KNOWLEDGE AND STRUCTURE

Guido Fioretti [*]
CEEL, Trento, Italy
ICER, Torino, Italy

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Abstract

This article presents a formalization of knowledge based on a connectionist model of a firm's structure. Transaction costs are not ignored, but integrated with the knowledge-based approach. A numerical example on the canonical comparison of "Japanese" versus "American" organizational structures illustrates the power of the model.

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1 Introduction

According to common wisdom, arguments based on transaction costs can be extended from general justification of the existence of firms [7] to justification of particular firm structures [32]. According to Williamson's account, transaction costs arise within firms because individual actors are boundedly rational. Thus, processing information is costly, and structure must be such that it minimizes these

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[*] via San Massimo 8, 10123 Torino, Italy. E-mail: fellow1@icer.it, guido.fioretti@lycos.com

costs. In particular, Williamson claimed that the passage from multifunctional to multidivisional structure of many large companies during the first half of the XX century [6] was due to lower transaction costs of the multidivisional form with respect to the multifunctional form.

More recently, Radner and Van Zandt developed the transaction costs approach in greater detail, resorting to techniques borrowed from computer science [22, 21, 29]. Firms are modelled as hierarchies of information processors that perform associative operations, e.g. summation. Each processor is performing operations in a serial fashion, whereas processors at the same level are doing their work in parallel. For any given amount of data to be processed, increasing (decreasing) the amount of parallel processing leads to longer (shorter) processing time and a larger (smaller) number of processors. In other words, the more ”flat” a structure, the shorter the processing time and the more the managers; on the contrary, the more ”vertical” a structure, the longer the processing time and the less the managers. If both the number of managers and time to make a decision are costly, an efficient frontier of optimal structures can be found.

Thus, transaction costs specify a set of feasible structures and identify a frontier of optimal structures. However, they do not suffice to single out one of them.

Not surprisingly, reality is much more complicated than Radner and Van Zandt’s model. We observe very different structures within the same industry, differing from one another in many more respects than ”flatness” or ”verticality”. Apparently, structural variety is not even limited to the optimality frontier, but extends to the whole set of economically feasible structures.

It seems sensible to guess that unpredictability and turbulence of real environments tend to enlarge the scope for structural variety. History and experience are likely to lead to firm-specific structures that must lie within the feasibility set specified by transaction costs, but that may be far from its optimality frontier.

Furthermore, decision-makers occasionally make errors. In order to minimize the probability that individual errors propagate to the whole firm, it is sensible to duplicate decision-making at least to some extent [24, 25, 26]. However, if several managers must be assigned to the same task, a firm is surely away from the frontier of optimal structures.

Finally, employees and their capabilities change with time, as well as the turbulence of the environment that they face. Thus, the frontier of optimal structures is likely to change as well. Consequently, it might even be rational for a firm to stay below the optimality frontier: in this way, a firm can be confident that it will never exit the changing border of the set of feasible structures.

Clearly, the scope for structural variety on the whole set of feasible structures is even larger than along its frontier of optimal structures. Thus, other forces must operate the choice of a particular structure, besides transaction costs.

Richardson and Loasby first pointed to firm-specific *knowledge* and *competencies* as determinants of structural and behavioral diversity of firms [23, 18]. More recently, Nelson and Winter embedded their insights into an evolutionary framework that identifies the *routines* employed by a firm as the ”genes” whereby its knowledge is reproduced, innovated and transmitted [20]. Finally, Hammond interpreted the shift from multifunctional to multidivisional structure in terms of aggregating and channeling information according to criteria that produce suitable knowledge [11].

Unfortunately, the knowledge-based approach lacks formalization. Furthermore, it is isolated from the transaction costs -based approach. This article attempts to overcome both shortcomings, presenting a model inspired to connectionist theories of knowledge formation in distributed intelligence systems.

The rest of the paper is organized as follows. Section 2 introduces basic concepts regarding information, knowledge and routines within the framework of a connectionist model derived from classifier systems. Section 3 presents two indicators of the performance of a firm as information processor. Section 4 applies these indicators to the analysis of a canonical topic of organization science, namely the coparison of ”American” vs. ”Japanese” organization paradigms. Finally, section 5 concludes.

2 Information and Knowledge

Mathematical information theory is concerned with the transmission of symbols through a channel where disturbs may act [28]. Durturbs have the effect of turning symbols into one another; in its turn, the receiver which is at the end of the channel attempts to reconstruct the original message as faithfully as possible. The receiver forms a subjective probability distribution of the symbols that he will receive, and measures these probabilities by means of the frequencies of the symbols that he already received. In this context, *information* is the reduction of uncertainty caused by measurement of subjective probabilities.

Information is basically the same concept in economics. However, this claim should be qualified by the observation that the economic value of information depends on its usefulness for economic agents, rather than its quantity [19, 3, 4]. If a market for information exists, information can be traded like any other good. Furthermore, if information can be accumulated and stored, then the concept of ”capital” can be stretched into that of ”human capital” [5].

A distinctive feature of information is that it is interpreted by its recipients. Human beings classify information into *mental categories*, a sort of broad containers for information. By doing so, human bounded rationality is able to deal with a smaller number of items. However, the main purpose of mental categories is that of blurring differences between any two pieces of information that are classified in the same category, while highlighting differences between any two pieces of information that are classified in different categories. [1] In this way, mental categories specify the objects, the actions and the scenarios that a decision-maker is able to envision. Ultimately, mental categories interpret information into a subjective representation of the world and its possibilities.

Let us use the term *knowledge* for this combination of information + interpretation. In principle, the term ”human capital” could do equally well. However, ”human capital” is generally used with a meaning of accumulating information

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[1] In reality, mental categories are constructed by association of single experiences with memorized ones. Thus, differences between pieces of information may not be ignored. Furthermore, since association works on pairwise similarity, mental categories may lack a unique classification criterium for all the items they entail. However, the above account is more than sufficient for the purposes of this paper.

the way it is received, whereas ”knowledge” is eventually used in a less crude way.

Another reason for stressing the difference between knowledge and human capital is that storing knowledge is not as simple as storing capital. Just like capital, knowledge is an asset. As such, a firm must be able to store it. However, memory management is very different from inventory management.

Cognitive sciences draw an important distinction between *declarative memory* on the one hand, and *procedural memory* on the other. Declarative memories store knowledge on a given support (e.g. a disk, or a book); thus, knowledge is retrieved by reaching the support itself. This kind of knowledge can be ”declared” by pointing at its memory location (e.g. the pointer to a memory cell in a computer, or the position of a book on a shelf). Procedural memory, on the contrary, does not store knowledge at any precise point in space. Procedural memory is made of information that flows along a circular path; thus, a piece of knowledge can only be retrieved by some other piece of knowledge that comes close to it (e.g. we sometimes know that, if we think a concept A, we will trigger a chain of associations that leads to B, then to C and, finally, to a concept X that we were not able to ”declare” from the beginning). In the parlance of artificial intelligence, declarative memory is also called *localized memory*, whereas procedural memory is also called *distributed memory*.

A procedural memory can arise in any system made of a large number of components that are linked by an even greater number of connections. This is the case of the brain of a single decision-maker, but also of a firm composed by many employees interacting with one another as well as of an economy composed by many firms. When the members of a firm perform a sequence of operations again and again, the ensuing routine is the content of a firm's procedural memory [8, 9].

Routines are that part of a firm's knowledge that is stored on a procedural, distributed memory. Blueprints and technical specifications, on the contrary, are that part of a firm's knowledge that is stored on declarative, localized memories.

Let us conceive a firm as composed by *organizational units* that entail both men and machines. Let us assume that organizational units are endowed with a set of categories which they use to classify information, a set of pieces of information to be produced, and a rule that specifies on which occasion a particular piece of information should be produced. Since organizational units represent compounds of men and machines, categories represent the situations that decision-makers endowed with particular machines are able to distinguish whereas the information that they produce represents the decisions they make. Rules specify which decision should be made in each situation.

Let us denote by $\mathcal{C}_j$ the set of categories organizational unit j is endowed with. Let us denote by I_j the set of pieces of information that unit j is able to produce. A rule f_j is a function $f_j : \mathcal{C}_j \mapsto I_j$.

Rule f_j is a piece of knowledge stored in unit j. Unit j acts as a localized memory for that part of a firm's knowledge that is exclusively concerned with j. It is declarative memory, since if we want to know what a unit can do, the best thing we can do is that we ask it.

Furthermore, if it happens that some units pass on information to one another, the corresponding sequence of actions is a routine. For instance, units 1, 2, 3 are involved in a routine if $f_1 = f_1(f_2(f_3(f_1)))$. In this example, units 1, 2, 3 act as a distributed memory for that part of a firm's knowledge that concerns their organization and coordination. It is procedural memory, since if we want to know what the three units can do together, we must trigger their interactions. Note that the units involved in a routine might belong to different firms, as e.g. in the case of routines that involve customer-supplier relationships.

Knowledge in localized and distributed memory can be modelled by endowing organizational units with the capability of classifying information. Taking inspiration from *classifier systems* [13, 14], let us represent both categories and information by means of strings of L characters that can be zeros, ones, or ”don't care” characters #. [2] Thus, $K = 3^L$ different strings can be produced.

Categories must entail at leat one #-character. In fact, categories are strings that match all information strings that have zeros and ones in the same positions where they have zeros and ones; on the contrary, it does not matter which characters information strings have where category strings have a #. In this way, a category string acts as a container that classifies all information strings that have zeros and ones in its same positions. For instance, the category string depicted in the left half of figure 1 is able to classify the four information strings depicted in the right half of the picture.

Information strings may have #-characters as well. However, these characters

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[2] Holland's classifier systems employ the terms ”conditions” and ”actions” where we said ”category” and ”information”.

$$\begin{array}{ccccc} \begin{bmatrix} \# \\ 1 \\ \# \\ 0 \end{bmatrix} & \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix} & \begin{bmatrix} 0 \\ 1 \\ 1 \\ 0 \end{bmatrix} & \begin{bmatrix} 1 \\ 1 \\ 0 \\ 0 \end{bmatrix} & \begin{bmatrix} 1 \\ 1 \\ 1 \\ 0 \end{bmatrix} \\ \text{a category string} & \multicolumn{4}{c}{\text{information strings matched by that category string}} \end{array}$$

Figure 1: A category string, and the four information strings that it is able to match. The category string does not distinguish these information strings from one another. Thus, four information strings are classified as one single piece of information.

have a different meaning as in category strings.

Let us consider a generic organizational unit j. If an information string produced by unit j has #-characters in the same positions where a category string owned by j has #-characters, then unit j simply carries on to other units the symbols that were matched by its category. For instance, if the category string had a # in a position that was matched by a 0 (1), then the information string produced by j has also a 0 (1) in that position. In this way, information clusters can propagate.

Category strings bid *money* [3] in order to classify information strings. If a category string suceeds to match an information string, it pays to the organizational unit that issued that string. Organizational units, in their turn, distribute their en-

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[3] Holland's classifier systems use the more neutral word ”strength”. In our context, ”money” helps intuitive understanding.

dowment of money among their categories.

At the interface between a firm and the market, information strings are paied by means of real money. Within a firm, money is likely to be an internal unit of account. However, in both cases money outlays are rewards for organizational units that issue information strings that other units appreciate (e.g. good decisions). It is the value of information.

Since money inflows deriving from ”selling” information allow to bid higher prices for ”buying” information, money paths tend to be stable. If a stable path is also a circular one, that path is associated to a routine.

However, money cannot be the only magnitude that decides which category string will classify a certain information string. Categories entailing a large number of #-characters will be better able to classify information — in the limit, a category string made only by #-characters would be able to classify any information string. However, a general-purpose category string would represent a decision-maker who is not able to distinguish information strings from one another.

Consequently, classifier systems employ two magnitudes in order to decide which category string classifies which information string. The second magnitude is the *specificity* of a string, defined as the number of its non-#-characters.

Among the category strings that are able to match an information string, the one is preferred that is enough specific and offers enough money. A function must weight these two criteria in order to yield the probability that a category string classifies an information string.

Let indices $k, k' = 1, 2, \ldots K$ denote category strings and information strings, respectively. Let $p_{kk'}$ denote the probability that a category string of type k classifies an information string of type k'. Let $c_{kk'}$ denote the amount of money that category string k passes on to information string k': this is the cost of acquiring information k'. Let s_k be the specificity of category string k and let $s_{k'}$ be the specificity of information string k', where $s_{k'} \geq s_k$. Then, $p_{kk'}$ must be such that $\partial p_{kk'}/\partial c_{kk'} > 0$ and $\partial p_{kk'}/\partial (s_{k'} - s_k) < 0$.

Following the multinomial logit model, let us choose the following expression:

$$p_{kk'} = \frac{e^{-\beta \frac{1+(s_{k'}-s_k)}{1+c_{kk'}}}}{\sum_{k'} e^{-\beta \frac{1+(s_{k'}-s_k)}{1+c_{kk'}}}} \tag{1}$$

where the ones have the purpose of including the limit cases $s_{k'} - s_k = 0$ and $c_{kk'} = 0$. Let us posit that if connections between k and k' are not feasible either because $s_{k'} < s_k$ or because $c_{kk'} < 0$, or both, then it is $p_{kk'} = 0$.

Formula 1 concerns the probability of establishing a connection between one category string of a certain type and one information string of a certain type. If we assume that money for classifying information string k' by means of category string k is always available, then 1 is identical with the probability that a unit endowed with a category string of type k establishes a connection with a unit that issues an information string of type k':

$$p_{i(k)j(k')} \equiv p_{kk'} \tag{2}$$

where $i(k)$ means that unit i is endowed with a category string of type k and unit j

can produce an information string of type k'.

The above assumption implies that management occasionally redistributes money in order to enable ”poor” units to adopt solutions that have been found by ”rich” units. This amounts to concede that the credit assignment algorithm may be eventually overridden for the sake of the firm’s well-being. Although such a procedure can only occur at exceptional times if the structure of rewards is not to be destroyed, it distinguishes relationships within firms as opposed to market relationships.

Notably, with equations 1 and 2, we ended up to describe the structure of a firm by means of a random graph. Interestingly, random graphs have been used to model markets as well [16, 17, 15, 31].

It is worth to remark that equation 1 entails elements from theories of the firm based on transaction costs as well as from theories of the firm based on competence and knowledge. On the one hand, the cost supported by k in order to acquire information k' is a transaction cost in Williamson’s sense: rationality is a scarce resource, so the information that it produces is sold at a positive price. On the other hand, the difference between specificity of k' and specificity of k generates firm-specific, distributed knowledge.

The case considered by transaction costs economics is obtained by assuming $s_{k'} - s_k = 0$ for $\forall k, k'$. By making this assumption, equation 1 depends on transaction costs only.

On the contrary, the case considered by evolutionary economics is obtained by assuming $c_{kk'} = 0$ for $\forall k, k'$. By making this assumption, equation 1 depends on knowledge only.

3 The Comparative Statics of Organizational Structures

A firm can attain structural optimality if it finds itself in an environment that allows prediction, and if it is capable of making predictions. Let us be more specific by making the following definitions:

Definition 1 *The environment of a firm is* perfectly predictable *if it behaves according to deterministic laws that are known by the firm, and if these laws do not require unavailable data in order to be applied.* [4]

Definition 2 *Within a firm, a decision-maker is* infallible *if he makes decisions that do not impair the attainment of firm's goals.*

Definition 1 regards information classification into categories. In a perfectly predictable environment, information classification is not necessary.

Definition 2 regards the rules f whereby organizational units produce information strings. If all rules of all units are correct, duplication of information processing is not necessary.

Clearly, infallible decision-makers in a perfectly predictable environment are an abstraction. However, that of a firm composed by infallible agents that do not

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[4] This definition excludes stochastic environments, even if a firm would identify a probability distribution fot all possible events. It excludes deterministic chaos as well, since deterministic chaos arises out of deterministic laws that require data to be known with infinite precision.

require information processing duplication and do not need to classify information because it regards a predictable environment, is a useful benchmark state. The extent of information classification and information processing duplication can be measured with respect to this state.

Furthermore, let us consider a firm that is used to carry out information classification and information processing duplication to a certain extent, tailored to a certain level of environment impredictability and decision-makers fallibility. Let us suppose that, at a certain point in time, the environment becomes more predictable and the firm hires better managers. Then, this firm has a *tendency* to decrease information classification and information processing duplication.

Thus, information classification and information processing duplication can be used to define *potential functions* of organizational structures. According to these potential functions, structures with little information classification and little duplication of information processing, should be preferred.

Remarkably, reality provides examples where information classification and duplication of information processing enhance a firm's competitive advantage. For instance, [30] maintain that Toyota has been able to develop new models faster than any American or Japanese competitor because within this firm *i)* technical specifications fluctuate within broad ranges that are narrowed as late as possible (broad categories), and *ii)* a large number of alternative projects is carried out at the same time (information processing duplication).

However, it is easy to conceive examples like the one reported above as disequilibrium states. If Toyota would operate in a perfectly predictable environment and if its managers were infallible, technical specifications could be narrowed at the very beginning and only one project would be carried out at a time. Even if most firms operate with disequilibrium structures most of the time, it is sensible to compare alternative structures with respect to the equilibrium benchmark state.

3.1 A First Potential Function: Information Classification

Money surplus has been proposed a kind of potential function for market economies [1, 10]. However, within firms both money and specificity should be considered.

Taking inspiration from 1, let us define *information surplus* $u_{kk'}$ as follows:

$$u_{kk'} = \frac{1+(s_{k'}-s_k)}{1+c_{kk'}} \tag{3}$$

Information surplus $u_{kk'}$ represents the information that is wasted when a category of type k classifies an information string of type k'. It is directly proportional to the number of #-characters in excess in k over k', and inversely proportional to the importance of the connection between k and k'.

It is convenient to stipulate that connections between k and k' are not established if either $s_{k'} < s_k 1$, or $c_{kk'} < 0$, or both. Thus, for any feasible connection it is $s_{k'} \geq s_k$ and $c_{kk'} \geq 0$; consequently, $u_{kk'} \geq 0$.

Information surplus of the whole firm is the sum of the information surpluses of its connections. However, since connections occur with specific probabilities, addends must be weighted:

$$U = \sum_{kk'} p_{kk'} u_{kk'} \tag{4}$$

If a firm starts with a structure $\mathcal{S}_*$ and arrives at a structure $\mathcal{S}^*$, its overall information surplus decreases by the amount ΔU:

$$\Delta U = \sum_{\mathcal{S}_i=\mathcal{S}_*}^{\mathcal{S}^*} \Delta U_i \tag{5}$$

$$\Delta U_i = U|_{\mathcal{S}_i} - U|_{\mathcal{S}_{i-1}} \tag{6}$$

where the series of structures $\{\mathcal{S}_i\}$ extends from $\mathcal{S}_*$ to $\mathcal{S}^*$. If $\Delta U_i < 0$ for $\forall i$, then the firm has a spontaneous tendency to move from structure $\mathcal{S}_*$ to structure $\mathcal{S}^*$.

3.2 A Second Potential Function: Parallelism of Information Processing

Let H denote the number of different category strings employed by a firm, and let H' denote the number of different information strings that its units can produce. Since K is the maximum number of strings that can be generated, it is $H \le K$ and $H' \le K$. Furthermore, since the purpose of category strings is to classify various information strings under the same heading, it must be $H < H'$.

Duplication of information processing takes place if two or more chains of at least three organizational units are involved in information paths that begin wuth the same k' and end with the same k. Let us begin with the case of three organizational units.

Chains of three organizational units have only one unit between the two extremes. Let $k' \rightarrow k_1 \rightarrow k'_1 \rightarrow k$ be the possible information paths, where k_1 is an index of types of category strings and k'_1 is an index of types of information strings. Similarly to k and k', $k_1 = 1,2,\ldots H$ and $k'_1 = 1,2,\ldots H'$.

The probability that two or more chains of three organizational units are involved in information processing duplication is:

$$v_1 = \frac{1}{HH'} \sum_{k=1}^{H} \sum_{k'=1}^{H'} \sum_{k_1=1}^{H} \sum_{k'_1=1}^{H'} p_{kk'_1} p_{k_1 k'} \tag{7}$$

where oefficient $1/HH'$ ensures that $0 \leq v_1 \leq$.

Let us consider chains of four organizational units. Since there are two units between the two extremes, paths are $k' \to k_1 \to k'_1 \to k_2 \to k'_2 \to k$, where k_2 and k'_2 have the same meaning as k_1 and k'_1, respectively. The probability that two or more chains of four organizational units are involved in information processing duplication is:

$$v_2 = \left(\frac{1}{HH'}\right)^2 \sum_{k=1}^{H} \sum_{k'=1}^{H'} \sum_{k_1,k_2=1}^{H} \sum_{k'_1,k'_2=1}^{H'} p_{kk'_1} p_{k_1 k'_2} p_{k_2 k'} \tag{8}$$

The generic n-th term of this series takes the form:

$$v_n = \left(\frac{1}{HH'}\right)^n \sum_{k=1}^{H} \sum_{k'=1}^{H'} \sum_{k_1,k_2,\ldots k_n=1}^{H} \sum_{k'_1,k'_2,\ldots k'_n=1}^{H'} p_{kk'_1} p_{k_1 k'_2} \cdots p_{k_n k'} \tag{9}$$

Since the more units are involved, the less probable it is that information processing duplication occurs, $\{v_n\}$ is a decreasing series. Thus, in a firm with multiple paths up to order N we can measure information processing duplication by means of:

$$V = \frac{1}{N} \sum_{n=1}^{N} v_n \tag{10}$$

where coefficient $1/N$ ensures that $0 \leq V \leq 1$.

Note that, since we did not specify which organizational units own which strings, equation 10 does not distinguish between information processing duplication, triplication, quadruplication and so on. This is clearly a limitation of the above measure, that reacts to strings variety rather than strings multiplicity. However, its simplicity is likely to make it useful in all the cases where firm size is proportional to variety of jobs.

Similarly to 5 and 6, we can say that if a firm starts with a structure $\mathcal{S}_*$ and arrives at a structure $\mathcal{S}^*$, information processing duplication decreases by the amount ΔV:

$$\begin{aligned} \Delta V &= \sum_{\mathcal{S}_i = \mathcal{S}_*}^{\mathcal{S}^*} \Delta V_i && (11) \\ \Delta V_i &= V|_{\mathcal{S}_i} - V|_{\mathcal{S}_{i-1}} && (12) \end{aligned}$$

where the series of structures $\{\mathcal{S}_i\}$ extends from $\mathcal{S}_*$ to $\mathcal{S}^*$. If $\Delta V_i < 0$ for $\forall i$, then the firm has a spontaneous tendency to move from structure $\mathcal{S}_*$ to structure $\mathcal{S}^*$.

4 From Hierarchy to Multihierarchy

The purpose of this section is to illustrate the meaning of the concepts expounded hitherto on a practical example. Comparison of hierarchies and multihierarchies was prompted by the superior performance of many Japanese firms with respect to their American competitors during the 1980s, and soon became a canonical topic in organization science. Western investigators pointed to communication between marketeers and engineers, personnel rotation and flexible teams composed by people from different departments as key factors of the success of Japanese firms [12]. [5]

Japanese-style firms have been characterized as *multihierarchies*, i.e. structures where cross-connections between departments originate from superimposition of multiple hierarchies. Figure 2 illustrates the difference between hierarchies and multihierarchies in a highly simplified setting. Both structures entail a commanding unit (0) (the boss) and two functional units (1) and (2) (e.g. engineering and marketing) that process information stemming from two sources (I) and (II) (e.g. technological constraints and market surveys). Contrary to simple hierarchy, the multihierarchy forces engineers to take account of esthetical aspects and marketeers to take account of technical aspects.

Let us compute potential functions U and V for the hierarchy and the multihierarchy of figure 2, respectively. If a firm is endowed with infallible managers and if it operates in a perfectly predictable environment, it should move to the structure that has lower U and lower V.

Sources (I) and (II) produce information that is purchased by units (1) and (2). Let s_I and s_{II} be the specificities of the information strings issued by (I) and

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[5] Subsequent investigation yielded a much richer, often different picture of Japanese-style manufacturing. However, here the issue is that of comparing idealized structures that have been widely discussed in the literature.

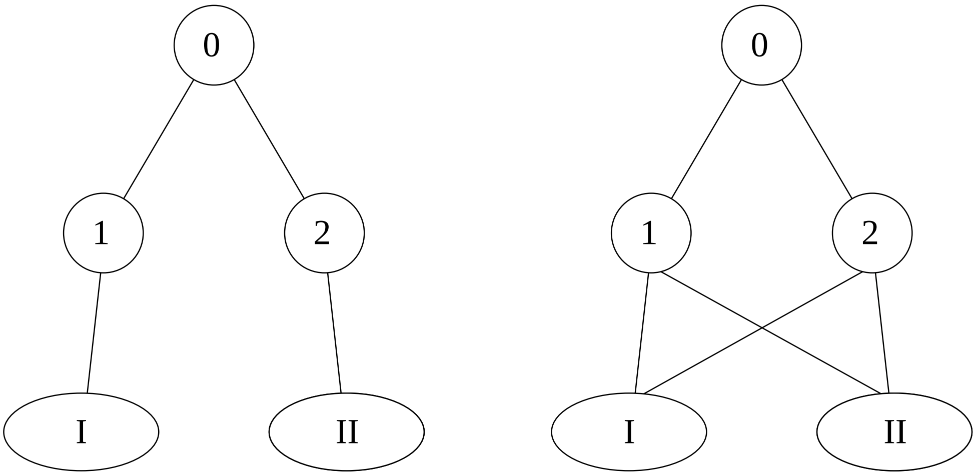

Figure 2: In the ”American” hierarchy on the left, units (1) and (2) rely on information issued by (I) and (II), respectively. In the ”Japanese” multihierarchy on the right, units (1) and (2) rely on information issued by both (I) and (II)

(II), respectively. Let s_1 and s_2 be the specificities of the categories owned by (1) and (2), respectively. Let c_{1I} and c_{1II} be the cost beared by (1) in order to obtain information issued by (I) and (II), respectively. Let c_{2I} and c_{2II} be the cost beared by (2) in order to obtain information issued by (I) and (II), respectively. Finally, let p_{1I}, p_{1II}, p_{2I} and p_{2II} denote the connection probabilities between firm units (1) and (2) and information sources (I) and (II).

In their turn, units (1) and (2) produce information that is purchased by (0). Let p_{01} and p_{02} denote the probabilities of establishing a link from (0) to (1) and from (0) to (2), respectively.

Let us consider information surplus U. We can ignore connections between (0) and (1), (2), since they are the same in both structural settings.

Following 5 and 6, hierarchy and multihierarchy yield the following values of

U:

$$U_h = p_{1I}\left[\frac{1+(s_I - s_1)}{1+c_{1I}}\right] + p_{2II}\left[\frac{1+(s_{II}-s_2)}{1+c_{2II}}\right] \tag{13}$$

$$\begin{aligned} U_{mh} &= p_{1I}\left[\frac{1+(s_I - s_1)}{1+c_{1I}}\right] + p_{2II}\left[\frac{1+(s_{II}-s_2)}{1+c_{2II}}\right] \\ &\quad + p_{1II}\left[\frac{1+(s_{II} - s_1)}{1+c_{1II}}\right] + p_{2I}\left[\frac{1+(s_I-s_2)}{1+c_{2I}}\right] \end{aligned} \tag{14}$$

Let us ignore transaction costs, since they can be offset by resource transfers. Thus, let us analyze the meaning of equations 13 and 14 with the assumption that $c_{1I} = c_{1II} = c_{2I} = c_{2II}$ and that, in the hierarchy, $p_{1I} = p_{2II} = 1$.

Then, it is easy to see that $U_{mh} < U_h$, i.e. that a firm has a tendency to swith from a hierarchical to a multihierarchical structure if $(s_{II} - s_1) < (s_I - s_1)$ and $(s_I - s_2) < (s_{II} - s_2)$. These inequalities can be interpreted in two ways.

The first one is to remark that if we simplify s_1 and s_2 on both sides, the above inequalities reduce to $s_{II} < s_I$ and $s_{II} < s_I$, respectively. Since these inequalities are inconsistent with one another, we are led to the conclusion that for a firm endowed with infallible managers who face a predictable environment, hierarchy is better than multihierarchy. Thus, the shift from hierarchy to multihierarchy that took place in the 1980s was due to greater market turbulence.

The second one is to observe that the above inequalities could be made compatible with one another if units (1) and (2) would be endowed with two categories each, one specific for technical information and the other specific for market information. The two inequalities would become $(s_{II} - s_3) < (s_I - s_1)$ and

$(s_I - s_4) < (s_{II} - s_2)$, which could be made compatible by an appropriate choice of s_3 and s_4. Although mathematically feasible, this solution is meaningless because it implies that the engineers are better at evaluating market signals than marketeers are, and that marketeers are better at evaluating technological possibilities than engineers are.

However, it is important to remark that meaningful choices of s_3 and s_4 would be able to soften the stength of these inequalities. Thus, if market turbulence suggests to switch to a multihierarchical structure, potential inefficiencies should be balanced by increasing the capabilities of organizational units. If engeneers must take account of market signals and if marketeers must take account of technological constraints, then engineers should acquire some marketing capability and marketeers should acquire some technical capability.

Let us consider information processing duplication V. The multihierarchy on the right half of figure 2 duplicates both information paths of the hierarchy shown in the left half of figure 2. In fact, path $(\mathrm{I}) \rightarrow (1) \rightarrow (0)$ can be duplicated by $(\mathrm{I}) \rightarrow (2) \rightarrow (0)$ whereas $(\mathrm{II}) \rightarrow (2) \rightarrow (0)$ can be duplicated by $(\mathrm{II}) \rightarrow (1) \rightarrow (0)$. Since both duplicating paths cross only one organizational unit, V coincides with v_1.

Application of formulas 7 and 10 yields:

$$V_h = \frac{1}{HH'} \left(p_{01} p_{1I} + p_{02} p_{2II} \right) \tag{15}$$

$$V_{mh} = \frac{1}{HH'} \left(p_{01} p_{1I} + p_{02} p_{2I} + p_{02} p_{2II} + p_{01} p_{1II} \right) \tag{16}$$

Let us suppose that each organizational unit owns only one category string and issues only one information string. Since category strings are owned by (0), (1) and (2), it is $H = 3$. Since information strings are produced by (I), (II), (1) and (2) it is $H' = 4$.

If we assume for simplicity that all probabilities are equal to one, then we obtain $V_h = 1/6$ and $V_{mh} = 1/3$. Again, we are led to the conclusion that for a firm endowed with infallible managers who face a predictable environment, hierarchy is better than multihierarchy.

5 Conclusion

This article formalized several notions pertaining to evolutionary literature on industrial economics, including knowledge and routines. Furthermore, it set a bridge between knowledge-based and transaction costs -based theories of the firm.

Application of the proposed tools to the well-known comparison of ”American” and ”Japanese” organizational styles yielded sensible results. However, qualitatively similar results had been previously achieved either by empirical investigations [27] or by means of more traditional models [2].

Thus, in a qualitative comparison of highly stylized structures the formulas developed hitherto have, at most, a methodological value. However, the level of detail of the model presented herein allows empirical evaluation of highly specific structures, including exact descriptions of circulating information and its interpretation by particular organizational units. Since the bridge between knowledge-based and transaction costs -based models is set at a more microscopic level than the ones where most knowledge-based and transaction costs -based models operate, this model offers possibilities of applications in the field of expert systems design.

However, one should never forget that — being derived from an artificial intelligence approach — the generation of semantics is absent from this model. Thus, expert systems based on this model cannot generate information interpretations beyond those specified by the modeller.

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