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Summary

There are more and more industries in which firms are specialized in the production of a component of the final good. This is especially true in high-tech industries. The basic question is why don't these firms merge ? We paradoxically show that industries which are typical candidates for composite good industries, are those in which high levels of investments in specialized and component based knowledge are a major source of benefits. In this important case, strictly complementary assets should be separately owned. The basic argument is linked to imperfect competition which changes the ability to extract payoff (power) and the effect of specialized investments on the quality of the composite good. Separate ownership in the case of at least 3 components both powers the individual incentive to invest and is stable with respect to unilateral deviations.

Keywords: Composite goods, incomplete contracts, property rights, dual Cournot competition, lateral disintegration.

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1 Introduction

There is now a growing class of products with the property that they are only useful if they are combined with other goods. Consumers often purchase a bundle of goods which pools these complementary components and their willingness to pay is based on this bundle rather than on each component. These composite or system goods introduced by Matutes - Regibeau [22] or even, in some sense, by Cournot [8] [1] were largely developed with respect to network economics[2]. The properties of these peculiar market structures are now quite well-known.

In this paper, we do not present new properties of these industries. We want to tackle the conditions of the existence of separately owned composite good industry. The basic question is why several firms producing complementary components do not merge ? This question is particularly puzzling 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 major source of benefits.

To illustrate this point, let us come back to an older by very symptomatic example. In the 80th and more precisely at the beginning of the PCs, one can say roughly speaking that only two firms operate in this market : IBM which developed the hardware, and Microsoft which provided the MS-Dos operating system. One could of course always argue, in the line of Becker-Murphy [4], that this situation corresponds to some natural division of labor. But, one must also concede that the profitability of this industry largely relies on investments in specialized knowledge realized at each component level. Moreover, these investments in human capital are typically non-contractible and specific to each activity. The question that immediately raises in this case is why IBM did not control both activities and why this firm even powered the development of Microsoft.

If one tries to answer this question, one must ask in fact what are the nature and boundaries of a firm and therefore enters into the line of research opened by Coase [6] seminal contribution. But both the transaction cost and the standard market approach surprisingly conclude that this two firms have an incentive to merge.

The point of view of the transaction cost approach (Williamson [36] [37] [38]) can be sumerized as follows. In the IBM/Microsoft example, as well as in many composite good industries, one notices that one deals with strong relationship-specific investments : one firm develops the

[1] 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 which was latter identified by Sonnenschein [30] as the dual of the standard Cournot model. (For a explicit references to this case see also Economides-Salop [13] or more recently Economides [11] or Colombo-Rossini [7]).

[2] See for instance the special Issue "'Network Economics" of the IJIO [12] in 1996 or Soubeyran[31] and Soubeyran-Stahn [32]

hardware, the other the software. These investments makes therefore both firms strongly interdependent. Moreover, if both actors have in mind that one can perhaps implement the specific software on other plat-forms or use other existing software as operating systems without, in both cases, too high costs, one typically identifies a potential double hold-up problem. But in this case, it is quite difficult to understand why these two firms did not merge.

Of course, one could always argue, as Holmström and Roberts [20], that the transaction cost approach considers the market as a black box. From that point of view, this approach can only spell out the costs and benefits of integration in a manner that relies on the presence of an impersonal market. Put in other words, one could perhaps argue that the existence of composite good industry can be explained by the nature of the competition.

If one simply looks at this new ingredient, one again concludes that both firms have a strong incentive to merge. On the market, one observes that the consumers are willing to pay a price which takes into account both hardware and software prices, these two prices being set strategically by both firms. If the profits are higher if they do not merge, one would have an explanation of the existence of composite good industries. Unfortunately, this argument does not work. In fact, this market structure is known since a long time. The case was studied in chapter 9 of Cournot's book [8] and was identified latter (Sonnenschein [30]) to a Dual Cournot Game (DCG for short). In this chapter, Cournot reports that the firms in a composite good industry have a strong incentive to merge[3].

One can however argue that these firms do not necessarily merge in order to improve their profit levels. They can simply find an agreement in a bargaining process in which the equilibrium payoffs of the Dual Cournot Game are used as outside options or *statu quo* points. Moreover, if one assumes that the relation-specific investments are made by the different parties before the negotiation takes place and are assumed to be non-contractible, one enters in the standard property right approach that was developed by Grossman - Hart [15], Hart - Moore [17] or Hart [16]. Does this *modus operandi* explain the IBM/Microsoft puzzle ?

If the two firms do not merge, i.e. if there is no transfer of property rights that gives for instance to IBM the right to control the market stage, one deals with a situation in which both firms strategically select their investments *ex ante* and enter, *ex post*, into a bargaining process in order to set prices. If both firms meet *ex post*, their best common pricing strategy clearly coincides to the one of a monopoly. This decision even leaves some surplus with respect to a situation in which they do not cooperate (i.e. play a DCG). If one assumes as usually in the literature, that the players share this surplus according to the solution of a Nash bargaining game or any kind of strategical mechanism which implement this solution[4], one observes that

[3]This result was also stated by Economides [11] in a model very closed to this one but in which he only concentrates himself on the market structure

[4]For a detailed description of the Nash Bargaining solution and the mechanisms which implement this solution,

each firms receives in addition to its the *statu quo* payoff a half of the total net surplus.

Even if one extends Cournot's result to agents with heterogeneous unit constant costs, we prove that the equilibrium profits in a DCG remain the same for both players. But these profits are the *statu quo* payoffs in the bargaining process. The Nash sharing rule[5] therefore yields *ex post* returns for each player which are independent of the *statu quo* payoffs. This means that any change in the allocation of the property rights, that modifies, in the spirit of Grossman - Hart [15], the outside options, does not really affect the *ex post* returns of each player. Put in an other way, this implies that the *ex ante* equilibrium choices are independent of the property right allocation and therefore leave the boundaries of the firm indeterminate. So how can we explain the existence of composite good industries with complementary components ?

This indeterminacy can be reduced by introducing two new ingredients. First of all, it seems quite logical to assume that the first best *ex post* choice, i.e. the monopoly pricing strategy, is affected in a non trivial way by the *ex ante* investments in specialized knowledge. As Economides [11][6], we consider that these decisions which are made at the level of each component, modify the quality of the composite good. But the components of a composite good are strongly interdependent, it is therefore fairly natural to assume the final quality is determined by the lowest level of specific investment. This first ingredient, as we will see it later, however remains insufficient to remove all the indeterminacy. This is why we also introduce some non cooperative behaviors in order to explain the organisation of a composite industry within firms.

To introduce these non cooperative behaviors, we essentially say that the production of a composite good requires a given set of basic activities to which we initially associate a property right. A firm is identified to a subset of activities and the structure of the composite good industry is associated to a partition of these basic activities. Firms are therefore coalitions which pool property rights and as legal entity have the right to participate to the *ex post* bargaining process. The payoff generated by this activity must however be redistributed to the initial property right owners. From that point of view, any firm, i.e. any coalition, has to be stable. This means that no initial property right owner has an incentive to joint an other firm or to create his own firm.

More precisely, we consider a subgame perfect equilibrium of a four step game. In the first

the reader is referred to the book of Osborne - Rubinstein [25]

[5]In fact, in the case of monetary returns, these *ex post* payoffs are the *statu quo* profits to which one adds a half of the surplus generated by the negotiation. This surplus, if the *statu quo* profits are the same, coincides with the monopoly profit minus two times the *statu quo* profits. Hence, the *ex post* payoffs are equal to the half of the monopoly returns and are independent of the threat points.

[6]From that point of view, our model can be viewed as a generalization to a multi-activity setting of the model of Economides [11]. We however add into this picture some features which are issued from the property right approach. The quality of the composite good is linked to *ex ante* non contractible investments in knowledge and we introduce an endogenous way to define the number of activities pooled by a firm.

step, each initial property right owner, which is identified to a basic activity, has the ability to pool his right with other players in order to form a firm. The output of this firm will be a part of the composite good and is identified to the set of activities pooled together. In this case, each initial property right owner becomes a shareholder of the newly created firm. This means that he transfers to the firm the right to sell the product and to set the price of the bundle of components[7]. In return he obtains a part of the profit realized by this firm. After this reallocation of the property rights, each initial owner of a basic activity chooses, as usually in the literature on property rights, a level of investment in specialized knowledge. This investment are measured, as in Hart [16], in a monetary expenditure which is *in fine* largely covered by the profit share obtained from the firm. We assume that these investments are not contractible *ex ante*[8]. They however largely modify the quality of the composite good. This characteristic, which is given by the lowest quality of the components, is observed in the third step of the game. In this one, the firms exercise their residual right to set prices. They however have the ability either to cooperate or to play a DCG. The profits of each firm are, in any case, shared between its shareholders in the last step of this game.

Within this framework, it then becomes essential to verify if our conjectures on the *statu quo* payoffs of the bargaining game are true. This implies that we first have to study the property of the payoffs of a DCG independently of the investments in knowledge and the partition of the set of basic activities into firms. If these payoffs are the same for each firm and in aggregate lower than the payoff of a monopoly, one can conclude that the firms have an incentive to cooperate and to share the surplus as it is predicted in a standard cooperative game argument.

If one now has in mind that these profits are also shared within the firms, it becomes possible to study the *ex ante* levels of investment in specialized knowledge for any alternative structure of the composite good industry. If this non-cooperative game is solved for any property right allocation, one perfectly knows what an initial property-right owner can expect by joining a coalition (i.e. a firm).It simply remains to selected the partitions of the set of basic activities which are stable against unilateral deviations and to make sure that these coalitions, as in the standard property right approach, implement an efficient solution.

We even go a step further. In fact, we show that if one assumes that 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 his own firm. In this case, each initial owner gains by taking part to the price negotiation and this deviation does not modify the incentive to invest of the other players as long as the expected returns are high enough.

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[7]For some references to price bundling strategies see for instance the book edited by Fuerderer- Herrmann-Wuebker [14]

[8]We assume that the quality or other particulars 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-Moore [18], Maskin-Tirole [23], [24] or Segal [29].

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 what we call the Dual Cournot Game. This preliminary but very important step allows us, in section 4, to conclude that the firms always have an incentive to negotiate. The outcomes are those obtained in a Nash bargaining process. Section 5 is devoted to the strategical analysis of the investments in specialized knowledge. The conditions of the existence of composite good industries are discussed in section 6. Some concluding remarks are made in section 7. Proofs are relegated to an appendix

2 The model

In order to gain in clarity, we present our model in two steps. We first confine our attention to the basic set-up and to the description of the different players. We move, in a second step, to the discussion of the game considered in this paper.

2.1 The basic set-up

To illustrate a composite good industry in the simplest way, we introduce a set $I = \{1, \ldots, I\}$ of basic activities which are combined in order to obtain a composite or a system good. These activities are sharp complements. This means that the consumption of one unit of the composite good requires a fixed proportion a_i of the output of each activity $i \in I$. These outputs are realized, for each $i \in I$, at an unit cost c_i.

Each basic or specialized activity $i \in I$ is initially owned by an agent who is identified, for simplicity, to the index i of the activity he owns. This agent takes two kinds of decisions.

He can commit himself to merge or to pool his property right over his basic activity with some other agents in order to create a firm. The job of this newly created firm, as we will see it in more details later, is to sell the set of components which are pooled together and to cover their production costs. If this happens, each agent looses his residual right to control the price of his own component, but, in return, he receives a part of the profit realized by this firm.

This money can by used by this agent in order to improve his knowledge on the basic activity he realizes. We assume for simplicity that this production of knowledge has constant return to scale with respect to the level e_i of monetary expenditure. The improvement is nevertheless bounded from above , i.e. $e_i \in [0, \bar{e}_i]$. As in the literature on incomplete contract, we also assume that the quality or other particulars of a specialized component are not verifiable by an outside party. This investment is therefore non-contractible.

These investments matter for the consumers because they increase the quality q of the composite good. But its components are in fact complements, this is why we assume, as Economides

[11], that only the lowest level of investment influences the quality. If this index is set to 1 when no effort occurs, we assume throughout this paper that $q = 1 + \min_{i \in I} \{e_i\}$.

It now remains to show how the quality influences the demand. In order to model this fact in a simple way, we consider a discrete choice model characterized by a continuum $[0, 1]$ of consumers. Each of them has an intrinsic valuation $x \in [0, \bar{x}]$ of the composite good. His willingness to pay is however largely influenced by the level q of quality. If fact, we assume that this willingness to pay is given by[9] $q \cdot x$. It remains to introduce a cumulative function $G(x)$ which describes the distribution of x across the population. Concerning this function, we assume that its density $g(x)$ is strictly positive and non decreasing i.e. $g(x) > 0$ and $g'(x) \geq 0$. This means that if the price decreases for a given level of quality, or if the quality increases for a given price, there are less and less consumers who decide to enter the market.

Under these assumptions, it is matter of fact to observe that $D(\frac{p}{q}) = 1 - \int_{p/q}^{\bar{x}} 1 \cdot dG = 1 - G(p/q)$ and that this demand is zero for prices which are higher than $\bar{p} = \bar{x} \cdot q$. Because the quality index is bounded below by 1, we also assume that $\sum_{i \in I} a_i \cdot c_i < \bar{x}$. This assumption makes sure that the total unit production cost is always lower than the highest reservation price.

Let us now move to the description of the firms. Their formation is endogenous. Each firm $f \subset I$ is simply a subset of activities the property rights of which are pooled together. The set of firms $F = \{f\}_{f=1}^{F}$ therefore describes a partition of the set of basic activities. From that point of view, each firm is interpreted as an entity producing a composite good which is a sub-component of the final good and which is obtained by activating the pooled basic activities. The part of the demand of the composite good served by a firm f is therefore given by $\alpha_f = \sum_{i \in f} a_i$

As a property right holder, each firm has the right to set the price p_f for this composite good. But this firm must also cover the production costs of each activity. Its unit production cost[10] is therefore given by $c_f = \sum_{i \in f} \frac{a_i}{\alpha_f} \cdot c_i$ where $\frac{a_i}{\alpha_f}$ denotes the part of the contribution of the basic activity $i \in f$ to the production of one unit of the sub-component realized by f. This activity generates some profit which is shared between the initial holders of the pooled activities.

It therefore becomes important to know how the profit is shared within each firm and who manages the firm.

Concerning this last point, we implicitly assume that one of the agent $i \in f$ is chosen as the manager of firm f and that his objective is to maximize the profit. This simplifying assumption rules out the complication related to the delegation of authority and to the design of a

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

[10] We do not assume here that there are some additional costs related to the fact that activities must be pooled together. In this paper, we wants to illustrate the idea that firms has no incentive to merge. Adding such additional costs would simply enforces the argument.

hierarchy[11].

With regard to the profit sharing rule, we simply assume that the profits are equally shared between the members. A justification of this assumption can be founded in the idea that this money is used by each initial owner of an activity in order to improve his knowledge of his technology and *in fine* to improve the quality of final good. But the effect of one unit of money invested is the same for everybody. From that point of view, and even if these efforts are non-contractible, it seems quite logical to share profits equally. This gives to each agent the same incentive to invest.

2.2 The description of the game

In order to summarize the presentation of the model, let us describe the steps of the game that we will study in the rest of this paper (see figure 1)

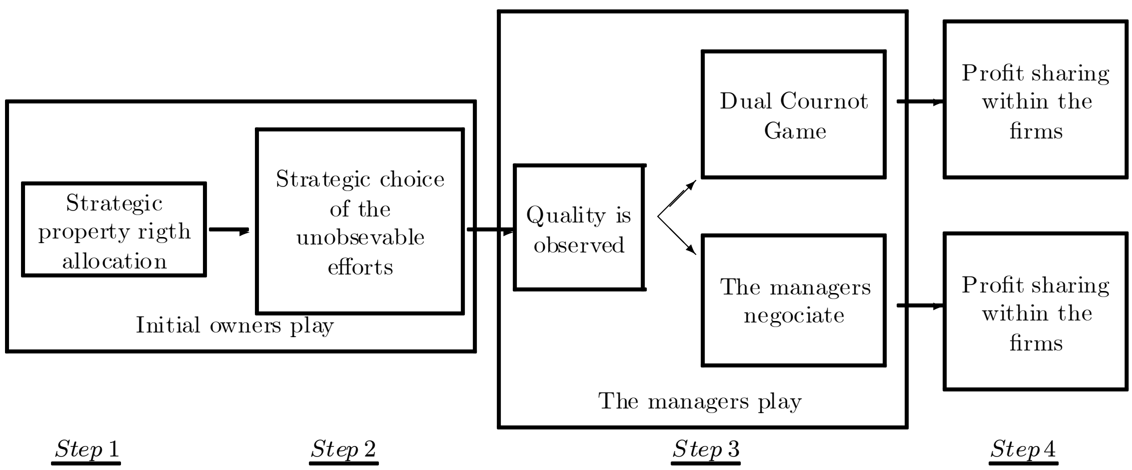

Figure 1: The game

Step 1 and 2 are played by the initial owners of the basic activities. In the first step firms are created. This means that we are looking for a partition $F = \{f\}_{f=1}^{F}$ of the set of activities $i \in I$ in a way that no individual $i \in I$ has an incentive to move from the coalition f to which he belongs. In a second step, the initial owners define their level of investment in specialized knowledge. This decision is assumed to be non-contractible and the monetary costs associated to this decision are financed by the profit shares obtained in the last step of the game.

[11]For a discussion of the problems related to these topics, the reader is refered to Aghion-Tirole [1] or to Hart-Moore [19].

Step 3 and 4 are essentially played by the managers of the firms created in step 1. We assume that these managers observe the quality of the final commodity before playing step 3. They first have to decide whenever or not they want to negotiate in order to define the price of the sub-components produced by each one. If the negotiation fails, they play a Dual Cournot Game. In this case, each firm sets its price p_f in a non-cooperative manner. In the other instance, they define a common pricing strategy. If this last alternative is chosen, there is some gain from the cooperation. This means also that there is some money left which has to be shared between the firms. For that purpose, we suppose that they enter into a Nash Bargaining process in which the *statu quo* options are given by the equilibrium payoffs of the Dual Cournot Game. Finally, in step 4, each manager shares the profit within the firm.

If one wants to analyze this game, it now becomes important to study the properties of the equilibrium payoffs of a DCG. In fact, one has to make sure that the firms always have an incentive to cooperate independently of the property right allocation and of the investment levels. This study gives us also the threat points of the bargaining process. This is why we dedicate the next section to the analysis of this Dual Cournot Game.

3 The Dual Cournot Game

If no agrement is reached, each manager $f \in F$ chooses the price p_f of the sub-component he produces by maximizing his profit. He however disposes of some informations in order to take this decision. At that step of the game, the property rights are allocated. The set F of firms is therefore common knowledge. The investments in specialized knowledge are taken as given and the quality q of the composite good is observed. Moreover, if one has in mind that we are in a configuration in which the negotiation has failed, one can even assume that every manager has the knowledge of the characteristics of the other firms. Both the contributions $\left((a_i)_{i\in f}\right)_{f\in F}$ to the composite goods, and the unit costs $\left((c_i)_{i\in f}\right)_{f\in F}$ are common information. As a consequence, each firm chooses a price which solves $\forall f \in F$

$$p_f \in \arg\max_{p_f \geq c_f} \left(p_f \cdot \sum_{i\in f} a_i - \sum_{i\in f} c_i \cdot a_i\right) \cdot D\left(\frac{1}{q} \cdot \sum_{f\in F}\left(\sum_{i\in f} a_i\right) \cdot p_f\right)$$

If one introduces $\alpha_f := \sum_{i\in F} a_i$ and $c_f := \sum_{i\in F} \frac{a_i}{\alpha_f} c_i$, one can say that :

Definition 1 *An equilibrium of a Dual Cournot Game is a vector* $\left(p_f^*\right)_{f\in F}$ *of prices with the* *property that :*

$$\forall f \in F \qquad p_f^* \in \arg\max_{p_f \geq c_f} (p_f - c_f) \cdot \alpha_f \cdot D\left(\frac{1}{q} \cdot \left(\sum_{g \in F \setminus \{f\}} \alpha_g \cdot p_g^* + \alpha_f \cdot p_f\right)\right) \tag{1}$$

The study of this game first requires some informations on the properties of the demand. But one knows that the behavior of the consumers is captured by a discrete choice model and that the density of the distribution of the willingness to pay is positive and non decreasing. It follows that $D(\frac{p}{q}) = \int_{p/q}^{\bar{x}} 1 \cdot dG = 1 - G\left(\frac{p}{q}\right)$ and it is a matter of fact to observe that :

Lemma 1 *Under the assumption that $g(x) > 0$ and $g'(x) \geq 0$, the demand function $D(\frac{p}{q}) = \int_{p/q}^{\bar{x}} 1 \cdot dG$ is continuous and at least C^2 on $]0, \bar{x}[$. Moreover $\forall \frac{p}{q} \geq \bar{x}$, $D(\frac{p}{q}) = 0$ and $\forall \frac{p}{q} < \bar{x}$, (i) $D(\frac{p}{q}) > 0$, (ii) $D'(\frac{p}{q}) < 0$, (iii) $lim_{p/q \to \bar{x}^-} D'(\frac{p}{q}) < 0$, and (iv)[12] $D"(\frac{p}{q}) \square 0$.*

Let us now observe that a DCG always exists. In fact, if at least two firms choose prices with the property that $p_f > \bar{x} \cdot q$, the payoff of every firm is zero independently of the choice this firm could make. Nobody having an incentive to deviate, this is therefore an equilibrium. But these situations are not very interesting : nobody produces even if there are opportunities to make profits[13]. This is why we restrict the analysis to equilibria in which production occurs. That can be done by introducing an upper bound on the price sets. An equilibrium $\left(p_f^*\right)_{f \in F}$ of constrained DCG therefore solves

$$\forall f \in F \qquad p_f^* \in \underset{p_f \in \left[c_f, \bar{p}_f\left(p_{-f}^*\right)\right]}{\arg\max} (p_f - c_f) \cdot \alpha_f \cdot D\left(\frac{1}{q} \cdot \left(\sum_{h \in F \setminus \{f\}} \alpha_h \cdot p_h^* + \alpha_f \cdot p_f\right)\right) \tag{2}$$

with $\bar{p}_f\left(p_{-f}^*\right) = \frac{1}{\alpha_f}\left(q \cdot \bar{x} - \sum_{h \in F \setminus \{f\}} \alpha_h \cdot p_h^*\right)$. We denote the profit of player f by $\pi_f(p_f, p_{-f}^*)$ where p_{-f}^* stands for $(p_h^*)_{h \in F \setminus \{f\}}$.

The reader however notices that a Nash equilibrium of this constraint DCG may perhaps lead to a situation in which profits are equal to zero. This situation occurs when p_f^* hits the boundary of its domain. But

Proposition 1 *As a consequence of lemma 1, one can assert that if there exists an equilibrium then $\forall f \in F$, $p_f^* \in \left]c_f, \bar{p}_f\left(p_{-f}^*\right)\right[$ and one observes that $D\left(\frac{1}{q} \cdot \sum_{f \in F} \alpha_f \cdot p_f^*\right) > 0$ and $\pi_f(p_f^*, p_{-f}^*) > 0$.*

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[12] *The fact that the demand is concave is directly implied by the assumption that $g' \geq 0$. The reader however notices that this assumption can be weakened. Log-concavity of the demand is enough to maintain our argument. This property can be obtained by assuming that the elasticity of g is greater than the elasticity of the demand function.*

[13] This directly follows from the fact that even if the quality is low (i.e. $q = 1$), the highest reservation prices $\bar{p} = \bar{x} \cdot q$ is assumed to be higher than the total unit production cost.

This last result is simply related to the fact that the demand is strictly decreasing up to $\bar{x}$ and then becomes zero. It however induces a more interesting property : if an equilibrium exists, it is an interior solution of program (2). This means that one verifies for each firm the following first order condition :

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

If one defines $m_f^* := \left(p_f^* - c_f\right) \cdot \alpha_f$ as the share of the final price that firm f takes over the final demand and if one notes that $D(\cdot)$, $D'(\cdot)$ and q are independent of the choice of a peculiar firm f, one must concede that every firm $f \in F$ takes the same margin m^* over the final demand. At equilibrium, every firm therefore earns the same profit although they have different unit costs. More formally :

Proposition 2 *At equilibrium every firm $f \in F$ takes the same margin m^* which is implicitly defined by :*

$$m^* = \frac{q \cdot D\left(\frac{1}{q} \cdot (|F| \cdot m^* + c)\right)}{-D'\left(\frac{1}{q} \cdot (|F| \cdot m^* + c)\right)} \tag{3}$$

If this common margin exists and is unique, each firm earns the same gross profit given by :

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

It remains to make sure that this common margin m^* exists and is unique. For that purpose it could be promising to operate a change of variable which is given by :

$$x = \frac{1}{q} \cdot (|F| \cdot m + c) \tag{4}$$

Equation (3) becomes :

$$f(x) := \frac{q \cdot x - c}{|F|} + q \cdot \frac{D(x)}{D'(x)} = 0 \quad \text{with} \quad x \in \left]\frac{c}{q}, \bar{x}\right] \tag{5}$$

It is therefore sufficient to show that there exists a unique x which satisfies the preceding equation in order to assert that :

Proposition 3 *There exists a unique common margin m^*. The common profit level $\pi^{DCG}(q, |F|, c)$ is therefore well defined and strictly positive.*

4 The efficient bargaining solution among firms

At that point of the analysis, we know what happens if the negotiation fails. It therefore remains to establish that each firm has a strong incentive to cooperate whatever the property right allocation and the levels of individual investments are. We will even prove that the Nash bargaining process induces, as we have guessed, a solution which is independent, in some sense, of the allocation of the property rights. In fact, we show that the manipulation of the structure of property rights does not affect the payoffs through changes in the *statu quo* options. This result is essentially due to the fact that the profits are the same for each firm if the outside option is played.

So let us first verify that the negotiation is profitable. This is the case when the sum of the profits obtained by each firm in a DCG is lower than the profits they can obtain by deciding to play together the monopoly price. If one now notices that each firm realizes the same profit at a given DCG equilibrium and that the case of a monopoly is a particular DCG for which $|F| = 1$, it simply remains to check that for $|F| \geq 2$,

$$|F| \cdot \pi^{DCG}(q, |F|, c) < \pi^{m}(q, c) := \pi^{DCG}(q, 1, c)$$

From an intuitive point of view, one remarks that a DCG shares common properties with pricing games in which one observes a phenomena known as "double marginalization". In fact, these games are simply a version of a DCG in which the price choices are sequential. So one can hope that a similar profit reducing phenomena is at work and that one can assert that :

Proposition 4 *The firms always have an incentive to enter into the bargaining process because* $|F| \cdot \pi^{DCG}(q, |F|, c) < \pi^{DCG}(q, 1, c)$.

From that point of view, one can conclude that there is a gain from the negotiation. It however remains to share this surplus. In this paper we do not enter into the bargaining process itself, this is why we adopted, as it is often done in this literature, a normative point of view. We simply use the Nash Bargaining (NB) solution[14]. It follows that

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

$$\begin{aligned} \left(\pi_f^{NB}(q, |F|, c)\right)_{f \in F} \quad &\in \quad \arg\max_{(\pi_f)_{f \in F}} \sum_{f \in F} \log\left(\pi_f - \pi^{DCG}(q, |F|, c)\right) \\ & \qquad s.t. \quad \textstyle\sum_{f \in F} \pi_f = \pi^m(q, c) \end{aligned} \tag{6}$$

[14] For the mechanisms which implement the Nash Bargaining solution, the reader is referred for instance to the book of Osborne-Rubinstein [25].

Moreover one observes that

Proposition 5 *After an efficient Nash bargaining process with DCG threats, each firm obtains the same outcome* $\pi^{NB}(q, |F|, c) = \frac{1}{|F|} \cdot \pi^m(q, c)$*. This outcome is, in this peculiar case, independent of the statu quo point of the negotiation.*

5 The investments in specialized knowledge

At that point of the study, we can now move to the analysis of the *ex ante* strategical choices of the initial owners of a basic activities. If one has in mind that one seeks for a subgame perfect equilibrium, it is time to examine the equilibrium levels of investments in specialized knowledge. This decision is motivated by the fact that each agent has the opportunity, for each structure F of the industry, to improve the part of the profit he receives from the firm he decided to joint. If one remembers that the profits are shared equally within each firm in order to give to everybody the same incentive to invest, and if one denotes by f_i the firm to which i belongs, the profit of agent i net of his investment in specialized knowledge is given by :

$$\pi_i = \frac{1}{|f_i|} \cdot \pi_{f_i}^{NB}(q, |F|, c) - e_i = \frac{1}{|F| \cdot |f_i|} \cdot \pi^m(q, c) - e_i$$

If one also has in mind that the quality of the final good is related to the lowest level of investment i.e. $q = 1 + \min_{i \in I} \{e_i\}$, each agent has a strong incentive to choose the same level of investment as the other players. If he does not act in this way he looses money. The question is now how we can identify this common level e_F of investment. For that purpose, it becomes important to know the effect of a change in the quality level on the monopoly payoff.

Proposition 6 *One can assert that 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 fact that only the lowest level of investment affects the quality is quite interesting. It tells us, at least from an intuitive point of view, that if at least one agent has no incentive to invest then nobody invests. In the opposite case, one would also expect that everybody invests the largest possible amount of money $\bar{e} = \min_{i \in I} \{\bar{e}_i\}$. If one however simply seeks for Nash equilibria of this investment game, one must concede that this intuition is not necessarily true. The lowest level of investment only being taken into consideration, nobody has, in this game, the opportunity to signal that he is willing to invest more even it is better for every body. More formally, one observes that :

Lemma 2 *Let $\mathcal{E}_F \subset [0, \bar{e}]$ denote the set of common Nash equilibrium levels of investment and let $e_{\min} = \inf(\mathcal{E}_F \backslash \{0\})$ (if of course $\mathcal{E}_F \backslash \{0\} \neq \emptyset$). One observes that*
(i) $e_F = 0$ is the unique equilibrium if and only if at least one agent has no incentive to invest, or more formally iff

$$\exists i \in I, \forall e \in]0, \bar{e}], \quad \pi^m(q, c) - \pi^m(1, c) < |F| \cdot |f_i| \cdot e$$

where $q = 1 + e$ is the quality of the composite good.
(ii) If several equilibria exist, then $\mathcal{E}_F = \{0\} \cup [e_{\min}, \bar{e}]$
(iii) In this last case the set of Nash equilibria is completely Pareto ranked.

From that point of view, it seems quite meaningfull to allow a pre-play communication in order to select a focal equilibrium in the sense of Schelling [28]. This is why we restrict ourself to the undominated Nash equilibria[15]. More precisely, we say that :

Definition 3 $(e_i^*)_{i \in I} \in \prod_{i \in I} [0, \bar{e}_i]$ *are undominated Nash equilibrium levels of investment in specific knowledge if and only if :*
(i) $(e_i^*)_{i \in I} \in \prod_{i \in I} [0, \bar{e}_i]$ is a Nash equilibrium i.e.

$$\forall i \in I \quad e_i^* \in \arg \max_{e_i \in [0, \bar{e}_i]} \underbrace{\frac{1}{|F| \cdot |f_i|} \cdot \pi^m(1 + \min_{i \in I} \{e_i, e_{-i}^*\}, c) - e_i}_{\pi_i(e_i, e_{-i}^*, F, c)}$$

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

$$\forall i \in I \quad \pi_i(e_i', e_{-i}', F, c) \geq \pi_i(e_i^*, e_{-i}^*, F, c)$$

with at least one strict inequality.

Let us now sum up our previous results in order to compute the equilibrium payoffs of each player. If one denotes by :

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

the net rate of return of a unit of money invested at the industry level, one remarks by negation of lemma 2(i) that investments occur if every agent is willing to do so, which implies after an

[15] This selection device in the set of Nash equilibria is rather mild. It is of course possible to use stronger selection devices like the concept of Strong Nash equilibria introduced by Aumann [2] or the notion of coalition-proof Nash equilibria developed by Bernheim - Peleg - Whinston [5]. But this is not necessary. In our case, the set of undominated Nash equilibria coincides to both the strong Nash and the coalition-proof equilibria.

algebraic manipulation that $1 + r \geq \frac{1}{n} |F| \cdot \max_{f \in F} \{|f|\}$. The returns must therefore be high enough in order to make sure that investments occur. But this is often the case in knowledge based industries. Moreover because profits are increasing and convex in quality (see proposition 6), the only undominated Nash equilibrium coincides to the highest level of investment. More formally, one observes that :

Proposition 7 *According to this selection device, the equilibrium payoffs of that specialized investment game are for all $i \in I$ given by :*

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

6 The structure of the industry

We now move to the basic purpose of that paper : does it make sense to consider composite goods industries ? or more precisely, under which conditions are we sure to observe industries in which complementary assets are separately owned? To answer this question, we will now explicitly make us of the two basic ingredients which are the quality index and the notion of stability against unilateral deviations.

In our model, we put a strong emphasis on the idea that the component based investments in specialized knowledge basically modify the quality of the final composite good. We even assumed that this characteristic affects in a non-trivial way the global profit opportunities in the whole industry. As a consequence and even if the structure of the property rights do not affect the *statu quo* points of the bargaining process, this allocation nevertheless matter. It modifies the individual incentives to invest and therefore the negotiated monopoly solution. This is why, we first concentrate our attention onto partitions which are optimal from a global point of view before introducing further refinements. In other words, let us first,, in the line of Coase's fundamental insight, looking at the boundary of the firms through efficiency considerations.

But if one remembers that the decision of investment follows a discrete choice model, it becomes important to make sure that there is at least at the aggregated level some incentives to invest. Otherwise the question of the optimal structure of the industry does not really make sense. This is why we assume for the moment that $r \geq 0$.

Under this harmless restriction, let us now take, what one can call, the standard point of view of the property right approach. In that case, one would argue that the optimal partitions of the set of basic activities are those which induces a common investment level equal to $\bar{e}$. If one also has in mind (see proposition 7) that investments occurs if and only if $1+r \geq \frac{1}{n} \cdot |F| \cdot \max_{f \in F} \{|f|\}$, one can say that :

Definition 4 *The set $\mathcal{O}$ of optimal property right allocations which power the incentives to invest is given by :*

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

It is however a matter of fact to observe that the set $\mathcal{O}$ can be relatively large, especially if the returns of the investments in specialized knowledge are important. The reader even notices that this set always contains the situation where there is only one firm as well as the one in which each basic activity is an independent firm. Some refinements must therefore be introduced.

This is where our second ingredient enters into the story. If one has in mind that each initial owner of an activity takes the decision to pool his property rights with other agents, it seems plausible to seek for industrial structures which are stable against unilaretal deviations. More precisely :

Definition 5 *Let $F \in \mathcal{F}$ be a partition of the set of basic activities and let $\mathcal{U}_i$ be the subset of partitions obtained by an unilateral deviation of the initial owner of activity i. We say that a partition F^* is stable with respect these deviations if and only if :*

$$\forall i \in I, \; \nexists F \in \mathcal{U}_i, \quad \pi_i^{IG}(F, c) > \pi_i^{IG}(F^*, c)$$

We denotes this set of stable industrial structures by $\mathcal{N}$.

At that point, the reader may be surprised that the introduction of a non-cooperative argument refines a set of cooperative solutions. This is conceivable only if each Nash equilibrium given by definition 5 is optimal in the sense of definition 4. The intuition beyond this property is quite simple and is related to the fact that the profits are shared two times. In fact, given the incentive efficient sharing rule applied within the firms, one observes that any unilateral deviation from a situation in which nobody invests cannot bring off the investments at the industry level. From that point of view, the total amount of profit to share remains constant. Each agent has therefore an incentive to create his own firm and to become involved in the profit distribution obtained in the bargaining process among firms instead of earning a share of this profit. This means that :

Proposition 8 *As long as $r \geq 0$, one observes that $\mathcal{N} \subset \mathcal{O}$ where $\mathcal{N}$ denotes the set of Nash equilibria*

But this result does not really mean that we refine the set of optimal industrial structures. 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 his own situation : the same amount of profit allocated at the firm level is now shared between a fewer number of agents. If one denotes by $\mathcal{I} = \{F \in \mathcal{F} \, |\forall f, f' \in F, \quad ||f| - |f'|| \leq 1\}$ the set of all partitions with the property that the difference in the number of agents per coalition is smaller than one, one can assert :

Proposition 9 *The set of Nash equilibria has the property that* $\mathcal{N} \subset \mathcal{O} \cap \mathcal{I}$

Finally, if one wants to make sure that the set of Nash equilibria is non-empty, it remains to observe that :

Proposition 10 *If* $r \geq 0$*, one can show that the partition* $\{\{i\}\}_{i \in I} \in \mathcal{N}$

But this last proposition also means that as long as the global returns of the investments in specialized knowledge are non negative, a situation in which the composite good industry is totally disintegrated is a partition which is both optimal and stable with respect to unilateral deviations[16]

Let us now introduce the idea that the investments in specialized knowledge is the key to the profitability of the industry. Because we are in a world in with investments either occur or not, one can capture the idea by assuming that the profits at the industry level are largely higher if the investments occur than in the other case. A simple but perhaps extreme way of doing this is to assume that the rate of return r is greater than 1.

In this case, let us now consider a partition of the industry which is different from $\{\{i\}\}_{i \in I}$. This means that several agents have the opportunity to create his own firm. If there exists for at least one agent a deviation of that kind in which the investment is maintained, this player has an incentive to act in this way. In this case he becomes involved in the profit distribution obtained in the bargaining process among firms instead of earning a share of this profit. It may however

[16] This results is, in some sense, opposed to the one claimed by Hart ([16] p 46). We must however emphasizes that, in our approach, the impact of both the outside options and the private investments are quite different. Concerning the first point, we consider as Holström - Roberts [20] that the hold-up problems are milder in composite good industries : owing one component alone is useless for consumers. This is why we take the Dual Cournot Game as an outside option instead of a comptitive market on which the component can be sold. With regards to the second point, the reader notices that the private investments matter because they improve the quality of the composite good. But this also implies that the payoff of each player is therefore not independent of the investments of the other agents.

happen that another agent who belongs to another firm in the newly created industry structure is no longer willing to invest. Under the assumption that $r > 1$, this last case can nevertheless be rule out for every partition which belongs to $\mathcal{I}$ and therefore includes by proposition 10 the set $\mathcal{N}$ of Nash equilibria.

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. In the case of two players, it is often the case that one player is the mirror of the other one and induces as it is the case in our paper some indeterminacy. One can therefore assert that :

Proposition 11 *In knowledge based composite good industries ($r > 1$) including at least* 3 *activities, the only stable industry structure is the one in which each initial owner of a basic activity creates his own firm. In the case of* 2 *activities the structure of the industry remains indeterminate.*

This surprising result, in case of at least 3 activities, therefore confirms the intuition of Holström - Roberts ([20] p 92) as they claimed that "*In market networks, interdependencies are more than bilateral, and how one organizes one set of transaction depends on how the other transaction are set up. The game of influence is a complicated one and leads to strategic consideration that transcend simple two-party relationship.*"

7 Conclusion

This last result concludes quite naturally our paper. In fact, our objective was to show that firms which are specialized in the production of a component of the final good do not necessarily merge. This result essentially says that industries which are typical candidates for composite good industries, are those in which high levels of investments in specialized knowledge are a major source of benefits.

Our approach basically relied upon the standard view of the boundary of a firm which involves both incomplete contracts and property rights. We however introduced two new ingredients. On the one hand, we assumed that the investments in specialized knowledge modified in a non trivial way the nature of the demand through an effect of quality. This implied, with respect to the classical property right approach, that not only the *statu quo* points but also the first best *ex post* market strategy were affected in a non trivial way by the *ex ante* decisions of investment. On the other hand, and in order to remove the indeterminacy of the efficient property right allocation, we also introduced some non-cooperative behaviors. In fact we said that a property right allocation is stable if and only if no initial property right owner has an incentive to joint an other firm or to create his own firm.

Our approach however reminds particular in some respects. First of all, the reader surely noticed that we analyzed the market structure through what we have called a Dual Cournot Game. This implies that each basic component or group of components produced by a firm is a bottleneck. There is therefore no competition between the producers of a given component. The introduction of this new feature would surely 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* points of the negotiation again matter in the profit sharing rule. One also remarks that we have 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 other not would surely appear. Finally, one could argue that we used a very poor concept of formation of coalitions : the stability with respect to unilateral deviation. This is why it could be interesting to look at the same question by using more demanding notions (see Chwe [9] or Ray - Vohra [27]) or stability concepts developed in the economy of networks (see Dutta - Mutuswami [10] or Jackson - Wolinsky [21]).

Finally, we want 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 - Zingales [26] or Stoles -Zwiebel [35]). 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 itegrated, one can also adress questions related to mutual adjustments, coordination and competence (see for instance Barney [3], Soubeyran-Stahn [33] [34]).

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APPENDIX

The proofs which are obvious are not explicitly given.

A Proof of proposition 1

Let us first check that the optimal solution to (2) never hits the boundaries of $\left[c_f, \bar{p}_f\left(p^*_{-f}\right)\right]$. If the upper bound is reached, then one observes, by the first order condition, that :

$$\lim_{p_f \to \bar{p}_f\left(p^*_{-f}\right)} \partial_{p_f}\pi_f(p_f, p^*_{-f}) \geq 0 \Rightarrow \left(\bar{p}_f\left(p^*_{-f}\right) - c_f\right) \cdot \frac{\alpha_f}{q} \cdot \lim_{\frac{p}{q} \to \bar{x}} D'(\tfrac{p}{q}) \geq 0 \tag{7}$$

Moreover one knows, by the viability assumption of the industry, that :

$$q \cdot \bar{x} > \alpha_f \cdot c_f + \sum_{h \in F \backslash \{f\}} \alpha_h \cdot c_h$$

By construction of $\bar{p}_f\left(p^*_{-f}\right)$, one has

$$q \cdot \bar{x} \equiv \alpha_f \cdot \bar{p}_f\left(p^*_{-f}\right) + \sum_{h \in F \backslash \{f\}} \alpha_h \cdot p^*_h$$

But $\forall h \in F \backslash \{f\}$, $p^*_h \geq c_h$, it follows that $\left(\bar{p}_f\left(p^*_{-f}\right) - c_f\right) > 0$. From equation (7), one deduces that $\lim_{\left(\frac{p}{q}\right) \to \bar{x}} D'(\frac{p}{q}) \geq 0$, which is the desired contradiction. As a corollary, one can even assert that, at equilibrium, $D\left(\frac{1}{q} \cdot \sum_{f \in F} \alpha_f \cdot p^*_f\right) > 0$.

Let us now assume that a firm has an incentive to choose $p^*_f = c_f$. In this case, one must have $\partial_{p_f}\pi_f(p_f, p^*_{-f})\big|_{p_f = c_f}$ □ 0. But by computation, one obtains that

$$\partial_{p_f}\pi_f(p_f, p^*_{-f})\big|_{p_f = c_f} = D\left(\frac{1}{q} \cdot \sum_{h \in F \backslash \{f\}} \alpha_f \cdot p^*_f + c_f\right) \;\square\; 0$$

But we have just noticed that this quantity is at equilibrium strictly positive. It follows that $p^*_f > c_f$ and that the profits are strictly positive. ■

B Proof of proposition 3

Let us first observe that

$$f\left(\frac{c}{q}\right) = q \cdot \frac{D(\frac{c}{q})}{D'(\frac{c}{q})} < 0 \text{ and that } lim_{x \to \bar{x}} f(x) = \frac{q \cdot \bar{x} - c}{|F|} > 0 \text{ because } D(\bar{x}) = 0$$

We can therefore assert that $\exists x^* \in]c/q, \bar{x}[$ with the property that $f(x^*) = 0$. It remains to verify that f is increasing in order to conclude that x^* is unique. By Lemma 1, it is immediate that :

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

■

C Proof of proposition 4

Let us first remember that the common margin is obtained by solving equation 5. i.e.

$$f(x) := \frac{q \cdot x - c}{|F|} - q \cdot h(x) = 0 \quad \text{for} \quad x \in \left] \frac{c}{q}, \bar{x} \right] \quad \text{with} \quad h(x) = \frac{D(x)}{-D'(x)} \tag{8}$$

One also observes that the profit of the industry can be written as :

$$P(q, |F|, c) = |F| \cdot \pi^{DCG}(q, |F|, c) = |F| \cdot q \cdot h(x) \cdot D(x)$$

If one treats the number of firms as a continuous variable, one observes that :

$$\partial_{|F|} P(q, |F|, c) = q \cdot \left(|F| \cdot \left(h'(x) \cdot D(x) + h(x) \cdot D'(x) \right) \cdot \partial_{|F|} x + h(x) \cdot D(x) \right) \tag{9}$$

If one now applies the Implicit Function Theorem to equation 8, one can say that

$$\partial_{|F|} x = \frac{-h(x)}{|F| \cdot h'(x) - 1} > 0$$

because, by Lemma 1, $h'(x) = -\frac{(D'(x))^2 - D(x) \cdot D"(x)}{(D'(x))^2} < 0$. By substitution in equation 9, one obtains after some manipulations that :

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

It follows that $\forall |F| \geq 2, \quad P(q, |F|, c) < P(q, 1, c) = \pi^{DCG}(q, 1, c)$ ■

D Proof of proposition 5

If one computes the first order conditions associated to program 6, one observes that

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

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

E Proof of proposition 6

With a usual change of variable (see equation 4), one can say that

$$\pi^m(q, c) = \max_{x \in [c/q, \bar{x}]} (q \cdot x - c) \cdot D(x) \tag{10}$$

If one remembers that the solution x^* is an interior one, one observes by the standard Envelop Theorem that $\partial_q \pi^m(q, c) = x^* \cdot D(x^*) > 0$. It follows that :

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

But, by the first order condition of program 10, x^* satisfies $q \cdot D(x^*) + (q \cdot x^* - c) \cdot D'(x^*) = 0$. One deduces that $(D(x^*) + x^* \cdot D'(x^*)) = \frac{c}{q} \cdot D'(x^*)$. Moreover by Lemma 1 and by the Implicit Function Theorem applied to the first order condition of program 10, one obtains that :

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

One can therefore conclude that :$\partial^2_{q,q}\pi^m(q,c) = \frac{c}{q} \cdot D'(x^*) \cdot \frac{\partial x^*}{\partial q} > 0$. Hence $\pi^m(q,c)$ is strictly convex in the quality of the composite good. ■

F Proof of Lemma 2

In a preliminary step, let us notice two obvious facts. First of all, this game always admits a trivial equilibrium in which everybody plays $e_i = 0$ and secondly if an equilibrium exists it must be a symmetric one otherwise there always exists a player who has an incentive to reduce his investment and by doing this improves his situation.

Point (i)

Let us now seek for a necessary and sufficient condition which ensures that $e_i = 0$ is the unique equilibrium

Let us first verify that this condition is necessary. If

$$\exists i \in I, \forall e \in]0, \bar{e}], \quad \pi^m(1+e,c) - \pi^m(1,c) < |F| \cdot |f_i| \cdot e \tag{11}$$

is true, one observes, because $\partial_q \pi^m > 0$, that $\exists i \in I$ with the property that

$$\forall e_i \in]0,\bar{e}], \forall e_{-i} \in]0,\bar{e}]^{n-1} \quad \frac{1}{|F| \cdot |f_i|}\pi^m\left(1 + \min_{j\in I}\{e_j\}, c\right) - e_i < \pi^m(1,c)$$

In this case the best reply of this agent is always to play $e_i = 0$. But if at least one agent plays 0 the best reply of the others is also to play 0. If follows that under condition (11), $(e_i)_{i\in I} = 0$ is the unique equilibrium.

In order to verify that this condition is also sufficient, let us assume that condition (11) is not satisfied. In this case, one can construct $\forall i \in I$ a quantity $e_i^* > 0$ which does not verify equation (11) and one can define $e_F^* = \max\{e_i^*\}$. Now let us assume that everybody plays e_F^*. By construction of the game (i.e the valuation of the quality through a min function), nobody has an incentive to increase e_i. If nobody also has an incentive to decrease e_i, the proof is finished because $e_F^* > 0$ is another Nash equilibrium.

So let us assume that, say agent i, has an incentive to perpetrate this deviation. His payoff after this deviation is $\pi_i' = \frac{1}{|F| \cdot |f_i|}\pi^m(1+e',c) - e'$ with $0 \,\square\, e' < e_F^*$. But $\pi^m(q,c)$ is convex in q, so the holds for hence π_i'. By a standard inequality of convexity on π_i', one deduces for $\lambda = \frac{e'}{e_F^*}$ that

$$(1-\lambda) \cdot \frac{1}{|F| \cdot |f_i|} \cdot \pi^m(1,c) + \lambda \cdot \left(\frac{1}{|F| \cdot |f_i|} \cdot \pi^m(1+e_F^*,c) - e_F^*\right) \geq \pi_i'$$

But by construction of e_F^*, we know that $\pi^m(1+e_F^*,c) - |F| \cdot |f_i| \cdot e_F^* \geq \pi^m(1,c)$ and one can conclude that

$$\frac{1}{|F| \cdot |f_i|} \cdot \pi^m(1+e_F^*,c) - e_F^* \geq \pi_i'$$

Point (ii)

If condition 11 is not fulfilled, it makes sense to suppose that $\mathcal{E}_F \backslash \{0\} \neq \emptyset$ and to define $e_{\min} = \inf(\mathcal{E}_F \backslash \{0\})$. If $e_{\min} = \bar{e}$, the proof is finished. So let $e_{\min} < \bar{e}$ and let us take any $e_F^* > e_{\min}$. It remains to verify that playing e_F^* is for everybody a best replay. But let us first remember that $e_{\min}$, when played by everybody, is a Nash equilibrium, hence $\forall i \in I$, $\pi^m(1+e_{\min},c) - |F| \cdot |f_i| \cdot e_{\min} \geq \pi^m(1,c)$. It remains therefore to apply the same argument[17] as in the second part of the proof of point (i) in order to make sure that e_F^* is a Nash equilibrium

Point (iii)

If condition 11 is not fulfilled, and if $e_{\min} = \bar{e}$, the proof is again finished. So let $e_{\min} < \bar{e}$. If one takes any e and e' with the property that $e_{\min} \leq e < e' \leq \bar{e}$ and if one knows that these quantities are symmetric Nash equilibria, it is quite easy, with again the same arguments as those developed in point (i) and (ii),to show that $\forall e, e' \in [e_{\min}, \bar{e}]$ and $e < e'$ one has :

$$\left(\frac{1}{|F| \cdot |f_i|}\pi^m(1+e,c) - e\right) < \left(\frac{1}{|F| \cdot |f_i|}\pi^m(1+e',c) - e'\right)$$

One can therefore deduces that these equilibria are all strictly Pareto ranked. ■

G Proof of proposition 7

By lemma 2 and proposition 6, one knows that there are only two common levels of investment which can be undominated Nash equilibria. Either nobody invests or everybody invest $e_F = \bar{e}$. If one has in mind that this second case only occurs if nobody has an incentive to deviate from this strategy, this means that :

$$\forall i \in I, \quad \frac{1}{|F| \cdot |f_i|} \cdot \pi^m(1,c) \leq \frac{1}{|F| \cdot |f_i|} \cdot \pi^m(1+\bar{e},c) - \bar{e}$$

But this implies that $1 + r \geq \frac{1}{n} \cdot |F| \cdot \max_{f \in F} \{|f|\}$ and the definition of the equilibrium payoffs follow quite easily. ■

H Proof of proposition 8

In a preliminary step, let us prove that $\{\{i\}\}_{i \in I} \in \arg\min_{F \in \mathcal{F}} \left(\frac{|F|}{n} \cdot \max_{f \in F} \{|f|\}\right)$. In fact, one immediately notices that $\left.\left(\frac{|F|}{n} \cdot \max_{f \in F} \{|f|\}\right)\right|_{\{\{i\}\}_{i \in I}} = 1$. Let us now assume that $\exists F \in \mathcal{F}$, with the property that $\frac{|F|}{n} \cdot \max_{f \in F} \{|f|\} < 1$. This means that $\forall f \in F$, $\frac{|F|}{n} \cdot |f| < 1$. If one sums these quantities over all $f \in F$, one obtains that $\sum_{f \in F} \frac{|F|}{n} \cdot |f| = |F| < 1$ which is the desired contradiction.

After this preliminary comment, let us assume that proposition 9 is not true. This means that there exists a partition $F \in \mathcal{N}$ and $F \notin \mathcal{O}$. Because $F \notin \mathcal{O}$ then $1 + r < \frac{|F|}{n} \cdot \max_{f \in F} \{|f|\}$. By our preliminary result, this partition cannot be identified to $\{\{i\}\}_{i \in I}$. F contains therefore at least one coalition composed of at least two basic activities. If one agent 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 he deviates and creates his own firm. If F' denotes the partition obtained after this deviation, This player, by proposition 7, receives in the Investment Game (IG) :

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

By our preliminary remark, we know that $F \neq \{\{i\}\}_{i \in I}$, one therefore verifies that $\frac{n}{(|F|+1)} \geq 1$. If one moreover remembers that $r \geq 0$, this implies that $\frac{1}{(|F|+1)} \cdot \pi^m(1+\bar{e},c) - \bar{e} \geq \frac{1}{(|F|+1)} \cdot \pi^m(1,c)$. It follows that $\pi_i^{IG}(F', c) \geq \frac{1}{(|F|+1)} \cdot \pi^m(1,c)$. Let us now compute the profit of this player before he deviates. If one remembers that $F \notin \mathcal{O}$, one can assert that $\pi_i^{IG}(F, c) = \frac{1}{|F| \cdot |f|} \cdot \pi^m(1,c)$ with $|f| > 1$. It is now a matter of fact to observe that $|F| \cdot |f| > (|F| + 1)$. This implies that $\pi_i^{IG}(F', c) > \pi_i^{IG}(F, c)$, or, in other words, that this agent has an incentive to deviate. ■

I Proof of proposition 9

[17] One simply identifies $e_{\min}$ to e_i^* and e_F^* to itself.

Let us assume the contrary. This means that $\exists F \in \mathcal{F}$, $F \in \mathcal{N}$ and $F \notin \mathcal{O} \cap \mathcal{I}$. By proposition 9 we know, because $F \in \mathcal{N}$, that $F \in \mathcal{O}$ and one deduces that $F \notin \mathcal{I}$. This means that F contains at least one coalition f with the property 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 denotes 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. Player i therefore 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 $\pi_i^{IG}(F', c) > \pi_i^{IG}(F, c)$. But this contradict the fact that $F \in \mathcal{N}$. ■

J Proof of proposition 10

Let $F_0 = \{\{i\}\}_{i \in I}$. One first observes that $1 + r \geq \frac{1}{n} \cdot |F_0| \cdot \max_{f \in F_0} \{|f|\} = 1$, thus investments in knowledge occur and the profit of each player is $\frac{1}{n} \cdot \pi^m(1+\bar{e}, c) - \bar{e}$. Now let us assume that at least one agent i_0 has an incentive to deviate from F_0 by playing F_i. In this case, he only has the opportunity to form a coalition with another agent. In this case, he 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 the investments respectively occur or not after deviation. One obviously observes that :

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

hence agent i_0 has no incentive to deviate if the investment is maintained after deviation. Let us now consider the second case. We know that $r \geq 1$. It follows that :

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

because for $n \geq 2$, $\frac{1}{n} \geq \frac{1}{2(n-1)}$. In this case agent i_0 has also no incentive to deviate.

■

K Proof of proposition 11

Before showing this result, let us make to preliminary remarks :

Remark 1 *Let $F \in \mathcal{I}$ and let $\mathbb{E}(x)$ denotes the integer part of x. If $k := n - \mathbb{E}\left(\frac{n}{|F|}\right) \cdot |F| \geq 1$ then $\max_{f \in F} \{|f|\} = \mathbb{E}\left(\frac{n}{|F|}\right) + 1$ and if $k = 0$ then $\max_{f \in F} \{|f|\} = \mathbb{E}\left(\frac{n}{|F|}\right) = \frac{n}{|F|}$*

If $|F| = 1$ the result is obvious. One also observes that $\max_{f \in F} \{|f|\} \geq \frac{n}{|F|}$ because otherwise $\sum_{f \in F} |f| < n$. Let us now assume that $\max_{f \in F} \{|f|\} \geq \mathbb{E}\left(\frac{n}{|F|}\right) + 2$ and $|F| \geq 2$. In this case, one notes that $\exists f_0 \in F$ with the property that $|f_0| \; \square \; \mathbb{E}\left(\frac{n}{|F|}\right)$ otherwise $\sum_{f \in F} |f| \geq |F| \cdot \mathbb{E}\left(\frac{n}{|F|}\right) + |F| + 1 > n$. Let us now take $f_{\max} \in \arg\max_{f \in F} \{|f|\}$, the largest coalition, one remarks that $|f_{\max}| - |f_0| \geq 2$. But this contradict the fact that $F \in \mathcal{I}$. it follows that $\max_{f \in F} \{|f|\}$ is either equal to $\mathbb{E}\left(\frac{n}{|F|}\right)$ or to $\mathbb{E}\left(\frac{n}{|F|}\right) + 1$. This obviously implies remark 1. ■

Remark 2 *If $F \in \mathcal{I}$ and $k \geq 2$ then $(|F|+1) \cdot \left(\mathbb{E}\left(\frac{n}{|F|}\right) + 1\right) \; \square \; 2 \cdot n$.*

By computation one observes that :

$$\begin{aligned} (|F|+1) \cdot \left(\mathbb{E}\left(\frac{n}{|F|}\right) + 1\right) &= n - k + \mathbb{E}\left(\frac{n}{|F|}\right) + |F| + 1 \\ &\square \; n + \mathbb{E}\left(\frac{n}{|F|}\right) + |F| - 1 \text{ because } k \geq 2 \\ &\square \; n + \frac{n}{|F|} + |F| - 1 = g(|F|) \end{aligned}$$

From a quick study of $g(|F|)$ on $\{1, \ldots, n\}$, one notes that $g(|F|) \square \max\{g(1), g(n)\} = 2n$. ■

Let us now move to the main proof. So let us assume that $\exists F \neq \{\{i\}\}_{i \in I}$ with the property that $F \in \mathcal{N}$ and let us seek for a contradiction. Because $F \in \mathcal{N}$, one knows that $F \in \mathcal{I}$, and this will be useful later. Moreover, because $F \neq \{\{i\}\}$ there exists a non-empty set I_D of agents who has the possibility to create their own firm. Let us assume that one of these agents deviates in that way et let us denote by F_i the partition obtained after deviation. One first notes that

Lemma 3 *$\exists i \in I_D$, with the property that $F_i \in \mathcal{O}$*

Proof

Let us assume that $\forall i \in I_D$, one observes that $F_i \notin \mathcal{O}$ and let us seek for a contradiction.
One first notes by construction of $\mathcal{O}$ that this condition induces that :

$$\forall i \in I_D, \quad 1 + r < \frac{1}{n} \cdot |F_i| \cdot \max_{f \in F_i} \{|f|\} \tag{12}$$

Moreover by construction of the deviation, one knows that $\forall i \in I$ (i) $\forall i \in I$, $|F_i| = |F| + 1$ and (ii) $\max_{f \in F_i} \{|f|\} = \max_{f \in F} \{|f \backslash \{i\}|\}$. This either means that :

- $\exists i \in I_D$ such that $\max_{f \in F} \{|f \backslash \{i\}|\} = \max_{f \in F} \{|f|\} - 1$. Because $F \in \mathcal{I}$, this implies by remark 1 that $k \square 1$ and $\exists i \in I_D$, $\max_{f \in F} \{|f \backslash \{i\}|\} \square \mathbb{E}\left(\frac{n}{|F|}\right)$. But in this case $\frac{1}{n} \cdot |F_i| \cdot \max_{f \in F_i} \{|f|\} \square \frac{1}{n} \cdot (|F| + 1) \cdot \mathbb{E}\left(\frac{n}{|F|}\right) \square 2$. If one has in mind that by assumption $r > 1$. One contradicts condition 12.
- or $\forall i \in I_D$, $\max_{f \in F} \{|f \backslash \{i\}|\} = \max_{f \in F} \{|f|\}$. In this case, because $F \in \mathcal{I}$, one observes that $k \geq 2$. By remark 2, one has that $\forall i \in I_D$,

$$\frac{1}{n} \cdot |F_i| \cdot \max_{f \in F_i} \{|f|\} = (|F| + 1) \cdot \left(\mathbb{E}\left(\frac{n}{|F|}\right) + 1\right) \square 2$$

which again contradicts condition 12.

■

By the preceding lemma we are now sure that $\exists i \in I_D$, with the property that $F_i \in \mathcal{O}$. In this case, the proof is almost finished. One simply has to observe that if either ($|f_i| \geq 2$ and $|F| > 1$) or ($|f_i| > 2$ and $|F| \geq 1$), then :

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

because $|F| + 1 < |F| \cdot |f_i|$. The only case in which this inequality is not satisfied $|f_i| = 2$ and $|F| = 1$. But this means that $n = 2$, a case which is considered later. There exists therefore a profitable deviation from F.

Let us finally consider the case $n = 2$. By computation one typically observes that $\forall i = 1, 2$, $\pi_i^{IG}(\{\{1, 2\}\}, c) = \pi_i^{IG}(\{\{1\}, \{2\}\}, c)$. This means that the industrial structure remains indeterminate

■

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