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Knowledge Spillovers, Mergers and Public Policy in Economic Clusters

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Abstract. This paper investigates how market concentration affects research activity in an economic cluster. The firms in the cluster play a two-stage game. In the first stage the firms choose whether or not to engage in costly research that generates technological improvements that spill over to the other firms in the cluster. The more firms engaged in research the richer or more profitable is the pool of knowledge that spills over. In the second stage after the knowledge spillovers have occurred, firms compete in quantities. We solve for the symmetric mixed strategy equilibrium to the first stage of the game, and find that too low a degree of concentration in the cluster will destroy firms' incentives to undertake research and so the cluster risks stagnation. We explore whether a merger can stimulate research activity by increasing concentration in the cluster. Finally, we consider a public policy response to stagnation and analyze whether a direct public subsidy to stimulate research is preferable to a self-financing arrangement.

Key words: Agglomeration, clusters, mergers, perfect spillovers.

JEL Classifications: L10, O38.

I. Introduction

Economic clusters are defined as geographic groupings of firms whose products are related, either as complements in the case of upstream downstream relations, or as substitutes in the case of horizontal competition. Well known examples of clusters include the film industry in Hollywood, Italian leather manufacture in Northern Italy, Silicon Valley in California, the finance industry in New York, and the household furniture industry in North Carolina. These clusters constitute a diverse set of industries employing different technologies and serving different kinds of consumers. A natural question to ask is what advantage the geographic proximity of being part of a

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cluster might confer on firms in the cluster. In the 1920s Marshall, asking a similar question about steel making and machining firms clustered around Sheffield, concluded that it was "something in the air". More recently Krugman, Lucas and Porter have similarly concluded that the advantage is the informal knowledge that buzzes around such places.

The idea that geographic or spatial concentration of production facilitates the creation and diffusion of ideas has now become a basic theme in the literature on economic geography and growth. Nevertheless, the micro-foundation of how that knowledge creation occurs and spills over to other firms is not very clear.[1] This paper attempts to bridge that gap. Specifically we investigate what factors affect a firm's incentive to engage in creating the kind of knowledge that "goes into the air" and spills over to other firms in the cluster. The knowledge creation we have in mind could be about technical improvements such as changes in product design or capability, or upgrading production systems, or it could be from marketing and developing new customers. This kind of knowledge cannot be patented, and therefore can benefit other firms. When firms are agglomerated in one geographic area the knowledge can spill over through various channels such as the movement of personnel, or through common input suppliers and customers.[2]

However, creating knowledge, even that which "goes into the air", is a costly activity for a firm. A firm's incentive to incur the cost will be affected by its view of how many other firms are actively involved in knowledge creation. On the one hand there is an adverse effect because the firm can free ride on others' costly efforts. On the other hand the greater is the number of firms engaged in knowledge creation the richer is the potential pool of ideas available to them all, and the greater is the potential benefit to them all.[3] It is not a priori clear how the size of the cluster, or the number of firms in close proximity, affects the knowledge creation within, and hence, the economic vitality of the cluster. Shedding light on this issue is important for policy-makers because many economic development policies in OECD countries are cluster-based initiatives.

We begin by building a model of non-cooperative knowledge creation and competition among firms who are part of a cluster in which there are perfect knowledge spillovers. In this respect we follow Cabral (2000). An innovative feature of our analysis that stands in contrast to the approach of Cabral and others, however, is that we explicitly model the cumulative effect of research

[1] That agglomeration mechanisms dealing with knowledge creation have received little attention is a point made in Duranton and Puga (2003) in their survey of the micro-foundations of agglomeration.

[2] See Baptista (2000) for recent empirical evidence.

[3] Some of these conflicting effects are documented in the extensive literature on R&D. See, for example, Dybvig and Spatt (1983), Spence (1984), Katz (1986), d'Aspremont and Jacquemin (1988), Kamien et al. (1992), Leahy and Neary (1997).

effort when more than one firm engages in research.[4] Specifically, there are N identical firms that play a two-stage game. In the first stage each firm chooses whether to engage in costly knowledge creation. If a firm incurs the cost then the knowledge the firm creates spills over perfectly to the other firms. Knowledge creation in this setting may be best understood as a cumulative process where one firm's innovations build on another's. In a world of perfect spillovers each firm in the cluster benefits from the cumulative effect of knowledge creation. The direct implication is that each firm will implement the "best" innovation, the one that is most profitable. Once the spillovers have occurred and the innovations made, then in the second stage the firms compete in quantities.

We adopt a symmetric mixed strategy solution to the question of whether firms engage in costly research in the first stage. That is, each firm contributes to the information pool in the first stage with some probability. The alternative would be an asymmetric solution in which some firms do costly research and others do not. A mixed strategy solution is preferable for several reasons. First, firms are assumed to be identical and in the symmetric mixed solution, unlike the asymmetric one, the firms will have identical profit outcomes. Second, research effort that gives rise to knowledge "in the air" is likely to be non-contractible and non-enforceable. A mixed strategy is a way to model how informal or implicit cooperation among firms can arise when there are spillovers. By contrast, if research effort were assumed to be contractible and enforceable, as is often the case in the R&D literature, then it would make sense to allow firms to cooperate explicitly in the knowledge creation process and to internalize spillover effects (see De Bondt and Veugelers, 1991; Kesteloot and Veugelers, 1994).[5]

When we solve for the optimal knowledge creation strategy we find, perhaps not surprisingly, that too many firms in the cluster can destroy the incentive to innovate. In that case no firm engages in knowledge creation, and so the cluster stagnates. Merging, or more generally an alliance among firms, is one potential mechanism to restore economic vitality to the cluster. A merger will trigger the incentive to undertake costly knowledge creation not only by the firms that merge, *but also* by the remaining firms in the cluster. Moreover, provided that knowledge creation is sufficiently productive, in a sense that we establish in the paper, mergers or coalitions can not only be profitable, but also socially desirable *and* Pareto improving. This stands in sharp contrast to Gaudet and Slant (1992) who in a similar Cournot model, albeit without knowledge creation, find that mergers are inefficient.

[4] Assuming spillovers to be "high" but not perfect significantly increases the technical complexity of the analysis without affecting our qualitative conclusions.

[5] Contractability and enforceability are the reasons why cooperative agreements tend to be very simple. See Cabral (2000), p. 1034, fn 3.

Merger or coalition formation can play an important role in safeguarding the vitality and competitive edge of the economic cluster. However mergers may not occur, particularly in clusters where entry is relatively easy. Subsidizing the cost of knowledge creation would then appear to be the only mechanism to avoid industrial stagnation. In the US one such public program has been the establishment of manufacturing technology centers (MTCs) for small manufacturing firms (Shapira, 1993). The business service centers serving small firms in the economic clusters in Emilia–Romagna, Italy and the US agricultural extension model, whose services transfer technology in the agricultural sector, are other examples of this form of public assistance to small firms.[6]

There is some question, however, of whether the goal of a self-financing knowledge creation assistance program is sustainable and/or desirable.[7] We show that the answer to this depends critically on the impact of the policy on market structure. Failure to account for the relationship between market forces and market structure can lead to inappropriate public policy.

The remainder of the paper is structured as follows. In Section II we describe how knowledge is created and spills over to firms in an economic cluster. Solving for the mixed strategy equilibrium identifies two threshold numbers of firms in the cluster. Below the first, firms in the cluster undertake research with certainty and above the second no firms undertake research. In Section III we consider whether there is a profit incentive among firms in the cluster to merge in order to restore the economic vitality of the cluster. Section IV considers the role of public policy to stimulate knowledge creation and the importance of designing appropriate mechanisms to fund the research. Our main conclusions are presented in Section V.

II. A Cournot Model of Knowledge Spillovers and Competition

Consider a market or economic cluster that contains N identical firms that act as Cournot competitors. We do not model explicitly how such a cluster might be formed. Recent developments in economic geography, see, for example, Fujita and Thisse (2003), are certainly consistent with the suggestion that clustering of related activities is likely to occur. We could also appeal to Anderson and Neven (1991) to conclude that agglomeration of Cournot firms is an equilibrium outcome. The inverse market demand for the firms' product is linear and given by:

[6] See Feller (1993) and Bianchi and Gualtieri (1990).

[7] Since 1988 the funding of MTCs comes from the budget of the National Institute of Technology and Standards and was originally provided for a six-year period. Feller (1993) questions the goal of self-financing MTCs.

$$P = A - Q, \tag{1}$$

where P is product price and Q is aggregate output; $Q = \sum_{i=1}^{N} q_i$. Production costs for each firm exhibit economies of scale and are given by:

$$C(q_i) = F + c.q_i, \tag{2}$$

Where F are fixed costs. The firms play a two-stage research/quantity game. In the first stage the firms choose whether or not to engage in costly research activities and in the second stage they compete in quantities. We look for a perfect equilibrium to the two-stage game.

Consider a benchmark case in which *no* firm in the first stage of the game chooses to undertake research. From standard analysis we know that in the second stage each firm produces the output $q_i^{\mathrm{C}} = (A - c)/(N + 1)$, the equilibrium product price is $P^{\mathrm{C}} = (A + Nc)/(N + 1)$, individual firm profits are $\pi_i^{\mathrm{C}} = ((A - c)^2/(N + 1)^2) - F$ and consumer surplus is $CS^{\mathrm{C}} = N^2(A - c)^2/2(N + 1)^2$. The term $(A - c)^2$ is a measure of the potential surplus in the market, and without loss of generality we normalize this measure to equal one.

Instead of assuming quantity competition in stage two we could assume that the N firms in the cluster produce perfect complements and compete in prices.[8] In this case Q denotes the number of packages of the N complementary goods demanded, while the price $P = \sum_{i=1}^{N} p_i$ is the aggregate of the prices set by the firms for their N goods. Again in the case where there is no research in stage one the stage two outcome is described by a set of prices $P_i^{\mathrm{B}} = (A - c)/(N + 1)$ and each firm earns profit $\pi_i^{\mathrm{B}} = ((A - c)^2/\ (N + 1)^2) - F$. The two cases are formally equivalent.

Now let us consider research in the first stage of the game. To do research each firm must incur a cost r. Firms' research efforts will have an impact on the potential market surplus available in stage two of the game. To model the impact of knowledge creation on market surplus we assume that when a firm incurs the cost r it receives a draw from a uniform distribution on the interval [0, S]. The draw is a measure of the increase in market surplus that accrues to all firms from the firm's research. In other words, if the firm's draw is s then through spillovers the knowledge creation increases the measure of market surplus to $1 + s$.

Knowledge creation in the cluster is a cumulative process with one firm's innovation building on another – in the spirit of the well known phrase "standing on the shoulders of giants". To capture the cumulative effect of knowledge creation we assume that the only draw that is implemented is the

[8] Sonnenschein (1968) and Gaudet and Salant (1992) explore the equivalence between quantity competition among perfect substitutes and price competition among perfect complements.

maximum draw $s(n)$ of all the firms' efforts, where n is the number of firms engaged in knowledge creation. The expected value of this maximum is:

$$s(n) = \frac{n}{n+1} S. \tag{3}$$

Observe that our approach to knowledge creation in (3) is equivalent to assuming that there are complementarities in research but that there are decreasing returns to these complementarities, or $s'(n) > 0$ but $s''(n) < 0$. An alternative approach might be to assume that the total spillover is the summation of all firms' research outcomes, in which case $s(n) = n.S/2$. In this case there would be constant returns to research complementarities. We show in the Appendix that this alternative strengthens our results.[9]

As a result of the complementary and cumulative effect of knowledge creation and perfect spillovers, the expected profit, not including the cost of knowledge creation, to each firm in the industry is

$$E\pi_i(N, n) = \frac{1 + s(n)}{(N+1)^2} - F. \tag{4}$$

In stage one of the game we solve for a symmetric mixed strategy solution in which each firm in the cluster undertakes research with the same probability q^*. A mixed strategy solution implies that the actual number of firms n that in fact do research is a random variable. This means that the expected gain in market surplus $s(n)$ is also a random variable, drawn from a binomial distribution. Suppose that firm 1 undertakes research with probability q and the remaining $N-1$ firms each undertake research with probability $\bar{q}$. The expected profit to firm 1, ignoring fixed costs, is

$$\begin{aligned} E(\pi_1(N,q,\bar{q},S,r)) = \frac{1}{(N+1)^2}\Bigg[1 + S\Bigg[& q.\bar{q}^{N-1}\frac{N}{N+1} + \\ & \sum_{j=1}^{N-1}\left(q\binom{N-1}{j}\bar{q}^{N-1-j}(1-\bar{q})^j\right. \\ & \left. +(1-q)\binom{N-1}{j-1}\bar{q}^{N-j}(1-\bar{q})^{j-1}\right)\left(\frac{N-j}{N-j+1}\right)\Bigg]\Bigg] - q.r. \end{aligned} \tag{5}$$

In a symmetric Nash equilibrium, firm 1's mixed strategy is such that when the other $N-1$ firms do research with probability q^* then firm 1's best response is to choose $q = q^*$. That is, the equilibrium probability q^* of firm 1 engaging in research in the first stage must satisfy the first-order condition

[9] We are grateful to an anonymous referee for suggesting this approach, which would be relevant, for example, if research identified mutually separate groups of new consumers.

Table I. Nash equilibrium research probability $q^*(N, \rho)$

Research cost Ratio (ρ)	Number of firms in the market (N)										
	5	6	7	8	9	10	11	12	13	14	15
0.0001	1.0000	1.0000	1.0000	1.0000	1.0000	0.8668	0.7253	0.6159	0.5293	0.4597	0.4028
0.0002	1.0000	1.0000	1.0000	0.9259	0.7453	0.6127	0.5122	0.4340	0.3718	0.3213	0.2798
0.0003	1.0000	1.0000	0.9644	0.7560	0.6082	0.4989	0.4156	0.3503	0.2981	0.2557	0.2207
0.0004	1.0000	1.0000	0.8352	0.6543	0.5252	0.4292	0.3555	0.2976	0.2513	0.2135	0.1824
0.0005	1.0000	0.9858	0.7469	0.5841	0.4671	0.3797	0.3125	0.2596	0.2172	0.1828	0.1543
0.0010	0.9623	0.6956	0.5211	0.3990	0.3102	0.2435	0.1922	0.1521	0.1201	0.0943	0.0732
0.0020	0.6750	0.4720	0.3360	0.2410	0.1725	0.1218	0.0833	0.0537	0.0306	0.0122	0.0000
0.0030	0.5323	0.3537	0.2353	0.1537	0.0957	0.0534	0.0220	0.0000	0.0000	0.0000	0.0000
0.0040	0.4349	0.2716	0.1649	0.0925	0.0418	0.0054	0.0000	0.0000	0.0000	0.0000	0.0000
0.0050	0.3598	0.2080	0.1103	0.0450	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0060	0.2980	0.1557	0.0655	0.0061	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0070	0.2453	0.1112	0.0274	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0080	0.1990	0.0722	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0090	0.1577	0.0374	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0100	0.1203	0.0061	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0110	0.0859	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0120	0.0542	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0130	0.0247	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0140	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0150	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

$\partial E(\pi_1(N, q, q^*, S, r))/\partial q|_{q=q^*} = 0$. Differentiating (5) with respect to q and simplifying gives the first-order condition:[10]

$$\frac{\partial E(\pi_1(N, q, q^*, S, r))}{\partial q} = \frac{1 - (1 - q^*)^N (1 + N.q^*)}{N(1 + N)^3 q^{*2}} S - r = 0. \tag{6}$$

It is convenient for our subsequent analysis to define the parameter $\rho = r/S$, which is the ratio of the cost of research r to the *maximum* potential benefit of research S. Solving (6) for q^* gives the Nash equilibrium probability with which each firm in the cluster undertakes research. Since Equation (6) is a polynomial of degree $N - 1$ in q^*, an analytical solution, which we denote by $q^*(N, \rho)$, can be provided only for $N = 2$, 3, 4 or 5.[11] For $N > 5$ we must rely upon numerical techniques.

When each firm engages in research with probability $q^*(N, \rho)$ the expected profit to each firm is:

$$E\pi_i^*(N, S, r) = \frac{(1 + S)q^*(N, \rho)(N + 1) - S(1 - (1 - q^*(N, \rho))^{N+1})}{(N + 1)^3 q^*(N, \rho)} - r.q^*(N, \rho) - F. \tag{7}$$

Table I gives $q^*(N, \rho)$ for a range of values of N and ρ.

From Equation (6) we can show that $\partial q^*(N, \rho)/\partial N < 0; \partial q^*(N, \rho)/\partial r < 0; \partial q^*(N, \rho)/\partial S > 0$. The probability with which each firm undertakes research is a decreasing function of the cost of research r, a decreasing function of the number of firms N and an increasing function of the maximum potential returns to research S. More generally, we have:

THEOREM 1. Let $\underline{N}$ be the solution to $N(1 + N)^3 = 1/\rho$ and $\overline{N}$ be the solution to $\overline{N} = \sqrt{1/2\rho} - 1$. The Nash equilibrium probability $q^*(N, \rho)$ with which each firm engages in research is:

(i) $q^*(N, \rho) = 1$ for $N \leq \underline{N}$,
(ii) $q^*(N, \rho) = 0$ for $N \geq \overline{N}$,
(iii) $q^*(N, \rho)$ is the solution to

$$\frac{1 - (1 - q)^N (1 + N.q)}{N(1 + N)^3 q^2} = \rho \quad \text{for } \underline{N} < N < \overline{N}.$$

[10] These and other calculations have been performed using *Mathematica* and *Matlab*. Details can be obtained from the authors on request.

[11] The solution for $N = 2$ is given in Appendix A. Others can be obtained from the authors on request.

Theorem 1 sheds new light on the concept of critical mass used by Porter (1988) to define an economic cluster.[12] In our model, the number of firms in the cluster must be less than $\overline{N}$ for the cluster to have the "knowledge dynamism" underlying competitive success. This is because a firm undertaking research can expect to appropriate only a $1/(N+1)^2$ share of the benefit from research. Too high a degree of spatial concentration or high N means too low a degree of market power. As a result, the greater is N the less is the benefit to a firm of spending on knowledge creation compared to the cost. It is here that we see the familiar downside of spillovers. We are likely to see stagnation, or nothing "in the air" in clusters with large numbers of firms, high N, or in which the ratio of the rewards to research to the costs of research, $S/r = 1/\rho$, is low. By contrast, there is a value of N below which the synergies from research dominate the temptation to free ride on the efforts of others and all firms undertake research with certainty. A lower degree of spatial concentration, or lower N, means a higher degree of market power and a greater benefit that can be appropriated from knowledge creation. In short, research activity can be stimulated provided that the research reward/cost ratio is sufficiently high.[13]

Theorem 1 also suggests that ease of entry to the cluster, making competition in the cluster tougher, could destroy the incentives to undertake costly knowledge creation and generate knowledge spillovers. Suppose that the number of firms N in the cluster is determined by free-entry. If *no* firms undertake research the equilibrium number of firms is:

$$N^0 = \sqrt{1/F} - 1. \tag{8}$$

If the sunk cost $F < 2\rho$ then the equilibrium number of firms N^0 is greater than the $\overline{N}$ defined in Theorem 1. Free entry then undermines firms' incentives to undertake research. In other words, when cost and entry conditions result in a cluster becoming very fragmented, the appropriability problem characteristic of spillovers undermines each firm's incentive to engage in modernization programs. Such clusters risk stagnation.

III. Mergers and Economic Clusters

If excessive fragmentation or too many firms in a cluster destroys the incentives of firms to engage in knowledge creation, then a decrease in market

[12] Porter (1988) defines clusters to be "critical masses – in one place – of unusual competitive success in particular fields" and cites Silicon Valley and Hollywood as being the world's best known clusters.

[13] With constant returns to research complementarities, so that $s(n) = n.S/2$, we have a similar result. Define $\overline{\overline{N}} = \sqrt{1/2\rho} - 1$. Then $q^*(N, \rho) = 0$ for $N \geq \overline{\overline{N}}$ and $q^*(N, \rho) = 1$ for $N < \overline{\overline{N}}$.

Table II. Minimum number of firms for a profitable merger $M(N, S)$

Return to research	Number of firms in the market (N)										
	5	6	7	8	9	10	11	12	13	14	15
0.50	4	5	5	6	7	7	8	8	8	10	10
0.60	4	5	5	6	6	7	8	8	8	10	10
0.70	4	5	5	6	6	7	8	8	8	10	10
0.80	4	5	5	6	6	7	8	8	8	10	10
0.90	4	4	5	6	6	7	8	8	8	10	10
1.00	4	4	5	6	6	7	7	8	8	9	9
1.10	4	4	5	6	6	7	7	8	8	9	9
1.20	4	4	5	6	6	7	7	8	8	9	9
1.30	4	4	5	5	6	7	7	8	8	9	9
1.40	4	4	5	5	6	7	7	7	8	8	8
1.50	4	4	5	5	6	7	7	8	8	9	9
1.60	4	4	5	5	6	7	7	8	8	9	9
1.70	4	4	5	5	6	6	7	8	8	8	10
1.80	4	4	5	5	6	6	7	8	8	8	10
1.90	4	4	5	5	6	6	7	8	8	9	9
2.00	4	4	5	5	6	6	7	8	8	9	9
2.10	4	4	5	5	6	6	7	7	8	9	9
2.20	4	4	5	5	6	6	7	7	8	9	9
2.30	4	4	5	5	6	6	7	7	8	9	9
2.40	4	4	5	5	6	6	7	7	8	9	9
2.50	4	4	5	5	6	6	7	7	8	9	9
$M(N)$	4	5	6	7	8	9	9	10	11	12	13

fragmentation is a way to restore these incentives. A coalition or merger among firms is an obvious way to achieve this. However, mergers may fail to occur for two reasons. First, mergers may not arise when post-merger entry into the market is relatively easy, thus undermining the firms' incentives to merge in the first place. Second, mergers may not be profitable even if post-merger entry is effectively blockaded. For example, in the context of the symmetric Cournot model that we have specified, a merger of M firms in an N firm market is unprofitable unless $M > 0.8N$; i.e., unless at least 80% of the firms in the market join the merged entity: the merger paradox identified by Salant et al. (1983).

With knowledge spillovers, however, there is a novel twist to the merger paradox. If entry is blockaded, a merger might trigger the incentive for firms to engage in knowledge creation. Provided that the new number of firms. $N - M + 1$, is less than $\overline{N}$ the merger induces knowledge creation by the

Table III. Post-Merger probability of research $q^*(N–M(N, S) + 1, \rho)$

Return to research (S)	Number of firms in the market (N)										
	5	6	7	8	9	10	11	12	13	14	15
0.50	1.0000	1.0000	0.8063	0.9176	1.0000	0.6824	0.7533	0.5371	0.4005	0.6369	0.4791
0.60	1.0000	1.0000	0.8063	0.9176	0.6057	0.6824	0.7533	0.5371	0.4005	0.6369	0.4791
0.70	1.0000	1.0000	0.8063	0.9176	0.6057	0.6824	0.7533	0.5371	0.4005	0.6369	0.4791
0.80	1.0000	1.0000	0.8063	0.9176	0.6057	0.6824	0.7533	0.5371	0.4005	0.6369	0.4791
0.90	1.0000	0.6770	0.8063	0.9176	0.6057	0.6824	0.7533	0.5371	0.4005	0.6369	0.4791
1.00	1.0000	0.6770	0.8063	0.9176	0.6057	0.6824	0.4826	0.5371	0.4005	0.4408	0.3420
1.10	1.0000	0.6770	0.8063	0.9176	0.6057	0.6824	0.4826	0.5371	0.4005	0.4408	0.3420
1.20	1.0000	0.6770	0.8063	0.9176	0.6057	0.6824	0.4826	0.5371	0.4005	0.4408	0.3420
1.30	1.0000	0.6770	0.8063	0.5209	0.6057	0.6824	0.4826	0.5371	0.4005	0.4408	0.3420
1.40	1.0000	0.6770	0.8063	0.5209	0.6057	0.6824	0.4826	0.3577	0.4005	0.3095	0.2462
1.50	1.0000	0.6770	0.8063	0.5209	0.6057	0.6824	0.4826	0.5371	0.4005	0.4408	0.3420
1.60	1.0000	0.6770	0.8063	0.5209	0.6057	0.6824	0.4826	0.5371	0.4005	0.4408	0.3420
1.70	1.0000	0.6770	0.8063	0.5209	0.6057	0.4239	0.4826	0.5371	0.4005	0.3095	0.4791
1.80	1.0000	0.6770	0.8063	0.5209	0.6057	0.4239	0.4826	0.5371	0.4005	0.3095	0.4791
1.90	1.0000	0.6770	0.8063	0.5209	0.6057	0.4239	0.4826	0.5371	0.4005	0.4408	0.3420
2.00	1.0000	0.6770	0.8063	0.5209	0.6057	0.4239	0.4826	0.5371	0.4005	0.4408	0.3420
2.10	1.0000	0.6770	0.8063	0.5209	0.6057	0.4239	0.4826	0.3577	0.4005	0.4408	0.3420
2.20	1.0000	0.6770	0.8063	0.5209	0.6057	0.4239	0.4826	0.3577	0.4005	0.4408	0.3420
2.30	1.0000	0.6770	0.8063	0.5209	0.6057	0.4239	0.4826	0.3577	0.4005	0.4408	0.3420
2.40	1.0000	0.6770	0.8063	0.5209	0.6057	0.4239	0.4826	0.3577	0.4005	0.4408	0.3420
2.50	1.0000	0.6770	0.8063	0.5209	0.6057	0.4239	0.4826	0.3577	0.4005	0.3095	0.3420

merged firms *and* by the firms that remain outside the merger. The merged firms then benefit through knowledge spillovers from the non-merged firms.

In our model there are four parameters that determine the profitability of mergers: N, F, r and S. To simplify the analysis, and make profitability a function of N and S only, we assume first that initially the pre-merger number of firms in the cluster is such that each firm just breaks even. Second, we assume that each firm, at the margin, just chooses not to engage in knowledge creation. These two assumptions imply that $F = F(N) = 1/(N+1)^2$ and that $r = r(N, S) = S/2(N+1)^2$. Given these conditions on the parameters we can identify the minimum number of firms $\underline{M}(N, S)$ that have to merge in order for the merger to be profitable.

Table II identifies $\underline{M}(N, S)$ for a range of values of N and S. We also report for comparison the lower limit $\underline{M}(N)$ on the number of firms that have to merge for the merger to be profitable in the absence of knowledge spillovers. Table III identifies the post-merger equilibrium probability of knowledge creation, $q^*(N_m, \rho)$, where $N_m = N - \underline{M}(N, S) + 1$ is the post-merger number of firms.[14] In other words, if the minimum number of firms $\underline{M}(N, S)$ merge, Table III describes how this affects the probability with which the remaining number of firms in the cluster undertake knowledge creation activities. (Recall that the pre-merger probability is $q^*(N, \rho) = 0$.)

Not surprisingly, the equilibrium probability $q^*(N_m, \rho)$ of knowledge creation is an increasing function of post-merger market concentration. It is also not surprising that the proportion of firms $\underline{M}(N, S)/N$ that have to merge for the merger to be profitable is decreasing in S, the potential returns to knowledge spillovers, and that the proportion of firms that need to merge for the merger to be profitable is generally less than the 80% limit. What is, on first sight, rather more surprising is that the proportion of firms, $\underline{M}(N, S)/N$, required for a profitable merger is *decreasing* in N, the initial number of firms in the cluster. By contrast, the proportion $\underline{M}(N)/N$ of firms required for a profitable merger when there are *no* knowledge spillovers is an *increasing* function of N for $N \geq 5$.[15] In other words, the presence of knowledge spillovers implies that the size barrier for a merger to be profitable is lower in more fragmented economic clusters: clusters containing large numbers of relatively small firms. These are precisely the markets that are at risk of stagnation and for which merger or coalition formation could be the answer.

This result reflects a balance between two sets of externalities. In the absence of knowledge spillovers, mergers create significant external benefits for the outside firms, with the result that profitable mergers have to be

[14] The associated values of F and r are given in Appendix A, Tables V and VI.

[15] Ignoring the integer constraints there is a strictly decreasing relationship between N and $\underline{M}(N, S)$ for $N \geq 5$.

Table IV. Critical Values of S

N	5	6	7	8	9	10	11	12	13	14	15
$\underline{S}$	0.155172	0.164384	0.076916	0.077386	0.077994	0.064871	0.048297	0.048236	0.033195	0.033132	0.024292
S	0.84375	0.826298	0.523066	0.556193	0.529254	0.411559	0.425912	0.418221	0.336511	0.344285	0.278456

larger in more fragmented markets. By contrast,with knowledge spillovers mergers induce insiders and outsiders to engage in knowledge creation. This creates a reverse spillover from the outsiders to the merged firms that is stronger the larger the number of outsiders. The knowledge spillovers more than offset the external benefits of a merger, leading to the outcome we have noted.

One remaining question is whether these profitable mergers are socially desirable. In the absence of knowledge creation and spillovers all mergers in quantity competition are socially undesirable (Gaudet and Salant, 1992). However, this is not the case once we introduce knowledge spillovers between the merged and non-merged firms. Rather, we have the following:

THEOREM 2. Assume a profitable merger of exactly $\underline{M}(N, S)$ firms. There is a value of S, denoted $\underline{S}$, such that for $S > \underline{S}$ all profitable mergers increase total surplus.

The possibility that mergers can increase total surplus by inducing knowledge creation and spillovers that would otherwise not take place has implications for merger policy. Although the primary focus of the anti-trust authorities tends to be on how consumer welfare is affected by merger activity rather than on total welfare, the presence of knowledge spillovers allow us to state an even stronger result.

THEOREM 3. Assume a profitable merger of exactly $\underline{M}(N, S)$ firms. There is a value of S, denoted $\overline{S}$, such that for $S > \overline{S}$ a merger of $\underline{M}(N, \overline{S})$ firms is profitable for insiders and outsiders *and* it increases cosumer surplus .

If the gains from knowledge creation are great enough, a merger of $\underline{M}(N, \overline{S})$ firms is Pareto improving. The intuition is simple to see. When $S > \overline{S}$, the returns to knowledge creation are sufficiently great that the tendency for the merger to increase prices is more than offset by the additional knowledge creation activities to which the merger give rise. Table IV gives approximate values $\underline{S}$ and $\overline{S}$ indicating that both $\underline{S}$ and $\overline{S}$ are decreasing in N. Mergers are more likely to be Pareto improving when the market is initially fragmented because of the strong knowledge synergies to which the merger gives rise.

IV. Public Policy and Research Activity

Mergers may induce expenditure on knowledge creation and lead to Pareto improving welfare gains, but will occur only when post-merger entry to the cluster is blocked. When entry is relatively easy there may be a role for public policy to facilitate knowledge creation. We noted in the introduction that Manufacturing Technology Centers, the agricultural extension model and business service centers of Emilia–Romagna in Italy could be considered examples of such public assistance to small manufacturing firms in an economic cluster.

Our interest is in two aspects of the design of this kind of public policy. First, the policy could be designed to stimulate firms' knowledge creation through direct subsidy to the firms with no attempt at recovery of the subsidy. Alternatively, the policy could be designed to make knowledge creation activities self-financing by requiring that all firms subscribe to the program, perhaps through a lump-sum tax of r.

With direct subsidy all firms in the cluster essentially face a zero cost of knowledge creation and so engage in knowledge creation activities with certainty. Expected profit of each firm is:

$$E\pi_i^s(N, S, F) = \frac{1 + \frac{N}{N+1}S}{(N+1)^2} - F. \tag{9}$$

If expected profits are positive entry will occur. The post-subsidy equilibrium number of firms N^s is such that $E\pi_i^s(N^s, S, F) \geq 0 > E\pi_i^s(N^s + 1, S, F)$. Comparison of (8) and (9) indicates that $N^s > N^0$. The subsidy, by stimulating knowledge creation, encourages entry to the cluster.

Suppose instead that the creation of knowledge spillovers is self-financing, with each firm in the market underwriting the cost through a lump-sum tax of r. In this case we have again that firms engage in knowledge creation with certainty because r is effectively a sunk cost of entry. The expected profit of each firm is now:

$$E\pi_i^f(N, S, F, r) = \frac{1 + \frac{N}{N+1}S}{(N+1)^2} - r - F. \tag{10}$$

Denote the free-entry number of firms in this case as N^f. Suppose that the lump sum r is given by $r = r^0 = S/2(N^0 + 1)^2$. In the absence of this policy each firm would not engage in costly knowledge creation at the free-entry equilibrium. It follows that:

$$E\pi_i^f(N^0, S, F, r^0) = \frac{(N^0 - 1)S}{2(N^0 + 1)^2} > 0. \tag{11}$$

$N^{\mathrm{f}} > N^0$ and self-financing of knowledge creation leads to additional entry. However, if the costs of knowledge creation are higher than r^0, the opposite could happen. Specifically:

$$r > \frac{2N^0}{N^0+1}.r^0 \Rightarrow E\pi_i^{\mathrm{f}}(N^0, S, F, r) = \frac{(N^0 S - (N^0+1)^3 r)}{(N^0+1)^3} < 0. \tag{12}$$

In other words, for r "large enough", the effect of compelling firms to subscribe to the policy might lead to less entry than there would be in the absence of the program.

Whether or not a policy to stimulate knowledge creation increases or decreases entry is in itself not sufficient to indicate whether the policy is socially desirable. What is necessary is to identify the impact of the policy on total surplus. If we maintain our free-entry assumption and assume that $r \geq r^0$, then total surplus in the absence of the program is consumer surplus with N^0 firms:

$$TS^{\mathrm{f}}(N^0, S) = \frac{1}{2}\left(\frac{N^0}{N^0+1}\right)^2. \tag{13}$$

With a public policy to stimulate knowledge creation, no matter how it is financed, total surplus is consumer surplus minus the costs of the knowledge creation activities:

$$TS^{\mathrm{f}}(N^{\mathrm{m}}, S, r) = \frac{(N^{\mathrm{m}})^2}{2}.\frac{\left(1+\frac{N^{\mathrm{m}}}{N^{\mathrm{m}}+1}S\right)}{(N^{\mathrm{m}}+1)^2} - N^{\mathrm{m}}r, \tag{14}$$

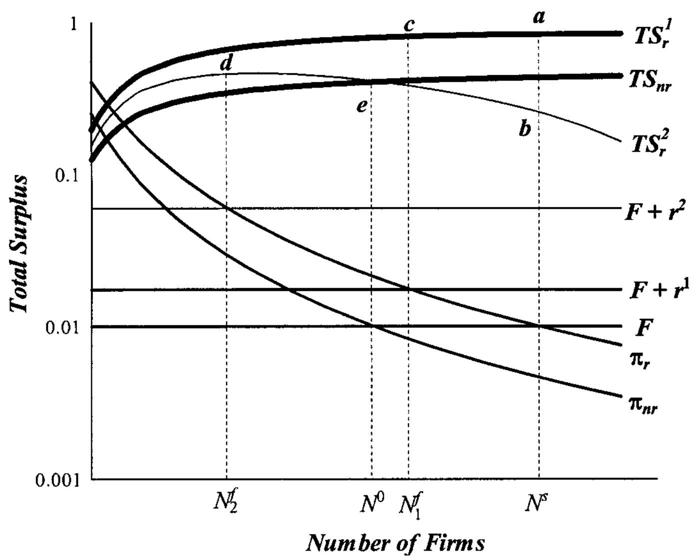

Figure 1. Research policy and total surplus.

where N^{m} is the free-entry equilibrium number of firms under the public policy, so that $N^{m} = N^{s}$ or N^{f} depending upon how the program is financed.

Consider first the situation in which costs are $r = r^{0}$, so that in the absence of a policy each firm chooses not to engage in knowledge creation. Introducing the policy in this case leads to additional entry no matter how it is financed and the impact on total surplus is

$$TS^{f}(N^{s}, S, r^{0}) > TS^{f}(N^{f}, S, r^{0}) > TS^{f}(N^{0}, S). \tag{15}$$

THEOREM 4. Assume that $r = r^{0}$. Public policy to stimulate knowledge creation stimulates entry and increases social surplus no matter how it is financed. However, public subsidy of knowledge creation is preferable in this case to a self-financing arrangement.

When the cost of knowledge creation is relatively low, the additional entry under a policy of subsidized knowledge creation (as compared to self-financing and the no-policy equilibrium) adds to the pool of the knowledge and more than justifies the additional knowledge creation costs incurred.

If knowledge creation costs are higher than r^{0} then we find a different situation. For r close to r^{0}, Theorem 4 continues to hold with the result that public subsidy is socially desirable. As knowledge creation activities become more costly, the additional entry induced by public subsidy also becomes increasingly costly, making this form of subsidy less desirable. Nevertheless, a self-financing public policy may still be socially desirable: the benefits of knowledge creation and spillovers more than offset their costs and the decreased entry the self-financing arrangement induces. Finally, there will be a point at which costs of knowledge creation are sufficiently high that no form of public intervention can be justified.

This is illustrated in Figure 1. When the research cost is r^{1}, total surplus with public funding of knowledge creation is ***a***, self-financing gives total surplus of ***c*** and the knowledge-creation total surplus is ***e***. Now assume that the research cost is r^{2}. This reduces the total surplus of the public policy from TS_{r}^{1} to TS_{r}^{2}. There is no impact on the no-knowledge-creation equilibrium, or on the free-entry number of firms with a public subsidy. However, the total surplus from the public subsidy is decreased to ***b***. If the policy is self-financed, the free-entry equilibrium number of firms is reduced from N_{1}^{f} to N_{2}^{f} and total surplus is reduced from ***c*** to ***d***. In the case illustrated, self-financing of knowledge creation is socially desirable but the public subsidy is not.

Figure 1 implies the following relationship between knowledge creation costs and the desirability of public policies to stimulate knowledge creation:

(i) When costs are relatively low (near to r^{0}), public subsidy is preferred;

(ii) for intermediate values of costs, self-financing is prefered;
(iii) for high values of costs neither type of policy can be justified on efficiency grounds.

This is consistent with the kinds of situations in which government programs to stimulate knowledge creation have been advocated. These are generally intended to stimulate research activity by small manufacturing firms that find it difficult, if not impossible, to protect their research findings. This is just the kind of environment in which knowledge creation costs are likely to be relatively low and so in which public funding will be beneficial.

V. Conclusion

This paper explores the micro-foundations of an important theme in economic geography and growth, that knowledge spillovers are a key source of the positive externalities underlying agglomeration or economic clusters. Knowledge spillovers are product, or productivity, improvements that can easily be implemented by all firms and therefore can lead to increased efficiency of the entire cluster. Nevertheless, creating the knowledge in the first place is costly for a firm. Because of free riding effects there is an adverse impact on knowledge creation activity from having too many firms in the cluster. On the other hand, a large number of firms actively engaged in discovering new ways of doing things creates a rich potential pool of knowledge and knowledge spillovers.

This paper has investigated the tension between competition and cooperation in an economic cluster and the effect that this has on the likelihood that a firm puts "something in the air". If there are many firms in the economic cluster, so that fragmentation of the cluster is high, the private profit incentive is too weak for firms to expend resources on knowledge creation efforts. Decreased fragmentation, perhaps through a merger, may be necessary to stimulate knowledge creation. We have identified the circumstances under which merging is profitable. In addition we have shown that there are circumstances in which mergers are not only profitable, but are also Pareto improving as a result of the knowledge creation and knowledge spillovers they generate.

Merger, however, cannot be relied upon to maintain the competitive edge of a cluster, particularly when entry is relatively easy. This is a condition that may very likely hold in a relatively fragmented cluster. These economic clusters are at risk of stagnating. The alternative is a public policy response to stimulate knowledge creation. However, the design of such public policy matters because of its impact on the market structure of the cluster.

We have shown that if the cost of knowledge creation is relatively low, both public subsidy and self-financing arrangements, perhaps through lump-sum taxes, stimulate entry and increase social welfare. However, a policy of public subsidy of the costs of knowledge creation is preferable. By contrast, when knowledge creation is somewhat more costly, the costs of additional entry induced by public subsidy more than offset the benefits. In such cases, the preferable approach is to make the public policy self-financing, perhaps through lump-sum taxation of market participants. The potentially detrimental effects from increased concentration that self-financing induces in these cases are more than offset by the benefits that flow from the knowledge spillovers created by the program.

Appendix A

1. $s(n) = n.S/(n+1)$
Suppose that $N=2$.
Assume that firm 1 undertakes research with probability q_1 and firm 2 with probability q_2. Then the expected profit to firm 1, ignoring fixed costs, is

$$E\pi_1(2, q_1, q_2, S, r) = q_1 q_2 \left(\frac{1+s(2)}{9} - r\right) + q_1(1-q_2)\left(\frac{1+s(1)}{9} - r\right) + q_2(1-q_1)\frac{1+s(1)}{9} + \frac{1}{9}(1-q_1)(1-q_2). \quad \text{(A.1)}$$

From this we have

$$\frac{\partial E\pi_1(2, q_1, q_2, S, r)}{\partial q_1} = \frac{1}{54}(3-2q_2)S - r. \quad \text{(A.2)}$$

It follows that the Nash equilibrium research probability is

$$q^*(2,\rho) = \begin{cases} 1 & \text{for } \rho < 1/54, \\ 3/2 - 27\rho & \text{for } 1/54 \le \rho \le 1/18, \\ 0 & \text{for } 1/18 < \rho. \end{cases} \quad \text{(A.3)}$$

2. $s(n) = n.S/2$
Substituting $N.S/2$ for $N.S/(N+1)$ and $(N-j)S/2$ for $(N-j)S/(N-j+1)$ in (5), differentiating with respect to q and simplifying gives the first order condition:

$$\frac{\partial E\pi_1(N, q_1, q_2, S, r)}{\partial q_1} = \frac{1}{2(1+N)^2}S - r = 0 \quad \text{(A.4)}$$

so that the research probability is

$$q^*(N,\rho) = \begin{cases} 0 & \text{for } \rho \le 1/2(1+N)^2, \\ 1 & \text{for } \rho > 1/2(1+N)^2. \end{cases} \quad \text{(A.5)}$$

Profit to each firm is

$$\pi(N, q, q, S, r) = \frac{2 + N.q^*(N, \rho).S}{2(1 + N)^2} - q^*(N, \rho).r - F. \tag{A.6}$$

Adopting the same approach as in the text, if $\rho = 1/2(1 + N)^2$ then any two firm merger is profitable. More generally, provided that S is not "too small" any j-firm merger is profitable.

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