An Organizational Cybernetics Framework for Aligning Incentives in Collaborative Supply Chains

Marco de trabajo basado en Cibernética Organizacional para el Alineamiento de Incentivos en Cadenas de Suministro Colaborativas

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Abstract The potential of supply chain collaboration to outperform non-collaborative supply chain solutions is widely accepted by both practitioners and academics. Nevertheless, it is also well known that this improvement does not come without meaningful challenges to be tackled. One of them is the need for aligning incentives among the various supply chain partners. This work applies Beer's Organizational Cybernetics to design a conceptual framework for aligning incentives in collaborative supply chains. Our approach combines the Ashby's Law of Requisite Variety, Petri Nets and Espejo's Organizational Double Loop Learning. As a result, complexity asymmetries between the various echelons of the supply chain are balanced, which increases their confidence in the collaborative solution

Keywords: PSupply chain collaboration; Incentive alignment; Organizational cybernetics; Petri Nets; Supply chain complexity.

Resumen El potencial de la colaboración en cadenas de suministro para mejorar el rendimiento de las mismas es ampliamente aceptado tanto por profesionales como por académicos. Sin embargo, también es de sobra conocido que esta mejora exige hacer frente a desafíos importantes. Uno de ellos es la necesidad de alinear incentivos entre los diferentes miembros de la cadena de suministro. Este trabajo aplica la Cibernética Organizacional de Beer con el objetivo de diseñar un marco conceptual para el alineamiento de incentivos en cadenas de suministro colaborativas. Nuestra aproximación emplea la Ley de la Variedad Requerida de Ashby, Redes de Petri y el Doble Ciclo de Aprendizaje Organizacional de Espejo serán necesarios. Como resultado, las complejas asimetrías entre los eslabones de la cadena de suministro son balanceadas, lo cual incrementa la confianza de éstos en la solución colaborativa.

Palabras clave: Cadenas de suministro colaborativas; Alineamiento de incentivos; Cibernética Organizacional; Redes de Petri, Complejidad en las cadenas de suministro

1. Introduction

Uncertainty drives the dynamics of the new business environment where firms operate, which is marked by an intense competition. This competition does not focus on the firm level, but it covers the whole supply chain. Because of this, supply chain management has taken a key role within the organizational strategy. In this sense, collaborative solutions for supply chains have widely shown to perform significantly better than traditional ones based on local optimization, both from an operational (Disney and Towill, 2003; Costas et al.,

2015) and financial perspective (Cao and Zhang, 2011; Ponte et al., 2016a).

Under these circumstances, collaboration has been referred to as "the driving force behind effective supply chain management" (Min et al., 2005). However, collaborative solutions are still far from being widespread in practice (Fawcett et. al, 2015). Or, in other words, not many firms have truly capitalized the actual potential of supply chain collaboration (Min et al., 2005). This could be explained from the perspective of the complexity of implementing collaboration in supply chains. It must

be highlighted that it requires an integrative framework that considers different dimensions (Simatupang and Sridharan, 2005), such as information sharing, process integration, decision synchronization, and the use of a global performance scorecard.

These four features are necessary, but not sufficient. Besides, incentive alignment is essential to make all the echelons truly believe in the collaborative solution, which is indispensable to create a robust structure and make collaboration viable in long term (Puche et al., 2016). Otherwise, opportunistic behaviours commonly arise, which commonly leads supply chain collaboration to failure (Fawcett et. al, 2015).

From this perspective, this work proposes the use of Beer's Organizational Cybernetics (Beer, 1959) —the science of efficient organizations— to align incentives within supply chains. In this sense, we develop a conceptual framework for tracing, calculating and displaying the incentive scores between the different echelons of production and distribution systems. We note that this theory offers the possibility of achieving a scientifically-designed organization, which would constitute a system endowed with the capabilities of learning, adaption and evolution. Hence, this approach sets forth a defense of holism against reductionism in the application of the scientific method

2. Conceptual framework

Ashby (1964) proposed the concept of variety with the aim of measuring the degree of complexity of a system. This variety is expressed as the number of possible states and real or potential behaviours that may arise in a given problem or situation. Ashby (1964) also proposed the Law of Requisite Variety as an ontology and heuristic for complexity management strategies (Espejo, 2015). Following these propositions, the Organizational Cybernetics (Beer, 1985), including the Variety Engineering and the Viable System Model, seem particularly well positioned to be applied as the structure over which design these strategies.

From a cybernetic point of view, controlling a situation means being able to deal with its complexity, that is, its variety. Overall, we can consider that, the variety of firms organizational environment is much greater than the variety of the operations that they undertake to provide the products and services in that environment. The variety of these operations is, in turn, much greater than the variety in the management in charge of its control, as the managerial team cannot be aware of everything that takes place in the operations (Beer, 1985). This situation implies that managers should be

capable of developing requisite variety, so that they can cope with the enormous variety present in the environment in which they operate, as well as in the production operations for which they are responsible. The Law of Requisite Variety of Ashby should be thus considered in order to develop the requisite variety (Ashby, 1964).

This law is built on the idea that only variety destroys (absorbs) variety, which entails that control is only possible if the variety of the controller is equivalent to the variety of the situation to be controlled (Beer, 1981). That is, complex problems require solutions in accordance with their complexity. From this perspective, Organizational Cybernetics provides two types of mechanisms to comply with the requirements proposed in Ashby's Law of Requisite Variety: (1) a horizontal unfolding of variety; and (2) a vertical unfolding of variety. These mechanisms, supported by a set of tools, constitute what Beer (1979) referred to as Variety Engineering. Beer's theory interprets the organizational structure as the solution to the problem of variety, that is, the tool with which to handle variety is the organizational structure.

With regard to the horizontal unfolding of variety (Fig. 1a), we employ a series of homeostatic regulators. This approach allows one to link the previously mentioned components: environment, operations, and management. Variety in each of these components is unequal and should be balancer (that is, in equilibrium), with a view to maintaining the viability of the operations. The varieties of these three components can be balanced through the design of mechanisms: (1) to reduce variety, which are known as attenuators, of the environment in relation to the operations and of those in relation to management; and (2) to increase variety, the so-called amplifiers, of management in relation to operations and of those in relation to the environment (Beer, 1985).

The vertical unfolding of variety (Fig. 1b) consists of breaking down the environment into sub-environments (smaller environments contained in the initial environment), and these in turn into even smaller sub-sub-environments, and so on successively, in such a way that even smaller operations in each of these sub-environments are linked within the initial operations. The same process is followed with management. The purpose of this breakdown is that the variety that these parts of the system confront is smaller and hence more manageable. It should be highlighted that these parts are not fragments of the initial system, but they should have the complete requisites to constitute fully operative systems similar to the overall system, except the fact that they have a more limited scope of action (Beer, 1979).

Fig. 1 Horizontal (a) and vertical (b) unfolding of variety

Beer (1985) makes use of the Viable System Model (VSM) to elaborate on these ideas. The VSM emerges as an illustration of the central nervous system in human organizations in the sense of homomorphic mapping, where homomorphic indicates equality, or structural invariance, upon which five structural components, i.e. Systems One to Five, appear in this neuroscientific model. These are considered necessary and sufficient structural conditions for the viability of any organization (Beer, 1981). In other words, this ensures its capabilities for an independent existence, self-regulation, learning, adaptation and evolution, being all of them needed to guarantee its survival in the face of changes that may occur in its environment over time, even if they have not been foreseen. Therefore, the VSM can be established as an organizational model for any organization.

In this way, the VSM enables the understanding of the complexity of organizations, allowing us to place them in a simple structure from which to comprehend and to analyse them (Beer, 1985). The VSM may also be seen as a design and diagnostic tool that examines the health of organizations and offers a series of recommendations to improve their effectiveness (Schwaninger, 2006).

Different research works have illustrated the breadth of application of the VSM (Puche Regaliza 2015, 2014; Espinosa & Walker, 2013), including studies related to logistics distribution network (Sitch & Groten, 2015) and supply chain management (Chronéer & Mirjam-dor, 2009). Nonetheless, although cybernetics the-

ories enjoy great recognition because of their theoretical plausibility, they are not free from some criticisms (Jackson & Floor, 1988).

Finally, we note that a learning process is necessary due to the high complexity and dynamism associated to the environment in which supply chains currently operate. In this regard, Espejo (2015) proposes the use of the Organizational Double Loop Learning which is built on the well-known learning cycle between actors and agents (OADI model) and the Shared Mental Model (SMM) associated. In the OADI model, actors: (1) observe (O) situational agents and their ecosystem; (2) assess (A) these observations; (3) design (D) actions; and (4) finally implement (I) them. In addition, collectively, actors produce a SMM. This constitutes the organizational system's cognitive processes. Once again, the VSM defines a conceptual scheme that facilitates this essential learning process.

3. Supply chain implementation

The framework that we presented in Section 2 to align incentives aims to prevent the supply chain echelons from deviating from the collaborative behaviour looking at optimizing the supply chain as a whole. In this sense, the framework would help to create an atmosphere of greater awareness about the collaborative approach throughout the supply chain. To capture the previous ideas and implement the framework, we first focus on measuring the variety of each supply chain echelon. It entails identifying all possible states that can be defined

By way of example, we build on the widely-employed Automatic Pipeline Feed-back Order-Based Production Control System (APIOBPCS) model (John et al., 1994). The APIOBPCS model describes the operational behaviour of a single echelon of a production and distribution system by focusing on products at an aggregate level. We refer to Lin et al. (2016) for a recent literature review on the exploitation of these supply chain archetype over the last three decades.

With the aim of describing the dynamic behaviour of the different echelons of the supply chain, the APIOB-

PCS model has been modelled by means of Petri Nets. These nets are bipartite graphs composed of transitions (which refer to events) and places (which cover the conditions of the system), in which the relation between both elements is described through arcs. By way of example, the following figure (Fig. 2) generically describes the behavior of an echelon (producer-consumer scenario) according to the previously mentioned APIOBPCS model. Note that transitions are represented by means of a rectangle, while places are described through a circle.

Fig. 2 Petri Net of any echelon in the supply chain

The sequence of events of the considered supply chain is as follows. It should be noted that the following cycle occurs once per period. At the beginning of the period, the material is moved downstream. Hence, the echelon receives the product associated to the order that has been placed some (i.e. the lead time) periods ago. This receipt is called the completion rate, or COMRATE, and as soon as it reaches the echelon, it becomes serviceable stock. Given that we focus on a single echelon, we assume that what is requested will be received after the lead time. However, if we considered the whole supply chain, the COMRATE would be constrained by the on-hand inventory that is available by the sup-

plier when it sends the product. Later, the demand is received, which is satisfied as long as on-hand inventory is available. Finally, at the end of each period, the state of the echelon's inventory, which considers both the on-hand and on-order inventory, is updated. This is taken into consideration, together with the forecast of future demand, to decide the order rate, or ORATE.

Let us have a quick glance to this Petri Net, just to create awareness about its value in terms of dealing with variety in each node. Generally speaking, each node of the supply chain has to manage the shipping loop (the reason why the node exist is to serve customers

downstream) and to manage the sourcing loop so to be able to avoid stock outs and backorders. Besides the factory has to deal with the manufacturing loop. A model for such service level can be done with a colored stochastic Petri Net (David & Alla, 2005), where the information flow need some token colors and the material flow need some other colors. Of course some transitions have to deal with uncertainty (risk management, which consists on identifying sources of risk such as delays, variability, etc.) prioritizing them and preparing proactive and reactive defense (backorders are defensive reactions once demand has not been fulfilled, for instance). Once supply chain nodes reach a degree of understanding about how much complexity each one is exposed to a linear contract can be discussed and agreed.

To implement the proposed framework based on Organizational Cybernetics, the Petri Net must be particularized for all nodes in the supply chain. In order to consider the supply chain in its entirety, it will be necessary to link all echelons that compose it according to the usual relations. On the one hand, the quantity received by an echelon is what the upper one (i.e. his supplier) has previously sent. On the other hand, the echelon's demand is the order issued by the lower echelon (i.e. his customer).

From this perspective, we make use of the vertical unfolding of variety to accurately assess the complexity of each echelon. That is, we define the next lower levels of recursion for each one of the states defined in Fig. 2. In this way, the total complexity of each echelon can be obtained. In case one needs to work with several linked supply chains, the next higher levels of recursion must be defined in the same manner.

Finally, if the complexity of each echelon is sufficiently different and creates incentives to move away from the collaborative behavior, it will be necessary to use the horizontal unfolding of variety to balance the number of states of the echelons, that is, to balance its variety (its complexity). To do this, it is essential to define and design suitable variety attenuators and amplifiers for each specific case.

4. Conclusions

In the implementation of efficient and viable collaborative solutions for supply chains, it is essential to consider the alignment of incentives among the different supply chain nodes (Ponte et al., 2016b). In this work, we propose a conceptual framework from which to cope with this issue based on Beer's Organizational Cybernetics. This would enable to balance the com-

plexity asymmetries between the different echelons of the supply chain.

In addition, Petri Nets are proposed as a powerful mechanism for supply chain modelling from this perspective, as they consider the number of states of each supply chain echelon. In the example shown in this article based on the well-known APIOBPCS model, with 6+2 transitions and 8 states, we are able to describe the dynamics of one supply chain echelon. It allows us to quantify the complexity of each echelon in order to later balance this complexity in all the echelons through the use of the mechanisms of vertical (defining recursions) and horizontal (defining attenuators) unfolding of variety.

This framework (Fig. 3) would allow the development of a mathematical model that will quantitatively shape the variety of the supply chain and the percentage of complexity that will be assumed by each of the nodes that compose it. In this way, the mathematical model will represent an invariant formed by the contracts signed between the nodes with the agreements of the assigned percentages of variety plus the actual variety managed by each node, which is quantified through its Petri Net (and recursions in sub-Petri Nets mode). This invariant will allow the readjustment of the payment systems between the different nodes, considering both the contracts signed, the required variety of each node to perform its activity optimally, and the residual variety of each node caused by its inadequate operation. Thereby, we will obtain a theoretical model that quantifies the payment made by each node because of absorbing the part of assigned variety. We thus offer a measuring method complexity (Indulska et al., 2009) in favour of decision-making and collaboration between nodes in the supply chain.

Fig. 3 Organizational Cybernetics framework for aligning incentives in collaborative supply chains

In this field, several extensions can be outlined, which define avenues for future research. First, we could focus on completing the model for all echelons in the

supply chain. Second, the number of states could be optimized using heuristics and metaheuristics, considering a NP-hard problem. A third line would involve balancing its complexity by defining necessary recursion levels and designing necessary attenuators and amplifiers of variety. Fourth, a simulation-based study would undoubtedly help in the process of implementing the complete model for aligning incentives in real-world supply chains.

Overall, this article underlines that knowledge of Organizational Cybernetics would be of incalculable value for managers wishing to manage collaborative supply chains successfully, which is becoming essential to cope with the current complex and rapidly changing business environment.

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