Density (dis)economies in transportation: revisiting the core-periphery model

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Abstract

We study how density (dis)economies in interregional transportation influence location patterns in a standard new economic geography model. Density economies may well delay the occurrence of agglomeration when compared to the case without such economies, while agglomeration is both more likely and more gradual under density diseconomies than under density economies.

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1 Introduction

While the new economic geography (henceforth, NEG) literature has devoted much attention to the analysis of the spatial impacts of *exogenously* falling transport costs, it has given rather little consideration to the *endogenous* determination of these costs and its potential impact on the location process.[1] This is a handicap because it is a well-established fact that density economies are very prevalent in the case of rail and air freight (see, e.g., Harris, 1977; Braeutigam *et al.*, 1984), since increasing density allows capital expenses to be spread over more ton-miles.[2] However, the case of density diseconomies also deserves some attention. Several studies suggest that such density diseconomies may indeed well exist for the trucking industry, or could at least be present if the negative external costs of this industry (pollution, congestion, accidents) were internalized at market prices (see, e.g., Ying, 1990; Forkenbrock, 2001).

The purpose of this paper is to revisit a standard NEG model in which unit shipping costs between regions vary with the total volume of trade and, therefore, with the spatial distribution of supply and demand. As recently pointed out by Fujita and Mori (2005, p.152), "when the transport development is considered in this context, the impact on the spatial organization of the economy may be quite different." We confirm this claim by showing the the qualitative properties of the spatial equilibrium crucially depend on the presence of density (dis)economies. Density economies may well delay the occurrence of agglomeration when compared to the case without such economies, while agglomeration is both more likely and more gradual under density diseconomies than under density economies.

The remainder of the paper is organized as follows. Section 2, presents the model as an extension of Ottaviano *et al.* (2002).[3] Section 3 analyzes how density (dis)economies in inter-regional transportation influence industrial location.

2 The model

There are two regions, labeled $i = 1, 2$, and two production factors: mobile skilled and immobile unskilled workers. Let L (resp., A) stand for the mass of skilled (resp., unskilled) workers. The unskilled are evenly spread across the two regions, each of which hosts an exogenously given mass $A/2$ of them, while the distribution of skilled workers is endogenous. Without loss of generality we assume that, whenever agglomeration of mobile workers takes place, it occurs in

[1] See Mori and Nishikimi (2002) for the locational impacts of density economies in a neoclassical trade model.

[2] Density economies (resp., diseconomies) are said to exist when a one percent increase in all outputs, holding network size, production technology, and input prices constant, increases the firm's cost by less (resp., more) than one percent.

[3] Using a two-country four-region framework similar to the one developed in this paper, Behrens *et al.* (2006) investigate the impacts density (dis)economies in *international transportation* have on the internal spatial structure of trading partners. The main difference with the present paper is that they do not study density (dis)economies in infranational transportation.

region 1, and we denote by $1/2 \leq \lambda \leq 1$ the share of skilled workers living in region 1.

As in Ottaviano *et al.* (2002), all agents are endowed with one unit of labor and $\overline{q}_0$ units of the numéraire. There are two consumption goods: a homogenous good (q_0) and a continuum of varieties of a horizontally differentiated good (indexed by v). An agent residing in region i solves the following problem:

$$\max_{q_{ii}(v),\, q_{ji}(v)} \sum_{j=1,2} \left[\alpha \int_0^{n_j} q_{ji}(v)\mathrm{d}v - \frac{\beta-\gamma}{2} \int_0^{n_j} [q_{ji}(v)]^2 \mathrm{d}v \right] - \frac{\gamma}{2} \left[\sum_{j=1,2} \int_0^{n_j} q_{ji}(v)\mathrm{d}v \right]^2 + q_0$$

given her budget constraint $\sum_{j=1,2} \int_0^{n_j} p_{ji}(v) q_{ji}(v) \mathrm{d}v + q_0 = y_i + \overline{q}_0$, where $\alpha > 0$, $\beta > \gamma > 0$ are parameters; $[0, n_j]$ is the range of varieties produced in region i; $q_{ji}(v)$ and $p_{ji}(v)$ are the quantity and the consumer price of variety v in region i when produced in region j; and y_i is the agent's income which depends on her skilled or unskilled status. Let $n \equiv n_1 + n_2$ stand for the total mass of varieties. Solving the consumption problem yields the following demand functions:

$$q_{ji}(v) = a - (b + cn)p_{ji}(v) + c\left(\int_0^{n_i} p_{ii}(z)\mathrm{d}z + \int_0^{n_j} p_{ji}(z)\mathrm{d}z \right) \tag{1}$$

where $a \equiv \alpha b$, $b \equiv 1/[\beta + (n-1)\gamma]$ and $c \equiv \gamma b/(\beta - \gamma)$ are positive bundles of parameters.

Production takes place in two sectors. The first one supplies the homogeneous good under perfect competition, using unskilled labor as the only input of a constant-returns technology. Without loss of generality, the unit input requirement is set to one. The second one is monopolistically competitive and supplies the differentiated good employing both factors under increasing returns to scale. Following Ottaviano *et al.* (2002), firms in this sector face a fixed requirement of $\phi > 0$ units of skilled labor, whereas their marginal unskilled labor requirement is set equal to zero without loss of generality. Skilled labor market clearing thus implies that $\phi n_1 = \lambda L$ and $\phi n_2 = (1-\lambda)L$.

Shipping the homogeneous good is costless, so that in equilibrium the unskilled wage is equal to one everywhere. To ship one unit of the differentiated varieties across regions firms have to pay $\widehat{\tau} > 0$ units of the numéraire. In what follows, we refer to $\widehat{\tau}$ as the *unit shipping cost*, which is endogenously determined in equilibrium but taken as given by each firm. Let w_i stand for the skilled wage in region $i = 1, 2$. Assuming that regional product markets are segmented, a firm located in region i and producing variety v maximizes its profit

$$\Pi_i(v) = p_{ii}(v)q_{ii}(v)\left(A/2 + \phi n_i\right) + (p_{ij}(v) - \widehat{\tau})q_{ij}(v)\left(A/2 + \phi n_j\right) - \phi w_i$$

with respect to $p_{ii}(v)$ and $p_{ji}(v)$. As shown by Ottaviano *et al.* (2002), because there is a continuum of (zero-measure) firms the equilibrium prices are as follows:

$$p_{ii}^* = \frac{2a + cn_j\widehat{\tau}}{2(2b + cn)} \qquad \text{and} \qquad p_{ji}^* = p_{ii}^* + \frac{\widehat{\tau}}{2}, \tag{2}$$

and the equilibrium can be expressed as follows: $q_{ii}^* = (b + cn)p_{ii}^*$ and $q_{ji}^* = q_{ii}^* - (b + cn)\widehat{\tau}/2$. We assume throughout that $\widehat{\tau} \leq 2a/(2b + cn)$ for trade to occur between the two regions at these equilibrium prices, regardless of the spatial distribution of skilled workers.

Finally, the equilibrium wages of the skilled are such that all operating profits are absorbed by the wage bill. Substituting the equilibrium prices and quantities into the profits and solving for the wages finally yields:

$$w_i^* = (b + cn)\left[(A/2 + \phi n_i)\,(p_{ii}^*)^2 + (A/2 + \phi n_j)\left(p_{jj}^* - \widehat{\tau}/2\right)^2\right]/\phi. \tag{3}$$

Skilled workers migrate to the region offering them the highest utility level. As shown by Ottaviano *et al.* (2002), the indirect utility in region i is given by $V_i^* = S_i^* + w_i^* + \overline{q}_0$, where

$$S_i^* = \frac{a^2 n}{2b} - a(n_i p_{ii}^* + n_j p_{ji}^*) + \frac{b + cn}{2}\left[n_i (p_i^*)^2 + n_j (p_{ji}^*)^2\right] - \frac{c}{2}(n_i p_{ii}^* + n_j p_{ji}^*)^2$$

is the individual consumer surplus evaluated at the market outcome. A *spatial equilibrium* is such that no skilled worker has an incentive to change location, conditional upon the fact that the product and labor markets clear at the equilibrium prices (2) and (3). Let

$$\Delta V^*(\lambda) \equiv V_1^*(\lambda) - V_2^*(\lambda) = \frac{n(b + cn)}{2\phi(2b + cn)^2}\left(\lambda - \frac{1}{2}\right)\widehat{\tau}(\lambda)\left[-\varepsilon_1 \widehat{\tau}(\lambda) + \varepsilon_2\right] \tag{4}$$

denote the indirect utility differential between the two regions, where

$$\varepsilon_1 \equiv Ac(2b + cn) + \left(6b^2 + 6cnb + c^2 n^2\right)\phi > 0 \qquad \varepsilon_2 \equiv 4a(3b + 2cn)\phi > 0.$$

A spatial equilibrium arises at $\lambda^* \in (0, 1)$ when $\Delta V^*(\lambda^*) = 0$, or at $\lambda^* = 0$ if $\Delta V^*(0) \leq 0$, or at $\lambda^* = 1$ if $\Delta V^*(1) \geq 0$. Such an equilibrium always exists because ΔV^* is a continuous function of λ. An interior equilibrium is stable if and only if the slope of (4) is negative in a neighborhood of the equilibrium, whereas each agglomerated equilibrium is stable whenever it exists.

3 Density (dis)economies and industry location

For a given spatial distribution λ and a given value of unit shipping costs $\widehat{\tau}$, the total volume of trade between the two regions at the market outcome is as follows:

$$\begin{aligned} X^* &\equiv n_i\,(A/2 + n_j \phi)\,q_{ij}^* + n_j\,(A/2 + n_i \phi)\,q_{ji}^* \\ &= \rho_0 - \rho_1 \lambda(1 - \lambda)(\widehat{\tau} - \rho_2), \end{aligned} \tag{5}$$

where

$$\rho_0 \equiv \frac{A(b + cn)n(a - b\widehat{\tau})}{2(2b + cn)} > 0 \qquad \rho_1 \equiv \frac{n^2[4b\phi + c(n\phi + A)]}{2(2b + cn)} > 0 \qquad \rho_2 \equiv \frac{4a\phi}{4b\phi + c(n\phi + A)} > 0.$$

To capture the idea of density (dis)economies, we assume that unit shipping costs between regions vary with the volume of interregional trade X, i.e. $\widehat{\tau} \equiv f(X)$, with $f'(\cdot) < 0$ in the presence of density economies, $f'(\cdot) > 0$ in the presence of density diseconomies, and $f'(\cdot) = 0$ when there are no density effects.

Expression (5) shows that X^* is quadratic in λ. To simplify the subsequent developments, we capture the idea that shipping costs are influenced by the volume of trade by taking a linear approximation of the foregoing function, evaluated at an arbitrary reference point $\overline{\lambda} \in (1/2, 1]$, say $\overline{\lambda} = 1$:

$$\widehat{\tau}(\lambda) \simeq f[X^*(1)] + f'[X^*(1)] \cdot \left.\frac{\partial X^*}{\partial \lambda}\right|_{\lambda=1} (\lambda - 1) = \tau - \xi(1 - \lambda) \tag{6}$$

where

$$\tau \equiv f[X^*(1)] > 0 \qquad \xi \equiv \rho_1(\widehat{\tau} - \rho_2)f'[X^*(1)].$$

In the above expression, τ stands for the *fixed unit transport cost*, which is determined by technology and infrastructure; whereas $\widehat{\tau}$ is, as stated above, the unit shipping cost which depends on τ but also on aggregate interregional trade flows. Put differently, τ is exogenous, whereas $\widehat{\tau}$ is endogenously determined by the geography of supply and demand.

Equation (6) implicitly defines $\widehat{\tau}$ as a function of X^*, since X^* depends itself on $\widehat{\tau}$. Solving (6) for $\widehat{\tau}$ yields the closed-form solution

$$\widehat{\tau}(\lambda) = \frac{\tau + f'\rho_1\rho_2(1 - \lambda)}{1 + f'\rho_1(1 - \lambda)},$$

where $f' \equiv f'[X^*(1)]$ to alleviate notation. We now discuss the different types of stable equilibria that may emerge. Our aim is to characterize the equilibrium distribution λ^* as a function of the density (dis)economies f' and the exogenous fixed unit transport cost τ.

(i) Full agglomeration ($\lambda^* = 1$) is a stable spatial equilibrium if and only if $-\varepsilon_1\widehat{\tau}(1) + \varepsilon_2 > 0$ or, equivalently,

$$\tau < \varepsilon_2/\varepsilon_1,$$

a condition that does not depend on the sign of f' because $\widehat{\tau}(1) = \tau$. As expected, full agglomeration is a spatial equilibrium if and only if transport costs are sufficiently low, which is the standard NEG result (Fujita *et al.*, 1999; Fujita and Thisse, 2002).

(ii) Full dispersion ($\lambda^* = 1/2$) is a stable spatial equilibrium if and only if $-\varepsilon_1\widehat{\tau}(1/2) + \varepsilon_2 < 0$ or, equivalently,

$$f' < \frac{2(\varepsilon_1\tau - \varepsilon_2)}{\rho_1(\varepsilon_2 - \rho_2\varepsilon_1)} \equiv \overline{f'}, \tag{7}$$

where it is straightforward to check that $\varepsilon_2 - \rho_2\varepsilon_1 > 0$. The threshold $\overline{f'}$ is positive if and only if τ – the fixed unit transport cost – is high enough, so that $\varepsilon_1\tau - \varepsilon_2 > 0$. Hence, full dispersion is more likely when density economies and/or fixed unit transport costs are sufficiently high. Cleary, under density economies ($f' < 0$), multiple stable equilibria exist for all $f' < \overline{f'}$ and $\tau < \varepsilon_2/\varepsilon_1$ (see Figure 1). However, under density diseconomies ($f' > 0$), there are never multiple stable equilibria, whereas stable partial agglomeration may occur. It is worth pointing out that such a result never arises in very closely related frameworks of economic geography (Fujita et al., 1999; Fujita and Thisse, 2002).

(iii) Partial agglomeration ($1/2 < \lambda^* < 1$) arises if and only if $f' > \overline{f'}$ and $\tau > \varepsilon_2/\varepsilon_1$. It is readily verified that the spatial equilibrium is such that $\lambda^* = 1 - \overline{f'}/(2f')$, which lies in the admissible interval $(1/2, 1)$. Finally, one can verify that the derivative of (4) is negative at this equilibrium, thus showing that partial agglomeration is stable. Note that in this configuration, increasing density diseconomies (higher value of f') favor agglomeration.

Let us summarize the equilibrium relationship between the spatial distribution λ^*, the fixed unit transport costs τ, and density (dis)economies f' in the following Proposition and in Figure 1:

Proposition 1 (spatial equilibria) *For given values of the exogenous parameters τ and f', the stable spatial equilibria are as follows:*

(i) full dispersion only when $f' < \overline{f'}$ and $\tau > \varepsilon_2/\varepsilon_1$;

(ii) full dispersion and full agglomeration when $f' < \overline{f'}$ and $\tau < \varepsilon_2/\varepsilon_1$;

(iii) full agglomeration only when when $f' > \overline{f'}$ and $\tau < \varepsilon_2/\varepsilon_1$;

(iv) partial agglomeration only when $f' > \overline{f'}$ and $\tau > \varepsilon_2/\varepsilon_1$.

Insert Figure 1 about here.

Some comments are in order. In the case of density economies, dispersion may remain a spatial equilibrium even when the fixed unit trade costs reach low values. Stated differently, when $f' < \overline{f'}$ and $\tau < \varepsilon_2/\varepsilon_1$ the economy would be fully agglomerated in the absence of density economies, yet may remain dispersed in the presence of such economies. Further, there may be multiple equilibria in the case of density economies. The intuition underlying this result it that full agglomeration yields low value of shipping costs, which allows this full agglomeration to be sustained; whereas full dispersion yields high values of shipping costs, which also allows this configuration to be sustained. Finally, the transition between the configurations is catastrophic. Once a sufficient mass of firms simultaneously deviates from the dispersed configuration, the increase in trade volumes and the associated decrease in shipping costs are large enough to trigger a *self-reinforcing* process of agglomeration. Turning to density diseconomies, the agglomeration process starts for higher values of the fixed trade costs τ and is more gradual than in the presence of density economies. This is due to the fact that shipping costs are lower than τ when there is initially a dispersed configuration, which then makes agglomeration more likely. Yet, this agglomeration process is *self-defeating*, in the sens that when firms agglomerate they raise shipping costs $\widehat{\tau}$ by reducing trade volumes, which then makes such a move unprofitable for the other firms.

Finally, our results suggest that a switch from a transportation technology exhibiting density economies to one exhibiting density diseconomies, may have a strong impact on the space-economy, *even if transport costs are constant.* In the light of these findings, it may be interesting to investigate how the process of agglomeration differed between the 19th century (where railroads were the main mode of land transportation, subject to strong density economies), and the 21st century (where trucking is the main mode of land transportation, subject to weak density economies, or even diseconomies).

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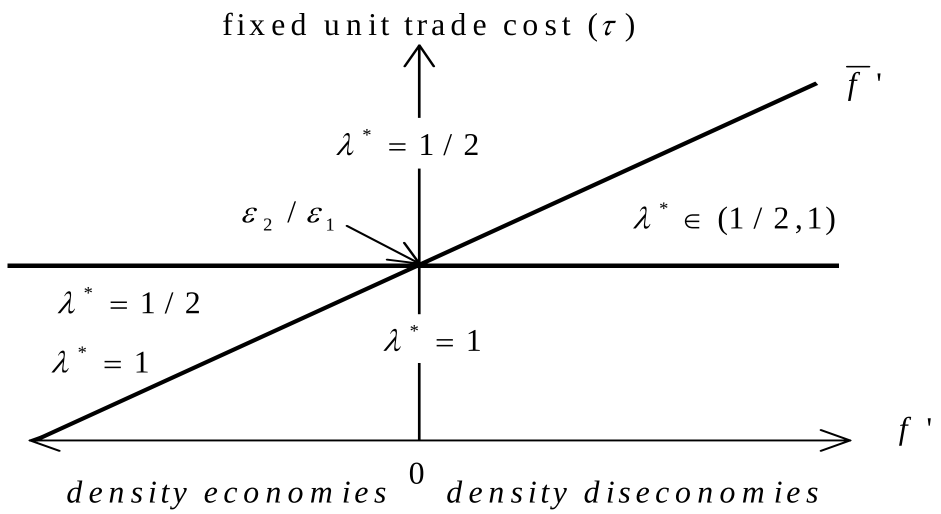

Figure 1. Spatial equilibria