n^2 - b]^{(\theta-1)/\theta} = (w + \tau) n
\]
(3.5)

From (3.4) and (3.5) we have the number of employees (\( n \)) and the largest arc distance between the firm and the customers (\( d \)) in long-run equilibrium:

\[
n_i = \frac{-1 + \sqrt{1 + 4\theta b(\theta - 2)(c_i + c)}}{2(\theta - 2)(c_i + c)}
\]

\[
d_i = \frac{1}{r} \left\{ \frac{MI (kA)^{\theta-1}}{MI (kA)^{\theta-1} - (\theta - 1)rf(c_i + c)} \right\}^{^1_{\theta-1}} - 1
\]
(3.6)

where \( f(c) \) satisfies:

\[
f(c) = \frac{(w + \tau)^{\theta^{\theta-1}}(\theta - 2)^{\theta-2}}{2c(\theta - 1)^{\theta-1}} \frac{\sqrt{1 + 4\theta b(\theta - 2)c - 1}}{[(\theta - 1)\sqrt{1 + 4\theta b(\theta - 2)c}]^{\theta-1}}
\]
(3.7)

Here \( d_i \) is the radius of the market from which a firm earns zero profit. If a firm has a larger market (with radius \( d > d_i \)), she will earn positive profits. In this case, more firms will be abstracted into the circle. In contrast, if a firm has a smaller market (\( d < d_i \)), she will earn negative profit, and then some firm will exit the market in the long run. Thus if this structure is the equilibrium structure, there are \( 1/(2d_i) \) number of firms distributed evenly along the circle.

3.2 Structure 2

In this structure half of the firms specialize in producing \( X \) and the other half specialize in producing \( Y \). Denote \( d \) as the largest distance between the firm and her customers. Since the population density for \( X \) (\( Y \)) is 0.5\( M \), from (2.2) her demand functions for \( X \) and \( Y \) are respectively:

\[
x = \int_0^d \frac{MI}{(p_x + \delta r p_x)^{\theta}} d\delta = \frac{B}{2p_x^{\theta}}
\]

\[
y = \int_0^d \frac{MI}{(p_y + \delta r p_y)^{\theta}} d\delta = \frac{B}{2p_y^{\theta}}
\]
(3.9a)

(3.9b)

where \( B \) satisfies (2.2).

With the similar analysis above we have that the profit maximization of the firm which produces \( X \) (\( Y \)) is represented as:

\[
\max \{((0.5) B)^{1/\theta} A^{(\theta-1)/\theta} \left[ n - (c_i + c)n^2 - b \right]^{(\theta-1)/\theta} - (w + \tau) n \}
\]
\[
st : n > 0
\]
(3.10)

Similar to the deduction in the first structure, we have the number of employees (\( n \)) and the largest distance (\( d \)) in long-run equilibrium:

\footnote{In this model the solutions are divided into three cases, \( \theta > 2 \), \( \theta = 2 \), and \( \theta < 2 \). For simplicity we only show the first case, the others have the same properties.}


\[
\begin{align*}
n_2 &= \frac{-1 + \sqrt{1 + 4\theta b(\theta - 2)(c_1 + c)}}{2(\theta - 2)(c_1 + c)} \\
d_2 &= \frac{1}{r} \left\{ \frac{MIA^{\theta - 1}}{MIA^{\theta - 1} - 2(\theta - 1)rf(c_1 + c)} \right\}^{\frac{1}{\theta - 1} - 1}
\end{align*}
\]

(3.11)

(3.12)

where \( f(c) \) satisfies (3.8).

Similarly, since \( d_2 \) is the radius from which the firm earns zero profit, there are \( 1/(2d_2) \) number of firms specializing in X and \( 1/(2d_2) \) number of firms specializing in Y in equilibrium. In this situation the firms in each group, specializing in X or in Y, distribute evenly along the circle. Since the markets for X and Y are independent, there is not any requirement about the relationship between the distributions of these two groups.

3.3 Structure 3

In this structure each firm generalizes in producing X and Y in a production line with all workers vertically specializing in it. Due to the symmetry of X and Y, each employee uses half of working time in producing X and the other half in producing Y.

The same as in Structure 2, the demand functions for X and Y satisfy (3.9a) and (3.9b) respectively. When production chain (0, 1] is divided evenly into \( n \) pieces of subintervals, each worker’s effective production time is \( [(1 - (c_2 + c)n - b)/n] \) in which half is used to produce X and the other half to produce Y. According to Lemma 1, the firm’s output is \( x = y = 0.5A[n - (c_2 + c)n^2 - b] \). Thus the problem of profit maximization of the firm is represented as:

\[
\max \left\{ 2(0.5B)^{1/\theta} A^{(\theta - 1)/\theta} \left[ 0.5(n - (c_2 + c)n^2 - b) \right]^{(\theta - 1)/\theta} - (w + \tau)n \right\} \\
\text{s.t. } n > 0
\]

(3.13)

With the similar analysis above we have that the number of employees \( n \) and the largest arc distance between the firm and the customers \( d \) in long-run equilibrium:

\[
\begin{align*}
n_3 &= \frac{-1 + \sqrt{1 + 4\theta b(\theta - 2)(c_2 + c)}}{2(\theta - 2)(c_2 + c)} \\
d_3 &= \frac{1}{r} \left\{ \frac{MIA^{\theta - 1}}{MIA^{\theta - 1} - (\theta - 1)rf(c_2 + c)} \right\}^{\frac{1}{\theta - 1} - 1}
\end{align*}
\]

(3.14)

(3.15)

where \( f(c) \) satisfies (3.8).

Similarly, if this structure is the equilibrium structure, there are \( 1/(2d_3) \) number of firms distributed evenly along the circle.

3.4 Structure 4

In this structure each firm generalizes in producing X and Y in respective production lines. Due to the symmetry of X and Y, half of the workers specialize in producing X and the other half specialize in producing Y.

The same as in Structure 3, the demand functions for X and Y satisfy (3.9a) and (3.9b) respectively. We assume that there are \( 2n \) workers in the firm, among them \( n \) workers produce X and the other \( n \) workers produce Y in different production lines. In this case, each worker has to pay the average management cost for the operation of the firm \( (2cn) \), as well as the entry cost \( (b/n) \) and the coordination time \( (c/n) \) for the vertical division of labor in her production line. Thus her effective production time is \( [1 - (c_1 + 2c)n - b/n] \).

According to Lemma 1, the firm’s output is \( x = y = A[n - (c_1 + 2c)n^2 - b] \). Thus the problem of profit maximization of the firm is represented as:
max \{2(0.5B)^{1/\theta} A^{(\theta-1)/\theta}[n-(c_1+2c)n^2-b]^{(\theta-1)/\theta} - 2(w+\tau)n\} \quad (3.16)

st : n > 0

With the similar analysis above we have that the number of employees \(n\) and the largest arc distance between the firm and the customers \(d\) in long-run equilibrium:

\[
n_4 = \frac{-1+\sqrt{1+4\theta b(\theta-2)(c_1+2c)}}{2(\theta-2)(c_1+2c)} \quad (3.17)
\]

\[
d_4 = \frac{1}{r}\left\{\left[\frac{MIA^{\theta-1}}{MIA^{\theta-1}-2(\theta-1)rf(c_1+2c)}\right]^{\frac{1}{\theta-1}} - 1\right\} \quad (3.18)
\]

where \(f(c)\) satisfies (3.8).

Similarly, if this structure is the equilibrium structure, there are \(1/(2d_4)\) number of firms distributed evenly along the circle.

### 3.5 The best structure in long-run equilibrium

The four structures mentioned above represent four strategies in horizontal specialization and standardization respectively. Since they are a firm’s strategies, she will choose one that maximizes her profit. In this subsection we will find the best strategy in long-run equilibrium.

Lemma 2 In long-run equilibrium the best strategy takes place in the structure with the minimum radius out of \(d_1, d_2/2, d_3\) and \(d_4\). If \(d_1\) is the minimum between the four radii, for example, specializing in the standardized product \(Z\) is the best strategy in long-run equilibrium. First, we show that generalizing in \(X\) and \(Y\) is an inferior strategy to specializing in standardized product \(Z\). Intuitively speaking, the larger the area of market a firm faces, the larger the profit a firm earns. Since \(d_1 > d_2\) \((d_4 > d_1)\), a firm which specializes in standardized product \(Z\) in an area with radius \(d_1\) \((d_4)\) earns positive profits, while in the same area the firm has zero profit by generalizing in \(X\) and \(Y\), where the \(X\) and \(Y\) are produced in one production line (in different lines). It means that a firm would not choose the strategy of generalizing in \(X\) and \(Y\). Second, we show that specializing in \(X\) or \(Y\) is an inferior strategy to specializing in standardized product \(Z\). In an area with radius \(d_2\) two firms, one specializing in \(X\) and the other specializing in \(Y\), earn zero profit. Since \(d_2 > d_1\), they will earn positive profits if the area is divided evenly into two parts and one firm specializes in standardized product \(Z\) in a part. It means that a firm would not choose the strategy of specializing in \(X\) or \(Y\). From the analysis above, specializing in standardized product \(Z\) is the best strategy when \(d_1\) is the minimum between the four radii. In Proposition 1 we describe the equilibrium by comparing the radii.

**Proposition 1** There is a unique long-run equilibrium in this model in which we have three potential situations.

1. Structure 1 is the best structure if and only if (3.19) and (3.20) are satisfied. The equilibrium firms satisfy (3.6) and (3.7).

\[
k^{\theta-1} \geq \frac{f(c_1+c)}{f(c_2+c)} \quad (3.19)
\]

\[
2\left[\frac{MIA(kA)^{\theta-1}}{MIA(kA)^{\theta-1}-(\theta-1)rf(c_1+c)}\right]^{\frac{1}{\theta-1}} \leq \left[\frac{MIA^{\theta-1}}{MIA^{\theta-1}-2(\theta-1)rf(c_1+c)}\right]^{\frac{1}{\theta-1}} + 1 \quad (3.20)
\]

2. Structure 2 is the best structure if and only if (3.21) and (3.22) are satisfied. The equilibrium firms satisfy (3.11) and (3.12).
Through the comparison between the four radii, we have Proposition 1. Inequalities (3.19) and (3.20) come respectively from \(d_1 \leq d_3\) and \(d_1 \leq d_2/2\), inequalities (3.21) and (3.22) come respectively from \(d_3/2 \leq d_1\) and \(d_3/2 \leq d_1\), and inequalities (3.23) and (3.24) come respectively from \(d_3 \leq d_1\) and \(d_3 \leq d_2/2\). Since \(d_3/2 \leq d_3\), Structure 4 is not the best strategy in long-run equilibrium.

According to Proposition 1, the conditions of the best structures are shown in Figure 1. First, when the degree of substitution of standardized goods for \(X\) and \(Y\) is large enough (i.e. \(k\) approaches to 1), the point will drop into Area 1 and thus standardization and specialization is the best strategy. Next, when the extent of the market \((MIA/r)\) and/or the productivity \((A)\) are large enough, the point will drop into the Area 2. Thus, individualization and specialization is the best strategy. Third, when the transaction costs associated multi-variety production is small enough (i.e. the coordination time in multi-variety production \(c_2\) approaches to that in specializing in one variety of good production \(c_1\)), Area 3 will extend and cover any given point in Figure 1, thus individualization and generalization is the best strategy. In the next section we will give further explanations.
4. Applications and discussions

4.1 The determinants of standardization and specialization

In this subsection, we show the effects of market and technology on specialization and standardization. The determinants include the extent of the market which increases with population \((M)\), individual income \((I)\) and market transaction efficiency \((1/r)\), the degree of substitution of standardized goods for individualized goods \((k)\), productivity \((A)\), and the coordination time associated with multi-variety production \((c_2)\). For exogenous variables, the number of workers vertically producing in a production line is an index of the vertical division of labor within a firm \((n)\), the number of varieties produced by a firm \((m)\) is an inverse index of the horizontal specialization of a firm, and the number of varieties offered in a market is an inverse index of the degree of standardization in a market.

**Corollary 1** The correlations between endogenous and exogenous variables are summarized in Table 1.

<table>
<thead>
<tr>
<th>Exogenous var.</th>
<th>Endogenous var.</th>
<th>The degree of vertical division of labor in a production line ((n))</th>
<th>The number of varieties produced in a production line ((m))</th>
<th>The number of varieties offered in the market</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population ((M))</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Individual income ((I))</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Market efficiency ((1/r))</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Productivity ((A))</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Coordination time ((c_2))</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Substitution ((k))</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Sign +(-) denotes that there is positive (negative) correlation between endogenous and exogenous variables.

Now we explain intuitively Corollary 1 through comparative statics. Assume that a market is in an equilibrium state at the beginning. First, as the extent of the market [which is positively correlated with population \((M)\), individual income \((I)\), and/or market efficiency \((1/r)\)] and/or productivity \((A)\) increases, firms earn more profits. This attracts more firms to enter while each firm increases production. Why does the firm produce more? With more firms, each firm has a smaller market radius. But with larger market scale or higher productivity, the firm gets positive profits even in this smaller market radius. The consumers pay less traffic costs and hence are willing to pay a higher price for the same quantity. Accordingly, each firm increases output. To increase the output a firm increases the number of workers and the vertical division of labor within a firm accordingly increases. Next, the larger the coordination time associated with multi-variety production \((c_2)\), the less flexible a firm has. Thus a firm is more willing to seek the static advantage in production. As a result, the fewer varieties a firm produces and the higher the degree of vertical division of labor. Last, the higher the degree of substitution of standardized goods for individualized goods \((k)\), the easier a firm achieves the economy of specialization via product standardization. Consequently, a firm produces fewer varieties and accordingly has a higher degree of vertical division of labor.

Besides the effects on vertical and horizontal specialization in a firm, changes in market and technology also affect the product standardization in a market. There is a trade-off between incomes and production costs in the increase in the number of varieties in a market. On the one hand, due to the degree of substitution of standardized goods for individualized goods, the more varieties offered in a market, the higher the market demand. Moreover, the lower the degree of substitution and/or the larger the extent of the
market, the larger the market demand. It is because more individualized goods are consumed and the increase in utility from consuming an individualized good is higher than consuming a standardized good. On the other hand, the increase in variety in a market will increase the production costs. If a firm produces more varieties, the production costs are increased through the increase in coordination costs. If variety is increased through more firms entering into the market, the production costs are increased through having more workers involved in the production. Thus, the higher productivity and/or the fewer coordination time associated with multi-variety production, the lower is the marginal production costs in the increase in variety. With the larger extent of the market, more marginal market demand will be achieved from the increase in variety but the marginal production cost will not change. Thus in the new equilibrium more varieties will be offered in the market. The analysis of the effects of other factors is similar.

4.2 Horizontal specialization and vertical division of labor

In this subsection we want to explain the following phenomenon: in clothing industry, the degree of vertical division of labor in a “small shop” (Fraser 1983 p526, Hiebert 1990), which usually produces custom-made clothing, is lower than that in a specialized clothing firm, where the production of standardized goods is finely subdivided into many operation sequences. In Chicago in 1900s, for example, it took sixty workers to produce a coat, fifty to make a pair of pants, twenty a vest, and eighty to eighty-five to produce a single overcoat (Fraser 1983 p543).

**Corollary 2** The production line which produces more varieties will have a lower degree of vertical division of labor.

The consistency between horizontal and vertical specialization is due to coordination costs in a production line. The vertical division of labor requires the workers in the production line to spend time to coordinate. The more workers vertically specializing in a production line, the more coordination time each worker spends. Besides, switching from the production of one variety to another, say from jean to skirt, they need to reorganize the division of labor. Thus, the more varieties a production line produces, the more coordination time each worker needs to spend. Therefore, a production line which produces more varieties prefers a lower degree of vertical division of labor. This explains why “small shops” in the clothing industry, which usually engage in custom-made production, have lower degrees of vertical division of labor than the specialized clothing firms.

It is notable that, this conclusion has a precondition: each worker uses the same knowledge in production across all varieties of goods. In some cases this assumption is satisfied. In the clothing industry, for example, the workers need almost the same knowledge in a specialized function, such as cutting, sewing, buttonhole making, or pressing, in producing different kinds of clothing.

However, if the precondition is not satisfied, the factor, the knowledge required in production, may impose the opposite tendency between horizontal specialization and vertical division of labor. This is because, if it requires different or partially different knowledge in producing different varieties (kinds) of goods, the worker in a production line which produces more varieties needs to learn more knowledge (pay more entry costs in this model). The larger the amount of entry costs, the larger the economy of scale the firm has, and hence the larger the degree of vertical division of labor the firm should have.

In reality, because of the impact of various factors, it is hard to ascertain the relationship between the horizontal specialization and vertical division of labor. Detailed situations should be analyzed to judge which factors are dominant.

4.3 The function of standardization

In this subsection we will answer this question: Why is product standardization introduced in an economy?
Corollary 3 Standardization lowers the threshold which brings into play the advantage of specialization, which includes horizontal specialization and vertical division of labor, in a production line.

Intuitively speaking, there are two reasons why standardization lowers the threshold which brings into play the advantage of specialization in a production line. First, as shown in Corollary 2, due to using less coordination costs, a specialized production line has a higher degree of vertical division of labor relative to a generalized production line. It means that a specialized production line has a larger amount of fixed inputs, i.e. more workers and machines are invested in production. Therefore, a minimum extent of market is needed to bring into play the advantage of specialization. Moreover, the larger the extent of the market, the more advantage the specialized production line has.

Next, before the introduction of standardized goods, a specialized production line can only satisfy a small part of the market demand, the demand of those consumers who prefer the products the production line produces. After the introduction of standardized goods, a specialized production line which produces standardized goods can satisfy the whole market demand. Due to the increase in demand, a specialized production line is easier to bring into play the advantage of specialization.

In Fraser’s case study of men’s clothing industry (Fraser 1983 p526-7), for example, although the sewing machine was invented in 1846, handwork for custom-made clothing continued to predominate until the Civil War (1861-1865). The demand for uniforms in this period made sewing machines ubiquitous throughout the industry. The mass production of uniforms inspired critical refinement in the production of standardization body types, while printed paper patterns were also introduced in the 1860s, further facilitating standardization production. Thus, the factory-made clothing began to supplant tailor-made men’s garments especially after 1870s.

4.4 The duality in clothing industry

In this subsection we will explain the duality in the vertical division of labor and the sizes of establishments in clothing industry.

Through studying the manufacture of women’s garment in New York market, Belfer (1954) points out the difference between the men’ and women’s clothing industries. Section work (the method of production with mass vertical division of labor in a production line) was first introduced into the men’s clothing industry. For women’s clothing industry, by contrast, the style factor is dominant. Moreover, changing styles require flexibility in production techniques, and the whole garment system (the method of production with a skilled operator sews the entire garment) provides the entrepreneur with more elasticity than the section work system.

But there are two questions to which Belfer has not answered. First, why does the production with greater vertical division of labor have less flexibility? Second, why does the women’s clothing industry not achieve the economies of specialization through clothing standardization to the same extent as the men’s clothing industry?

First, the vertical division of labor requires workers in the production line to spend time to coordinate. Changing from producing one variety to another, say from jean to skirt, the division of labor has to be reorganized. Thus, the more varieties a production line produces, the more coordination time each worker has to spend. In addition, the more workers vertically specializing in a production line, the more coordination time each worker spends. Therefore, a production line which produces more varieties prefers less degree of vertical division of labor.

Second, as we know, relative to men, women tend to prefer the individuality of clothing more. Thus women lose more from consuming standardized goods instead of individualized goods. This implies that, relative to the men’s clothing manufacturing, it is less efficient to achieve economies of specialization through clothing standardization in women’s clothing manufacturing. There is in fact lower degrees of standardization in women’s clothing and hence lower degrees of vertical division of labor in the production
lines in the manufacturing of women’s clothing.

Besides showing in the vertical division of labor, the duality also shows in the sizes of establishments. From U.S. Census Bureau, we have the size distributions of the establishments in men’s and boys’ cut and sew apparel manufacturing (code: 31522) and women’s and girls’ cut and sew apparel manufacturing (code: 31523). Since the distributions have not changed significantly in recent decade, we only show the distributions in 2002.

Table 2: The size distributions of the establishments in clothing industry in 2002

<table>
<thead>
<tr>
<th>Employees per establishment</th>
<th>1-4</th>
<th>5-9</th>
<th>10-19</th>
<th>20-49</th>
<th>50-99</th>
<th>100-249</th>
<th>250-499</th>
<th>500-999</th>
<th>1000+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution in 31522</td>
<td>24.7</td>
<td>11.7</td>
<td>11.7</td>
<td>18.7</td>
<td>12.2</td>
<td>13.9</td>
<td>4.8</td>
<td>1.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Distribution in 315223</td>
<td>37.3</td>
<td>13.5</td>
<td>14.7</td>
<td>17.9</td>
<td>8.3</td>
<td>5.2</td>
<td>2.1</td>
<td>0.8</td>
<td>0.2</td>
</tr>
</tbody>
</table>

The numbers in distributions are percentages.

Table 2 shows that, relative to men’s and boys’ apparel manufacturing, women’s and girls’ apparel manufacturing have larger proportions in the ranges of employees under 20 but less proportions in the ranges of employees over or equal to 20. Given other conditions, it is reasonable to assume that the size of establishment is positively correlated to the degree of vertical division of labor in its production line. It implies that, the different tendencies to individuality is one of the significant reasons for the different sizes of establishments between men’s and boys’ apparel manufacturing and women’s and girls’ apparel manufacturing.

4.5 Three periods in the car industry

Market, technology and organization structure are closely correlated. Faunce (1965) divides the process of industrialization into three periods, which are respectively characterized by the usage of simple machines, specialized machines, and flexible machines. With the case of the automobile industry, Gartman (2004) divides consumption pattern into three periods, luxury consumption in craft production, mass consumption in mass production, and customization in flexible production. In this subsection we analyze the causalities between market conditions, technology and organization in the aspects of specialization and standardization.

Table 3: Specialization and standardization in three periods

<table>
<thead>
<tr>
<th>Variables</th>
<th>Periods</th>
<th>The degree of vertical division of labor in a production line</th>
<th>The number of varieties produced in a production line</th>
<th>The number of varieties offered in the market</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple machines</td>
<td>Low</td>
<td>Large</td>
<td>Large</td>
<td></td>
</tr>
<tr>
<td>Specialized machines</td>
<td>High</td>
<td>Small</td>
<td>Small</td>
<td></td>
</tr>
<tr>
<td>Flexible machines</td>
<td>Wide range</td>
<td>Wide range</td>
<td>Large</td>
<td></td>
</tr>
</tbody>
</table>

First, the characteristics in the period of using simple machines are generalization and individualization. From the aspect of the extent of the market, since the population size and individual incomes are small, it is hard to consume the output from large-scale production. Besides, from the aspect of
technology, simple machines (tools) are flexible in transferring from the production of one variety to another. Thus firms in this period adopt custom-made production. It is characterized by product individualization and a low degree of vertical division of labor in a production line.

Next, the characteristics in the period of using specialized machines are standardization and specialization. By nature, these involve exchanging flexibility for productivity and consuming standardized products instead of individualized products. For increasing the productivity, special purpose machines are developed. But they are unhandy to change from the production of one variety to another. Besides, high productivity can also be realized from specialization. Through vertical division of labor in a production chain, workers focus on a small range of tasks, from which they can save learning costs and allow more improvements. However, since having more workers involves more costs of reorganization in multi-variety production, vertical division of labor is at the expense of flexibility.

For example, Henry Ford is a pioneer in introducing mass production into modern industries (Rubenstein 2001). For producing a motor vehicle which could be purchased by working people, he introduced the famous Model T in 1908. In 1909 it was priced at $650. After installing the moving assembly lines in his factory in 1913, Ford finally hit the $500 target. In its last year production, in 1927, a Model T could be purchased for just $290, and totally 15 million Model Ts had been manufactured since the beginning.

However, mass production requires that the population and individual incomes are large enough to consume the high output level from standardized production. But it is not universal. For example, when Eiji Toyoda, an engineer who had practiced in Ford Company in 1950, wanted to copy the mode of mass production in Japan, he found that this mode is limited by the small-scale and diversified demand in Japan. In the change from simple machines to specialized machines, productivity is greatly improved but at the expense of flexibility. It suits large-scale production with a small number of varieties. For Japan’s market, what Toyota Company did was to improve the specialized machine systems in another direction, i.e. to improve the flexibility in multi-variety production by keeping about the same productivity level, but with more varieties produced. Thus lean production, a more flexible alternative to mass production, was applied to Toyota Company (Womack et al. 1990).

Besides, mass production requires that consumers are willing to accept the standardized products instead of individualized products. However, it is less acceptable as people’s purchasing power increases. In the automobile industry (Gartman 2004, Rubenstein 2001), for example, the design of Ford’s Motor T focused on satisfying the basic requirement – traffic. As purchasing power increased, people wanted the vehicle to represent their status, to accord with their culture, to appropriate to their gender and occupation, etc. This made the production become more diverse and small-scale.

Third, for adapting to this tendency, a firm would, just like what Toyota Company did, make the production more flexible in multi-variety production conditioned by keeping the advantage of specialization. It is mainly caused by two opposite factors. When the impact of flexibility (the decline in transfer costs associated with multi-variety production) is dominant, a firm will produce more varieties in less vertical division of labor within a firm. In contrast, when the extent of market is large enough to achieve the advantage of specialization than that from flexibility, a firm will produce fewer varieties in a higher degree of vertical division of labor within a firm.

However, no matter which factor is dominant, more varieties are offered in the market. The difference is that in the former case it is realized by more varieties produced by a firm; while in the later case, larger market attracts more firms into the market, thus more varieties is realized by a higher degree of market segmentation.

5. Conclusion

A Hotelling long-run equilibrium model based on the microeconomics of optimization is developed to explore the effects of market conditions, such as the extent of the market and the degree of substitution
of standardized goods for individualized goods, and technology, such as productivity and coordination time associated with multi-variety production, on vertical division of labor within a firm, horizontal specialization of a firm and product standardization. The conclusions are summarized in Table 1.

In application, several phenomena are analyzed. First, we show that, the firm which produces more varieties will have a lower degree of vertical division of labor within the firm. This conclusion explains that in the clothing industry, the degree of vertical division of labor in a “small shop”, which usually produces custom-made clothing, is fewer than that in a specialized firm.

Second, we show that product standardization lowers the threshold which brings into play the advantage of specialization. However, standardization is at the expense of consumer preference for consuming individualized product. As a consequence, the higher the degree of the substitutability of standardized product for individualized product, the easier product standardization is introduced to achieve the economies of specialization. From this conclusion it is easy to understand why mass production for standardized clothing started from the demand for uniforms in Civil War (1861-1865). Although the sewing machine was invented in 1846, it could not change the predomination in handwork for custom-made clothing.

Third, production technology and the corresponding organization structure acclimatize itself to consumption. Conversely, the consumption pattern is constrained by the production technology. According to the characteristics of production and consumption, say in the automobile industry, the process of industrialization is divided into three stages, craft production for customization, mass production for standardized consumption, and flexible specialization for individualized consumption. Our model shows the tendencies and their causalities in these three periods.

However, due to the complexity in this model, we omit the discussion of integration or disintegration (vertical division of labor) between firms. It is one of the important strategies of a firm which closely correlates with standardization and agglomeration in the process of industrialization (Scott 1983a, 1983b, 1984 and 1996).

6. Appendix

Proof of Lemma 1:
Suppose that interval (0, 1] is divided evenly into n pieces of independent intervals, according production function (2.3), worker 1’s output is

$$X_1 = A\left(\frac{l}{s_1 - s_0} - b\right)$$

and worker i’s output (2 ≤ i ≤ n) is

$$X_i = \min\{X_{i-1}, A\left(\frac{l}{s_i - s_{i-1}} - b\right)\}$$

where $X_n = X$. Thus we have the firm’s output

$$X = \min_{1 ≤ i ≤ n}\{A\left(\frac{l}{s_i - s_{i-1}} - b\right)\}$$

Thus the arrangement for output maximization is that (0, 1] is evenly divided into n independent subintervals ($s_i - s_{i-1} = 1/n$), where each worker produces in one subinterval. The firm’s maximum output level is

$$X = A(nl - b)$$

Proof of Corollary 1:
Here we just deduce one of the conclusions: the vertical division of labor within a firm and the
number of varieties in the market increase with the extent of the market and/or productivity, but the number of varieties produced by a firm decreases as the extent of the market and/or productivity increases. The deductions of the other conclusions in Corollary 1 are similar.

When \( M, I, r^1, \text{or } A \) increase, inequalities (3.21) and (3.22) are easier to satisfied. In this case, three situations will happen.

(1) The firm’s best strategy does not change. In this case, the degree of vertical division of labor, the number of varieties offered in the market, and the number of varieties produced by the firm will not change.

(2) The firm’s best strategy changes from Structure 1 to Structure 2. In this case, the number of varieties produced by the firm and the vertical division of labor will not change, but the number of varieties offered in the market will increase.

(3) The firm’s best strategy changes from Structure 3 to Structure 2. In this case, the firms will produce less number of varieties in a production line with higher degree of vertical division of labor, but the number of varieties offered in the market will not change.

In this model, since the number of varieties is an integer (one or two), its increase from one to two requires that the increase in the extent of the market and/or productivity exceeds some threshold. If not, the endogenous variables will not change. If we assumed that the number of varieties is continuous (the degree of vertical division of labor is taken as a continuous variable in this model), they would increase with the extent of the market and/or productivity continuously. When the variables are large enough, the continuity assumption can reflect more the tendency of the variables, but accordingly the model is much more complicated.

The three cases above show that the vertical division of labor within a firm and the number of varieties offered in the market increase with the extent of the market and/or productivity. But the number of varieties produced by a firm decreases as the extent of the market and/or productivity increases.

**Proof of Corollary 3:**

Form Proposition 1 we have that, (1) in the situation without standardization, a production line specializes in one variety of goods if and only if (3.21) is satisfied; (2) when product standardization is considered, a production line specializes in one variety of goods if and only if equation (3.19) or (3.21) is satisfied. Through comparing the two situations we have the conclusion.

**References**


U.S. Census Bureau, www.census.gov
