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Market size, division of labor, and firm productivity ☆

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ABSTRACT

We generalize Krugman's (1979) 'new trade' model by allowing for an explicit production chain in which a range of tasks is performed sequentially by a number of specialized teams. We demonstrate that an increase in market size induces a deeper division of labor among these teams which leads to an increase in firm productivity. The paper can be thought of as a formalization of Smith's (1776) famous theorem that the division of labor is limited by the extent of the market. It also sheds light on how market size differences can limit the scope for international technology transfers.

1. Introduction

In this paper, we develop a simple general equilibrium model in which an increase in market size leads to an increase in the division of labor which brings about an increase in firm productivity. In particular, we generalize Krugman's (1979) seminal 'new trade' model by opening the black box of the production function and allowing for an explicit production chain in which a range of tasks is performed sequentially by a number of specialized production teams. An increase in market size induces a deeper division of labor among these teams which leads to an increase in firm productivity. Underlying this is a trade-off between the fixed costs associated with establishing a team and the marginal costs associated with the degree of specialization of the team which firms solve differently depending on the size of the market.

At the broadest level, the paper can be thought of as a formalization of Smith's (1776) famous theorem that the division of labor is limited by the extent of the market in an environment in which the division of labor takes the same form as in his pin factory.[1] By embedding the pin factory into a framework of monopolistic competition, it overcomes the dilemma emphasized by Stigler (1951: 185) that "either the division of labor is limited by the extent of the market, and characteristically, industries are monopolized; or industries are characteristically competitive, and the theorem is false or of little significance." An increase in market size leads to both a deeper division of labor within firms as well as the entry of new firms.

While our theory is not explicit about the nature of the increase in market size, the usual interpretation of the Krugman (1979) model suggests trade liberalization as a natural example. Recently, many empirical studies have focused on the productivity effects of trade liberalization (e.g. Pavcnik, 2002; Trefler, 2004). Their results suggest that there are important trade-induced improvements in industry productivity either through gains in average firm productivity ('firm productivity effect') or through the reallocation of market share from less to more productive firms ('reallocation effect'). While our theory cannot speak to the reallocation effect, it can be thought of as a micro-foundation of the firm productivity effect.[2]

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[1] Recall that in Smith's (1776: 7) pin factory "one man draws out the wire, another straights it, a third cuts it, a fourth points it, a fifth grinds it at the top for receiving the head (…)".

[2] Well-known formal treatments of the reallocation effect include Melitz (2003) and Bernard et al. (2003).

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As such, the paper contributes to a growing literature on the sources of the firm productivity effect. Previous work has mainly emphasized fixed costs (e.g. Krugman, 1979), learning by exporting (e.g. Clerides et al., 1998), competition-induced innovation (e.g. Aghion et al., 2005), or a horizontal focusing on core competencies by multi-product firms (e.g. Eckel and Neary, 2010; Bernard et al., 2011). Only McLaren (2000) also studies the productivity gains of a trade-induced vertical restructuring of production. Both the source of the productivity gains as well as the link between trade liberalization and the vertical restructuring of production are very different in his model, however.

An additional implication of our model is that seemingly superior technologies developed in larger markets, characterized by lower fixed costs of establishing teams and a finer division of labor across teams, may not be appropriate for smaller markets. Firms in developing countries may therefore not have an incentive to adopt technologies from developed countries even if they are freely available to them. This observation offers a novel explanation for the localized character of technology which is usually rationalized by arguing that important components of technology are tacit in nature (e.g. Keller, 2004: 753). It essentially elaborates on the remark of Stigler (1951: 193) that American production methods will often be too specialized to be an appropriate model for industrialization in developing countries.

The remainder of the paper is organized as follows: we lay out the basic model, solve for the optimal organization of production, characterize the general equilibrium, analyze the effects of an increase in market size, consider the scope for international technology transfers, and offer some concluding remarks.

2. Basic setup

There are L consumers who are endowed with one unit of labor each. They have access to n final goods over which they have 'love of variety'-preferences

$$U=\sum_{i=1}^{n}u(x_i) \tag{1}$$

where $u(x_i)$ is the utility derived from consuming x units of final good i which is continuous and differentiable and satisfies $u'(x_i)>0$ and $u''(x_i)<0$. Consumers maximize this utility subject to their budget constraints $1=\sum_{i=1}^{n}p_ix_i$, where p_i is the price paid for good i and the wage rate is normalized to 1.

As can be seen from the first order conditions of the consumers' maximization problems, the resulting demands have elasticity $\varepsilon(x_i)=-\frac{u'(x_i)}{x_iu''(x_i)}$. Following Krugman (1979), we assume that $\varepsilon'(x_i)<0$ which is equivalent to assuming that the demand curves are less convex than in the constant elasticity case (linear demand curves would be an example). This assumption ensures that an increase in market size leads to an increase in firm output which is necessary for market size to affect the division of labor within firms. We also assume that $\varepsilon(0)>1+\frac{1}{\gamma}$ and that there exists an $\bar{x}>0$ such that $\varepsilon(\bar{x})=1+\frac{1}{\gamma}$, where γ is a cost parameter to be defined below.[3] These parameter restrictions guarantee the existence and uniqueness of a monopolistically competitive equilibrium.

The production of each final good requires the sequential performance of a number of tasks. Early tasks are concerned with obtaining raw materials which are then refined successively in later production stages. The set of these tasks is represented by a segment of length normalized to 2 which we call the production chain. To produce the final good, all tasks $\omega\in[0,2]$ have to be performed sequentially. If only tasks $\omega\in[0,\omega_1]$, $0<\omega_1<2$, are performed, a preliminary good ω_1 is obtained. This preliminary good ω_1 can then be transformed into a more downstream preliminary good ω_2, $0<\omega_1<\omega_2<2$, by performing the additional tasks $\omega\in[\omega_1,\omega_2]$ and so on. One unit of each task is required to produce one unit of the final good. Similarly, one unit of the relevant subset of tasks is required to produce one unit of a preliminary good.[4]

All production tasks associated with a given final good are performed by production teams within a single firm. Before being able to perform any tasks, a team needs to acquire a core competency $c\in[0,2]$ in the production chain which requires f units of labor. To perform one unit of each task in the range $[\omega_1,\omega_2]$, the team then further needs

$$l(\omega_1,\omega_2)=\frac{1}{2}\int_{\omega_1}^{\omega_2}|c-\omega|^{\gamma}d\omega \tag{2}$$

units of labor where $\gamma>0$ so that it gets worse at performing a given task the further away that task is from its core competency. Teams are symmetric in the sense that the parameters f and γ are the same across teams. The firm can choose how many teams are established, which core competencies they acquire, and which production tasks they perform.

3. Optimal organization of production

Eq. (2) implies that the cost of producing one unit of output is minimized if each task is performed by only one team, the teams' core competencies are uniformly distributed along the production chain, and each team performs a symmetric range of tasks around its core competency. The minimum total cost of producing y units of output conditional on a given number of teams t can therefore be written as

$$\mathrm{TC}=t\left(f+y\int_0^{\frac{1}{t}}\omega^{\gamma}d\omega\right) \tag{3}$$

since each team performs $\frac{2}{t}$ tasks of which half are to the right and half are to the left of its core competency.

The optimal number of teams solves a trade-off between fixed and marginal costs. This trade-off can be seen most clearly by rewriting Eq. (3) as $\mathrm{TC}=tf+\frac{yt^{-\gamma}}{\gamma+1}$. On the one hand, more teams imply higher fixed costs since more core competencies need to be acquired. On the other hand, more teams imply lower marginal costs since each team performs a narrower range of tasks around its core competency. Minimizing this expression with respect to t yields

$$t=\left(\frac{\gamma}{\gamma+1}\frac{y}{f}\right)^{\frac{1}{\gamma+1}} \tag{4}$$

Hence, the optimal number of teams is increasing in output. Intuitively, higher output makes marginal costs more important relative to fixed costs so that it is optimal to set up a larger number of more highly specialized teams. Notice that the range of tasks performed by each team is inversely proportional to the number of teams since the production chain is of a given length and production tasks are equally divided among teams.

As is easy to verify, Eqs. (3) and (4) imply that the average cost is given by

$$\mathrm{AC}=\left(\frac{\gamma+1}{\gamma}\frac{f}{y}\right)^{\frac{\gamma}{\gamma+1}} \tag{5}$$

Notice that the average cost is decreasing in output so that the production technology exhibits increasing returns to scale. Underlying this

[3] A polynomial of degree higher than 2 for the function $u(x)$ would satisfy this condition, as would any sum of more than one power function of x. For instance, the quadratic function $u(x)=ax-x^2/2$ with $x\in[0,a/2]$ yields a linear demand system and the following simple expression for the demand elasticity, $\varepsilon(x)=a/x-1$, which satisfies $\varepsilon'(x)<0$, $\varepsilon(0)>1+1/\gamma$, and $\bar{x}=\frac{a}{2+1/\gamma}$ such that $\varepsilon(\bar{x})=1+\frac{1}{\gamma}$.

[4] A similar representation of the production process has been used by Dixit and Grossman (1982).