Autonomous Co-operation and Control in Complex Adaptive Logistic Systems – Contributions and Limitations for the Innovation Capability of International Supply Networks

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Abstract. This paper aims to analyze the potential contributions of the organization principle autonomous co-operation and control to the innovation capabilities of logistics systems and their sub-systems like single organizations. Therefore, the concept of Complex Adaptive Logistics Systems (CALS) will be introduced and the essentiality of the heterogeneity of the elements within logistics systems for their innovation capabilities will be emphasized. One possible driver for homogeneity is the so-called dominant logic.

Keywords: Complex Adaptive Logistics Systems, Logistics, Complexity Science, Autonomous Co-operation, Innovations, Dominant Logic.

1 Introduction

Innovations are – among others – one important factor for the creation of corporate value and competitive advantage [e.g. 1,2,3,4]. Thereby, innovations can be understood as ideas, concepts, and practises in order to improve characteristics and features of products as well as of processes, which are perceived as new and valuable by any stakeholder of the respective organization [e.g. 5,6]. Innovations promise a certain benefit for which the relevant stakeholder groups might be willing to pay an extra premium [7]. Thus, the company's capability to be innovative can have a significant effect on its options for positioning on the markets and, in consequence, on the company's value [e.g. 8,9,10]. Therefore, the corporate innovation capability is crucial for the company's sustainable wealth.

But in times of real-time economies [11] and globalization [e.g. 12] companies are not isolated planning and acting organizations. Furthermore, companies are embedded in the diverse organizational structures of different international supply networks (ISN) and compete with other companies in the same or in other global production and distribution structures to a certain degree [13,14]. Companies, and therewith as ISN, do depend on the plans, performances, strategies, structures, and resources of other companies as well as on those of other networks. That is, why processes of

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co-evolution can be observed on both levels: the company level as well as the network level. Therefore, ISN can be understood and described as complex adaptive logistic systems (CALS) [15,16,17,18]. This understanding establishes – on the basis of a complexity science perspective – an analogy between supply networks and complex adaptive systems as they have been described in the literature e.g. [19,20,21,22]. In consequence, the question occurs, how value and competitive advantage can be achieved in ISN as CALS. More precisely, how can innovations be generated in the complex structures of value creating networks due to establish, maintain, and develop an innovation capability for the whole network.

An innovation aims on a successful market penetration. It is based on an efficient and effective innovation management [23], which comprises – at least - the planning of portfolios of technologies, resources, and innovations, the creation of innovations in cross-functional processes across the organization and beyond the organization's boundaries with its partners, like suppliers, customers, etc. [24]. Finally, a successful innovation management needs the intro-duction, integration, and implementation of the new features of products and processes into the markets in order to satisfy stakeholders' demands [25]. Therefore, one precondition of innovation capability in ISN is the existence of an efficient and effective innovation management in such a CALS, especially its before mentioned ability to initiate and maintain cross-functional processes for the creation of new ideas, concepts, and practises throughout the network organization with its different agents. From a complexity science perspective this leads to the question, what characteristics of CALS do promote or hinder the innovation capability of ISN.

To answer this question the paper intends to focus on the phenomenon of heterogeneity, as a precondition for any creation process in complex organizations as well as systems. In order to identify fields of activities needed for an innovation management impediments and facilitators of heterogeneity in CALS shall be identified. Due to the adaptivity feature of CALS the question of dominant logic becomes important for the innovation-aimed design of heterogeneity in such complex networks. Therefore, the paper would like to discuss autonomous co-operation and control as a learning-based approach to avoid problems of dominant logic in collective decision-making in CALS and, in order to establish and maintain a certain degree of heterogeneity, as a facilitating determinant of the ISN's innovation capability.

2 Heterogeneity as a Pre-condition for the Innovation-Capability of Complex Adaptive Logistics Systems (CALS)

The perspective, with which logistics systems are regarded in associated recent research, changed from the analysis of linear supply chains to complex and cross-national supply networks [16,17,26]. Due to that, several authors applied the concept of complex adaptive systems in the field of logistics (15,16,17,18), which leaded to the term of Complex Adaptive Logistics Systems (CALS).

According to McKelvey et al. (2008) [27] the main characteristics of CALS can be classified into an individual, an intra-systemic and an inter-systemic level. To begin with the perspective of the individual, in which the characteristics of the system's single entities are regarded, CALS consist of a large number of agents, which are interacting with each other simultaneously. Holland [21] called this parallelism, which means that the agents send signals to, and receive signals (e.g. resources, information, finances [16]) from other agents at the same time. Their incentives to interact with each other originate in their varying endowment with information [15], in other words, the agents are heterogeneous [20]. This is essential for the interaction, because if the agents would equal each other, they would be equipped with the same resources and therefore, they would not have any reason to interact and to exchange them [15]. Furthermore, interaction implies, that the agents react to the other agents' actions. Therefore, the agents' actions are dependent on the signals they receive, which means, that an agent's action can be a signal as well, that is, in turn, received by another agent [21]. This intra-systemic co-evolution highlights the complexity of CALS that can evolve by interaction between their elements. The agents' ability to react requires the existence of rules [20], which are, in turn, based on local information [16]. These rules need to be changeable over time to assure the system's capability to adapt to environmental changes [21]. What Holland [21] calls modularity means, that every agent develops routines of action sequences (combinations of single actions, which are called building blocks) by reacting to signals, which were send from the environment or by other agents. In new situations agents can revert to this further developed building blocks and test their appropriateness concerning their defined goals. The building blocks that experience positive feedbacks will be applied again [20,21]. Wycisk et al. (2008) [15] states this as the agent's ability to learn.

This leads to the intra-systemic perspective in which the system's organization is regarded. In order to develop own rules how to act and to react, the agents have to be able to render decisions without having to ask a super-ordinate controlling entity. Hence, the agents are autonomous, which means, they initiate their actions by themselves [19,20,22]. They are responsible for their own design, direction and development. In consequence, the system's developing structure is as well not controlled by any super-ordinate entity [28]. Instead, the system's structure evolves by itself with the autonomous decision making capabilities of its agents, it is self-organizing [29]. An essential requirement for a self-organizing system, in turn, is, that it does neither pass over a threshold, from which on it is totally uncontrolled and chaotic (the edge of chaos) [30,31], nor pass over a threshold, from which on its order is pre-configured (the edge of order) [32,33]. Kauffman [22] called this the melting zone.

Finally, and with regard to the mentioned co-evolution on the intra-systemic level, that results from the reciprocal reactions between the agents, co-evolution also takes place on the inter-systemic level. Agents do not only receive signals from other agents in the system, but also signals from the environment, to which they also send signals by their actions and interactions [22]. Therefore, CALS co-evolve with their environment and hence, possibly with other non-logistics systems, like the financial systems on which they are as well dependent to a certain degree.

With recourse to the above-mentioned definition of innovations, it becomes obvious that the existence and the degree of the characteristics of the CALS' individual levels, and therefore, the characteristics of their single elements, are essential for the whole systems to be innovative. The improvement of characteristics and features of products and processes in logistics systems is only possible, when their single elements are able to change their rules, in other words, if they are able to learn. By reacting to other element's respectively agent's actions, the others get feedbacks on their own actions and change, if necessary or meaningful, their own behavioral rules, to improve their own accomplishments and therewith the whole system's performance [34]. This reflects the co-evolution within a CALS as well as with its environment. The learning abilities of the systems' agents, in turn, are, as shown above, dependent on the degrees of interaction between them, and interaction can, as shown above, only take place if the elements are heterogeneous, at least to a certain degree. In consequence, the heterogeneity of a logistics system's agents can be regarded as a driver and homogeneity as a barrier for its innovation capability. Hence, the question arises, which aspects determine a logistics system's heterogeneity and what kinds of phenomena intensify their homogeneity.

3 Dominant Logic of Collective Decision-Making as a Barrier for Innovations in CALS

One phenomena that could possibly homogenate the behavioral rules of a logistics system's agents has been described by Prahalad and Bettis [35] as the so-called dominant logic. This concept was originally developed to explain problems that occur in firms that try to diversify their activities from areas in which they are successful to new areas and describes cognitive barriers of managers. They define the "(…) dominant general management logic (…) as the way in which managers conceptualize the business and make critical resource allocation decisions (...)" [35, p. 490]. Figure 1 illustrates the concept.

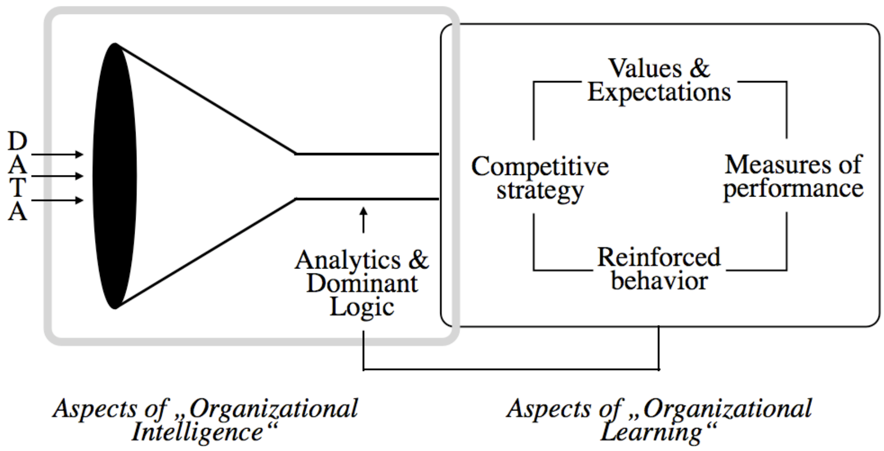

Fig. 1. The dominant logic [36, p. 7]

The ability to learn, as it was mentioned above as an inherent characteristic of CALS, plays an important role in the concept of the dominant logic [36]. The agents within a system repeat decision rules, that leaded to a good performance in the past and to them they got positive feedbacks from other agents via interaction [34]. This reinforced behavior of the single system's elements influences the behavioral rules of the agents within a logistics system (e.g. managers) and therefore the competitive strategies of the logistics system‘s sub-systems (e.g. logistics service providers, warehouses). These strategies as well as the resulting performances and how they are evaluated, in turn, influence the values and expectations of the single agents (e.g. managers), whereas these values and expectations reinforce, in turn, the single agents behaviors and therewith influence the strategies of the logistics systems‘ sub-systems [36]. This does not only apply to human elements in logistics systems, but as well to certain non-human ones, the so-called smart parts. Their programming include behavioral rules, which might, in turn, include values and expectations that are influenced by previous actions (in analogy to competitive strategy), certain ways to measure the actions‘ performances, and in the result possibly a reinforced behavior. Prahalad and Bettis [36] stated this circle as an organization‘s, or in this context a logistics system‘s, ability to learn. This ability shapes the system‘s modality, how to analyze information that flows into the system and is called a system‘s dominant logic [36].

The adaptivity of a system reflects its ability to, on the one hand, open its boundaries [37] to enable information inflow [38], and on the other hand to close the system‘s boundaries [39,40], to keep this inflow at a manageable level and therewith to prevent the system from information overload. Whereas the former is needed to react flexible to changes in the relevant environment, the latter maintains the system‘s stability [41]. Hence, the data that arrives at the system‘s boundaries has to be selected respectively filtered from irrelevant or less relevant data [36]. This selection, in turn, underlies a certain principle, which evolves over time and was called by Bettis and Prahalad [36] the organizational intelligence. The degree of filtering the incoming data is dependent on the analytics and the dominant logic, that is in turn dependent on the agent‘s and the sub-system‘s abilities to learn [36]. In logistics systems, that consist of a large number of organizations (sub-systems) and their agents [18], this intelligence might be cumulated and can therefore be called the intelligence of whole systems, in this case of CALS.

Subsuming these observations, the dominant logic of a system contributes on the one hand to select the incoming data and therewith to prevent the system from an information overload. On the other hand, it limits the amount of information that flows into the system and can therewith lead to a system‘s under-supply of relevant information. Latter occurs, if the dominant logic filters to much data or if it simply filters the wrong data, which means that the system‘s information processing capacity is burdened with irrelevant information. Therewith, the dominant logic decreases the adaptivity of CALS by negatively affecting its flexibility by decreasing the inflow of relevant information. This, in turn, leads to a decrease of the amount of information the system‘s sub-systems as well as their single elements are supplied with. Hence, the elements are equipped with a decreasing amount of information, which they can exchange between each other, which means, that their incentives to interact are decreasing as well. In other words, the dominant logic of CALS diminishes the heterogeneity of their elements and therewith decreases their innovation capabilities.

4 Autonomous Co-operation and Control – A Driver for Heterogeneity and Innovation Capability

In connection with the adaptivity and learning features of CALS the organizational principle of autonomous co-operation and control has been discussed [e.g. 15] and might therefore be a fruitful approach to countersteer against the described effects of a dominant logic in logistics systems as well as to decrease the intensity of a system's dominant logic itself. Because more and more centralized decision-making configurations have shown a lack of capacities and capabilities to cope with increasing complexity and dynamics in ISN respectively in CALS, the approach of autonomous co-operation and control gains more relevance for the design of global logistics network structures [42]. It becomes more feasible and realistic, because modern technologies (e.g. RFID), methods (e.g. collaborative route-planning), and instruments (e.g. multi-agent-modelling) deliver the necessary fundamentals [43]. The organizational principle of autonomous co-operation and control is based on the idea of self-organization, which has its origins in different fields of science, like cybernetics [44], chemistry [45], physics [46], and biology [47]. It aims at an explanation of the autonomous creation of ordered structures in complex systems and can be understood as "(…) processes of decentralized decision-making in heterarchical structures. It presumes interacting elements in non-deterministic systems, which possess the capability and possibility to render decisions. The objective of Autonomous Control is the achievement of increased robustness and positive emergence of the total system due to distributed and flexible coping with dynamics and complexity." [42, p. 9]. Besides all specific descriptions some common characteristics can be identified, which comprise decentralized decision-making, autonomy, interaction, heterarchy and non-determinism [42].

Decentralized decision-making refers to the delegation of decision-making power from a centralized entity (e.g. the disposition department or another planning unit) to the single elements of the system (e.g. employer, packages, industrial trucks) [42]. Therefore, not only one specific unit is capable and responsible for a certain number and quality of decisions, which are made for all the other elements in the system, but much more elements have the rights and capabilities to make decisions for their own area of responsibility. This is also described by the term of heterarchy. That means for an ISN that more elements that are equally enabled to undertake decision-making and that there is a significantly increasing decision-making capacity in comparison to a single-but-central-planning-unit. For the management of ISN this implies that the overall learning capabilities are increasing, too.

Another characteristic item, which is closely connected with the decentralized decision-making and which might be a pre-condition, is autonomy [48], which means, that every element in a system is responsible for itself [28]. That might include the responsibility for its own goals, strategies, means, organizational design, resources, etc. Autonomy needs a situation of a high-degree of non-determinism, otherwise the degrees of freedom were low and there were no chance for a free choice. Therefore, autonomy has a positive effect on the heterogeneity, if it leads to a situation, in which all elements of a system define their own aims, explore their own ways to achieve those aims, and learn about their environmental demands and the effects of their adaptivity and behavior. In this case, autonomy might be a facilitator for learning.

Interaction in ISN describes the fact that the system's elements are able to communicate directly with each other. Therefore, the elements (e.g. smart parts) are able to exchange more information for a certain problem-solving quicker, more precisely and demand-driven – in comparison to a centralized decision-making and order creation [42]. This implies a more target-oriented, effective, and efficient exchange of information. Because the single elements (e.g. RFID tags, intelligent sensors as well as personal executives) might be more capable to collect and process information they need for an upcoming decision, because only the needed portion of information is exchanged, not all the data for a whole ISN. Therefore, the overall amount of information an organization has to acquire and to compute might be increased, because more processes of the acquisition and procession of information can be executed parallel. This leads as well to higher and quicker learning processes, because feedbacks from the environment regarding a certain system's behavior can be recognized, interpreted, and exchanged more directly. The higher the degree of interaction is, the higher the learning capabilities will be, up to the point, which was already introduced as the edge of chaos [30,31].

These examples highlight the potentials of the implementation of autonomous cooperation and control and its associated technologies, in order to increase a logistics system's ability to learn. With recourse to the single aspects of organizational learning, mentioned by Bettis and Prahalad [36], as the determinants for the intensity of an organization's respectively a system's dominant logic, it can be stated, that the implementation of autonomous co-operation into logistics systems as well as the increase of its degree, might decrease the intensity of their dominant logics. Hence, logistics systems respectively CALS, that are organized by principles of autonomous cooperation have a higher degree of heterogeneity than systems that are organized by external control, which contributes therewith to their abilities to be innovative.

5 Conclusions

It has been shown, that the innovation capabilities of organizations within logistics systems respectively sub-systems of CALS are dependent on the degrees of heterogeneity of the systems' elements. One driver of homogeneity and therewith a barrier for innovations is the dominant logic, which in turn is dependent on the systems' as well as the systems' sub-systems' and elements' learning abilities. The adaptivity of a CALS as well as the phenomenon of dominant logic depend on the learning capabilities of such a system: The dominant logic diminishes the heterogeneity in a system; the learning capabilities increase the adaptivity of the system, but might be limited by an existing or evolving dominant logic; too much heterogeneity might lead to an excessive demand of the existing learning capabilities, which results in a dominant logic that reduces the heterogeneity, which might effect the innovation capability negatively. As one can see, there is a complex and ambiguous intertwining between learning capabilities, heterogeneity, and dominant logic. The implementation of the organization principle autonomous co-operation and control is a possible approach to countersteer against the intensity of the dominant logic as well as against the negative effects emanating from dominant logic by increasing the learning capabilities of CALS. Hence, autonomous co-operation facilitates the heterogeneity of the elements within CALS such as ISN and increases therewith their innovation capabilities.

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