E C O N O M I C S B U L L E T I N

Technical change and agglomeration

Carl Gaigné
INRA, UR122

Stéphane Riou
University of Saint-Etienne

Abstract

Although economic historians consider technical change to be a significant factor explaining the evolution of the spatial organization of an economy, economic geography still fails to address this important issue. By developing a simple two-region general equilibrium model under monopolistic competition, we show that agglomeration is triggered by technological progress shifting production towards more skill intensive techniques.

Citation: Gaigné, Carl and Stéphane Riou, (2007) "Technical change and agglomeration." *Economics Bulletin*, Vol. 18, No. 3 pp. 1-5
Submitted: March 2, 2007. **Accepted:** April 10, 2007.
URL: http://economicsbulletin.vanderbilt.edu/2007/volume18/EB-07R10003A.pdf

1 Introduction

Although economic historians consider technological change as being a significant factor explaining the evolution of the spatial organization of an economy (Mokyr, 1995), economic geography still fails to address this important issue (Fujita et al., 1999). It is recognized by now that technological change has favored the employment of more skilled workers at the expense of less skilled workers (see Acemoglu, 2002). In this paper, we show how such technological developments affect the agglomeration of industrial production.

Economic geography models usually assume that mobile firms require just one type of input: skilled mobile workers (see Fujita et al., 1999). Although some location models do allow for multiple requirements in terms of skills, they are either partial equilibrium models (Michel et al., 1996) or the needs for skilled and unskilled workers are independent (Forslid and Ottaviano, 2003) so that such approaches are inappropriate for analyzing the spatial effects of technical change.

The effects of the implementation of technical advances leading to a higher proportion of skilled workers over unskilled ones on the location process is captured in a simple manner in a general equilibrium model of location and trade under monopolistic competition. This model is developed in the next section. Section 3 determines and analyzes equilibrium wages as well as skill composition in each region. We show that, when the spatial distribution of firms is exogenous, technical changes in the economy promote the spatial concentration of skilled workers in the region hosting the majority of modern firms. Finally, section 4 analyzes the impact of technological change on the location of firms. It appears that the agglomeration of modern firms and skilled workers is more likely to occur when technologies are skill-intensive and trade costs are low enough.

2 The model

The economy consists of two regions, labeled $r = 1, 2$. Variables associated with each region will be subscripted accordingly. There are two production factors, skilled and unskilled labor as well as two sectors, traditional and modern sectors. We denote by H the total mass of skilled and by L the total mass of unskilled workers in the economy. Each worker supplies one unit of his type of labor inelastically. The two types of workers differ also in terms of mobility. Unskilled workers are perfectly mobile between sectors but geographically immobile, and are assumed to be uniformly distributed between the two regions: $L_1 = L_2 = L/2$. Skilled workers are mobile across regions and reside in the region offering them the higher indirect utility so that H_r the mass of skilled workers located in region r is endogenous. Such assumptions on spatial mobility are in line with empirical observations (see Faini, 1999).

All workers in the economy have the same Cobb-Douglas utility function $U = T^{1-\mu} M^{\mu}$, where $\mu \in (0, 1)$ is a constant, T a 'traditional' homogeneous good and M an aggregate of 'modern' differentiated goods. The sub-utility function M is given by

$$M \equiv \left(\int_0^n q(i)^{\rho} di \right)^{1/\rho} \text{ with } \rho \equiv \frac{\sigma - 1}{\sigma} \in (0, 1).$$

where n is the total mass of varieties available in the economy, $q(i)$ is the consumption of variety $i \in [0, n]$ and $\sigma > 1$ is the constant elasticity of substitution between any two varieties of the differentiated good.

The sector producing the homogeneous good is assumed to be perfectly competitive. This good is freely traded so that its price is the same everywhere ($p_1^T = p_2^T$). The production of one unit of the traditional good T requires one unit of unskilled labor so that profit-maximizing prices are given by $p_r^T = w_r^l$ where w_r^l is the wage rate prevailing in region r. We choose good T

as numeraire, what implies $w_r^l = 1$. We assume that this sector is always active in both regions whatever the spatial allocation of modern firms. A sufficient condition is that $\mu < 1/2$.

Firms in the modern sector produce under monopolistic competition and increasing returns by using skilled and unskilled workers. There is a one-to-one relation between firms and varieties. Trade between regions in modern goods implies trade costs, modeled as iceberg costs: for one unit of the differentiated good to reach the other region, $\tau > 1$ units must be shipped. Production of $x(i)$ units of variety i requires a production process and administration services. For instance, these services can include management and monitoring functions as well as research and development functions. More precisely, administration incurs a fixed input requirements of f units of both skilled and unskilled labour while production incurs a marginal input requirement of mx units of unskilled labour. In order to simplify the analysis, we assume that the fixed requirement of both skilled and unskilled workers is captured by a Cobb-Douglas type technology with a share η of skilled workers. This choice of technology serves only the purpose of simple illustration. The results hold for any constant returns to scale technology in which one technology is relatively skill intensive. Hence, an increase in η encapsulates the *technological bias hypothesis* by which the implementation of technical advances is reflected in a higher proportion of skilled workers over unskilled ones. Note that our model can be considered as an extension of Forslid and Ottaviano (2003) where they consider $\eta = 1$.

Hence, the total cost function of a modern firm producing in region r is expressed as follows

$$\begin{aligned} c_r(i) &= f(w_r^h)^\eta (w_r^l)^{1-\eta} + w_r^l m x_r(i) && (1) \\ &= f(w_r^h)^\eta + m x_r(i) && (2) \end{aligned}$$

where the second equality stems from the fact that $w_r^l = 1$ and w_r^h is the wage of skilled workers prevailing in region r.

In what follows, we can restrict the analysis to the case of a representative firm for each region since firms have the same access to the technology and to the demand. We also assume, without loss of generality that $m = (\sigma - 1)/\sigma < 1$. The price maximising the profit $\pi_r = p_r x_r - c_r$ of a firm set up in region $r = 1, 2$ is given by

$$p_r = 1 \tag{3}$$

Entry as well as exit of firms is free in each region so that profits are zero in equilibrium. The output of each firm can hence be expressed as

$$x_r = \sigma f (w_r^h)^\eta \tag{4}$$

It appears that, when wages are fixed, a marginal increase in η raises the level of production in both regions.

The total demand for a variety produced in region r implies:

$$x_r = \mu(R_r P_r^{\sigma-1} + \phi R_s P_s^{\sigma-1}) \qquad \text{with } \phi \equiv \tau^{1-\sigma} \tag{5}$$

where P_r (resp. P_s) and R_r (resp. R_s) are the CES price indices of region r (resp. of region $s \neq r$) and the income of region r (resp. of region $s \neq r$). They can be expressed as, respectively,

$$\begin{aligned} P_r &= (n_r + \phi n_s)^{1/(1-\sigma)} && (6) \\ R_r &= L/2 + w_r^h H_r && (7) \end{aligned}$$

Finally, define $\omega_r(s)$ as the utility of skilled workers living in region $r = 1, 2$ with

$$\omega_r(s) = w_r^h P_r^{-\mu} \tag{8}$$

3 Equilibrium wages and skill composition

In order to disentangle the various effects at work, it is convenient to first analyze the case where firms are supposed to be immobile, i.e. n_r is exogenous. The study of the configuration where they are mobile is reported in the next section.

We now consider labor and product markets clearing conditions for a given spatial distribution of firms and skilled workers. By using Shephard's lemma on (1) and by considering (4) and (3), skilled and unskilled labor market clearing implies

$$w_r^h H_r = \eta f (w_r^h)^\eta n_r \tag{9}$$
$$L_r^M = (\sigma - \eta) f (w_r^h)^\eta n_r \tag{10}$$

where L_r^M is the mass of unskilled labour located in region r and working in the modern sector. Trivial calculations reveal that $L_r^M / H_r = (\sigma - \eta) w_r^h / \eta$. In other words, for a given value of w_r^h, a rise in η favours the demand for skilled workers at the expense of unskilled workers in the modern sector in each region.

Plugging (4) and (6) as well as (9) and (7) in (5) generates a system of two linear equations in $(w_1^h)^\eta$ and $(w_2^h)^\eta$, that can be solved to obtain the equilibrium skilled wages as explicit function of the spatial distribution of firms n_r. We obtain:

$$(w_1^h)^\eta = \frac{\mu L}{2fn\,(\sigma - \mu\eta)} \frac{(\sigma + \mu\eta)(1-s)\phi^2 + 2\sigma s\phi + (\sigma - \mu\eta)(1-s)}{\sigma\phi - s(1-s)\,(1-\phi)\,[\phi(\sigma + \mu\eta) - (\sigma - \mu\eta)]} \tag{11}$$
$$(w_2^h)^\eta = \frac{\mu L}{2fn\,(\sigma - \mu\eta)} \frac{(\sigma + \mu\eta)s\phi^2 + 2\sigma(1-s)\phi + (\sigma - \mu\eta)s}{\sigma\phi - s(1-s)\,(1-\phi)\,[\phi(\sigma + \mu\eta) - (\sigma - \mu\eta)]} \tag{12}$$

where $s \equiv n_1/n$ is the share of modern firms established in region 1. By introducing (11) and (12) in (9), we get

$$\frac{w_1^h H_1}{w_2^h H_2} = \frac{s}{(1-s)} \frac{(\sigma + \mu\eta)(1-s)\phi^2 + 2\sigma s\phi + (\sigma - \mu\eta)(1-s)}{(\sigma + \mu\eta)s\phi^2 + 2\sigma(1-s)\phi + (\sigma - \mu\eta)s} \equiv \Lambda$$

with $\Lambda = 1$ when $s = 1/2$ and $\partial\Lambda/\partial\eta \gtreqless 0$ when $s \gtreqless 1/2$. This means that a change in technology favoring the employment of the skilled workers has a stronger impact on wages offered by each firm in the region hosting the majority of modern firms, regardless of the spatial distribution of skilled workers. Indeed, a rise in η increases more the income of the region accomodating the majority of firms (see (7) where we have introduced (9)) and, in turn, raises more operating profits of each firm located in that region. Hence, firms can offer higher wages in the region where they are more numerous, whatever the spatial distribution of workers.

Thus, technical change creates a strong incentive for the skilled workers to locate in the large region. When the spatial distribution of firms is fixed, the equilibrium spatial allocation of the skilled workers is reached when the utility of the skilled workers is identical in both regions, i.e. $\omega_1 = \omega_2$ or, equivalently, $w_1^h P_1^{-\mu} = w_2^h P_2^{-\mu}$ (see (8)). Hence, by introducing (9) and (11)-(12) in (8), we obtain

$$\frac{H_1}{H_2} = \frac{2\mu s\sigma\phi(1-\phi)(1+\phi)(P_1/P_2)^{\mu/(\sigma-1)}}{(1-s)[(\sigma + \mu\eta)s\phi^2 + 2\sigma(1-s)\phi + (\sigma - \mu\eta)s]^2}(2s-1)$$

where $\partial(H_1/H_2)/\partial\eta > 0$ when $s > 1/2$. Even though firms use the same technology in both regions, the implementation of technical advances leading to a higher proportion of skilled workers over unskilled ones induces the agglomeration of the skilled workers in the large region.

To summarize,

Proposition 1 *Assume that the spatial distribution of firms is exogenous. Technical changes favouring the employment of skilled workers promote the spatial concentration of skilled workers in the region hosting the majority of modern firms.*

4 Spatial equilibrium and stability

We can now analyse the location decision of the skilled workers when the spatial distribution of firms is endogenous. In this case, a spatial equilibrium arises when no skilled workers may get a higher utility level in the other region. We assume that local labour markets adjust instantaneously when some skilled workers move from one region to another region. We use (11) and (12) giving the equilibrium skilled wages as explicit function of the spatial distribution of firms n_r and taking into account the relationship between H_r and n_r (via (9)). Hence, a spatial equilibrium arises at $s \in (0,1)$ when $\Delta\omega(s) = \omega_1(s) - \omega_2(s) = 0$ or at $s = 0$ when $\Delta\omega(0) \leq 0$, or at $s = 1$ when $\Delta\omega(1) \geq 0$. Because $\Delta\omega(s) = \omega_2(s)[\Omega(s) - 1]$, where $\Omega(s) \equiv \omega_1(s)/\omega_2(s)$ or

$$\Omega(s) = \left[\frac{(\sigma+\mu\eta)(1-s)\phi^2 + 2\sigma s\phi + (\sigma-\mu\eta)(1-s)}{(\sigma+\mu\eta)s\phi^2 + 2\sigma(1-s)\phi + (\sigma-\mu\eta)s}\right]^{1/\eta}\left[\frac{1-s+s\phi}{s+\phi\,(1-s)}\right]^{\frac{\mu}{1-\sigma}} \tag{13}$$

where we have introduced (11) and (12) in (8).

Some comments are in order. First, due to trade costs, increasing local expenditures on differentiated good raises demand per firm for a given price index (market size effect). This in turn raises operating profits implying higher skilled wages. Hence, modern firms and skilled workers have an incentive to agglomerate in a single region. On the other hand, for given expenditures, more firms reduce the price index inducing a fall in local demand per firm and, therefore, in skilled wages (market crowding effect). This effect promotes the dispersion of modern firms and skilled workers. Further, market size and market crowding effects influence the spatial differential of skilled wages as follows. It is easy to check that skilled worker wages are higher in the region hosting the majority of firms ($s > 1/2$) whenever $\phi > (\sigma - \mu\eta)\,/\,(\sigma + \mu\eta)$. In other words, the market size effect dominates the market crowding effect when τ and σ are low as well as when μ and η are high. Finally, the second term of the RHS in (13) shows the existence of an additional effect inducing of the agglomeration of modern firms and skilled workers. Indeed, more firms raise the purchasing power for a given wage since fewer varieties are imported and burdened by trade costs (cost-of-living effect). This latter effect does not depend on technology parameters.

Inspection of (13) reveals that $\Omega(1/2) = 1$ so that full dispersion of firms ($s = 1/2$) and, thus, skilled workers ($H_1 = H_2 = H/2$) is always a spatial equilibrium. This symmetric configuration is stable if and only if for any marginal deviation from the symmetry, the equation of motion brings the spatial distribution of skilled workers back to the original one. Formally, we must have $\Omega'(1/2) < 0$. Some calculations show that full dispersion is a stable spatial configuration when $0 < \phi < \phi_b$ with

$$\phi_b \equiv \frac{(\sigma-\mu\eta)\,(\sigma-1-\mu\eta)}{(\sigma+\mu\eta)\,(\sigma-1+\mu\eta)} < 1$$

where $\phi_b > 0$ when $\sigma > 1+\mu\eta$ (no-black-hole condition, see Fujita et al. (1999)).[1] When $\phi > \phi_b$, full dispersion ceases to be stable.

Full agglomeration in region 1 is a spatial equilibrium when $\Omega(1) \geq 1$. It is straighforward to check that $\lim\limits_{\phi\to 0}\Omega(1) < 1$ and $\Omega(1) = 1$ when $\phi = 1$ as well as

$$\frac{\mathrm{d}\Omega(1)}{\mathrm{d}\phi} \lesseqgtr 0 \ \text{ when } \phi \gtreqless \sqrt{\phi_b} \qquad \left.\frac{\mathrm{d}\Omega(1)}{\mathrm{d}\phi}\right|_{\phi=1} = \frac{-\mu(2\sigma-1)}{\sigma(\sigma-1)} < 0$$

Hence, there exists a single value ϕ_s above which full agglomeration is a spatial equilibrium. In other words, whatever the value of $\eta \in (0,1]$, full agglomeration occurs when trade costs are low enough. Hence, even though the requirements in skilled labor are very low, full agglomeration

[1] When $\eta = 1$, we find the same result obtained by Forslid and Ottaviano (2003).

can be triggered, provided that trade costs are very low. Now, we can analyze how ϕ_s reacts to a change in η. The threshold value ϕ_s is implicitly defined by $\Omega(1) = 1$, or equivalently, by

$$A(\phi) = 1 \quad \text{with } A(\phi) \equiv \frac{1 + \mu\eta/\sigma}{2}\phi^{\frac{(\sigma-1+\mu\eta)}{\sigma-1}} + \frac{1 - \mu\eta/\sigma}{2}\phi^{\frac{-(\sigma-1-\mu\eta)}{\sigma-1}}$$

Trivial calculations reveal that $A(\phi = 1) = 1$, whereas we have

$$\frac{\partial A(\phi)}{\partial \eta} = \frac{\mu}{2\sigma}\left[\phi^{\frac{(\sigma-1+\mu\eta)}{\sigma-1}} - \phi^{\frac{-(\sigma-1-\mu\eta)}{\sigma-1}}\right] + \frac{\mu \ln(\phi)}{2\sigma(\sigma-1)}\left[(\sigma+\mu\eta)\phi^{\frac{(\sigma-1+\mu\eta)}{\sigma-1}} + (\sigma-\mu\eta)\phi^{\frac{-(\sigma-1-\mu\eta)}{\sigma-1}}\right]$$

that is negative because $1 > \phi > 0$ and $\sigma - 1 + \mu\eta > 0$. Hence, ϕ_s decreases with η. In addition, it is straighforward to check that $\mathrm{d}\phi_b/\mathrm{d}\eta < 0$.[2] As a result, the agglomeration of modern firms and skilled workers is more likely to occur when η increases because the interval of trade costs under which full dispersion (resp. agglomeration) takes place decreases (resp., increases).

To summarize,

Proposition 2 *Technical changes favouring the employment of skilled workers promote industrial clustering provided that trade costs are low enough and the share of expenditures for the modern industry is high enough.*

References

[1] Acemoglu D. (2002). Technical change, inequality, and the labour market. *Journal of Economic Litterature* 40, 7-72.

[2] Faini R. (1999). European migrants: an endangered species?, in *Market Integration Regionalism and the Global Economy*, Baldwin R., D. Cohen, A. Sapir & A. Venables (eds.), Chapter 8, Cambridge University Press, 228-253.

[3] Fujita, M., P. Krugman and A. Venables (1999). *The spatial economy. Cities, regions and international trade*, MIT Press, Cambridge (Mass.).

[4] Forslid R. and G. Ottaviano (2003). An analytically solvable core-periphery model. *Journal of Economic Geography* 3, 229 - 240

[5] Michel Ph., A. Perrot and J.-F. Thisse (1996). Interregional equilibrium with heterogeneous labour, *Journal of Population Economics* 9, pp. 95-114.

[6] Mokyr J. (1995). Urbanization, technological progress and economic history, in H. Giersch, ed., *Urban Agglomeration and Economic Growth*, Berlin: Springer Verlag, 1995, pp. 3-37.

[2] It is always true when the no-black-hole condition is checked.