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Do Investments in Specialized Knowledge Lead to Composite Good Industries?

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ABSTRACT. We try to understand why firms producing goods by means of complementary components do not merge, especially in industries in which investments in component-based knowledge matters. As Audretsch, we state that these activities are developed by "individuals" who do their best to appropriate the return from their knowledge and whose effort is non-contractible. The organization of the industry into firms is identified to a partition of the set of individuals. In this context, we prove that an organization in which each individual hold his own firms is both stable with respect to unilateral deviation and optimal in the line of the property right approach. If the returns are high enough, this structure is even the only one which shares both properties.

KEY WORDS: composite goods, dual Cournot competition, lateral disintegration, incomplete contracts, property rights.

JEL CLASSIFICATION: D23, D43, L22

1. Introduction

They are a growing number of knowledge-based industries producing composite goods and which involve a significant number of small and specialized firms. This phenomenon is observed world-wide, for instance, in the biotechnological or pharmaceutical industry. In the former sector, small firms already represented 40% of the total number of firms in US in 1991. The same evolution is now observed in Europe. For instance in France, there are 400 specialized biotechnology SMEs employing 15,000 peoples with a turnover of 2 billion Euros. A similar phenomenon is also observed in Germany and in UK.[1] More generally, this fragmentation of activities is often observed for composite goods. In this case, consumers purchase bundles of goods pooling complementary components while these modules are often produced by independent firms rather than by a completely integrated structure. But the growing literature on composite or system goods introduced by Matutes and Regibeau (1988) does not really provide an answer to the question of the modular structure of the industry because the underlying network[2] which organizes the production is often taken as given. So, what are the conditions which ensure the existence of specialized firms producing complementary components?

Put in an other way, our main purpose is to understand why several firms producing complementary components do not always merge, especially in high-tech industries and, more generally, in all industries in which high levels of investments in specialized and component-based knowledge are the major cause of benefits. In this case, both the transaction cost and the market structure approach predict a merger. Even Cournot's study (A. Cournot, 1974) of the *"Concours des producteurs"* case[3] reached, a long time ago, this strong conclusion which is not validated, for instance, within the biotechnological industry. So can this conclusion be reverse? Following Audretsch (1995, 2001a), we start from the idea that "individuals", or more precisely here the developers of some specific knowledge, play an important role in these industries. Firms are defined as a collection of individuals with the property that none of their members can obtain a higher return of their knowledge elsewhere.

To illustrate this point, let us come back to the structure of the biotechnological industry in US in the 90th (see Audretsch, 2001b). In this sector the large established firms buy the new

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components developed by specialized firms, combine and convert them into large scale marketed products. One could, of course, always argue in the line of Becker and Murphy (1992) that this situation corresponds to some natural division of labor. But, the profitability of this industry largely relies on investments in specialized knowledge realized on each component and these investments in human capital are non-enforceable and specific to each activity. So why these established firms do not control all these specialized activities and why they do even power the development of independent entities?

By trying to understand why these firms did not merge, we address the problem of the nature and boundaries of a firm and therefore enter into the line of research opened by Coase (1937) seminal contribution. But both the transaction cost and the standard market approaches surprisingly conclude that these firms have an incentive to merge.

The point of view of the transaction cost approach (Williamson, 1975, 1979) can be summarized as follows. In the previous example, as well as in many composite good industries, this approach emphasises that strong relationship-specific investments make these firms strongly interdependent. Moreover, if all these actors have in mind that, say, the molecule she produced can contribute to an other final product at not too high costs, the tenants of the transaction cost approach exhibit a double hold-up problem and conclude, on the basis of these two arguments, that these firms should merge.

We can, of course, always argue, as Holmstrom and Roberts (1998), that the transaction cost approach considers the market as a black box and therefore only spells out the costs and benefits of integration which relies on the presence of an impersonal market. Put in other words, we could perhaps argue that the existence of composite good industries is related to the nature of the competition on the final market.

This argument is again not really convincing. The tenants of this approach usually argue that firms have no incentive to merge if the aggregated profit of the separately owned components is, at the market stage, higher than the profit obtained in the merger case. But the market structure for composite goods is quite singular. The firms set the price of the component they produce and they know that consumers are willing to pay for the whole bundle of complementary components. These strategic interactions lead to "double marginalization" behaviors because each price setter misestimates the true elasticity of the demand and his real market power. This peculiar market structure is known since Cournot's book (Cournot, 1974, chapter 9) and it was latter identified (see Sonnenschein, 1968) as a case of Dual Cournot competition (DC for short). Nevertheless Cournot already reports that the firms have a strong incentive to merge.[4]

Till yet, we however do not take advantage from the fact that we consider knowledge-based industries. In this case, the production of complex commodities often requires the knowledge of several component-based domains, and the appropriability issue becomes crucial. From that point of view, the simplifying assumption which states that a final commodity is produced by an integrated firm does not make sense because this simplification strongly relies on the idea that this firm has the ability to appropriate all the knowledge embodied in the different components. So, if we assume, like Audretsch (1995, 2001a), that these specific knowledge-based activities are developed by "individuals" the question becomes: *"How can economic agents with a given endowment of new knowledge best appropriate the return from that knowledge?"* (Audretsch, 2001a, p. 40). It seems therefore more relevant to identify each specialized knowledge-based component to a decision center. We thereafter call it the *owner* or the *developer* of a component.

In this framework, a firm can be identified to a collection of basic activities with the property that each developer shares her knowledge inside the group and has no incentive to leave this group because she cannot obtain a better return from her knowledge elsewhere. Then, the structure of the industry, i.e. the set of firms producing a complex commodity, is a partition of the set of all basic activities with the property that none of the developers can improve the returns of his knowledge by moving to an other firm or by creating his own business.

Our approach departs from Audretsch's work because we assume that each holder of an initial activity is not only endowed with knowledge but also has the ability to improve it by specific investments. This allows us to fit with the standard property right approach.

In fact once the firms are settled and the leaders are chosen, we assume that these agents have the opportunity to invest a certain amount of money in each component under their control. These investments improve the knowledge of each activity developed by the firm and, by the way, enhance the quality of the final composite good. We however assume that only the lowest level of investment across all components matters. When a consumer buys a complex knowledge based commodity, she does not necessarily care about the components. She often says that this commodity is not performing if at least one component is of low quality.[5] From that point of view, it seems logical to assume that the different firms have a strong incentive to cooperate with regard to this decision. But an other feature of knowledge-based products matters . These investments are, due to their specificity, most of the time non-enforceable. So, even if the developers decides, inside a firm, to join their activities and to share their knowledge, it seems difficult to assert that the same happens across firms. These investments must be chosen in a strategical way. One could at most accept the idea that the best outcome is selected if several Nash equilibria occurs.

Even if the firms do not cooperate with respect to these investment decisions, we show that they have a strong incentive to act in this way when they set prices. This result is closely related to dual Cournot competition, especially to the "double marginalization" effect which is at work. Cooperation eliminates this inefficiency and therefore increases both profits and total surplus. But, these gains from cooperation must be shared. To solve this problem, we adopt in this paper a standard Nash bargaining approach[6] where the outside options are given by the payoffs that can be obtained if no cooperation occurs, i.e. the payoffs obtained in a DC game.

Since the firms both cooperates *ex post* i.e. at the market stage and choose *ex ante* their investments in a strategical way, our approach also fits with the standard property right theory developed by Grossman and Hart (1986), Hart and Moore (1990) or Hart (1995). Therefore, we address the question of both the determination of a stable structure of the industry and the question of the efficiency of this organization.

To sum up, we consider a subgame perfect equilibrium of a three step game. The first one is dedicated to the search of a stable partition of the set of elementary activities into firms. Such a partition is reached if none of the developers of a basic knowledge-based component has an incentive to leave the firm to which she belongs. At the end of this step, each developer transfers to the firm the right to sell the product and to set the price of the bundle of components[7] which are produced by the firm. In return, she obtains a part of the profit realized by this firm which is proportional to her contribution to the production of this sub-component. In the second step, the existing firms choose the level of investment for each controlled activity. These investments are not contractible[8] but strongly influence the quality of the final product. Due to these externalities, these investments are obtained by a Nash equilibrium and if several equilibria exist we select an undominated one. After these strategical choices, production takes place in each firm and the quality of the final good is observed. In a third step, it remains to set prices. Firms have the ability either to cooperate or to play a DC game.

We solve this game backward. We first exhibit some properties of DC competition. This enables us to prove that cooperation is the best issue in the last step of the game and gives us some information on the outside options of the bargaining process. In fact, we establish that every firm earns the same profit level if DC competition occurs. As a consequence, we verify that the Nash Bargaining process leads to an equal sharing of the monopoly profit between the different firms. After this step, it becomes possible to tackle the question of the choice of the investment levels in each specific knowledge. Because only the lowest level of quality matters, this game admits a large set of Nash equilibria (NE). We concentrate our attention on undominated equilibria and compute, for each partition of the set of activities, the profit obtained by the different firms. If each developer of a basic activity is able to foresee these different profit structures, she is able to decide to joint an existing firm or to create her own business. In other words, we are able to characterize all stable partitions of the set of activities, i.e. the set of existing firms. We show that every stable partition induced by our mechanism leads to an efficient allocation of the property rights in the sense of Grosman–Hart. We prove that if the investments in specialized and component-based knowledge are the major source of benefits, then every initial owner of a basic activity has a strong incentive to create her own firm. But this does not mean that this situation is the unique issue. If the return are not too high but nevertheless positive, this outcome is still valide among others.

The paper is organized in the following way. The model is depicted in Section 2. The other sections analyze the subgame perfect equilibrium of the game considered in this paper. Section 3 is devoted to the presentation of DC competition and to the Nash bargaining process. Section 4 describes the strategical investments in specialized knowledge. The conditions of the existence of composite good industries are discussed in Section 5. Some concluding remarks are made in Section 6. Proofs are relegated to an Appendix A

2. The model

To depict a composite good industry in the simplest way, we consider a set $I = \{1, \ldots, I\}$ of basic activities which are combined in order to produce a composite or a system good. These activities are sharp complements. This means that the production of one unit of the composite good requires a fixed proportion of the output of each activity $i \in I$. To simplify the analysis, we even assume that these contributions are the same and are all set egal to one.[9] However this does not mean that the components are the same. They have different unit production costs given by c_i for each $i \in I$.

The level quality of each component can also differ since it can be improved by a specific investment of a bounded amount of money $e_i \in [0, \bar{e}_i]$. The production of quality of each component exhibits constant returns to scale with respect to the level e_i of monetary expenditure. But, like Economides (1999) and since these activities are complements, we assume that the quality of the composite good is given by the lowest level of investment. This index of global quality is set to 1 when no effort occurs and egal to $q = 1 + \min_{i \in I}\{e_i\}$ in the other case.

Quality also matters on the demand side: the consumers base their willingness to pay on this index. More precisely, we consider a discrete choice model involving a continuum [0, 1] of customers. Each of these agents has an intrinsic valuation $x \in [0, \bar{x}]$ of the composite good. But she takes care of quality, being ready to pay[10] $q \cdot x$. A cumulative function $G(x)$ which describes the distribution of x across the population completes the description of the demand. Its density $g(x)$ is assumed to be strictly positive and non-decreasing i.e. $g(x) > 0$ and $g'(x) \geq 0$. Under these assumptions, the final demand is $D(\frac{p}{q}) = \int_{p/q}^{\bar{x}} 1 \cdot dG = 1 - G(p/q)$. This demand is zero for prices which are higher than $\bar{p} = \bar{x} \cdot q$. Our assumption on $g(x)$ becomes clear: if the price decreases, at a given level of quality, or if the quality increases at a given price, there are less and less new consumers who decide to enter into the market. Finally, we also assume that $c = \Sigma_{i \in I} c_i < \bar{x}$ in order to make sure that the total unit production cost is always lower than the highest reservation price whatever the level of quality is.

A firm is a endogenous subset $f \subset I$ of basic activities. The set of firms $F = \{f\}_{f=1}^{F}$ describes a partition of this set I. By choosing to pool several activities, a firm produces a module of the final good by pooling several activities. The unit production cost[11] of this module is therefore given by $c_f = \Sigma_{i \in f} c_i$. Moreover we assume that this firm has both the ability to set the price p_f of that module and to choose the levels of investments $(e_i)_{i \in f}$ in each component of the module. This firm supports an additional investment cost of $\Sigma_{i \in f} e_i$.

As soon as prices and investments are chosen, the returns are shared within the firms. Since we have assumed that one unit of each activity is required to produce the final good, the same holds at the module level. In other words, we can say that each activity $i \in f$ contributes in the same way to the production of given firm f. This allow us to assume equal profit sharing inside of each firm.

The game is played in three steps. In the first one, every developer of a specific knowledge-based activity has the opportunity to join a firm or to create her own business. The outcome of this first stage is a stable partition of the set of activities and each element of this partition represents a firm which produces a module of the final good. The second stage is dedicated to the investment game. Each firm invests a certain amount of money in order to improve the knowledge embodied in each different activity under her control. The levels of investments chosen by the different firms determine the quality of their module, hence, the quality of the final good. Quality decisions being not contractible the natural outcome of this stage is a Nash Equilibrium. However we allow pre-play communication in order to select a undominated equilibrium. The last step is dedicated to the price and quantity choices. We first show that the firms have an incentive to cooperate instead of entering into a DC competition. Profits resulting from this cooperation are shared between the firms by means of a Nash Bargaining process. To summarize, we solve the following game backwards

step 1. Firms settlement: a stable partition of the set of activities
step 2. Knowledge improvements: an undominated Nash equilibrium
step 3. Price and quantities: a Nash bargaining solution

3. Nash bargaining: the threat of DC competition

In order to make sure that cooperation occurs and to know the profit sharing rule, we need to study the outside option of this bargaining process. In order to achieve this goal, we proceed in three steps. We first introduce the notion of DC competition and check existence. We then exhibit several properties of this notion. This will help us in a third step to conclude that cooperation occurs and to determine the payoffs of each firm under Nash Bargaining.

So let us first assume that no agreement is reached. In this case, each firm $f \in F$ chooses the price p_f of her module. But, as usually for composite goods, the price paid by the consumers takes into account the prices of the different modules. Since the firms are aware of that fact, we deal with a game. In fact we say that[12]

Definition 1. A Dual Cournot equilibrium is a price vector $(p_f^*)_{f\in F}$ with the property that:

$$\forall f \in F$$

$$p_f^* \in \arg\max_{p_f \geq c_f} \underbrace{(p_f - c_f)\cdot D\left(\frac{1}{q}\cdot\left(\sum\nolimits_{g\in F\setminus\{f\}} p_g^* + p_f\right)\right)}_{\pi_f(p_f, p_{-f}^*)} \tag{1}$$

where p_{-f}^* stands for $(p_h^*)_{h\in F\setminus\{f\}}$

The study of this DC game requires some preliminary information on the properties of the final demand. Since the behavior of each consumer is summarized by a discrete choice model and the distribution $g(x)$ of the reservation prices is positive and non-decreasing, the final demand is given by $D(\frac{p}{q}) = \int_{p/q}^{\bar{x}} 1 \cdot dG = 1 - G(\frac{p}{q})$ and verifies the following properties:[13]

Lemma 1. *If* $g(x) > 0$ *and* $g'(x) \geq 0$, *the demand* $D(\frac{p}{q}) = \int_{p/q}^{\bar{x}} 1 \cdot dG$ *is (i) continuous and at least* C^2 *on* $]0, \bar{x}[$. *Moreover (ii)* $\forall \frac{p}{q} \geq \bar{x}, D(\frac{p}{q}) = 0$ *while (iii)* $\forall \frac{p}{q} < \bar{x}$, *we observe that* $D\left(\frac{p}{q}\right) > 0$, *(iv)* $D'\left(\frac{p}{q}\right) < 0$, *(v)* $\lim_{p/q\to\bar{x}^-} D'\left(\frac{p}{q}\right) < 0$, *and (vi)* $D''\left(\frac{p}{q}\right) \leq 0$.

By property (ii), this game admits trivial equilibria. More precisely, if there are at least two firms setting $p_f > \bar{x}\cdot q$, all profits are zero and nobody has an incentive to deviate. But these situations are not interesting since nobody produces even if profit opportunities exist.[14] So let us restrict to equilibria in which production occurs. This can be done by putting an upper bound on the price choices and by introducing a constrained DC equilibrium given by

$$\forall f \in F \quad p_f^* \in \arg\max_{p_f \in [c_f, \bar{p}_f(p_{-f}^*)]} \pi_f(p_f, p_{-f}^*),$$

$$\text{where } \bar{p}_f(p_{-f}^*) = \left(q\cdot\bar{x} - \Sigma_{h\in F\setminus\{f\}} p_h^*\right) \tag{2}$$

This transformation generates no new equilibrium but selects the ones which lead to strictly positive profits. More precisely, and since the demand is strictly decreasing up to $\bar{x}$ and becomes zero after $\bar{x}$, we can say:

Lemma 2. *If there exists a constrained equilibrium, then,* $\forall f \in F, p_f^* \in]c_f, \bar{p}_f(p_{-f}^*)[$. *More-over, at equilibrium, we observe that* $D\left(\frac{1}{q} \cdot \Sigma_{f \in F} p_f^*\right) > 0$ *and* $\pi_f(p_f^*, p_{-f}^*) > 0$.

This lemma also tell us that an equilibrium, if it exists, is an interior solution of each firm optimization program (2). We therefore verify the following first order conditions:[15]

$$\forall f \in F \quad (p_f^* - c_f) \cdot \frac{1}{q} \cdot D'\left(\frac{1}{q} \cdot \Sigma_{f \in F} p_f^*\right) + D\left(\frac{1}{q} \cdot \Sigma_{f \in F} p_f^*\right) = 0 \tag{3}$$

Let us note by $m_f^* := (p_f^* - c_f)$ the margin taken by firm f over her unit cost and by $c = \Sigma_{i \in I} c_i$ the unit production cost of the composite good. From equation (3) and the fact that $D(\cdot), D'(\cdot)$ and q are independent of the choice of a peculiar firm f, we notice that, at equilibrium, each firm $f \in F$ takes the same margin m^* although they have heterogeneous unit costs. This margin is implicitly defined by

$$m^* = \frac{q \cdot D\left(\frac{1}{q} \cdot (|F| \cdot m^* + c)\right)}{-D'\left(\frac{1}{q} \cdot (|F| \cdot m^* + c)\right)} \tag{4}$$

Reciprocally, if m^* solves equation (4), then, the price vector given by $(p_f^*)_{f \in F} = (m^* + c_f)_{f \in F}$ verifies the set of equations depicted in (3) and is an equilibrium of a DC game. We can therefore assert that:[16]

Lemma 3. *By Lemma 1 (i.e. the properties of the demand) equation (4) admits a unique solution. It follows that there exists a unique non-trivial DC equilibrium.*

After this tedious but necessary remarks on the existence of an equilibrium, let us exhibit **some helpful properties of Dual Cournot competition**. Equation (4) is, from that point of view, very important. It tells us that every firm takes at equilibrium the same margin over her costs. We can expect that the same holds for the equilibrium profit even when the unit costs are not the same. After some computations, this profit is given by

$$\pi^{DC}(q, |F|, c) = m^* \cdot D\left(\frac{1}{q} \cdot (|F| \cdot m^* + c)\right) = \frac{q \cdot \left(D\left(\frac{1}{q} \cdot (|F| \cdot m^* + c)\right)\right)^2}{-D'\left(\frac{1}{q} \cdot (|F| \cdot m^* + c)\right)} \tag{5}$$

Let us now introduce some comparative static results and let us consider the case in which more modules are produced (i.e. $|F|$ increases). We get:

Proposition 1. *At an interior DC equilibrium with heterogeneous costs:*

(i) *Each firm earns the same profit* $\pi^{DC}(q, |F|, c)$
(ii) *As the number of modules increases, the price and the profit of each firm decrease*
(iii) *At the industry level, the profit* $|F| \cdot \pi^{DC}(q, |F|, c)$ *decreases with the number of modules*
(iv) *However, the price paid by the consumers for the composite good increases*
(v) *From (iii) and (iv), the total surplus decreases with the number of modules.*

This proposition has *some interesting consequences on the Nash Bargaining process*. In fact, since the profit of each firm decreases with the number of independent price-setters (i.e. the number of modules), each firm gains from cooperation because this situation is equivalent to the existence of a unique price setter. Reciprocally, if cooperation occurs, neither a firm nor a group of firms has an incentive to reject this offer. By rejection, point (iii) tells us that the total profit of the industry decreases. Since, at equilibrium, every firm obtains the same profit (see point (i)), the firm or the group of firms which rejects cooperation necessarily earns less. In the price setting game, cooperation is unanimously supported by the existing firms. In this situation, the total surplus even increases.

The total benefit of cooperation is given by the monopoly profit, i.e. by $\pi^m(q,c) = (|F| \cdot \pi^{DC}(q,|F|,c))|_{|F|=1}$. It simply remains to share the surplus. In this paper, we do not want to enter into the bargaining process itself. This is why we adopt a normative point of view. We use the Nash Bargaining (NB) solution[17] and consider that the outside options are given by the payoff obtained by each player in DC competition. We say that:

Definition 2. The payoffs $(\pi_f^{\text{NB}}(q,|F|,c)_{f\in F}$ obtained after negotiation solve:

$$\left(\pi_f^{\text{NB}}(q,|F|,c)\right)_{f\in F} \in \arg\max_{(\pi_f)_{f\in F}} \sum_{f\in F} \log\left(\pi_f - \pi^{DC}(q,|F|,c)\right) \quad (6)$$
$$\text{s.t.} \sum\nolimits_{f\in F} \pi_f = \pi^m(q,c)$$

Let us recall that in DC competition each firm chooses, at equilibrium, the same margin over its unit cost and earns the same profit $\pi^{DC}(q,|F|,c)$ (see Proposition 1 (i)). Because the Nash bargaining solution relies on a symmetry assumption, every firm obtains, as an additional payoff to the *statu quo* situation, the same share of the surplus issued from cooperation. So, we get:

Proposition 2. *After an efficient Nash bargaining process with DC threats, each firm obtains the same share* $\pi^{NB}(q,|F|,c) = \frac{1}{|F|} \cdot \pi^m(q,c)$ *of the monopoly profit. This outcome is independent of the statu quo point of the negotiation.*

4. The investments in specialized knowledge

Since we are looking for a subgame perfect equilibrium, we can move to the analysis of the investments realized by each firm in each specialized knowledge under her control. This decision which is taken before production occurs takes into account the expected profit resulting from cooperation. Each manager of a firm $f \in F$ tries to maximize $\frac{1}{|F|} \cdot \pi^m(q,c)$ having in mind that the quality $q = 1 + \min_{i\in I}\{e_i\}$ of the final good is linked to her investments. Moreover she supports an additional monetary cost $\Sigma_{i\in f} e_i$ where e_i stands for her monetary investment in activity $i \in f$.

To understand these investment decisions, we need to know how the monopoly profit $\pi^m(q,c)$ reacts to a change in quality. So we first observe that:

Lemma 4. *The monopoly profit* $\pi^m(q,c)$ *is increasing and convex with respect to the level of quality of the final good.*

This property of convexity, associated to the idea that only the lowest level of investment matters, is quite interesting. It tells us, from an intuitive point of view, that if at least one firm has no incentive to invest, then nobody invests. In the opposite case, if every player invests then, each of them has an incentive to spend the largest possible amount of money $\bar{e} = \min_{i\in I}\{\bar{e}_i\}$ in each activity. But if we consider a NE of this investment game, this last intuition is not necessarily true. In fact, because only the lowest level of investment plays a role, nobody has the opportunity to signal that she is willing to invest more, even if this situation is better for every player. From that point of view, it seems meaningful to allow a pre-play communication process in order to select a focal equilibrium in the sense of Schelling (1960). This is why we only consider the set of undominated Nash Equilibria[18] (UNE). More precisely, we say that:

Definition 3. $(e_f^*)_{f\in F} \in \Pi_{i\in I}[0,\bar{e}_i]$ are undominated Nash equilibrium levels of investments if and only if:

(i) $(e_f^*)_{f\in F} \in \Pi_{i\in I}[0,\bar{e}_i]$ is a Nash equilibrium i.e.

$$\forall f \in F,\ (e_i^*)_{i\in f} \in \underset{(e_i)_{i\in f}\in \prod_{i\in f}[0,\bar{e}_i]}{\arg\max} \pi_f(e_f, e_{-f}^*, F, c) \quad (7)$$

(ii) there exists no other Nash equilibrium $(e_i')_{i\in I} \in \Pi_{i\in I}[0,\bar{e}_i]$ with the property that

$$\forall f \in F,\quad \pi_f(e_f', e_{-f}', F, c) \geq \pi_f(e_f^*, e_{-f}^*, F, c) \quad (8)$$

with at least one strict inequality.

Let us try to identify these equilibria. Since $q = 1 + \min_{i\in I}\{e_i\}$ every player f who solves (7) has a strong incentive to invest the same amount of money in each activity under her control. If she does not act in this way she necessarily losses money. This argument which holds for each player also extends across firms. Nobody has an incentive to invest more than the other players. At NE, everybody invests the same amount of money in each activity. If this NE is unique it is an UNE. If not, and since we use backward induction, it remains to show that the UNE investment level e_F^{ud} is unique.

So, which is the level of e_F^{ud}? Let us first observe that the profile of strategies which consists in investing $e_i = 0$ for all $i \in I$ is always a NE of this game. Hence if it is unique, the problem is solved. Let us assume that an other NE exists. Since, at a NE, every player invests the same amount of money, say e', and everybody has the opportunity to invest nothing, the payoffs must be greater (or equal) to the ones obtained in a situation in which nobody invest. Because the payoffs (the returns net of the investment costs) are convex but not increasing with respect to identical investment strategies, we can conclude that these payoffs (when identical strategies are chosen) are increasing for all $e \geq e'$. This property and the fact that the min function induces a coordination device allow us to conclude that every $e \geq e'$ is also a NE. Since the equilibrium profits increase with $e \geq e'$, we conclude that if at least two equilibria exist then the only UNE corresponds to a situation in which the maximal amount of money is invested. It remains to exhibit a necessarily and sufficient condition ensuring that at least two NE exist in order to state that:

Proposition 3. *We observe that:*

(i) *Investing $e_F = 0$ in each activity is the unique Nash equilibrium if and only if at least one agent has no incentive to invest independently of the choice of the other players. More formally $e_F^{ud} = 0$ iff $\exists f \in F$ $\pi^m(1+\bar{e}, c) - \pi^m(1, c) < |F| \cdot |f| \cdot \bar{e}$*

(ii) *If this last condition is not true, several Nash equilibria exist and $e_F^{ud} = \bar{e}$ is the unique undominated Nash equilibrium*

Let us sum up our previous results in order to compute the equilibrium payoff of each player. If we note:

$$r := \frac{(\pi^m(1+\bar{e}, c) - n \cdot \bar{e}) - \pi^m(1, c)}{n \cdot \bar{e}} \tag{9}$$

the net rate of return of a unit of money invested at the industry level, we remark by condition (i) of Proposition 3, that investments occur if every agent is willing to do so, in fact if and only if

$$\begin{aligned} &\forall f \in F \quad \pi^m(1+\bar{e}, c) - \pi^m(1, c) \geq |F| \cdot |f| \cdot \bar{e} \\ &\Leftrightarrow \quad 1 + r = \frac{\pi^m(1+\bar{e}, c) - \pi^m(1, c)}{n \cdot \bar{e}} \geq \frac{1}{n}|F| \cdot \max_{f \in F}\{|f|\} \end{aligned} \tag{10}$$

The returns must be high enough in order to make sure that investments occur. This is often the case in knowledge-based industries. We can conclude this section by the computation of the profits realized by each firm, once a partition F of the set of activities is chosen. In fact, we observe that:

Proposition 4. *According to this selection device, the equilibrium payoffs of the specialized investment game are given by*

$$\pi_f^{IG}(F, c) = \begin{cases} \frac{1}{|F|} \cdot \pi^m(1+\bar{e}, c) - |f_i| \cdot \bar{e} & \text{if } 1 + r \geq \frac{1}{n}|F| \cdot \max_{f \in F}\{|f|\} \\ \frac{1}{|F|} \cdot \pi^m(1, c) & \text{else} \end{cases} \tag{11}$$

5. The structure of the industry

At this first stage of the game, we know the profits realized by each firm, for every partition of the composite good into modules. We are able to examine the basic purpose of our paper i.e. the question of the structure of the industry. Two basic principles help us to answer this question.

First of all, we assume as Audretsch (1995; 2001a) that these specific knowledge-based activities are developed by "individuals". So, it seems more relevant to identify each specialized knowledge-based component to a decision center and to assert that the structure of the industry is *stable* if no initial owner or developer of a knowledge-based component has an incentive to leave the firm producing a module using her specialized component. More formally, we can associate to each partition $F \in \mathcal{F}$ of the set of activities and to each developer $i \in I$, a subset $\mathcal{D}(i, F)$ of partitions obtained by moving activity $i \in f_0$ to an other firm, or by allowing i to create her own business. This one is given by

$$\mathcal{D}(i, F) = \{F' \in \mathcal{F} | f'_0 = f_0 \backslash \{i\} \text{ and } f' = f \cup \{i\} \text{ for one } f \in F \text{ or } f = \emptyset\} \tag{12}$$

We know that the profit of a firm is equally shared between the different developers because, by our simplifying assumption, each activity contributes in the same way to the final product. Under a perfect foresight assumption, we can argue that the expected returns of developer i who joins firm f in the modularization structure F are given by

$$\pi_i(F, c) = \begin{cases} \frac{1}{|F| \cdot |f|} \cdot \pi^m(1+\bar{e}, c) - \bar{e} & \text{if } 1 + r \geq \frac{1}{n}|F| \cdot \max_{f \in F}\{|f|\} \\ \frac{1}{|F| \cdot |f|} \cdot \pi^m(1, c) & \textit{else} \end{cases} \tag{13}$$

Following Audretsch, the definition of a stable partition can be:

Definition 4. A structure $F^s \in \mathcal{F}$ of the industry is stable if and only if:

$$\forall i \in I, \quad \nexists F \in \mathcal{D}(i, F^s), \quad \pi_i(F, c) > \pi_i(F^s, c) \tag{14}$$

We denote the set of stable industrial structures by $\mathcal{S}$.

In our analysis, we also put a strong emphasis on the idea that firms have the opportunity to invest a certain amount of money in each component under their control and that these investments in each knowledge-based component are non-contractible at least across firms. These investments modify the quality of the final product and the profits of the industry. In the line of Coase, we can determine the boundary of the firms through efficiency considerations.

So, let us observe[19] that $\forall F \in \mathcal{F}, \frac{1}{n}|F| \cdot \max_{f \in F}\{|f|\} \geq 1$. If $r \leq 0$, by Proposition 4, nobody will invest whatever the structure of the industry is. Any structure is trivially efficient in this case. This is why we restrict our attention to situations in which the global return r of the investment is strictly positive. Under this assumption, the optimal structures are those which induce a common investment of $\bar{e}$. By Proposition 4, we know that investments occur if and only if $1 + r \geq \frac{1}{n} \cdot |F| \cdot \max_{f \in F}\{|f|\}$. Following the standard "property right" approach (see Grossman and Hart, 1986), we can say that:

Definition 5. The set $\mathcal{O}$ of optimal property right allocations which power the incentives to invest is given by

$$\mathcal{O} = \left\{ F \in \mathcal{F} \mid 1 + r \geq \frac{|F|}{n} \cdot \max_{f \in F}\{|f|\} \right\} \tag{15}$$

We are now able to understand why separately owned composite good industries emerge.

Proposition 5. *A structure of a knowledge-based industry such that each component is produced by an independent firm is stable and optimal*

The intuition beyond the proof of this proposition is simple. In this case, we observe that this structure is optimal because we have $\frac{|F|}{n} \cdot \max_{f \in F}\{|f|\} = 1$. So, let us assume that one developer deviates. The new structure $F \in \mathcal{D}(i, \{\{i\}_{i \in I}\})$ may be or not optimal. If not, she clearly has no incentive to deviate while in the other case the absence of deviation directly follows from the *"joint-bargaining paradox"*. This paradox, originally observed by Harsanyi (1977) (see also Chae and Heidhues (2003) states that an individual can be worse off, bargaining as a member of a group than bargaining alone in a pure-bargaining situation. This is typically what happens here, because any deviation gives rise to a group, i.e. a firm composed of two members, who shares profits inside and who takes part in the price bargaining process.

This last result does not mean that a completely disaggregated structure is the unique one which is stable and optimal. An argument using again the *"joint-bargaining paradox"* permits to show that:

Proposition 6. *Every stable structure of the industry is optimal*

In fact, if we assume the contrary, it is easy to verify that at least one agent has an incentive to create his own business. If she perpetrates this deviation, either the structure becomes optimal and everybody gains or at least she gains the right to participate directly to the final price bargaining process and therefore has the opportunity to escape to the *"joint-bargaining paradox"*. The reader notices that a similar argument cannot be applied to an optimal structure because the same deviation could induce a inefficient modularization of the industry.

But this last result does not mean that every optimal structure is stable. In order to illustrate that point, let us take a structure F of the industry with the property that every initial owner of a basic activity has an incentive to invest and let us assume that there exists at least two firms f and f' satisfying $||f| - |f'|| \geq 2$. In this case, an agent who belongs to the biggest coalition always has an incentive to move to the smallest one. This move does not modify the incentives to invest at the industry level, but it improves her own situation: the same amount of profit allocated at the firm level is now shared between a fewer number of agents.

If $\mathcal{I} = \{F \in \mathcal{F} | \forall f, f' \in F, ||f| - |f'|| \leq 1\}$ denotes the set of all partitions with the property that the difference in the number of activities per firm is smaller than one, we can prove that:

Lemma 5. *Every stable structure of the industry belongs to* $\mathcal{I}$.

This last lemma restricts the set of stable structures of the industry because we can conclude that $\mathcal{S} \subset \mathcal{I} \cap \mathcal{O}$. But even if a situation where each component is produced by an independent firm is stable, we cannot assert that this structure is the only one which shares this property. In order to obtain such a clear cut result, we had to require that the investments in specialized knowledge play a key role to the profitability of the industry. A simple but perhaps extreme way of achieving this consists in assuming that the rate of return r is greater than 1. Under this additional restriction we prove that:

Lemma 6. *Let us denote by $F(i)$ a modularization structure deduced from a partition F which has the property that agent i creates his own firm. Under the restriction that $r > 1$, we can assert that $\forall F \in \mathcal{I} \backslash \left\{\{i\}_{i\in I}\right\}$ there exists at least one agent i_0 who belongs to the largest firm $f \in F$ for which the new partition $F(i_0)$ remains optimal*

If we take any partition $F \in \mathcal{I} \cap \mathcal{O}$ which is different from $\left\{\{i\}_{i\in I}\right\}$, we expect that at least some agent i_0 has an incentive to create his own firm because by acting in this way she is sure that the optimal level of investment is maintained and that she escapes the *"joint-bargaining paradox"*. This is however not sufficient to prove that $\{\{i\}\}_{i\in I}$ is the unique stable partition. We also need at least three players to enrich the set of strategies, i.e. the alternative set of industrial structures. Under this additional restriction, we get:

Proposition 7. *In knowledge-based industries which include at least three activities and in which the global return r of the investment in specialized knowledge is greater than one, the only stable industry (modularization) structure has the property that each component is produced by an independent firm. In the case of two activities the structure of the industry remains indeterminate.*

To sum up, we can conclude that the emergence of small specialized firms is largely related to the rate of return of the investments in specialized knowledge. If this rate belongs to [0, 1] this structure is stable and optimal among some others. In other words, this means that this modularization structure will not necessarily be observed in this case, even if this outcome is possible. But it appears to be the only one which shares these two properties if the rate of return is greater then 1 and there are at least three activities.

6. Conclusion

This last result typically concludes our paper. In fact our main purpose was to understand why several firms producing complementary components may not merge, especially if one considers high-tech industries, or more generally, all industries in which high levels of investments in specialized and component-based knowledge are the central source of benefits. From that point of view, our paper provides some insights on the question of the modularization of a production process and focus on the main role of small firms in component good industries

Our approach basically relied upon the idea introduced by Audretsch (1995, 2001a) which states that these specific knowledge-based activities are developed by "individuals" who do their best to appropriate the returns from that knowledge. From that point of view, we looked at firms as groups of owners or the developers of basic components. We however added to this story the idea that the firms have the opportunity to invest in the development of the knowledge of each component. By doing so, each firm improves the quality of the final composite good and by the way its own profit. These investments being non-contractible across firms, our approach relied upon the standard view of the boundary of a firm which involves both incomplete contracts and property rights (see Grossman and Hart, 1986 or Hart and Moore, 1990, 1999). Within this setup, we prove that an organization of the industry with the property that each activity is owned by an independent firm is both stable with respect to Audretsch's argument and optimal with respect to the property right approach. We even show that if the returns of the investments in each component-based knowledge are high enough then this structure is the only one which is both stable and optimal as long as there are at least three basic components. Our proof relies both on the property induced by DC competition and on the joint bargaining paradox.

Our approach reminds particular in some respects. First of all, the reader notices that we analyzed the market structure using DC competition. This implies that each module produced by a firm is a bottleneck, in other word, there is no competition between the producers of a given component. The introduction of this new feature would modify the conclusions. If fact, if such a competition is introduced in an asymmetric way, it is no more clear that the profit equalization rule applies. In this case, one would expect that the *statu quo* point of the negotiation will matter for the profit sharing rule. We have also assumed that there are no externalities by pooling activities. The fact that we rule out negative externalities as quite natural with respect to the argument. One could however think at the introduction of positive ones. This would make our argument less extreme. Structures in which some activities are pooled and others are not would appear. We used a somewhat poor concept of formation of coalitions: the concept of stability with respect to unilateral deviations. This is why it could be interesting to look at the same question by using more demanding notions (Ray and Vohra, 1997) or stability concepts developed in the economy of networks (see Dutta and Mutuswami, 1997 or Jackson and Wolinsky, 1996).

We also want to emphasize that our approach in terms of production network applies to some other situations. For instance, if a leading firm which assembles the composite good is introduced in this picture, it may be possible to tackle the problem of access to the market and the question of power (i.e. extraction of payoff) within these industries (see Rajan and Zingales, 1998 or Stoles and Zwiebel, 1996). This opens the more general question of the manipulation of the set of players in a value chain (i.e. Foreclosure or Dual-Sourcing). Even if no leading firm is integrated, one can also address questions related to mutual adjustments, coordination and competences (see for instance Barney, 1991; Soubeyran and Stahn, 2002, 2004).

Finally, it could be possible to enrich our analysis by some empirical tests. Our main result is that the degree of modularization of a component based industry is linked to the rate of returns of the investments in knowledge. More precisely several stable structures including the extreme disintegration case may occur if the returns are low (i.e. smaller then one). But if these returns are high this outcome is the sole one. This suggests that there exists an inverse correlation between the concentration of a knowledge based industry and the profitability of the component based investments.

Appendix A

The proofs which are obvious are not given.

A. Proof of lemma 2

Let $(p_f^*)_{f\in\mathcal{F}}$ be a constrained Nash equilibrium of a DC game. We first show that $\forall f\in\mathcal{F}, c_f<\bar{p}_f(p_{-f}^*)$. By construction, we have $\forall f\in\mathcal{F}, c_f\leq\bar{p}_f(p_{-f}^*)$. So, let us assume that $\exists f_0\in\mathcal{F}$ such that $c_{f0}=\bar{p}_{f_0}(p_{-f_0}^*)$. It follows that $p_{f0}^*=\bar{p}_{f_0}(p_{-f_0}^*)=c_{f0}$. This last equation cannot hold for all $f\in\mathcal{F}$, otherwise the viability condition lead to $p_{f_0}^*+\sum_{f\in F\setminus\{f_0\}}p_f^*=\sum_{f\in F}c_f<q\cdot\bar{x}$, or to $p_{f_0}<\bar{p}_{f_0}(p_{-f_0}^*)$ which is a contradiction. Hence $\exists f_1\in\mathcal{F}$ with the property that $p_{f_1}^*>c_{f_1}$ whose first order condition is given by

$$\begin{aligned}&\partial_{p_{f_1}}\pi_{f_1}(p_{f_1},p_{-f_1}^*)|_{p_{f_1}=p_{f_1}^*}\\&\geq 0\Leftrightarrow(p_{f_1}^*-c_{f_1})\cdot\frac{1}{q}\cdot D'\left(\frac{1}{q}\cdot\sum_{f\in F}p_f^*\right)\\&\quad+D\left(\frac{1}{q}\cdot\sum_{f\in F}p_f^*\right)\geq 0\end{aligned}\tag{A.1}$$

Since $p_{f_0}^*=\bar{p}_{f_0}(p_{-f_0}^*)$, which is equivalent to $\Sigma_{f\in F}p_f^*=q\cdot\bar{x}$, we have $D(\frac{1}{q}\cdot\Sigma_{f\in F}p_f^*)=0$. Moreover $p_{f_1}^*>c_{f_1}$, hence equation (A.1) implies $D'(\frac{1}{q}\cdot\Sigma_{f\in F}p_f^*)\geq 0$. This is a contradiction because the demand is, by Lemma 1, strictly decreasing on $[0,\bar{x}]$. Then, $\forall f\in\mathcal{F}, c_f<\bar{p}_f(p_{-f}^*)$

Let us assume that $\exists f_2\in\mathcal{F}, p_{f_2}^*=\bar{p}_{f_2}(p_{-f_2}^*)$. Because the upper bound of f_2's choice set is reached, her first order condition is given by

$$\begin{aligned}&\lim_{p_{f_2}\to\bar{p}_{f_2}(p_{-f_2}^*)}\partial_{p_{f_2}}\pi_f(p_{f_2},p_{-f_2}^*)\\&\geq 0\Leftrightarrow(\bar{p}_{f_2}(p_{-f_2}^*)-c_{f_2})\cdot\frac{1}{q}\cdot\lim_{\frac{p}{q}\to\bar{x}}D'\left(\frac{p}{q}\right)\geq 0\end{aligned}\tag{A.2}$$

We have $\bar{p}_{f_2}(p_{-f_2}^*)-c_{f_2}>0$. So, by equation (A.2), we have $\lim_{\frac{p}{q}\to\bar{x}}D'(\frac{p}{q})\geq 0$. This contradicts the result (iii) of Lemma 1 because lime $\lim_{\frac{p}{q}\to\bar{x}}D'(\frac{p}{q})<0$. Then $\forall f\in\mathcal{F}, p_f^*<\bar{p}_f(p_{-f}^*)$.

Let us finally assume that $\exists f_3\in\mathcal{F}, p_{f_3}^*=c_{f_3}$. In this case, f_3's first order condition is given by

$$\begin{aligned}&\partial_{p_{f_3}}\pi_{f_3}(p_{f_3},p_{-f_3}^*)|_{p_{f_3}=c_{f_3}}\\&\leq 0\Leftrightarrow D\left(\frac{1}{q}\cdot\left(\sum_{f\in F\setminus\{f_3\}}p_f^*+c_{f_3}\right)\right)\leq 0\end{aligned}$$

From $D(\frac{p}{q})\geq 0$, it follows, by Lemma 1, that $\Sigma_{f\in F\setminus\{f_3\}}p_f^*+c_{f_3}\geq q\cdot\bar{x}$ or, by definition of $\bar{p}_{f_3}(p_{-f_3}^*)$, that $c_{f_3}\geq\bar{p}_{f_3}(p_{-f_3}^*)$ which is the desired contradiction.

By pooling the previous results, if an equilibrium of the constrained DC game exists, then, $\forall f\in\mathcal{F}, c_f<p_f^*<\bar{p}_f(p_{-f}^*)$ □

B. Proof of lemma 3

Let us first verify that a margin m^* which solves equation (4) exists and is unique. Let us define x by $x=\frac{1}{q}\cdot(|F|\cdot m+c)$ and let us write equation (4) as:

$$f(x):=\frac{q\cdot x-c}{|F|}+q\cdot\frac{D(x)}{D'(x)}=0\text{ with }x\in\left[\frac{c}{q},\bar{x}\right]\tag{A.3}$$

Observe that $f(\frac{c}{q})=q\cdot\frac{D(\frac{c}{q})}{D'(\frac{c}{q})}<0$ and from $D(\bar{x})=0$, we also have $\lim_{x\to\bar{x}}f(x)=\frac{q\cdot\bar{x}-c}{|F|}>0$. Then $\exists x^*\in]c/q,\bar{x}[$ such that $f(x^*)=0$ or, i.e. a margin which solves equation (4). If f is increasing that x^*, and therefore m^*, is unique. This follows from Lemma 1 because:

$$f'(x)=\frac{q}{|F|}+q\cdot\frac{(D'(x))^2-D''(x)\cdot D(x)}{(D'(x))^2}>0$$

It remains to address the question of the existence and the uniqueness of a constrained DC equilibrium. Since we can associate to each constrained DC equilibrium a unique margin m^* which solves equation (A.3) we have to verify that every solution of (A.3) induces a constrained DC equilibrium. So let us take a solution of (A.3) and let us construct $(p_f^*)_{f\in\mathcal{F}}$ such that $p_f^*=\frac{q\cdot x^*-c}{|F|}+c_f$. It remains to check that $\forall f\in F, p_f^*\in\underset{p_f\in[c_f,\bar{p}_f(p_{-f}^*)]}{\arg\max}\ \pi_f(p_f,p_{-f}^*)$. Because the industry is viable (i.e. $q\cdot x^*-c>0$), we have $\forall f\in F, p_f^*>c_f$. From $\Sigma_{f\in\mathcal{F}}p_f^*=q\cdot x^*<q\cdot\bar{x}$ we get $\forall f\in F, p_f^*<\bar{p}_f(p_{-f}^*)$. Finally p_f^* solves, by construction, the first order condition of the preceding maximization program and the second order condition is met, due to the property of the demand function (see Lemma 1) □

C. Proof of proposition 1

(i) Point (i) is an obvious consequence of equation (5).

(ii) Let us start with equation (A.3) given in the proof of Lemma 3. Define $h(x):=-\frac{D(x)}{D'(x)}>0$ and observe that $h'(x)\equiv\left(-\frac{D(x)}{D'(x)}\right)=-\frac{(D'(x))^2-D(x)\cdot D''(x)}{(D'(x))^2}<0$. By applying the Implicit Function Theorem to equation (A.3), we have:

$$\partial_{|F|}x^*=\frac{h(x)}{1-|F|\cdot h'(x)}>0\tag{A.4}$$

From $\forall f\in\mathcal{F}, p_f^*=\frac{q\cdot x^*-c}{|F|}+c_f$, and equation (A.3), we get $p_f^*=h(x^*)+c_f$. Therefore we can say that $\partial_{|F|}p_f^*=h'(x^*)\cdot\partial_{|F|}x^*<0$. If we observe that $\forall f\in\mathcal{F},\pi^{DC}(q,|F|,c)=\frac{q\cdot(D(\frac{1}{q}(|F|\cdot m^*+c)))^2}{-D'(\frac{1}{q}(|F|\cdot m^*+c))}$ $=q.h(x^*).D(x^*)$, we get $\partial_{|F|}\pi^{\mathrm{DC}}(q,|F|,c)=q\cdot(h'(x^*)\cdot D(x^*)+h(x^*)\cdot D'(x^*))\cdot\partial_{|F|}x^*<0$

(iii) Let us remark that the profit of the industry can be written as $P(q,|F|,c)=|F|\cdot\pi^{DC}(q,|F|,c)=|F|\cdot q\cdot h(x)\cdot D(x)$. Then:

$$\begin{aligned}\partial_{|F|}P(q,|F|,c)=q\cdot(&|F|\cdot(h'(x)\cdot D(x)\\&+h(x)\cdot D'(x))\cdot\partial_{|F|}x\\&+h(x)\cdot D(x))\end{aligned}\tag{A.5}$$

If one replaces $\partial_{|F|}x$ by its expression given in equation (A.4), we obtain after some manipulations:

$$\partial_{|F|}P(q,|F|,c)=q\cdot\partial_{|F|}x\cdot(-D(x))\cdot(|F|-1)<0\quad\text{for }|F|>1$$

(iv) Each consumer pays $p=\sum_{f\in\mathcal{F}}p_f^*=q\cdot x^*$ where x^* solves equation (A.3); hence $\partial_{|F|}p=q\cdot\partial_{|F|}x^*>0$

(v) Since, by point (iii), the total profit is decreasing it remains to check that the surplus of the consumers is decreasing.

So let us first observe that the surplus of a consumer who buys the good is given by $q \cdot x - p \geq 0$. Since $p = q \cdot x^*$, his surplus is $q \cdot (x - x^*)$. The total surplus of the consumers is given by $SC = q \cdot \int_{x^*}^{\bar{x}} (x - x^*) \cdot g(x) \cdot dx$. Hence:

$$\begin{aligned} \partial_{|F|}\mathrm{SC} &= -q \cdot ((x - x^*) \cdot g(x))|_{x=x^*} \cdot \partial_{|F|}x^* \\ &\quad - q \cdot \int_{x^*}^{\bar{x}} \partial_{|F|}x^* \cdot g(x) \cdot dx \\ &= -q \cdot \partial_{|F|}x^* \cdot (1 - G(x^*)) < 0 \end{aligned}$$

This ends the proof of proposition 1. □

D. Proof of proposition 2

The first order conditions associated to program (6) give

$$\begin{cases} \forall f \in F, (\pi_f^* - \pi^{DCG}(q, |F|, c))^{-1} - \lambda = 0 \\ \sum_{f \in F} \pi_f^* = \pi^m(q, c) \end{cases}$$
$$\Leftrightarrow \begin{cases} \forall f \in F, \pi_f^* = \pi^{DCG}(q, |F|, c) + \frac{1}{\lambda} \\ |F| \cdot \left(\pi^{DCG}(q, |F|, c) + \frac{1}{\lambda}\right) = \pi^m(q, c) \end{cases}.$$

It follows that $\forall f \in F, \pi_f^{\mathrm{NB}}(q, |F|, c) = \frac{1}{|F|} \cdot \pi^m(q, c)$. Hence each firm earns the same profit, although having different unit costs. □

E. Proof of lemma 4

With a usual change of variable, we get:

$$\pi^m(q, c) = \max_{x \in [c/q, \bar{x}]} (q \cdot x - c) \cdot D(x) \qquad \text{(A.6)}$$

Since x^* is an interior solution, we observe, by the standard Envelop Theorem, that $\partial_q \pi^m\ (q, c) = x^* \cdot D(x^*) > 0$. Then,

$$\partial^2_{q,q}\pi^m(q, c) = (D(x^*) + x^*.D'(x^*)).\frac{\partial x^*}{\partial q}$$

Using the first order condition of program (A.6), x^* satisfies $q \cdot D(x^*) + (q \cdot x^* - c) \cdot D'(x^*) = 0$. We deduce that $(D(x^*) + x^* \cdot D'(x^*)) = \frac{c}{q} \cdot D'(x^*)$. Moreover by Lemma 1 and the Implicit Function Theorem applied to the first order condition of program (A.6), we get:

$$\frac{\partial x^*}{\partial q} = -\frac{c \cdot D'(x^*)}{q^2 \cdot (2D'(x^*) + D''(x^*))} < 0$$

Then, $\partial^2_{q,q}\pi^m(q, c) = \frac{c}{q} \cdot D'(x^*) \cdot \frac{\partial x^*}{\partial q} > 0$. Hence $\pi^m(q, c)$ is strictly convex in the quality of the composite good. □

F. Proof of proposition 3

In a preliminary step, let us notice two obvious but important facts:

1. This game always admits a trivial equilibrium where each firm plays $((e_i)_{i \in f})_{f \in F} = 0$.
2. Every equilibrium is symmetric, i.e. the same amount of money is invested by each firm in each activity, otherwise there always exists a player who has an incentive to reduce his investment and, by doing so, improves her situation by reducing her costs.

Let us now move to the proof of the proposition. We proceed in 2 steps. Moreover, to simplify the notation, let us define
$$\Pi_f(e) := \frac{1}{|F|} \cdot \pi^m(1 + e, c) - |f| \cdot e$$

Step 1: If $\exists f \in F, \pi^m(1 + \bar{e}, c) - \pi^m(1, c) < |F| \cdot\ |f| \cdot \bar{e}$, then $\left((e_i)_{i \in f}\right)_{f \in F} = 0$ is the unique Nash equilibrium, hence the unique undominated Nash equilibrium

Proof

Let us first notice that $\Pi_f(e)$ is strictly convex in e because $\pi^m(1 + e, c)$ is strictly convex (see Proposition 1). Then, for $\lambda = \frac{e}{\bar{e}}$, $(1 - \lambda) \cdot \Pi_f(0) + \lambda \cdot \Pi_f(\bar{e}) \geq \Pi_f(e)$, and, by our assumption, $\exists f \in F$ such that $\Pi_f(\bar{e}) < \Pi_f(0)$. This means that $\Pi_f(0) > \Pi_f(e)$ and

$$\begin{aligned} &\exists f \in F, \forall e \in]0, \bar{e}], \pi^m(1 + e, c) - \pi^m(1, c) \\ &\quad < |F| \cdot |f| \cdot e. \end{aligned} \qquad \text{(A.7)}$$

Moreover, by remark 1, $\left((e_i)_{i \in f}\right)_{f \in F} = 0$ is a Nash equilibrium of this game. So let us assume that an other equilibrium exists. By remark 2, we know that this equilibrium is symmetric, so let $e^* \neq 0$ denotes this common investment level. Since e^* is a Nash equilibrium and because the min function enters in the definition of the payoffs, we can state, by the best reply property, that $\forall f \in \mathcal{F}, \forall e \in [0, e^*], \Pi_f(e) \leq \Pi_f(e^*)$. Hence it holds for $e = 0$ and one deduces, by the definition of $\Pi(e)$, that $\forall f \in \mathcal{F}, \exists e^* \in [0, \bar{e}]$, $\pi^m(1 + e^*, c) - |F| \cdot |f| \cdot e^* \geq \pi^m(1, c)$. But this last assertion contradicts condition (22). It follows that $\left((e_i)_{i \in f}\right)_{f \in F} = 0$ is, in this case, the unique Nash equilibrium.

Step 2: If $\forall f \in F, \pi^m(1 + \bar{e}, c) - \pi^m(1, c) \geq |F| \cdot\ |f| \cdot \bar{e}$, then $\left((e_i^*)_{i \in f}\right)_{f \in F}$ where $e_i^* = \bar{e}$ is the unique undominated Nash equilibrium

Proof

Because $\Pi_f(e)$ is strictly convex in e, we assert that $\forall e \in]0, \bar{e}[, \Pi_f(\bar{e}) > \Pi_f(e)$. The argument goes as before: we observe that for $\lambda = \frac{e}{\bar{e}}, (1 - \lambda) \cdot \Pi_f(0) + \lambda \cdot \Pi_f(\bar{e}) > \Pi_f(e)$, and, by our assumption, $\Pi_f(\bar{e}) \geq \Pi_f(0)$, hence $\forall f \in F, \forall e \in]0, \bar{e}[, \Pi_f(\bar{e}) > \Pi_f(e)$.

Let us now verify that $\left((e_i^*)_{i \in f}\right)_{f \in F}$ where $e_i^* = \bar{e}$ is a Nash equilibrium. Let us assume that an agent is willing to deviate by playing $(e_i)_{i \in f} \in \Pi_{i \in f}[0, \bar{e}_i]$. In this case, she obtains

$\frac{1}{|F|} \cdot \pi^m(1 + \min\left\{(e_i)_{i\in f}, \bar{e}\right\}, c) - \sum_{i\in f} e_i$.

Let $e = \min\left\{(e_i)_{i\in f}, \bar{e}\right\}$, then

$$\frac{1}{|F|} \cdot \pi^m(1 + \min\{(e_i)_{i\in f}, \bar{e}\}, c) - \sum_{i\in f} e_i \leq \frac{1}{|F|} \cdot \pi^m(1 + e, c) - |f| \cdot e = \Pi_f(e)$$

Because $\forall e \in [0, \bar{e}[, \Pi_f(e) \leq \Pi_f(\bar{e})$ which is the payoff of the agent before deviation then $\left((e_i^*)_{i\in f}\right)_{f\in F}$ with $e_i^* = \bar{e}$ is a Nash equilibrium.

Let us finally remember (see remark 2) that every Nash is symmetric. If $e^n \in [0; \bar{e}[$ represents this common investment strategy, the payoff of each player is given by

$$\forall f \in \mathcal{F}, \frac{1}{|F|} \cdot \pi^m(1 + e^n, c) - |f| \cdot e^n = \Pi_f(e^n)$$

But, the inegalities $\forall f \in \mathcal{F}, \Pi_f(e^n) < \Pi_f(\bar{e})$. imply that investing $\bar{e}$ in each activity is the unique undominated Nash equilibrium of this game □

G. Proof of proposition 5

Let $F_0 = \{\{i\}\}_{i\in I}$. We have $1 + r \geq \frac{1}{n} \cdot |F_0| \cdot \max_{f\in F_0}\{|f|\} = 1$. Then F_0 is an optimal structure. Let us assume that at least one agent i has an incentive to move to an other firm. If this happens the new structure of the industry can be any partition $F \in \mathcal{D}(i, F_0)$. In this case, she only has the opportunity to form a coalition with an other agent. After deviation, she either earns $\frac{1}{2(n-1)} \cdot \pi^m(1 + \bar{e}, c) - \bar{e}$ or $\frac{1}{2(n-1)} \cdot \pi^m(1, c)$ if investment respectively occurs or not, while before deviation she received $\frac{1}{n} \cdot \pi^m(1 + \bar{e}, c) - \bar{e}$. But

$$\frac{1}{n} \cdot \pi^m(1 + \bar{e}, c) - \bar{e} \geq \frac{1}{2(n-1)} \cdot \pi^m(1 + \bar{e}, c) - \bar{e}$$

hence agent i_0 has no incentive to deviate if the investment is maintained after deviation. Let us now consider the second case. From $r \geq 0$, we observe that

$$\pi^m(1 + \bar{e}, c) - n \cdot \bar{e} \geq \pi^m(1, c) \Rightarrow \frac{1}{n} \cdot \pi^m(1 + \bar{e}, c) - \bar{e} \geq \frac{1}{n} \cdot \pi^m(1, c) \geq \frac{1}{2(n-1)} \cdot \pi^m(1, c)$$

because if $n \geq 2$, then $\frac{1}{n} \geq \frac{1}{2(n-1)}$. We can conclude that $\forall i \in I, \forall F \in \mathcal{D}(i, F_0), \pi_i{}^{IG}(F, c) \leq \pi_i{}^{IG}(F_0, c)$. This means that $F_0 = \{\{i\}\}_{i\in I}$ is not only optimal but also stable. □

H. Proof of proposition 6

Since by Proposition 5 this result is true for $\{\{i\}_{i\in I}\}$, let us consider any structure $F \neq \{\{i\}_{i\in I}\}$ and let us assume that $F \in \mathcal{S}$ and $F \notin \mathcal{O}$. Because $F \notin \mathcal{O}$, then $1 + r < \frac{|F|}{n} \cdot \max_{f\in F}\{|f|\}$. Since $F \neq \{\{i\}_{i\in I}\}$, F contains at least one firm f_0 composed of at least two basic activities. If an agent $i_0 \in f_0$ who belongs to this set has an incentive to deviate the proof is finished because we initially assumed that $F \in \mathcal{N}$. So let us assume that she deviates and creates her own firm. If F_{i_0} denotes the partition obtained after this deviation, player i_0 receives:

$$\pi_{i_0}(F_{i_0}, c) = \begin{cases} \frac{1}{(|F|+1)} \cdot \pi^m(1 + \bar{e}, c) - \bar{e} & \text{if } 1 + r \geq |F_{i_0}| \cdot \max_{f\in F_{i_0}}\{|f|\} \\ \frac{1}{(|F|+1)} \cdot \pi^m(1, c) & \text{else if (A) holds} \end{cases}$$

(A) $\Leftrightarrow$ the previously erased condition

while, before deviation, she receives $\pi_{i_0}(F, c) = \frac{1}{|F|\cdot|f|} \cdot \pi^m(1, c)$, because $F \notin \mathcal{O}$. Since $F \neq \{\{i\}\}_{i\in I}$ and $r \geq 0$, we have

$$\pi^m(1 + \bar{e}, c) - (|F| + 1).\bar{e} \geq \pi^m(1 + \bar{e}, c) - n \cdot \bar{e} \geq \pi^m(1, c)$$

in other words $\pi_{i_0}(F_{i_0}, c) \geq \frac{1}{(|F|+1)} \cdot \pi^m(1, c)$. Remember that $|f_0| > 1$. Then we can assert that $|F| \cdot |f_0| > (|F| + 1)$ because $|F| \geq 2$. This means that $\pi_{i_0}(F_{i_0}, c) > \pi_i(F, c)$ and this contradicts the fact that $F \in \mathcal{S}$ □

I. Proof of proposition 7

Let us assume that it exists a partition $F \in \mathcal{S}$ and $F \notin \mathcal{O}$. It follows that (i) $1 + r < \frac{|F|}{n} \cdot \max_{f\in F}\{|f|\}$ because $F \notin \mathcal{O}$ and (ii) $F \neq \{\{i\}\}_{i\in I}$ by Proposition 6. By (ii), it exists at least one agent i_1 who forms a firm with another agent. Let us assume that she deviates and creates his own firm. If F_{i_1} denotes the partition obtained after this deviation, this player receives:

$$\pi_{i_1}(F_{i_1}, c) = \begin{cases} \frac{1}{(|F|+1)} \cdot \pi^m(1 + \bar{e}, c) - \bar{e} & \text{if } 1 + r \geq |F_{i_1}| \cdot \max_{f\in F_{i_1}}\{|f|\} \\ \frac{1}{(|F|+1)} \cdot \pi^m(1, c) & \text{elseif (A) holds} \end{cases}$$

(A) $\Leftrightarrow$ the previously erased condition

and since $F \neq \{\{i\}\}_{i\in I}$ and $r \geq 0$, we can say, as in the proof of proposition 6, that $\pi_{i_1}(F_{i_1}, c) \geq \frac{1}{(|F|+1)} \cdot \pi^m(1, c)$. Let us now compute the profit of player i_1 before she deviates. By remark (i) we have $\pi_{i_1}(F, c) = \frac{1}{|F|\cdot|f|} \cdot \pi^m(1, c)$ with $|f| > 1$, because i_1 is has not initially created his own firm. It follows that $|F| \cdot |f| > (|F| + 1)$ which implies $\pi_{i_1}(F_{i_1}, c) > \pi_{i_1}(F, c)$. This agent has an incentive to deviate. □

J. Proof of lemma 5

Let us assume that $\exists F \in \mathcal{F}, F \in \mathcal{S}$ and $F \notin \mathcal{O} \cap \mathcal{I}$. Since, by Proposition 7, $F \in \mathcal{O}$, we deduce that $F \notin \mathcal{I}$. This means that F contains at least one coalition f such that $\exists f' \in F, |f| - |f'| > 1$. So let us assume that one agent $i \in f$ decides to joint coalition f'. This new partition is denoted by F'. Because $F \in \mathcal{O}$, we know that investment takes place under F. This means that $1 + r \geq \frac{1}{n} \cdot |F| \cdot \max_{f\in F}\{|f|\}$. But after deviation $|F'| = |F|$ and $\max_{f\in F}\{|f|\} \geq \max_{f\in F'}\{|f|\}$. Investment also occurs after deviation. Therefore player i obtains $\pi_i^{IG}(F', c) = \frac{1}{|F|\cdot(|f'|+1)}$ $\pi^m(1 + \bar{e}, c) - \bar{e}$ and before deviation, he earned $\pi_i^{IG}(F, c) = \frac{1}{|F|\cdot|f|} \cdot \pi^m(1 + e, c) - \bar{e}$. But f and f' were chosen such that $|f| - |f'| > 1$, hence $\pi_i^{IG}(F', c) > \pi_i^{IG}(F, c)$. This contradict the fact that $F \in \mathcal{N}$. □

K. Proof of lemma 6

By the standard Euclidian division rule $n = E\left(\frac{n}{|F|}\right) \cdot |F| + k$ where $k \in N, k < |F|$ and $E(\cdot)$ stands for the integer part of $\frac{n}{|F|}$. By construction of $\mathcal{I}$ we get:

$$\forall F \in \mathcal{I}, \max_{f \in F}\{|f|\} = \begin{cases} \frac{n}{|F|} & \text{if } k = 0 \\ E\left(\frac{n}{|F|}\right) + 1 & \text{if } k \geq 1 \end{cases}$$

After this remark, let us start the proof. Let us choose $F \in \mathcal{I}\backslash\{\{i\}_{i \in I}\}$ and let us construct $F(i)$. By the previous remark and the early definition of $F(i)$, we have

$$\forall i \in I, \frac{1}{n}|F(i)| \max_{f \in F(i)}\{|f|\} =$$
$$\begin{cases} \frac{1}{n}(|F|+1)\max_{f \in F}\{|f|\} \text{ if } k \neq 1 \\ \left\{ \begin{array}{ll} \frac{1}{n}(|F|+1)(\max_{f \in F}\{|f|\} - 1) & \text{if } i \in f^{\max} \\ \frac{1}{n}(|F|+1)(\max_{f \in F}\{|f|\}) & \text{else} \end{array} \right\} \text{else.} \end{cases}$$

with $f^{\max} \in \arg\max_{f \in F(i)}\{|f|\}$

Let us select an agent i_0. This agent is chosen so that she belongs to one of the largest firm i.e. $i_0 \in f^{\max} \in \arg\max_{f \in F(i)}\{|f|\}$. By doing so, we get:

$$A := \frac{1}{n} \cdot |F(i_0)| \cdot \max_{f \in F(i_0)}\{|f|\}$$
$$= \begin{cases} \frac{1}{n} \cdot (|F|+1) \cdot \frac{n}{|F|} & \text{if } k = 0 \\ \frac{1}{n} \cdot (|F|+1) \cdot E\left(\frac{n}{|F|}\right) & \text{if } k = 1 \\ \frac{1}{n} \cdot (|F|+1) \cdot \left(E\left(\frac{n}{|F|}\right) + 1\right) & \text{if } k \geq 2 \end{cases}$$

since $r > 1$, we have:

It remains to consider the case $k \geq 2$, where

- for $k = 0$ $\quad A = \frac{(|F|+1)}{|F|} \leq 2 < 1 + r$ since $|F| \geq 1$
- for $k = 1$ $\quad A \leq \frac{1}{n} \cdot (|F|+1) \cdot \frac{n}{|F|} = \frac{(|F|+1)}{|F|} < 1 + r$ since $E\left(\frac{n}{|F|}\right) \leq \frac{n}{|F|}$.
- if $k \geq 2$ $\quad A = \frac{1}{n} \cdot (|F|+1) \cdot \left(\frac{n-k}{|F|} + 1\right)$ if $k \geq 2$

$$A = \frac{1}{n} \cdot \left(\frac{|F|^2 + (n-k+1) \cdot |F| + (n-k)}{|F|}\right)$$
$$\leq \underbrace{\frac{1}{n} \cdot \left(\frac{|F|^2 + (n-1) \cdot |F| + (n-2)}{|F|}\right)}_{g(|F|)}$$
since $k \geq 2$ and $\partial_k A \leq 0$

Because the right-hand side of the preceding inequality is convex in $|F|$, it follows that

$$A \leq \max\{g(1), g(n)\}$$
$$= 2\max\left\{\frac{n-1}{n}, \frac{n^2-1}{n^2}\right\} \leq 2 \leq 1 + r$$

Then $\forall F \in \mathcal{I}\backslash\{\{i\}_{i \in I}\}, \exists_{i_0} \in f^{\max}$, with the property that the deviation $F(i_0) \in \mathcal{O}$. □

L. Proof of proposition 8

By Lemma 5, we know that for $r > 0, \mathcal{S} \subset \mathcal{I}$. Then we only need to verify that no structrure $\forall F \in \mathcal{I}\backslash\{\{i\}_{i \in I}\}$ is stable. Moreover by Lemma 6 we know that for $r > 1$ and $\forall F \in \mathcal{I} \backslash\{\{i\}_{i \in I}\}, \exists_{i_0} \in f^{\max}, F(i_0) \in \mathcal{O}$. It remains to check that agent i_0 is better off if she perpetrates the deviation $F(i_0)$, i.e. creates her own firm. Let us denote by $f_{i_0} \in F$ the firm to which i_0 initially belongs. Since $F \neq \{\{i\}_{i \in I}\}$ and $i_0 \in f^{\max}$, we observe that $|f_{i_0}| \geq 2$. Moreover, since $n \geq 3$, if $|f_{i_0}| = 2$ then $|F| > 1$. Finally, because $|f_{i_0}|, |F| \in N$, we have $|F| + 1 < |F| \cdot |f_{i_0}|$. This last inequality implies:

$$\pi_i^{IG}(F(i), c) = \frac{1}{|F|+1}\pi^m(1+\bar{e}, c) - \bar{e} > \pi_i^{IG}(F, c)$$
$$= \frac{1}{|F| \cdot |f_{i_0}|}\pi^m(1+\bar{e}, c) - \bar{e}$$

Then the deviation $F(i_0)$ is profitable. Finally if $n=2$, after computation we observe that $\forall i = 1, 2, \pi_i^{IG}(\{\{1,2\}\}, c) = \pi_i^{IG}(\{\{1\},\{2\}\}, c)$. Therefore, the structure of the industry remains indeterminate. □

Notes

[1] A large and instructive material concerning these industries can be found in a special issue of Small Business Economics edited by Fuchs (2001).

[2] See for instance the special Issue "Network Economics" of the IJIO (Economides and Encaoua, 1996) in 1996 or Soubeyran (1983) and Soubeyran and Stahn (2001).

[3] In chapter 9, entitled *"Du Concours des Producteurs"*, Cournot introduces, in a very modern way, the case in which two firms choose prices for products which are complementary from the point of view of the consumer. He largely studies this situation and concludes that both firms have an incentive to merge. This case was latter identified by Sonnenschein (1968) as the dual of the standard Cournot model. (For an explicit reference to this case see also Economides and Salop (1992) or more recently Economides (1999) or Colombo and Rossini (1997).

[4] This result was also stated by Economides (1999) in a model very close to ours but in which he only concentrates on the market structure.

[5] A similar assumption was introduced by Economides (1999). From that point of view, our model can be viewed as a generalization of his work to a multi-activity setting. We however add into this picture some features of knowledge-based industries and provide an endogenous way to define the number of activities pooled by a firm.

[6] For a detailed description of the Nash Bargaining solution and the mechanisms which implement this solution, the reader is referred to the book of Osborne and Rubinstein (1990).

[7] For some references to price bundling strategies see for instance the book edited by Fuerderer et al. (1999).

[8] We assume that the quality or some other characteristics of a specialized component are not verifiable by an

outside party. We take therefore the notion of incomplete contract as granted. For further discussions on this notion see Hart and Moore (1999), Maskin and Tirole (1999a, 1999b) or Segal (1999).

[9] The model easily extends to situations in which the required amount of components are different since our assumption only works as a normalization rule.

[10] It becomes clear why we decided to normalize the level of quality to 1 in the case in which no investment occurs.

[11] We implicitly assume that there are no additional costs nor gains from modularization. Even if one of the previous situations may perhaps be more acceptable, we do not want to create incentives either to split or to merge.

[12] The reader may perhaps be surprised that we simply sum up these different prices. This holds because each unit of final product requires one unit of each activity. However the results of this section do not rely on this peculiar assumption.

[13] Property (vi) is the only one which is deduced from $g' \geq 0$. So, if the reader finds this assumption not suitable, a weaker is the log-concavity of the demand. This restriction can be obtained by assuming that the elasticity of g is greater than the elasticity of the demand.

[14] Even if the quality is low (i.e. $q = 1$), we know that the highest reservation prices $\bar{p} = \bar{x} \cdot q$ is always greater than the unit production cost of the composite good. Profit opportunities are therefore available.

[15] Under the restrictions imposed on the demand (see Lemma 1), we know that these conditions are not only necessary but also sufficient for the description of an equilibrium.

[16] For a more general existence result of a DC equilibrium, the reader is referred to Soubeyran and Stahn (2001). In this paper, the authors show, by applying Tarski's fixed point theorem, that a decreasing demand function with an upper reservation price is enough for existence.

[17] For the mechanisms which implement the Nash Bargaining solution, the reader is referred for instance to the book of Osborne and Rubinstein (1990).

[18] This selection device is rather mild. It is, of course, possible to use stronger selection devices like the concept of Strong Nash equilibria introduced by Aumann (1959) or the notion of coalition-proof NE developed by Bernheim et al. (1987). But this is not necessary. In our case, the different selection devices lead to the same set of equilibria.

[19] Otherwise $\forall f \in F, \frac{|F|}{n} \cdot |f| < 1$, then but by summing over all $f \in F$, we obtain $\sum_{f \in F} \frac{|F|}{n} \cdot |f| = |F| < 1$, a contradiction.

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