A Stochastic Model using Self-Organization to explore the ICT Industry Evolution

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Abstract— **Motivated by the recent restructuring and convergence of the information technology (IT) and telecommunications (TELCO) industries and the business trend towards the formation of networks, this research focuses on examining the evolutionary dynamics of the convergent Information and Communication Technology (ICT) industry. The Agent-based Computational Economics (ACE) and Network Economics (NE) theories provide the theoretical background for studying the collaborative behaviour of firms in this economy, while the self-organization approach, adopted by the physics discipline, guide the development of a stochastic model depicting the value interactions of firms in the ICT industry. The paper's results, derived from the mathematical solution of this model, reveal the potential that the ICT industry will soon reach at a consolidation phase, featured by many firms or networks of firms of equivalent market power.**

Index Terms— **Network Economics (NE), Agent-based Computational Economics (ACE), Self-organization approach**

I. Introduction

For decades, the Information Technology (IT) and the Telecommunication (TELCO) industries had been characterized as relatively stable environments, which encouraged firms to sustain their market positions without any uncertainty [1]. However, in the last decade, a turbulent market has emerged due to several dramatic changes in the environment conditions, such as the market liberalization, the trend towards public firm's privatization, the technology evolution and the convergence of information, communications and media industries. As result, a process of major restructuring of these industries has been initiated. The resulting Information and Communication Technology (ICT) industry is now including firms that provide services of voice, data, and multimedia, which tend to be delivered over integrated wired and wireless IP networks.

Most firms need to cooperate with others to establish standards and create a single network of compatible users. T he same firms also compete for their share to that network. The term *co-opetition* captures the tension between cooperation and competition prevalent in network industries [7]. Various research studies have investigated that in the future, groups of firms in complementary markets will form collaborative networks in which knowledge is created and shared for business purposes. These are commonly called as multi-firm network organizations. Such organizations are the result of growth strategies of ICT actors, pursued through mergers, acquisitions and strategic partnerships across as well as within the same industrial environment.

This research aims at explaining the evolution of the convergent ICT industry with the aid of an analytical self-organization model. More specifically, the research question addressed concerns the emergence of self-organized markets in a decentralised technology-dominated economy. Such markets emerge as the result of multiple interacting firms (agents) who are themselves pursuing those interactions that are the most advantageous (valuable) ones, i.e. they are self-organized. The fundamental characteristic of these markets concerns a high degree of complexity, measured by either the number of agents that may interact, and thus total number of potential interactions, or the multiplicity of interactions that any agent of the network may hold. Moreover, such markets are characterised by rapid pace of evolution, mainly resulting from the intense cooperation activities of the less powerful agents. The rate of interactions decreases as more powerful agents emerge, and thus the market inserts into a consolidation phase. Using a stochastic model, this research reveals that the self-organization potential of the emergent ICT market may lead to the existence of many individual or network-structured agents with equivalent market power that keep an intense competitive relationship, and only a few agents holding the dominant and follower positions.

In Section 2, we discuss the research background of networks economics, which underline the formation of networks in the ICT industry, and justify on the use of self-organization and computational economics approach. Section 3 discusses the development of a stochastic model depicting the structure as well as the dynamics of the ICT industry, while Section 4 concludes with results, provided by the solution of the stochastic model's equations, and suggestions for future research.

II. THEORETICAL BACKGROUND

A. Network Economics

Many observers describe the current global economy as “flat” and “interconnected” [3].In such an economy, sustainable competitive advantage must thrive from creative, innovative and sophisticated use of knowledge as strategic factor that enables dealing with the challenges of pervasive globalization. It becomes clear that current strategies, structure and processes are inadequate for the firms considering the need to continuously generate new products and services. So, firms must create a structure that allow them to access new technologies, realize economies of scale and scope in their activities and shorten development time. This structure can take the form of a collaborative network in which knowledge is created and shared for business purposes.

Networking is a term familiar to most people either through social networks or through technological networks. One helpful definition of a business network is a group of firms using their combined talents and resources to co-operate for joint functions [2]. Alternatively, a complex business market can be seen as a network where the nodes are business units — manufacturing and service companies and the relationships between them are the threads. Both the threads and the nodes in the business context have their own particular content. Both are ‘‘heavy’’ with resources, knowledge and understanding in many different forms [4].

Networks have a fundamental economic characteristic; the value of connecting to a network depends on the number of the other people already connected to it. This fundamental value proposition goes under many names; network effects, network externalities and demand-side economies of scale. The network externalities signify the fact that the value of a unit of the good increases with the number of units sold. These all refer to the point that “bigger is better” in economics of network, introducing the essence of positive feedback which is the most potent force in the network economy [7].

There are many different types of networks and each is shaped by its objectives and membership. The following list provides several characteristic types of business networks [5]:

- A broad, non-industry specific network of companies or businesses that co-operate to varying degrees on issues of concern in their locality.
- A "cluster" of companies or businesses in the same or complementary industries which co-operate in a more defined manner.
- More formal "strategic alliances" that focus on commercial outcomes and which may incorporate one or more joint ventures on an ongoing or ad hoc basis.
- Supply chain initiatives/lead firm networks that are built around a dominant company in an industry or region wanting to build more efficient supply capabilities.
- Business communication networks that focus mainly on providing education and business development opportunities for members.

The unifying theme is firms co-operating and sharing knowledge or resources to increase their competitiveness. Firms seek benefits from participating in networks to achieve outcomes beyond their individual business capabilities.

B. Self-Organization and Agent-based Computational Economics (ACE)

The concept of self-organization introduced and caused a great revolution in physics and chemistry [14], [13] the last three decades. The main idea of the self-organization theory is based in the foundation that in complex systems where a large number of subsystems and multiple interactions between them are present, order against disorder emerged. In this line of reasoning, it is more than evident that network markets are maybe one of the clearest example of self-organized behaviour. Indeed, network systems reveal a high non-linear and self-interaction behaviour, since any small piece of crucial information about firms may trigger a very large response in decision strategies. Moreover, a network system is adaptive in the sense that firms change their decisions based on local or global received information about other firms. As a result, a network market turns to be considered as a very high complex system because of the presence of local and non-local interactions between them. Our ultimate research purpose involves defining whether a stable self-organized pattern of the examined market (network) exists, by investigating the evolution of their value because of the dyadic interactions developed between the individual firms (network nodes) participating in that. Moreover, the possibility of the proposed self-organized model to predict qualitative as well as quantitative aspects of real markets is explored.

The modern ICT industry is characterized by interaction, both direct and indirect between individual firms, considering the different ways in which they interact. Agent-based computational economics (ACE) is the computational study of economies modeled as evolving systems of autonomous interacting agents [9]. The ACE considers individual firms (network nodes) as agents [17] and supports that, as they learn over time from their previous experience about the consequences of particular interaction the interactions of agents finally take place through networks Thus the ACE theory can be used to model the actions of agents, where agents in that case include the individual firms or subnets of the examined market.

III. A SELF-ORGANIZATION MODEL FOR THE ICT BUSINESS NETWORK EVOLUTION

A. The Business Case

In the convergent ICT industry, firms compete to obtain or sustain their current competitive advantage. To do so, they decide to join forces and integrate with other partners. Integration may take several forms. At the one end (highest integration), we find mergers and acquisitions (e.g. OTE decided to fully acquire its subsidiary Cosmote). At the other end (lowest integration), we find cooperation agreements (e.g.

Vodafone Hellas cooperated with HellasOnLine to provide a commercial service package). At the intermediate section, we find strategic alliances, such as joint ventures and minority investments.

The selection of a specific integration mode may depend on several parameters, relating to either the organization itself (e.g. firm size, competitive position) or the environment (e.g. uncertainty, competition intensity). More recent research [6] has indicated that the type of integration pursued by firms may also depend on the value of the dyadic interaction. After that, each interaction – modelled as a link between two modes of a network- takes a value. Hereinafter, this value is measured in terms of value of resources/services exchanged. Moreover, each node has its own value, hereinafter measured in terms of knowledge that the firm possesses [8].

The following two sections discuss a research attempt to model the cooperation dynamics of the ICT industry applying a self-organization approach that explains the way in which firms choose to cooperate with other firms in the same industry. To this end, we have developed a model depicting the structure of the ICT industry in terms of a large network, consisting of smaller networks resulting from firms' cooperative activities. In this network, firms, comprising the network nodes, interact with other firms and decide those with which they wish to integrate taking into consideration the value of the potential partner as well as the value of the exchange between them. The interaction and cooperation between the network nodes may result in different integration modes, ranging from the most severe merger or acquisition to the joint venture and eventually to the less severe, but most common, contract-based agreement. While mergers and joint ventures result in the creation of a new entity as well as increase of partners' value, acquisitions and alliances result in increments to partners' current value.

B. Modeling Value Interactions within the ICT Network

Firms of the ICT industry are modelled as 'principal' nodes (P) in the network, if they comprise independent entities not resulting from other firms' alliance or integration. Instead, ICT firm are considered as 'secondary' nodes (S), if they have resulted from two 'principal' partners' integration (either joint venture or merger or acquisition). Firms' power is modelled in terms of value of resources and knowledge that they own. By defining the power of the firm in terms of knowledge, managers have the capability to assess their firms' market position in terms of knowledge. Moreover, they are provided with a new approach towards assessing the power of their competitors and partners based on the knowledge that they possess or the knowledge to which they have access. This new approach can help them to make more informed decisions on which networks to enter and with which partner to ally.

After that, firms' integration attempts are motivated by their desire to either acquire access to new resources or exploit complementarily of resources, and thus increase the value of their own resources. Due to value asymmetry, we have assumed that 'secondary' firms have not the power to either acquire 'primary' partners or merge with them or create a new joint venture. However, they have the power to acquire only 'secondary' partners. Firms' interaction is also assigned a value, hereinafter defined in interdependence with the power (value of knowledge) of the interacting firms.

Our research model is based on a set of business rules, defining the way as well as the results of firms' interaction within a network. First of all, there are four cases for 'principal' partners, P to interact: (i) Join an alliance, so each of them receives an added value, (ii) Acquire each other, so only the acquirer receives an added value, (iii) Create a new entity (joint venture) S with its own value, while the P partners keep on their traditional operations, and (iv) Merge into a new one S with its own value, while the P partners cease their operation. Second, there are two cases for a 'principal' and a 'secondary', P and S, partners to interact: (i) Join an alliance, so each of them receives an added value, or (ii) P acquires S, so only P receives an added value. Third, there are two cases for 'secondary' partners, to interact: (i) Join an alliance, so each of them receives an added value, or (ii) Acquire each other, so only the acquirer receives an added value.

Based on the self-organization approach applied in this research stream, the number of interactions that a firm establishes in a network is analogous to its accumulated value at the time of interaction. The following table presents all the alternative value interactions, as they were defined above. In the next section, we have developed a set of equations for modelling 7 out of the 8 business cases described in Table 1.

Table 1. Business Cases for ICT Partners' Interaction

Partners' Pair	Value For P	Value For S	Business Case
(P, P)	P+dP	-	Two primary partners' strategic alliance
	P+dP	-	Acquisition of P
	P-dP	S+dP	Merger of P resulting into the creation of the S.
	P+dP	S+dS	Creation of a new entity S as result of a joint venture between P.
(P, S)	P+dP	S+dS	One primary partner P and one secondary S partner ally.
	P+dP	S-dS	Acquisition of S from P.
(S, S)	-	S+dS	Two secondary partners ally
	-	S+dS	Acquisition of S from another S

C. The stochastic Model

As stated above, we consider a closed economy, in which firms are distinguished between primary and secondary in relation to their nature. In order to describe the evolution of the values of the two firm populations, the following set of differential equations is proposed:

$$\dot{P} = aP + bP^2(1-\frac{P}{K}) - cP^2 + (d+f_1)PS + \delta P \qquad (1)$$

$$\dot{S} = cP^2 + f_2 SP - dSP + \delta S \qquad (2)$$

where with dot we denote time rates and a,b,c,d,f_1,f_2 are constant coefficients modeling the corresponding rates of value changes. The various terms enters in the above evolution equations follows closely the discussion done in the previous section.

Indeed, in the first evolution equation of primary nodes, the first term on the right hand side models the increase of primary nodes value which is expected to be analogous to their present value: the bigger the value the higher the increase. The second term models the effect of two primary nodes alliance. This mechanism is expected to be limited by a saturation parameter (the term into the parenthesis) which models the fact that economy strategies limit the number of alliances in real markets. The third term models the alliance of two primary nodes in order to create a secondary node. This means that part of their value is loosen and gained from the population of secondary nodes, the first term in the second evolution equation. More over, the fourth term stands for the alliance of one primary with one secondary node, either in order both to increase their value with a rate f_1, either with acquisition of the secondary node from the primary with a rate d. The last term finally models random fluctuations of primary nodes value either because of random effects either because of the emerged complexity due to the multiple local and long range interactions.

In the second evolution equation of the secondary nodes, the second term on the right hand side models the alliance of one primary with one secondary node in order both to increase their value, the third term models acquisition of secondary nodes from a primary one while the last term again stand for random fluctuations of secondary nodes value because of system complexity.

In the context of the proposed model, the following assumption is of crucial importance; it is assumed that time duration of interactions between nodes is inversely proportion of their value. This is a reasonable assumption in real economy, since large firms are less flexible than small firms, when alliances are taking place. In the self-organization terminology, this means that evolution of secondary nodes is slaved to the evolution of primary ones, i.e. the secondary nodes are interpret as the fast variables and the primary nodes as the slow variables. As a result, since secondary nodes evolves in a fast time scale their random fluctuation average out and more over the second evolution equation can be considered that always reach its stationary state at any instant of time, in the time scale of the primary nodes, which results to the following evolution system,

$$\dot{P} = aP + bP^2(1-\frac{P}{K}) - cP^2 + (d+f_1)PS + \delta P \qquad (3)$$

$$\dot{S} = 0 \quad \text{or} \quad cP^2 + f_2 S - dPS = 0 \qquad (4)$$

Substituting (4) $\left(S = \left(c/d - f_2\right)P\right)$ to equation (3) the following final evolution equation for the system under consideration is obtained,

$$\dot{P} = aP + \frac{b}{K}P^2\left[K\left(1-\frac{c}{b}\frac{f_1-f_2}{d-f_2}\right) - P\right] + \delta P \qquad (5)$$

Equation (5) is a stochastic evolution equation. This kind of stochastic evolution equations are well known in literature and turned to be powerful tools in order to describe complex systems in many different fields, as physics, chemistry, biology, material science e.t.c. (see for example [12], [16]). To proceed further, it is noted that integration of Eq. (5) is not straightforward because of the rapid fluctuating last term. As a result some extra considerations about this term are needed. Indeed, in the simplest case we assume that random fluctuations coincide with a white noise process, $\delta P \equiv \dot{w}$ e.g. [15],

$$\langle \delta P \rangle = 0, \qquad \langle \delta P(t)\delta P(t') \rangle = \sigma^2 \delta(t-t') \qquad (6)$$

where σ^2 is the amplitude of fluctuations. Under this assumption Eq. (5) has the following form,

$$\dot{P} = g(P) + \sigma \dot{w},$$
$$g(P) = aP + \frac{b}{K}P^2\left[K\left(1-\frac{c}{b}\frac{f_1-f_2}{d-f_2}\right) - P\right] \qquad (7)$$

which in literature is referent as the well known generalized Langevin evolution equation [Gardiner]. The solution of this type of equation yields the probability $\mathrm{P}(P,t)$, which is the probability to find the value P of an arbitrary firm at arbitrary time t. For the stationary probability density $\mathrm{P_S}(P)$ the following solution is obtained [12],

$$\mathrm{P_S}(P) = N e^{\frac{2}{\sigma^2}\int^{P} g(u)du} \qquad (8)$$

where N is a normalization parameter. The stationary solution for the probability $\mathrm{P_S}(P)$ is the main result of the present article. It gives the distribution of firm values in a closed economy when interactions between firms are evolved in time. The distribution takes into account random effects as well as effect arising due to sort and long range interactions between nodes, trying to explore complexity. In Figure 1 a plot of the stationary distribution for arbitrary model parameters is given

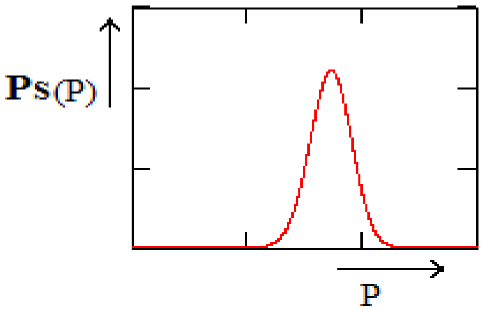

Figure 1: Stationary probability distribution from primary firm's value and for arbitrary model parameters.

Summarizing, the following two findings of the preliminary analytical stochastic model proposed are of main importance. First, the analytical model predicts that the ICT industry, herein considered as a complex adaptive system, exhibits a self-organized behavior and its evolution approaches a stable equilibrium state, instead of blow up and leading to chaotic dynamics. Second, in the emerging stationary state, there is a great probability that the industry will include firms or networks of firms possessing equivalent value, while firms or networks of firms with smaller and greater value are expected to emerge with decreasing probability. The most probable medium value of the firms or networks as well as deviations from this value can be predicted in terms of the model parameters in an analytical way.

IV. Conclusions and Future Work

This paper explains the evolution of the convergent ICT industry with the aid of an analytical self-organization model. More specifically, it addresses the emergence of networks that have occurred from multiple interacting agents in a decentralized technology-dominated economy. The emerging market is characterized by the high degree of complexity and also the rapid pace of evolution. The use of an analytical stochastic model is used to show that the evolution of ICT market exhibits self-organized behaviour leading the market system under consideration to insert into a consolidation phase. Moreover, the stochastic model has indicated that, in the stationary state, the emergent ICT industry will be characterized by the existence of many individual or network-structured agents with equivalent market power and only few agents holding the dominant and follower positions.

Our current research exhibits several limitations. The developed research model was introduced in a more or less phenomenological way. Indeed, the coefficients and the absolute values of the firm power in the proposed stochastic evolution equation are not parameterized. This is not an easy task since real data from existing markets as well as specific quantitative considerations for interaction mechanisms between firms are needed. In future, in order to parameterize the coefficients and absolute values of the firm power, a method for measuring the Intellectual Capital (IC) of the firm will be used. More specifically, the power of the firm will be determined in terms of its knowledge assets by applying a DIC method for measuring its Intellectual Capital. Moreover, the proposed model may be generalized to more complex situations where more than two population firms (IT and Telco) are considered. Indeed, taking as an example the present world economical crisis, there are market systems that are not stable in respect of system fluctuations (in contrast to the previous studied system) resulting in avalanche-like dynamic which eventually lead to chaotic dynamics with undetermined consequences. These systems may be examined in a robust way in the context of critical serf-organized systems.

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