Architecture of Resilience: Entropy, Connectivity, and Institutional Market Structures

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Extended Abstract

One of the ways to study and represent complex systems is to describe them as networks, in which different nodes are connected to others. Depending on the field of investigation, the nodes can be individuals, companies or other agents, and connections can be established by measuring the volume of monetary transactions, belonging to the same group or much more. It is possible to use the network structure to describe complex systems by adapting it to the most diverse research needs. The objective of this work will be to build a theoretical model that relates the connectivity architecture of a network with the type of output it provides and the related market institutional arrangement that derives from it. To this end, the relationships between information, know-how and entropy will be considered; in fact, these three elements will determine the degree of complexity of the output produced by the system which, in turn, will determine the consequent organizational form of the market. The market structure is an expression of the connectivity architecture of a complex system, such as to guarantee stability over time in the production of the same output. These architectures will therefore be more or less rigid, depending on the final product, and based on these characteristics it will be possible to deduce the efficiency and redundancy capacity and, eventually, the overall resilience of the system.

The work moves from the framework theorized by Hidalgo (2015) that focuses attention on the information and know-how that individuals and networks can store and use.

What the agents of a network exchange, be they individuals or businesses, are information, knowledge, and know-how. Each node of the network has a limited capacity to collect information. Similarly, a network, with related relationships, describes a system of information flows between nodes and, overall, it has also a limited capacity to contain information. The economy of each country, region, industry, or district can therefore be described as a network within which information circulates and whose capacity to accumulate and transmit knowledge and know-how is limited. Comparing different networks with each other, the result is an unequal spatial accumulation of knowledge and know-how between the networks depending on their organization and extension.

On this view, the composition of a nation's exports informs us about the knowledge and know-how of its inhabitants. In these terms, economic development consists not in the ability to buy commodities but rather in the ability to create and innovate goods and services (Hidalgo, 2015). The outputs produced by a network are nothing more than the expression of the system's ability to process the available knowledge and know-

how, through adequate technologies and institutions that avoid the dispersion of information, by concretely transforming them into ordered states, i.e., the outputs of production processes. The products of an economy can therefore be described as physical expressions of information in which the practical applications of knowledge and know-how are contained.

The complexity of an output can be viewed as the ability of a specific system to organize the information contained in it. Among the different identifiable networks, such as the economic structures of different countries, the ability to create products of different complexity is distributed on a global scale in a heterogeneous manner.

To be able to produce highly complex products, larger and more organized networks are needed. They can contain a lot of knowledge and at the same time exhibit high computation capacity. Therefore, the connectivity architecture with which a system is structured to produce complex products will be decisive. In this sense, central to the network and its hierarchy is the ability to organize a "Smithian" division of labor between the different nodes. The division of labor is also accompanied by the division of knowledge and know-how. Computing and information capacities are thus distributed in the network. The fragmentation of know-how leads to the emergence of a difficulty, introducing a combinatorial problem, that of connecting the nodes in a structure that allows us to reconstruct what was fragmented. This is where the vulnerability of a network arises. For complex products, it is necessary to fragment tasks, knowledge, and calculation capacity. By distributing these quantities along the network in a hierarchical manner, the risk that a shock could interrupt fundamental connections to produce output exposes the network to idiosyncratic vulnerabilities.

To give an example, to encompass the knowledge and know-how needed to manufacture computers requires networks with a different connectivity structure than that needed to produce pins. A certain output complexity requires a specific connectivity architecture with specific characteristics of vulnerability, efficiency, redundancy, and resilience. The business networks needed to produce computers will be different from those to produce pins. The institutional form that the different markets for these products will take will also be different.

The work aims to generalize and identify the relationships between knowledge, know-how, production complexity, entropy, and connectivity architecture with the different market forms.

A greater amount of knowledge and a high computational capacity can lead to the production of outputs with a high degree of complexity. A product can be understood as a specific and organized composition of information; the greater its complexity, the greater the organizational specificity of the information contained in it and the lower the entropy of the complex system that generates the specific product. In this work, entropy is therefore understood as a measure of dispersion or loss of information within a system. The greater the complexity of the output – i.e., *organized complexity* - the lower the dispersion of information in the system.

To obtain highly complex outputs, the connectivity architecture of the production system able to guarantee adequate knowledge, calculation capacity and division of labor will be highly rigid, with invariant intermediate forms and scale-free distribution with the presence of hubs and subsystems organized around them. Such relationships between companies and business systems will impact the form of products' market that will emerge, depending on their degree of complexity. In general, highly complex products can be produced in institutional forms close to monopoly and more generally characterized by oligopolies. Examples are the automotive, high-tech sectors, and pharmaceutical ones, all characterized by highly complex outputs. On the contrary, for low-complexity products, the final market is generally organized into forms that tend more towards competition, e.g., clothing, low-skilled services, and agriculture. For low-complexity products, the connectivity structure of the system will inevitably be different, characterized by a distributed arrangement and the absence of hubs.

To summarize, the different connectivity architectures depend on the degree of complexity of the output to be produced. These different architectures imply fundamental features in terms of redundancy, efficiency, vulnerability, and resilience of the systems.

In fact, for complex outputs, network architectures are needed that can store ever-increasing knowledge and know-how and that can specifically organise them without creating entropy in the system. In this sense, high standards of efficiency will be necessary, benefiting from economies of scale and reducing unnecessary costs. In this view, a framework modelling the trade-off between system efficiency and system redundancy will be proposed, useful for mitigating vulnerability and developing network resilience.

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