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District formation and local social capital: a (tacit) co-opetition approach

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Abstract

This paper considers a model of district formation as a local socio-economic system incorporating the mix of local cooperation and competition, termed *co-opetition*. There are heterogeneous firms distinguished by their "stand-alone" district-dependent production and transportation cost. Every firm chooses its location when its production cost is affected by local socio-economic spillovers generated by other firms in the district. The firms take into account the reciprocal nature of local spillovers: while reducing their own costs, the firms also reduce the costs of their rivals. We show that the location game with a linear demand function yields an equilibrium for any number of firms and districts. We characterize both "agglomeration" equilibria, when all firms locate in one district, and "dispersed" equilibria, when firms locate in different districts. We demonstrate that a dispersed equilibrium can emerge only if firms' and districts' characteristics possess a sufficient degree of heterogeneity. © 2002 Elsevier Science (USA). All rights reserved.

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1. Introduction

Why do firms in some industries tend to agglomerate in some districts rather than to spread evenly over space? The literature that attempts to answer this question rests heavily on Marshall's (1890) view of externalities that identifies three possible reasons for agglomeration of firms and workers: first, the local availability of intermediate and final goods leads to lower transportation costs, second, "the labor market pooling" saves costs of matching between local firms and workers, and, third, the presence of "localized technological spillovers" reduces costs of transmitting ideas and innovations. The Marshallian approach was employed by Krugman [1] and Fujita and Thisse [2], who emphasized the links between agglomeration and externalities in mass production, creation of a larger market for workers with industry-specific skills, insuring both a lower probability of unemployment and a lower probability of labor shortage, and, finally, informational spillovers based on the accumulation of human capital and face to face communication. These points were reinforced in Saxenian's [3] study of the development of two industrial regions, Silicon Valley and Massachusetts' Route 128, over the last two decades. Saxenian argues that the major difference between the two regions was their approach to organization of production within local industrial systems determined by three aspects: regional institutions (universities, business associations, local governments, local culture incorporating labor market behavior and attitudes towards risk-taking), industrial structures (social division of labor, the degree of vertical integration and the nature of the links between consumers, suppliers, and competitors), and internal firm organization (the degree of hierarchical and horizontal coordination, centralization, the allocation of responsibilities and the degree of specialization within the firm).

A local industrial system is, in fact, much more than a cluster of factors of production. Firms in the district are connected by dense network of social, institutional, cultural and technical links that lead to the creation of *social capital*. This notion of social capital[1] provides an extension of human capital that goes beyond natural or physical capital. It represents norms and values that create the fabric of the society and glue individuals and institutions together and constitute a necessary link for its governance. In this paper we focus on local aspects of social capital and, thus, turn our attention to *local social capital*. The notion of geographical proximity plays a crucial role in the emergence and sustainability of local social capital in a territorial entity (district). Via repeated exchange and face to face contacts, geographical proximity raises the level of coordination, trust and learning among companies and institutions in the district.[2] Coordination and

[1] See Coleman [4], Granovetter [5], Collier [6], and Paldam and Svenden [7].
[2] Lucas [8], Weitzman [9], and Fujita and Thisse [2].

cooperation play an important role in the emergence of local public goods, public and private associations, institutions, educational programs, training programs, and infrastructure.[3] The high level of trust leads to collaboration and informal information sharing among the individuals even if they are employed by rival firms. The "locality" of spillovers reflects the role of geographical proximity also manifested through creation of local networks and professional communities with shared knowledge and skills, easy flow of information, repeated exchange, and emergence of coordination and trust. It creates mutual monitoring and peer pressure that may increase incentives for better job performance.[4]

Shared values and loyalty within a network do not exclude fierce competition within the same community. Indeed, Saxenian observes that: "The characteristic feature of Silicon Valley is the mix between competition and a great amount of informal or formal cooperation." This mix, termed *co-opetition* by Brandenburger and Nalebuff [13], together with the notion of local social capital represents the fundamental trait of a district captured in our model.

The incorporation of the notion of local social capital separates our paper from the Dixit–Stiglitz general equilibrium models of "new geography" (see discussion of the related literature below) that do not directly introduce non-pecuniary externalities. (Krugman [1] even calls these externalities "too vague" and having too many "diffuse effects.") We argue that most of these vague effects are related to local social capital spillovers, and while sacrificing the general equilibrium aspect of the model, we focus on the impact of local social capital spillovers in a partial equilibrium setting. We consider a two-stage non-cooperative game that incorporates the notions of co-opetition and local social capital spillovers among heterogeneous firms. In the first stage the firms choose a district in which to locate and, in the second, all firms engage in the Cournot competition in the international market. There are several facets of heterogeneity of firms and districts: firms differ in their stand-alone marginal cost of production that is dependent on the districts they are in, firms face different transportation costs to the international market where the final product is sold, and, finally, the districts are, in general, located at different distances from the international market.

By using the technique of potential functions pioneered by Rosenthal [14], we show that, under linearity of the demand function and commonality of the local social capital spillovers, the location game always admits an equilibrium in pure strategies. These equilibria are not necessarily efficient—we show that all the firms could be locked-in an "inefficient" district where local spillovers are strictly smaller than in an "efficient" district. We also provide an example where the firms find themselves in a Prisoners' Dilemma situation, where the only equilibrium is not Pareto efficient.

[3] Porter [10] and Nicolini [11].
[4] Granovetter [5] and Fujita and Thisse [12].

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The major assumption of our model is that the marginal cost of production of a firm is reduced by a factor that *depends on the number of firms in the same district*. While competing in the product market, all firms located in the same district lower their production cost through the local social capital spillovers. However, the reciprocity of the cost reduction mechanism lowers the production costs of other firms,[5] and *strengthening yourself as well as your rivals may have an ambiguous combined effect.* Specifically, in making its location decision, a firm should take into account three factors: its stand-alone production and transportation costs in the districts it considers, a positive agglomeration effect of local spillovers in a district with other firms, and a negative reciprocal effect of lowering the costs of its rivals. The combined effect of these three factors is far from obvious. However, we were able to demonstrate that *the positive local capital spillovers effect outweighs the negative reciprocal due to the lowering of rivals' costs* (Proposition 3.1). That is, the firm's own benefits from agglomeration are stronger than the benefits it generates for its rivals. Thus, the dilemma faced by every firm is reduced to comparison of its stand-alone production and transportation costs versus the (positive) spillover effect. This immediately implies that, in absence of sufficient heterogeneity, the firms tend to cluster rather than locate in different districts. Indeed, we consider two special cases, *district independence*, where the stand-alone costs of each firm do not vary across districts, and *firm independence*, where the stand-alone marginal costs are the same for every firm that locates in a particular district. We show that in both cases only an *agglomeration* equilibrium, when all firms locate in one district, is possible. Thus, a *dispersed* equilibrium, when firms locate in different districts, can emerge only if firms' and districts' characteristics exhibit a sufficient degree of heterogeneity of their stand-alone marginal costs.

Even though the vast majority of the results in this paper deal with the notion of unilateral deviations in the framework of Nash equilibria, we use the concepts of a *strong Nash equilibrium*, stable under all deviations of all possible groups of firms, and of a *coalition-proof Nash equilibrium* immune against only *credible* deviations of groups of firms, to investigate a possibility of joint deviations by several firms.

The rest of the paper is organized as follows. In the next section we present the model and state the result on the existence of a Nash equilibrium in pure strategies. In Section 3 we characterize both agglomeration and dispersed equilibria. Section 4 deals with efficiency properties of Nash equilibria. Sections 5 and 6 analyze two special cases of *district independence* and *firm independence* of stand-alone marginal costs. In Section 7 we examine the case with two

[5] See Salop and Scheffman [15] for a discussion of the impact of firms' decisions on their rivals' costs.

industrial districts. The proofs of all results of the paper are relegated to the Appendix A.

Before proceeding with the model we relate our results to the existing literature.

1.1. Related literature

Our partial equilibrium framework differs from those of the new economic geography that use the Dixit–Stiglitz model of monopolistic competition to examine a model of an imperfectly competitive market structure. Their set-up does not impose a direct assumption of external economies and externalities which usually emerge as an outcome of market interactions involving economies of scale at the level of individual firms. Abdel-Rahman and Fujita [16] and Fujita and Thisse [12] show that high transportation costs induce firms to select their locations close to large markets of final goods. These locational choices have a positive impact on local labor markets, that, in turn, expands markets for final goods. However, the scarcity of land in these models limits the advantages of agglomeration forces and generates a congestion effect in favor of dispersion of activities. Similar agglomeration arguments, although in a somewhat different framework, have been examined by Fujita et al. [17]. Krugman [1] describes an economy with several regions, where the clustering of firms and workers is obtained as a result of increasing returns to scale at the firm level, iceberg transportation costs between regions and factor mobility. Krugman and Venables [18] consider a two-country framework with pecuniary externalities that is closer to our model. They exclude labor mobility between the countries but allow it between the manufacturing and agricultural sectors in each country. The lack of labor mobility between the countries is compensated by introduction of intermediate goods. Then, assuming that manufacturing goods are produced using both labor and intermediate goods, Krugman and Venables show that a region with a relatively large manufacturing sector offers a greater variety of intermediate goods and reduces production costs of final goods, thus, creating a further agglomeration in the region.

Our framework is related to the model of district formation with two feasible locations, price competition and differentiated goods in Belleflamme et al. [19] (BPT—henceforth). BPT argue that the formation and size of clusters depend on the relative strength of three distinct forces: the magnitude of localization economies, the intensity of price competition and the level of transportation costs. We respond to these challenges by extending the BPT framework and allowing for an arbitrary number of districts, an arbitrary (and not necessarily linear) functional form of local social capital spillovers, strategic interaction captured by Cournot competition, and heterogeneity of firms' transportation and production costs.

Yi [20][6] considered a model of formation of research coalitions in the R&D context. He proved the existence of an agglomeration equilibria in the model that satisfies both firm independence and district independence, i.e., when all the firms and all the districts are symmetric. Subsequently, Belleflamme [22] has shown the existence of a Nash equilibrium in the case of firm independence. Belleflamme [23] introduces a model with heterogeneous players. Assuming linearity of spillovers, he demonstrates the existence of an agglomeration equilibrium and indicates a possibility of dispersed equilibrium in the case of two districts.

Long and Soubeyran [24–26] studied *cost manipulation games* which is another application of the co-opetition approach. In the first stage of this model the agents choose the type of the game to be played in the second stage. The choice of the game is affected by manipulating some choice variables and can be made either cooperatively, as in co-opetititon, or via non-cooperative manipulations. Then, in a second stage, players actually engage in the game chosen in the first stage. Our model of district formation, where in the first stage the firms engage in tacit cooperation through choice of their neighbors while competing in the second stage, can obviously be related to the class of games considered by Long and Soubeyran. In a similar set-up, Mai and Peng [27] use the Hotelling model to introduce a cooperation between firms in the form of information exchange through communication. Combes and Duranton [28] specify the way by which mobility of workers between firms facilitates a flow of informational spillovers, while Soubeyran and Thisse [29] examine a role of information in the multi-stage process of district formation.

2. Model

We consider a model with a finite number n of heterogeneous firms producing a homogeneous commodity. Each firm chooses a district to produce its product that is subsequently sold in the international market (IM). The set of firms is denoted by N, and the (finite) set of districts by Δ. The distance between district α and the location of IM is denoted by d^α. The demand for firms' product is given by the linear inverse demand function $P = A - Q$, with A being a positive number, P the market price, and Q the total industry output.

If firm $i \in N$ is located alone in district $\alpha \in \Delta$, its constant marginal cost of production is given by c_i^α that depends both on the firm and the district it is located in. However, if the firm is not alone, its marginal cost of production is affected by a presence of other firms in the same district. As we indicated in the introduction, we focus here on the local nature of social capital spillovers

[6] See also Bloch [21].

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generated by geographical proximity of workers and firms in the district. The way the firms perform in local and global markets crucially depends on the local business environment. For example, a high quality transportation infrastructure, well-educated local employees and an efficient court system have an important effect on productivity, cost structure and competitiveness of companies in the district. Geographical proximity improves the flow information and level of local coordination, cooperation, and mutual trust. Proximity saves on inventory, transportation and search costs, and reduces delays and risk. There is a clear link between geographical proximity and costs that we introduce through the local social cost spillovers.

Formally, if there are m firms in district α, the marginal cost of production of firm i, c_i^α, in α is reduced by the local social cost spillover $\mu^\alpha(m)$ that depends on the district and the number of firms located in it. Thus, the actual production cost would be given by $c_i^\alpha - \mu^\alpha(m)$. We assume the commonality of the spillover coefficients, so that the value $\mu^\alpha(m)$ is the same for all firms in district α. Naturally, $\mu^\alpha(1) = 0$ for every α as no spillover would be generated in a district with a single firm. For analytical simplicity we assume that the local spillover factor is never sufficiently large to bring the production costs to zero. That is, $\mu^\alpha(m) < c_i^\alpha$ for every firm i, every district α and every positive integer m, not exceeding the total number of firms n.

We do not impose any restrictions on the shape of the local social capital spillover functions μ^α. In particular, they can be either concave or convex, and are not necessarily linear as in Belleflamme [23] and BPT. Although for the most results of the paper we will assume that the local spillover effects are positive and the functions $\mu^\alpha(\cdot)$ are strictly increasing in the number of firms in every district α, we would like to point out that our main result on the existence of a Nash equilibrium, Proposition 2.1, as well as Lemma 3.2, hold for arbitrary spillover functions. In particular, our existence result covers not only the environments with positive local social capital spillovers, but also models with negative local spillovers (congestion effects) when the functions μ decline with the number of firms in given district.

In addition to its production costs, each firm incurs a transportation cost of shipping its product to IM. The transportation costs are assumed to be heterogeneous, that is, firm i located in district α would incur a per-unit per-mile transportation cost of t_i^α. Since the distance between the district α and IM is d^α, the total per-unit cost for firm i to produce and ship a unit of good from district α with k firms, is given by

$$c_i^\alpha + t_i^\alpha d^\alpha - \mu_i^\alpha(k).$$

Since the first two terms are independent of the number of other firms in the district, we refer to

$$C_i^\alpha = c_i^\alpha + t_i^\alpha d^\alpha$$

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as the "stand-alone" cost that firm i would have to incur if it were to locate alone in the district.

The firms play a two-stage game, where in the first stage each firm chooses its location from the set of districts Δ, and in the second stage, the firms play a Cournot game[7] where their costs (which incorporate the spillover effect) are determined in the first stage. As usual, we adopt the notion of a subgame perfect equilibrium. Since the Nash equilibrium in the second stage of our model is unique, we reduce our two-stage game to a one-shot locational choice game. In this game each firm i's strategy set is Δ, and the payoff function of firm i is represented by its profit resulting from the locational choices of all firms.

The main result of the paper is that, regardless of the shape and slope of the local social spillover functions, there always exists a set of locational choices by all firms, such that no firm would find it beneficial to relocate to a different district. We have following proposition.

Proposition 2.1. *The locational game admits a pure strategies Nash equilibrium.*[8]

To provide an intuition of the proof of the proposition, we introduce some additional notation. Any strategy configuration $\delta = (\alpha_1, \alpha_2, \ldots, \alpha_n)$ can be represented in the partition form where $N_\alpha(\delta) = \{i \in N\colon\ \alpha_i = \alpha\}$ denotes the set of players (firms) who choose strategy (district) α in δ. Then $\{N_\alpha(\delta)\}_{\alpha\in\Delta}$ represents a partition of firms into different districts. Since there is a one-to-one correspondence between the original configuration and the corresponding partition, we shall use the partition form representation $\mathcal{N}(\delta) = (N_\alpha(\delta))_{\alpha\in\Delta}$ to represent players' choices.

Now let a strategy configuration $\delta = (\alpha_1, \alpha_2, \ldots, \alpha_n)$, and, hence, the partition $\mathcal{N}(\delta) = (N_\alpha(\delta))_{\alpha\in\Delta}$ be given. Since no confusion will arise, we use the notation N_α instead of $N_\alpha(\delta)$ for all $\alpha \in \Delta$. It is easy to verify that for each firm, the (interior) Cournot equilibrium output is the difference between the market price and the firm's marginal cost. Since the marginal cost of production of firm i in district α_i is $C_i^{\alpha_i} - \mu^{\alpha_i}(|N_{\alpha_i}|)$, the Cournot equilibrium output $x_i(\delta)$ of firm i and its profit are given by

$$\begin{aligned} x_i(\delta) &= P(\delta) - \left(C_i^{\alpha_i} - \mu^{\alpha_i}(|N_{\alpha_i}|)\right), \\ \pi_i(\delta) &= x_i(\delta)\left(P(\delta) - \left(C_i^{\alpha_i} - \mu^{\alpha_i}(|N_{\alpha_i}|)\right)\right) = x_i^2(\delta) \\ &= \left(P(\delta) - \left(C_i^{\alpha_i} - \mu^{\alpha_i}(|N_{\alpha_i}|)\right)\right)^2, \end{aligned} \tag{1}$$

[7] We assume that no firm will shut down in the second stage. This could be guaranteed by requiring that the total per-unit costs (including production and transportation) are sufficiently low, e.g., $C_i^\alpha \leqslant A/n$ for every $i \in N$ and every $\alpha \in \Delta$. This condition is not necessary to obtain our results but it substantially simplifies the arguments.

[8] Since we deal only with pure strategy Nash equilibria, we shall use the term "Nash equilibrium" instead of "pure strategy Nash equilibrium."

where $|X|$ stands for the cardinality of set X. The first order conditions immediately imply that the market price $P(\delta)$ is given by

$$P(\delta = \frac{A + \sum_{i \in N}(C_i^{\alpha_i} - \mu^{\alpha_i}(|N_{\alpha_i}|))}{n+1}. \tag{2}$$

Since the profit of firm i is given by $x_i^2(\delta)$, the expression $x_i(\delta) = P(\delta) - (C_i^{\alpha_i} - \mu^{\alpha_i}(|N_{\alpha_i}|))$ of the output and the per-unit profit of firm i, can be used as the proxy function to evaluate the profit of firm i. Expression (1) implies, therefore, that a firm will move from one district to another if it can increase its output in the new district.

The proof of Proposition 2.1 makes use of the potential functions approach pioneered by Rosenthal [14] and studied by Monderer and Shapley [30].[9] It is based on the construction of a potential function Φ over the set of all strategy profiles that satisfies the equality

$$\Phi(\delta) - \Phi(\delta') = x_i(\delta) - x_i(\delta') \tag{3}$$

for every firm i and every two strategy configurations δ and δ' that are identical for all players, except i. That is, the difference of the values of the function $\Phi(\cdot)$ is equal to the difference of the values of the proxy function $x_i(\cdot)$. Since the number of strategy profiles is finite, the function Φ possesses a maximum. Thus, expressions (1) and (3) would guarantee that this maximum yields a Nash equilibrium of our game.

Before turning to characterization of the set of Nash equilibria in the next section, we would like to point out that the assumption of commonality of local social capital factors in a given district cannot be easily dispensed with.[10] In the following example the local spillover factors for each firm are the same across districts, and the stand-alone marginal costs are the same for both firms. The only source of asymmetry is a different local spillover effect incurred by a firm from the presence of its rival.

Example 2.2. There are two firms 1, 2, and two districts α, β. The intercept A is 100 and $C_i^\alpha = 40$, for all $i = 1, 2$ and $\delta = \alpha, \beta$. The local social capital spillovers are given by $\mu_1^\delta(2) = 30$ and $\mu_2^\delta(2) = 12$, for $\delta = \alpha, \beta$. The firms' profits are given by the following matrix:

Firm 1/Firm 2	District α	District β
District α	1296, 324	400, 400
District β	400, 400	1296, 324

[9] See also Slade [31] for an application of potential functions to the Cournot oligopoly game, and Konishi et al. [32] to group formation games.

[10] See also Belleflamme [23].

Firm 1 would prefer to be located in the same district with firm 2 since it derives a substantial benefit from a common location. On the other hand, firm 2 would prefer to be alone in its district since the local spillover from a common location is outweighed by strong negative reciprocal effect of the cost reduction gained by its rival. The industry is caught in the “cat and mouse” dilemma, where firm 1 attempts to “catch” firm 2, whereas firm 2 tries to “escape” firm 1’s presence in the same district. Thus, this game does not possess a Nash equilibrium.

3. Characterization of locational equilibria

In the previous section we have shown the existence of a Nash equilibrium. We now turn to a characterization of Nash equilibria of the locational game by making a clear distinction between agglomeration equilibrium, where all firms are bunched in the same district, and dispersed equilibrium, where firms are split between different districts.

Definition. Let strategy configuration $(\alpha_1, \ldots, \alpha_n)$ be a Nash equilibrium. It is called an *agglomeration* equilibrium if $\alpha_i = \alpha_j$ for every two firms i and j. If there exist two firms, i and j, such that $\alpha_i \neq \alpha_j$, then the equilibrium is called *dispersed*.

We need more notation. For each positive integer $m = 1, \ldots, n$ and each district $\alpha \in \Delta$ denote

$$v^\alpha(m) = \frac{\mu^\alpha(m) - \mu^\alpha(m-1)}{n}$$

and

$$H^\alpha(m) = \mu^\alpha(m) - (m-1)v^\alpha(m).$$

The function $v^\alpha(m)$ underlines the reciprocity of the local cost reduction mechanism. It is a negative effect that represents the loss incurred by a firm in district α by *lowering* the costs of each of other $m-1$ firms in the district. The function $H^\alpha(m)$, therefore, captures the combined effect of two opposite forces: positive local social capital spillover $\mu^\alpha(m)$, resulting from tacit cooperation of m firms in the district, and negative effect of reciprocal local cost reduction of other $m-1$ firms. Our next result has important implications for our analysis. We show that for any given firm i, the positive benefit of lowering its cost through presence of other firms in the same district, outweighs the negative effect of lowering costs of i’s rivals. In other words, the net local spillover effect in every district α is strictly increasing in the number of the firms located in α.

Proposition 3.1. *For every $\alpha \in \Delta$, the function $H^{\alpha}(\cdot)$ is strictly increasing with $H^{\alpha}(1) = 0$.*

The following lemma is a necessary and sufficient condition for a firm to benefit by relocating from one district to another. As we indicated above, similarly to Proposition 2.1, this result does not require the functions μ^{α} to be increasing and, in particular, it can also cover environments with local congestion effects.

Lemma 3.2. *Let δ be a strategy configuration, where firm i chooses district $\alpha \in \Delta$. Firm i would benefit by moving from α to another district $\beta \in \Delta$ if and only if the following condition holds*:

$$H^{\beta}(|N_{\beta}| + 1) - H^{\alpha}(|N_{\alpha}|) > C_i^{\beta} - C_i^{\alpha}$$

or

$$C_i^{\alpha} - H^{\alpha}(|N_{\alpha}|) > C_i^{\beta} - H^{\beta}(|N_{\beta}| + 1).$$

The intuition behind this lemma is quite simple: firm i will move from district α, to district β only if the total benefits of moving to district β with $|N_{\beta}|$ firms outweigh the advantages of being one of the $|N_{\alpha}|$ firms in district α. Moreover, it allows us to decompose the total benefit of location of firm i in district γ with m other firms into two terms, its own unit cost, C_i^{γ}, and the net social capital effect, represented by the function $H^{\gamma}(m)$.

To proceed with our discussion, we shall call district α an *individually optimal* for firm i if it minimizes i's stand alone costs, i.e., $C_i^{\alpha} = \arg\min_{\beta \in \Delta} C_i^{\beta}$. Lemma 3.2 highlights the importance of the cost differentials of stand-alone costs. Indeed, together with Proposition 3.1, it immediately implies that if, in equilibrium, firm i stays alone in district α, then α is its individually optimal district. Otherwise, firm i would benefit by moving to its individually optimal district.

Proposition 3.3. *Let strategy configuration $(\alpha_1, \ldots, \alpha_n)$, be a Nash equilibrium. If $|N_{\alpha_i}| = 1$, then α is an individually optimal district of firm i.*

In general, individual optimality is not sufficient in order to determine the equilibrium location of a firm since the externality effect in other districts outweighs the difference in the stand-alone costs. Lemma 3.2 allows us to determine when it is not the case, and the firm has the dominant strategy of always choosing the same district.

Proposition 3.4. *The choice of district α is the dominant strategy of firm i if the inequality $C_i^{\alpha} < C_i^{\beta} - H^{\beta}(n)$ holds for all districts $\beta \neq \alpha$.*

We turn now to the characterization of agglomeration and dispersed equilibria. An agglomeration equilibrium in district α will emerge if there is no other district where the stand-alone cost to one of the firms is low enough to overcome the loss of the externality effect in the district with all other firms. Since $H^\alpha(1) = 0$ for every $\alpha \in \Delta$, Lemma 3.2 immediately yields:

Proposition 3.5. *The location of all firms in district α is a (agglomeration) Nash equilibrium if and only if $C_i^\alpha - C_i^\beta \leqslant H^\alpha(n)$ for every $\beta \in \Delta$ and every $i \in N$.*

Since, by Proposition 2.1, the locational game always possesses a Nash equilibrium, a violation of the necessary condition for the existence of an agglomeration equilibrium in Proposition 3.5 immediately yields a sufficient condition for the existence of a dispersed equilibrium:

Corollary 3.6. *Suppose that for every district α there exists a firm i and a district β such that $H^\alpha(n) < C_i^\alpha - C_i^\beta$. Then the only Nash equilibria of this game are dispersed.*

The existence of dispersed and agglomeration equilibria is not mutually exclusive. As the following example demonstrates, there are games that admit both types of equilibria:

Example 3.7. There are two firms 1, 2 and two districts α, β. Let $A = 100$, $C_1^\alpha = 25$, $C_1^\beta = C_2^\alpha = 40$, $C_2^\beta = 34$, $\mu^\alpha(2) = 12$, and $\mu^\beta(2) = 9$. The payoff matrix of this game is given by

Firm 1/Firm 2	District α	District β
District α	1156, 361	784, 361
District β	400, 400	441, 729

The game has one agglomeration equilibrium (α, α) and one dispersed equilibrium (α, β). Indeed, firm 1 has the dominant strategy α whereas, given firm 1's location at α, firm 2 is indifferent between α and β.[11]

In the case of two districts, one can obtain a complete characterization of the set of Nash equilibria. Let the set Δ consist of two districts, α and β. For each $i \in N$ denote $\widetilde{C}_i \equiv C_i^\beta - C_i^\alpha$ that represents the cost advantage (or disadvantage) of district α over district β.

Assume, without loss of generality, that firms are ordered in such a way that $\widetilde{C}_1 \geqslant \widetilde{C}_2 \geqslant \cdots \geqslant \widetilde{C}_n$. That is, the cost advantage of switching from β to α is

[11] One can provide an example with a larger number firms or districts which would show a possibility of co-existence of dispersed and agglomeration equilibria without this indifference.

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higher for firm i than for firm $i+1$. The firm independence of the external effect implies that if firm j is located in district α in equilibrium, so are all other firms i with $i<j$. Thus, all Nash equilibria of the locational game satisfy the *consecutive property* (Greenberg and Weber [33]): if, in equilibrium, two firms i, j with $i<j$ are located in the same district, every firm k with $i<k<j$ must be located in that district as well.

Proposition 3.8. *Let δ be a Nash equilibrium in an industry with two districts. Then δ is either an agglomeration equilibrium or there exists a cut-off number m, $1<m<n$ such that the firms $1,\dots,m$ are located in α whereas the firms $m+1,\dots,n$ choose β.*

4. Efficiency of equilibrium

We shall now investigate the issue of efficiency of an equilibrium. As usual, a strategy configuration δ is *Pareto efficient* if there is no other strategy configuration δ' such that $\pi_i(\delta') \geqslant \pi_i(\delta)$ for every firm $i \in N$ with a strict inequality for at least one i. It is immediate to observe that not all equilibria are Pareto efficient. It could even be the case that there is a Nash equilibrium in which every firm's profits are lower than at another Nash equilibrium.

Example 4.1. There are two identical firms 1, 2 and two districts α, β. Let $A=100$, $C_i^\alpha=40$, $C_i^\beta=55$ for $i=1,\ 2$, and $\mu^\delta(2)=36$ for $\delta=\alpha,\ \beta$. The payoff matrix of this game is given by

Firm 1/Firm 2	District α	District β
District α	1024, 1024	625, 100
District β	100, 625	729, 729

The game has two agglomeration equilibria and no dispersed equilibria. Both firms would prefer to be located in district α rather than in β. This phenomenon is consistent with the well-known empirical observations of industries locked into an inferior technology [34]. In our framework of simultaneous choices, this simply means that the emergence of districts with a higher level of technological externalities may not prevent all firms in an industry from locating in a district with inferior technological spillovers.

The following example demonstrates that a Pareto efficient Nash equilibrium may fail to exist and even a Prisoners' dilemma situation may arise:

Example 4.2. There are two firms 1, 2 and two districts α, β. Let $A=100$, $C_i^\alpha=40$, $C_i^\beta=25$ for $i=1, 2$, $\mu^\alpha(2)=24$, and $\mu^\beta(2)=6$. The payoff matrix of

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this game is given by

Firm 1/Firm 2	District α	District β
District α	784, 784	225, 900
District β	900, 225	729, 729

Both firms have the dominant strategy, namely, the choice of district β. Thus, there is a unique equilibrium (β, β), which is, obviously, Pareto inferior to the strategy configuration (α, α).

To provide a partial characterization of the set of Pareto efficient allocations, for each strategy configuration $\delta = (\alpha_1, \ldots, \alpha_n)$ define the following function:

$$G(\delta) = \frac{1}{n} \sum_{i \in N} \left[\mu^{\alpha_i}(|N_{\alpha_i}|) - C_i^{\alpha_i}\right],$$

that represents the negative of the mean local social spillover in the industry. By using (3), it is easy to verify that the function G is, in fact, a linear transformation of the total industry output $\sum_{i \in N} x_i(\delta)$ and the market price $P(\delta)$:

$$G(\delta) = -A + \frac{n+1}{n} \sum_{i \in N} x_i(\delta) = \frac{A}{n} - \frac{n+1}{n} P(\delta).$$

Lemma 4.3 states that every maximum of the function G is a Pareto efficient configuration. Since these maxima are attained under the highest level of total industry output, it follows that the lowest market price yields a Pareto efficient strategy configuration. This observation is important since it allows us to turn to welfare implications and to state that every maximum of function G also maximizes the consumer surplus.

Lemma 4.3. *Let δ be a strategy configuration such that $G(\delta) \geqslant G(\delta')$ for all strategy configurations δ'. Then δ maximizes the consumer surplus and is Pareto efficient with respect to firms' profits.*

It is important to consider a case where all firms are located in the same district. Then for a strategy configuration $\delta = (\alpha, \ldots, \alpha)$

$$G(\delta) = \mu^{\alpha} - \frac{1}{n} \sum_{i \in N} C_i^{\alpha}.$$

We now introduce the notion of a *cost efficient* district that maximizes difference between the value of the local social capital spillover and the average of all stand-alone marginal costs. That is,

Definition. A district $\alpha \in \Delta$ is cost efficient if

$$\mu^{\alpha}(n) - \frac{1}{n} \sum_{i \in N} C_i^{\alpha} = \max_{\beta \in \Delta} \left[\mu^{\beta}(n) - \frac{1}{n} \sum_{i \in N} C_i^{\beta}\right].$$

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Thus we have the following:

Corollary 4.4. *Let $\alpha \in \Delta$. If the strategy configuration $(\alpha, \ldots, \alpha)$ is Pareto efficient, then α is a cost-efficient district.*

The condition, stated in Lemma 4.3, is sufficient but not necessary for Pareto efficiency. The next two sections contain a study of two special cases where we sharpen Lemma 4.3 to provide necessary and sufficient conditions for a strategy configuration to constitute a Pareto efficient Nash equilibrium. The first is that of *district independence of stand-alone costs*, where the stand-alone marginal costs of every firm do not vary across the districts. The second is that of *firm independence of stand-alone costs*, where within every district all firms have the same stand-alone costs.

5. District independence of stand-alone costs

In this section we consider the case of district independence (DI) of stand-alone costs. That is, for every firm i, its stand alone marginal cost C_i^α is the same in all districts: $C_i^\alpha = C_i$ for all $i \in N$ and $\alpha \in \Delta$. Thus, the production and transportation per unit costs of a given firm i are identical in all districts and, moreover, all districts are equidistant from IM.

In this case no firm can alter its stand-alone cost by moving from district to district. The problem is, therefore, reduced to the maximization of the external effect represented by the function H^α. By Proposition 3.1, the external effect in every district is zero if a firm stays there alone, and is strictly positive if there are other firms in the district. Thus, no firm would leave a district it shares with other firms to be alone elsewhere. It follows, therefore, that for every district $\alpha \in \Delta$ the bunching of all firms at α is an equilibrium. We show also that no dispersed equilibrium will emerge in this case.

Proposition 5.1. *Under DI, there exists no dispersed equilibrium. Moreover, for every district $\alpha \in \Delta$ the location of all firms in α yields a Nash equilibrium. Thus, the set of Nash equilibria consists of $|\Delta|$ agglomeration equilibria.*

Lemma 4.3 allows us to demonstrate that under district independence there always exists a Pareto efficient equilibrium. Moreover, since in this case a district a is cost efficient if and only if $\mu^a(n) \geqslant \mu^\alpha(n)$ for all $\alpha \in \Delta$, only cost efficient districts would generate Pareto efficient Nash equilibria and, by Lemma 4.3, maximize the consumer surplus.

Proposition 5.2. *Under DI, the set of Pareto efficient Nash equilibria is non-empty. Moreover, for a district α the bunching of all firms at α is a Pareto efficient (agglomeration) Nash equilibrium if and only if α is a cost-efficient district.*

The above result shows that if the district independence of stand-alone marginal cost is satisfied, there is a strategy configuration which is Pareto efficient and is also stable with respect to firms' unilateral deviations. Since Pareto efficiency implies that there is no reallocation of all n firms which would benefit every firm, a natural question is whether there exists a Pareto efficient Nash equilibrium that is immune to coalitional deviations, not necessarily by single firms or by the "grand coalition" of all firms in the industry? To answer this question, we will utilize two refinement notions of Nash equilibrium: *strong Nash equilibrium* (Aumann [35]) and *coalition-proof Nash equilibrium* (Bernheim et al. [36]). A strong Nash equilibrium is a strategy configuration immune to all coalitional deviations, whereas a coalition-proof Nash equilibrium is immune only to *credible* coalitional deviations.[12] It is easy to see that a strong Nash equilibrium is always a coalition-proof Nash equilibrium, and a coalition-proof Nash equilibrium is always a Nash equilibrium. However, the reversed inclusions do not necessarily hold. We will now investigate the conditions which guarantee the existence of a strong Nash equilibrium or a coalition-proof Nash equilibrium.

The next example shows that District Independence of stand-alone costs is not sufficient to yield the existence of a strong Nash equilibrium:

Example 5.3. There are three identical firms, 1, 2, 3, and three identical districts α, β, γ. Let intercept A be equal to 100, whereas $C_i^\delta = 30$, $\mu^\delta(2) = 11$, and $\mu^\delta(3) = 14$ for all i and all $\delta = \alpha, \beta, \gamma$.

Obviously, this game admits three Pareto efficient agglomeration equilibria, (α, α, α), (β, β, β), and (γ, γ, γ). Since the districts are symmetric, we will prove only that the first is not a strong Nash equilibrium. To this end, it remains to demonstrate that two firms would benefit by moving from α to β. It is easy to verify, by using (1) and (2), that at (α, α, α) each firm's profits are equal to 441. However, if two firms move from α to β, their profits rise to 529, implying that (α, α, α) is not a strong Nash equilibrium.

We shall now state the necessary and sufficient conditions for the existence of a strong Nash equilibrium:

Proposition 5.4. *Suppose DI holds. Then for any $\alpha \in \Delta$, the strategy configuration $(\alpha, \dots, \alpha)$ is a strong Nash equilibrium if and only if the following condition holds for any $m = 1, \dots, n-1$ and any $\beta \in \Delta$:*

$$\mu^\alpha(n) \geqslant (1 + n - m)\mu^\beta(m) - (n - m)\mu^\alpha(n - m). \tag{4}$$

[12] A coalitional deviation by a coalition $S \subset N$ is credible if there is no further credible deviation by a subgroup of S. Thus, the credibility of a coalitional deviation is defined recursively. We do not give the formal definitions of a coalition-proof Nash equilibrium and a strong Nash equilibrium here. For the formal definitions see Bernheim et al. [36].

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Equation (4) can be interpreted in the following way. Suppose that all firms are located in district α. A group of m firms would find it beneficial to jointly move to district β if

$$\mu^{\beta}(m) - \mu^{\alpha}(n) > (n-m)\big(\mu^{\alpha}(n-m) - \mu^{\beta}(m)\big).$$

The left-hand side of this inequality is the net "technological" effect representing a difference in the cost reduction factor for a deviating firm after and before the move. The right hand side is a net "pecuniary" effect, which is a combination of cost effects on both m deviating firms and $n-m$ firms that stay in district α. Naturally, firms will move if a positive technological effect will be stronger than a pecuniary effect.

It is important to point out that the game in the Example 5.3 lacks not only a strong Nash equilibrium but also a coalition-proof Nash equilibrium. Indeed, after two-firms move from α to β, none of them would benefit by moving alone from β to γ and there will be no further deviations. Thus, the initial deviation of the two firms is credible and (α,α,α) is not a coalition-proof Nash equilibrium. It is natural, therefore, to ask whether, unlike in Example 5.3, the set of coalition-proof Nash equilibria could be non-empty even when the set of strong Nash equilibria is empty? The following example provides the affirmative answer to this question.

Example 5.5. There are four identical firms, 1, 2, 3, 4, and three identical districts α, β, γ. Let $A = 100$, $C^i_{\delta} = c = 20$, $\mu^{\delta}(2) = \mu(2) = 6$, $\mu^{\delta}(3) = \mu(3) = 8$, $\mu^{\delta}(4) = \mu(4) = 10$.

Since $\mu(4) < 2\mu(3)$, the condition in Proposition 5.4 is violated, and the game does not possess a strong Nash equilibrium. Since all districts are symmetric, we consider the strategy configuration $\alpha = (\alpha,\alpha,\alpha,\alpha)$ and show that it is a coalition-proof Nash equilibrium. Note that for each firm $i \in N$ its profit at α, is given by

$$\pi_i((\alpha,\alpha,\alpha,\alpha)) = \frac{(100 - c + \mu(4))^2}{25} = 324.$$

If two firms, 1 and 2, move from α to β, their profit would be

$$\pi_i((\beta,\beta,\alpha,\alpha)) = \frac{(100 - c + \mu(2))^2}{25} = 295.84, \quad \text{for } i = 1, 2.$$

If three firms, 1, 2, 3 move from α to β, their profit is

$$\pi_i((\beta,\beta,\beta,\alpha)) = \frac{(100 - c + 2\mu(3))^2}{25} = 368.64, \quad \text{for } i = 1, 2, 3.$$

Since α is a Nash equilibrium, only a switch by three firms would be beneficial. However, if after the three firms' move from α to β, firms 1 and 2 will further move from β to γ, we obtain

$$\pi_i((\gamma,\gamma,\beta,\alpha)) = \frac{(100 - c + 3\mu(2))^2}{25} = 384.16, \quad \text{for } i = 1, 2.$$

Since there will be no further deviations, the two firm deviation from β to γ is credible. Thus, the original three firm deviation from α to β is not credible, implying that the strategy configuration α is a coalition-proof Nash equilibrium.

6. Firm independence of stand-alone costs

Let us now examine industries that satisfy the assumption of firm independence (FI) of stand-alone costs. That is, within every district all firms have the same stand-alone marginal cost, i.e., $C_i^\alpha = C^\alpha$ for every $i \in N$ and every $\alpha \in \Delta$. This simply means that all firms in the same district incur identical production and transportation costs.

Then all firms are completely symmetric and the maximization of the externality effect would prevent a split of the firms between two or more different districts in equilibrium. Thus, there would be no dispersed equilibria. However, unlike the case of district independence, not all the districts would necessarily generate an agglomeration equilibrium. Indeed, only the districts which offer the best combination of the externality effect and the stand-alone cost would generate agglomeration equilibria. Specifically,

Proposition 6.1. *Under FI, all Nash equilibria are agglomerated. Moreover, the strategy configuration* $(\alpha, \ldots, \alpha)$ *is an equilibrium if and only if* $H^\alpha(n) \geqslant C^\alpha - C^\beta$ *for all* $\beta \in \Delta$*. Furthermore, since individually optimality is firm independent, every individually optimal district generates an agglomeration equilibrium. That is, if* $C^\alpha = \arg\min_{\beta \in \Delta} C^\beta$*, then the location of all firms in district* α *is an agglomeration equilibrium.*

In the next proposition we state the necessary and sufficient conditions for the existence of a Pareto efficient agglomeration Nash equilibrium under the firm independence requirement. (Recall that Example 4.2 demonstrates that, under FI, a Pareto efficient Nash equilibrium may fail to exist.)

Proposition 6.2. *Under FI, for a district* α *the strategy configuration* $(\alpha, \ldots, \alpha)$ *is a Pareto efficient (agglomeration) Nash equilibrium if and only if* α *is a cost-efficient district and* $H^\alpha(n) \geqslant C^\alpha - C^\beta$ *for all* $\beta \in \Delta$*. (Note that under FI, a district* α *is cost efficient if and only if* $\mu^\alpha(n) - C^\alpha \geqslant \mu^\beta(n) - C^\beta$ *for all* $\beta \in \Delta$*.)*

The next result provides the existence of a Pareto efficient Nash equilibrium when there is no significant difference in local spillovers across the districts. In this case every cost-efficient district generates a Pareto efficient Nash equilibrium.

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Corollary 6.3. *Assume that firm independence of stand-alone costs holds. Suppose that the following inequality holds for every two districts, β and γ:*

$$\frac{n}{n-1}\mu^{\gamma}(n) \geqslant \mu^{\beta}(n) \geqslant \frac{n-1}{n}\mu^{\gamma}(n).$$

Then for every cost-efficient district α, a strategy configuration $(\alpha, \ldots, \alpha)$ is a Pareto efficient (agglomeration) Nash equilibrium.

Finally, as in the previous section, we provide the necessary and sufficient conditions for the existence of a strong Nash equilibrium.

Proposition 6.4. *Suppose FI holds. Then for any $\alpha \in \Delta$, the strategy configuration $(\alpha, \ldots, \alpha)$ is a strong Nash equilibrium if and only if the following condition holds for every $m = 1, \ldots, n-1$ and every $\beta \in \Delta$:*

$$\mu^{\alpha}(n) - C^{\alpha} \geqslant (1+n-m)\bigl(\mu^{\beta}(m) - C^{\beta}\bigr) - (n-m)\bigl(\mu^{\alpha}(n-m) - C^{\alpha}\bigr).$$

7. Concluding remarks

In this paper we have adopted a tacit co-opetition approach to study a model of district formation with an arbitrary number of firms and districts. We focus on the interplay between firms' own benefits from tacit cooperation and benefits enjoyed by their rivals. We show that the firms' district choice is determined by their stand-alone production and transportation costs and positive benefits from agglomeration.

Our paper is an example of co-opetition phenomena of reciprocity of agents' interdependence. If an agent expects to benefit from partial cooperation with her rivals, she should anticipate providing reciprocal benefits to them as well. In our framework the net aggregate effect of the reciprocal cost-reduction mechanism is positive. That is, for any given firm i, the positive benefit of lowering its own cost through presence of other firms in the same district outweighs the negative effect of lowering rivals' costs. It would be interesting to consider an alternative model where the net reciprocal effect is not necessarily positive for all firms. One would expect a decline of the degree of partial cooperation among agents in this case.

Under our assumptions, we demonstrate the existence of a pure strategy subgame perfect equilibrium and show that an agglomeration equilibrium emerges if there is no sufficient degree of heterogeneity of firms' characteristics. It would be interesting to determine a minimal degree of heterogeneity that allows for a dispersed equilibrium, where firms locate in different districts.

It is worthwhile to extend the notion of local social capital spillovers in order to incorporate the inter-regional interaction and an effect of firms in other districts on the cost conditions of a given firm. In our framework it could be achieved by replacing the local capital spillover factor of a firm in district α, μ^{α}, by *quasi* *local capital spillover*, $\mu^\alpha(\{|N_\beta|\}_{\beta\in\Delta})$, that depends on the number of firms $|N_\beta|$ in each district β. The introduction of out-of-the-district effects would weaken the local spillovers while allowing a more general type of inter-regional interaction. It is difficult to analyze a general form of quasi local spillovers but the case of linear and separable cost-reduction functions could be tractable.

Another interesting direction of a future research is a characterization of the equilibrium number of districts and the relationship between the size of a district and its characteristics (firms' stand-alone costs and the values of local social capital spillovers). Even though it would be difficult to obtain a general result in this regard, one may possibly derive some conclusions in the case of linear local social capital spillovers.

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Appendix A

We first deal with the comparison of firm's profit under different strategy configurations:

Lemma A.1. *Consider two strategy configurations δ and δ' with $i \in N_\alpha(\delta)$ and $i \in N_\beta(\delta')$. Then the sign of the difference $\pi_i(\delta) - \pi_i(\delta')$ coincides with the sign of the following expression*:

$$\left((n+1)\big(\mu^\alpha(|N_\alpha(\delta)|) - C_i^\alpha\big) - \sum_{\gamma\in\Delta}\sum_{j\in N_\gamma(\delta)}\big(\mu^\gamma(|N_\gamma(\delta)|) - C_j^\gamma\big)\right)$$
$$- \left((n+1)\big(\mu^\beta(|N_\beta(\delta')|) - C_i^\beta\big) - \sum_{\gamma\in\Delta}\sum_{j\in N_\gamma(\delta')}\big(\mu^\gamma(|N_\gamma(\delta')|) - C_j^\gamma)\big)\right).$$

Proof of Lemma A.1. Recall that $\pi_i(\delta) = P(\delta) - (C_i^\alpha - \mu^\alpha(|N_\alpha(\delta)|))^2$ and $\pi_i(\delta') = P(\delta') - (C_i^\beta - \mu_I^\beta(|N_\beta(\delta)|))^2$. Since our assumptions imply that both expressions $P(\delta) - (C_i^\alpha - \mu^\alpha(|N_\alpha(\delta)|))$ and $P(\delta') - (C_i^\beta - \mu^\beta(|N\beta(\delta)|))$ are positive, it follows that a sign of the difference $\pi_i(\delta) - \pi_i(\delta')$ is the same as a sign of the expression $P(\delta) - (C_i^\alpha - \mu^\alpha(|N_\alpha(\delta)|)) - P(\delta') - (C_i^\beta - \mu^\beta(|N_\beta(\delta)|))$.

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However,

$$\begin{aligned}
&\big(P(\delta) - \big(C_i^\alpha - \mu^\alpha(|N_\alpha(\delta)|)\big) - \big(P(\delta') - \big(C_i^\beta - \mu^\beta(|N_\beta(\delta)|)\big)\\
&\quad = \frac{1}{n+1}\Bigg((n+1)\big(\mu^\alpha(|N_\alpha(\delta)|) - C_i^\alpha\big)\\
&\qquad\qquad - \sum_{\gamma\in\Delta}\sum_{j\in N_\gamma(\delta)}\big(\mu^\gamma(|N_\gamma(\delta)t|) - C_j^\gamma\big)\Bigg)\\
&\qquad - \Bigg((n+1)\big(\mu^\beta(|N_\beta(\delta')|) - C_i^\beta\big)\\
&\qquad\qquad - \sum_{\gamma\in\Delta}\sum_{j\in N_\gamma(\delta')}\big(\mu^\gamma(|N_\gamma(\delta')|) - C_j^\gamma\big)\Bigg). \qquad \square
\end{aligned}$$

Before turning to the proof of Proposition 2.1, we prove Lemma 3.2:

Proof of Lemma 3.2. Let a strategy configuration δ, where firm i choose district $\alpha \in \Delta$, be given. Suppose now that firm i contemplates a switch of her strategy from α to β. Consider the strategy configuration δ', where player i chooses β, whereas all other players choose the same strategies as in δ. Put $N_\gamma = N_\gamma(\delta)$ for every $\gamma \in \Delta$. By Lemma A.1, the difference in profits of firm i after and before the move, $\pi_i(\delta') - \pi_i(\delta)$, has the same sign as the expression

$$\begin{aligned}
&\Bigg((n+1)\big(\mu^\beta(|N_\beta(\delta')|) - C_i^\beta\big) - \sum_{\gamma\in\Delta}\sum_{j\in N_\gamma(\delta')}\big(\mu^\gamma(|N_\gamma(\delta')|) - C_j^\gamma\big)\Bigg)\\
&\quad - \Bigg((n+1)\big(\mu^\alpha(|N_\alpha(\delta)|) - C_i^\alpha\big) + \sum_{\gamma\in\Delta}\sum_{j\in N_\gamma(\delta)}\big(\mu^\gamma(|N_\gamma(\delta)|) - C_j^\gamma\big)\Bigg).
\end{aligned}$$

Since only districts α and β are affected by the move of firm i, the last expression can be simplified:

$$\begin{aligned}
&(n+1)\big(\mu^\beta(|N_\beta|+1) - C_i^\beta\big)\\
&\quad - \big((|N_\alpha|-1)\mu^\alpha(|N_\alpha|-1) + (|N_\beta|+1)\mu^\beta(|N_\beta|+1) - C_i^\beta\big)\\
&\quad - (n+1)\big(\mu^\alpha(|N_\alpha|) - C_i^\alpha\big) + \big(|N_\alpha|\mu^\alpha(|N_\alpha|) + |N_\beta|\mu^\beta(|N_\beta|) - C_i^\beta\big)\\
&\qquad = \big(-nC_i^\beta + (n - |N_\beta|)\mu^\beta(|N_\beta|+1) - (|N_\alpha|-1)\mu^\alpha(|N_\alpha|-1)\big)\\
&\qquad\quad - \big(-nC_i^\alpha + (n+1-|N_\alpha|)\mu^\alpha(|N_\alpha|) - |N_\beta|\mu^\beta(|N_\beta|)\big)\\
&\qquad = n\Bigg(\big(C_i^\alpha - C_i^\beta\big) + \frac{n-|N_\beta|}{n}\mu^\beta(|N_\beta|+1) + \frac{|N_\beta|}{n}\mu^\beta(|N_\beta|)\\
&\qquad\qquad - \frac{n+1-|N_\alpha|}{n}\mu^\alpha(|N_\alpha|) - \frac{|N_\alpha|-1}{n}\mu^\alpha(|N_\alpha|-1)\Bigg).
\end{aligned}$$

Since

$$H^{\alpha}(|N_\alpha|) = \frac{n+1-|N_\alpha|}{n}\mu^{\alpha}(|N_\alpha|) + \frac{|N_\alpha|-1}{n}\mu^{\alpha}(|N_\alpha|-1)$$

and

$$H^{\beta}(|N_\beta|+1) = \frac{n-|N_\beta|}{n}\mu^{\beta}(|N_\beta|+1) + \frac{|N_\beta|}{n}\mu^{\beta}(|N_\beta|),$$

it follows that the difference $\pi_i(\delta') - \pi_i(\delta)$ is positive if and only if $(H^{\beta}(|N_\beta| + 1) - H^{\alpha}(|N_\alpha|)) - (C_i^{\beta} - C_i^{\alpha}) > 0$. Thus, firm i will move from district α to β if and only if $H^{\beta}(|N_\beta|) - H^{\alpha}(|N_a|) > C_i^{\beta} - C_i^{\alpha}$. □

Proof of Proposition 2.1. For each strategy configuration δ, define the following function:

$$\Phi(\delta) = \sum_{\gamma\in\Delta}\left[-\sum_{j\in N_\gamma} C_j^{\gamma} + \sum_{m=1}^{|N_\gamma|} H^{\gamma}(m)\right].$$

Since Δ and N are finite sets, the function Φ possesses a maximum over the set of all strategy configurations. Let δ^* be such a maximum. We claim that δ^* is a Nash equilibrium. Suppose, in negation, that there exists a firm i which would benefit by moving to district β from district α that it chooses in δ^*. Consider the strategy configuration δ' where all players, except i, choose the same strategies as in δ, whereas player i chooses β instead of α. Thus, $N_\gamma(\delta') = N_\gamma(\delta^*)$ for all $\gamma \neq \alpha, \beta$, $N_\alpha(\delta') = N_\alpha(\delta^*) \setminus \{i\}$, and $N_\beta(\delta') = N_\beta(\delta^*) \cup \{i\}$. Put $N_\gamma^* = N_\gamma(\delta^*)$ for every $\gamma \in \Delta$. Then

$$\begin{aligned}
\Phi(\delta') &= \sum_{\gamma\in\Delta\setminus\{\alpha,\beta\}}\left[-\sum_{j\in N_\gamma^*} C_j^{\gamma} + \sum_{m=1}^{|N_\gamma^*|} H^{\gamma}(m)\right] \\
&\quad + \left[-\sum_{j\in N_\beta^*\setminus\{i\}} C_j^{\alpha} + \sum_{m=1}^{|N_\alpha^*|-1} H^{\beta}(m)\right] \\
&\quad + \left[-\sum_{j\in N_\beta^*\cup\{i\}} C_j^{\beta} + \sum_{m=1}^{|N_\beta^*|+1} H^{\beta}(m)\right] \\
&= \sum_{\gamma\in\Delta\setminus\{\alpha,\beta\}}\left[-\sum_{j\in N_\gamma^*} C_j^{\gamma} + \sum_{m=1}^{|N_\gamma^*|} H^{\gamma}(m)\right] \\
&\quad + \left[-\sum_{j\in N_\alpha^*} C_j^{\alpha} + \sum_{m=1}^{|N_\alpha^*|} H^{\beta}(m)\right] + C_i^{\alpha} - H^{\alpha}(|N_\alpha^*|)
\end{aligned}$$

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$$+\left[-\sum_{j\in N_\beta^*} C_j^\beta + \sum_{m=1}^{|N_\beta^*|} H^\beta(m)\right] - C_i^\beta + H^\beta(|N_\beta^*|+1)$$

$$= \Phi(\delta^*) + C_i^\alpha - H^\alpha(|N_\alpha^*|) - C_i^\beta + H^\beta(|N_\beta^*|+1).$$

Since by Lemma 3.2, $C_i^\alpha - H^\alpha(|N_\alpha^*|) - C_i^\beta + H^\beta(|N_\beta^* + 1) > 0$, it follows that $\Phi(\delta') > \Phi(\delta^*)$, a contradiction to the fact that δ^* is a maximum of the function $\Phi(\cdot)$. Thus, δ^* is, indeed, a Nash equilibrium. □

Proof of Proposition 3.1. Take any $\gamma \in \Delta$. The fact that $H^\gamma(1) = 0$ follows immediately from the definition of the function H^γ. For any positive integer $m = 1, \ldots, n-1$, consider the difference between $H^\gamma(m+1)$ and $H^\gamma(m)$. We have

$$\begin{aligned} H^\gamma(m+1) - H^\gamma(m) &= \frac{1}{n}\big((n-m)\mu^\gamma(m+1) + m\mu^\gamma(m) \\ &\quad - (n+1-m)\mu^\gamma(m) - (m-1)\mu^\gamma(m-1)\big) \\ &= \frac{1}{n}\big((n-m)\mu^\gamma(m+1) + (2m-n-1)\mu^\gamma(m) \\ &\quad - (m-1)\mu^\gamma(m-1)\big). \end{aligned}$$

Since the function $\mu^\gamma(\cdot)$ is strictly increasing, it follows that

$$H^\gamma(m+1) - H^\gamma(m) > \frac{1}{n}\big((m-1)\mu^\gamma(m) - (m-1)\mu^\gamma(m-1)\big) > 0. \quad \square$$

Let us now state a useful lemma. It states that if firm i has a greater comparative stand alone cost advantage in district β relatively to α than firm j, and if i chooses α in equilibrium, then, naturally, firm j will not choose β in the same equilibrium configuration.

Lemma A.2. *Let a strategy configuration δ be a Nash equilibrium, in which firm i chooses α. Suppose that there is a district $\beta \neq \alpha$ and a firm $j \neq i$ such that $C_i^\beta - C_i^\alpha \leqslant C_j^\beta - C_j^\alpha$. Then j does not choose β in equilibrium.*

Proof of Lemma A. 2. Suppose that i chooses α in equilibrium, and assume, in negation, that j chooses β. Then, by Lemma 3.2,

$$C_i^\beta - C_i^\alpha \geqslant H^\beta(|N_\beta|+1) - H^\alpha(|N_\alpha|)$$

and

$$C_j^\alpha - C_j^\beta \geqslant H^\alpha(|N_\alpha|+1) - H^\beta(|N_\beta|).$$

Since $C_i^\beta - C_i^\alpha \leqslant C_j^\beta - C_j^\alpha$, we obtain that $H^\beta(|N_\beta|) - H^\beta(|N_\alpha|+1) \geqslant H^\beta(|N_\beta|+1) - H^\alpha(|N_\alpha|)$. Thus, $H^\alpha(|N_\alpha|+1) + H^\beta(|N_\beta|+1) \leqslant H^\beta(|N_\alpha|) +$

$H^{\beta}(|N_{\beta}|)$, a contradiction to the fact that both functions $H^{\alpha}(\cdot)$ and $H^{\beta}(\cdot)$ are increasing. □

Proof of Proposition 3.8. Follows immediately from Lemma A.2. □

Proof of Lemma 4.3. Let a strategy configuration δ be given. Our assumptions imply that the output of each firm i, $x_i(\delta)$, is positive. Since $\pi_i(\delta) = (x_i(\delta))^2$, it follows that a strategy configuration that maximizes the total industry output, is Pareto efficient, and, therefore, the Pareto efficiency is achieved under the lowest market price. Since for every strategy configuration δ

$$G(\delta) = -A + \frac{n+1}{n}\sum_{i\in N} x_i(\delta) = \frac{A}{n} - \frac{n+1}{n}P(\delta),$$

it follows that a maximum of the function $G(\cdot)$, indeed, yields a Pareto efficient allocation. □

Proof of Proposition 5.1. Since for every two districts α, β and every firm i we have $C_i^{\beta} - C_i^{\alpha} = 0$, Lemma A.2 implies that the game does not admit a dispersed equilibrium. Moreover, by Proposition 3.1, $H^{\gamma}(1) = 0$ and $H^{\gamma}(m) > 0$ whenever $m > 1$ for every $\gamma \in \Delta$. Hence, for every α the strategy configuration $(\gamma, \ldots, \gamma)$ is a Nash equilibrium. □

Proof of Proposition 5.2. Suppose that stand-alone marginal costs are district independent. Let α be a cost-efficient district, i.e., $\mu^{\alpha}(n) \geqslant \mu^{\gamma}(n)$ for all $\gamma \in \Delta$. By Proposition 5.1, the strategy configuration $\bar{\alpha} = (\alpha, \ldots, \alpha)$ is a (agglomeration) Nash equilibrium. Take any strategy configuration δ and consider the difference $G(\bar{\alpha}) - G(\delta)$. We have

$$\begin{aligned} G(\bar{\alpha}) - G(\delta) &= \frac{1}{n}\left[n\mu^{\alpha}(n) - \sum_{i\in N} C_i - \left(\sum_{i\in N} \mu^{\gamma_i}(|N_{\gamma_i}|) - C_i\right)\right] \\ &= \frac{1}{n}\left(\sum_{i\in N} \mu^{\alpha}(n) - \mu^{\gamma_i}(|N_{\gamma_i}|)\right). \end{aligned}$$

Since $\mu^{\alpha}(n) \geqslant \mu^{\gamma}(n)$ for all $\gamma \in \Delta$ and all functions $\mu^{\gamma}(\cdot)$ are increasing, it follows that $G(\bar{\alpha}) - G(\delta) \geqslant 0$. Thus, by Lemma 4.3, the strategy configuration α is a Pareto efficient Nash equilibrium. To conclude, consider a district β with $\mu^{\beta}(n) < \mu^{\alpha}(n)$. Then Lemma A.1 implies that for every $i \in N$ $\pi_i((\beta, \ldots, \beta)) < \pi_i(\bar{\alpha})$, where $\beta =$. Thus, the location of all firms in β is not Pareto efficient. □

We use the following lemma, that whenever there exists a coalition of firms $S \subset N$ located in the same district which can benefit by dispersing its members to different districts, the members of S would also benefit if they jointly moved to

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the same district. Thus, without loss of generality, we may restrict our attention to cases when all deviating firms move to the same district:

Lemma A.3. *Let α be a strategy configuration where all firms choose district α. Let $\{S^k\}_{k=1,\dots,K}$ be a collection of non-empty and pairwise disjoint coalitions of firms in N and $\{\beta^k\}_{k=1,\dots,K}$ be a set of different districts in D. Put $S=\bigcup_{k=1}^K S^k$. Define by δ the strategy configuration where every firm in S^k chooses β^k, $k=1,\dots,K$, and all firms in $N\setminus\bigcup_{k=1}^K S^k$ choose α. Assume, without loss of generality, that $\mu^{\beta^K}(|S^K|)\leqslant\mu^{\beta^k}(|S^k|)$ for all k. Let δ' be a strategy profile where every firm in S chooses β^K and all other firms choose α. Then the inequality $\pi_i(\delta)>\pi_i(\alpha)$ for all $i\in S$ implies $\pi_i(\delta')>\pi_i(\alpha)$ for all $i\in S$.*

Proof of Lemma A.3. Let α be a strategy configuration where all firms choose district α. Let $\{S^k\}_{k=1,\dots,K}$ be a collection of non-empty pairwise disjoint coalitions of firms in N and $\{\beta^k\}_{k=1,\dots,K}$ be a set of different districts in D. Put $S=\bigcup_{k=1}^K S^k$. Define by δ the strategy configuration where every firm in S^k chooses β^k, $k=1,\dots,K$, and all firms in $N\setminus\bigcup_{k=1}^K S^k$ choose α. Let $\mu^{\beta^1}(|S^1|)\geqslant\mu^{\beta^k}(|S^k|)$ for all k. Let δ' be a strategy profile where every firm in S chooses β^1 and all other firms choose α. Assume that the inequality $\pi_i(\delta)>\pi_i(\alpha)$ for all $i\in S$.

Let $\mu^{\beta^K}(|S^K|)\leqslant\mu^{\beta^k}(|S^k|)$ for all k and take any $j\in S^K$. By Lemma A.1,

$$\mu^\alpha(n)<(n+1)\mu^{\beta^K}\left(\left|S^K\right|\right)-\sum_{k=1}^K\left|S^K\right|\mu^{\beta^K}\left(\left|S^K\right|\right)-(n-|S|)\mu^\alpha(n-|S|).$$

Since $\mu^{\beta^K}(|S^K|)\leqslant\mu^{\beta^k}(|S^k|)$ for all k we have

$$\mu^\alpha(n)<(n+1-|S|)\mu^{\beta^K}\left(\left|S^K\right|\right)-(n-|S|)\mu^\alpha(n-|S|).$$

Moreover, $\mu^{\beta^1}(|S^1|)\geqslant\mu^{\beta^k}(|S^k|)$ for all k yields

$$\mu^\alpha(n)<(n+1-|S|)\mu^{\beta^1}\left(\left|S^1\right|\right)-(n-|S|)\mu^\alpha(n-|S|).$$

But, by Lemma A.1, the last inequality implies that $\pi_i(\delta')>\pi_i(\alpha)$ for all $i\in S$, where δ' is a strategy profile where every firm in S chooses β^1 and all other firms choose α. □

Proof of Proposition 5.4. By Lemma A.3, it suffices to demonstrate that for every $\alpha\in\Delta$ an agglomeration equilibrium $(\alpha,\dots,\alpha)$ is strong if and only if there exists no coalition of size m, $1\leqslant m\leqslant n-1$, firms and a district β, such that a move of m firms to β would be beneficial for every member of the deviating group. By Lemma A.1, such a move would be beneficial if and only if $\mu^\alpha(n)<(n+1-m)\mu^\beta(m)-(n-m)\mu^\alpha(n-m)$. Thus, the violation of this condition for all m and α would guarantee that the location of all firms in α is a strong Nash equilibrium. □

Proof of Proposition 6.1. Since for every two districts α, β and every two firms i, j we have $C_i^\beta - C_i^\alpha = C_j^\beta - C_j^\alpha$, Lemma A.2 implies that the game does not admit a dispersed equilibrium. To complete the proof, note that Lemma 3.2 implies that the strategy configuration $(\alpha, \ldots, \alpha)$ is a Nash equilibrium if and only if $H^\alpha(n) \geqslant C^\alpha - C^\gamma$ for all $\gamma \in \Delta$.

Define: $C^\beta = \min_{\gamma \in \Delta} C^\gamma$. Since district α yields an agglomeration equilibrium if and only if $H^\alpha(n) \geqslant C^\alpha - C^\beta$, the non-negativity of the function $H^\alpha(\cdot)$ implies that, under FI, the cost-efficient district β generates an agglomeration equilibrium. □

Proof of Proposition 6.2. Assume that the firm independence of stand-alone costs holds. Condition (ii) is necessary and sufficient for a strategy configuration $\alpha = (\alpha, \ldots, \alpha)$ to be a Nash equilibrium. Suppose now that α is a cost-efficient district which satisfies $H^\alpha(n) \geqslant C^\alpha - C^\beta$ for all $\beta \in \Delta$. Take any strategy configuration $\delta = (\delta_1, \ldots, \delta_n)$ and consider the difference $G(\alpha) - G(\delta)$. We have

$$
\begin{aligned}
G(\alpha) - G(\delta) &= \left(\mu^\alpha(n) - C^\alpha\right) - \frac{1}{n} \sum_{i \in N} \left[\mu^{\delta_i}(|N_{\delta_i}|) - C^{\delta_i}\right] \\
&= \frac{1}{n} \sum_{i \in N} \left[\left(\mu^\alpha(n) - C^\alpha\right) - \left(\mu^{\delta_i}(|N_{\delta_i}|) - C^{\delta_i}\right)\right].
\end{aligned}
$$

Since for every $\beta \in \Delta$ $\mu^\alpha(n) - C^\alpha \geqslant \mu^\beta(n) - C^\beta$ and the function $\mu^\beta(\cdot)$ is increasing, it follows that $G(\alpha) - G(\beta) \geqslant 0$. Thus, by Lemma 4.3, the strategy configuration α is a Pareto efficient Nash equilibrium. To conclude, consider a district γ with $\mu^\gamma(n) - C^\gamma < \mu^\alpha(n) - C^\alpha$. Lemma A.1 implies that for every $i \in N$ we have $\pi_i(\alpha) > \pi_i(\gamma)$, where $\gamma = (\gamma, \ldots, \gamma)$. Thus, γ is not a Pareto efficient allocation. □

Proof of Corollary 6.3. Suppose that $\mu^\beta(n) \geqslant ((n-1)/n)\mu^\gamma(n)$ for every two districts β and γ. Take a cost-efficient district α. By Lemma 4.3, the strategy configuration $(\alpha, \ldots, \alpha)$ is Pareto efficient. Moreover, the inequality $\mu^\alpha(n) - C^\alpha \geqslant \mu^\beta(n) - C^\beta$ implies that $H^\alpha(n) \geqslant \mu^\alpha(n)/n \geqslant C^\alpha - C^\beta$ for every $\beta \in \Delta$. That is, the strategy configuration α is a Pareto efficient Nash equilibrium. □

Proof of Propositions 6.4. Follows from Lemma A.1 by using the same arguments as in the proof of Proposition 5.4. □

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