The actor-network model of economic networks in a geo-economic context: the conceptual considerations

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Abstract

Contemporary economic networks operate in a turbulent geo-economic context in which the external environment determines the formation or disintegration of such networks. The article focuses on economic networks through the prism of network analysis, actor-network theory, and network theory. As a consequence, the authors attempted to develop an actor-network model, taking into account the geo-economic context, social and technical actors, their roles and positions in the economic network, and network measures (centrality, knowledge/resource/task diversity, and redundancy). Due to the conceptual nature of the article, a less formalised, narrative literature review was used, which allowed for the free selection of literature and its interpretation in the context of the research question posed. As a result, a conceptual actor-network model for economic networks was created, understood as a framework for the analysis of the network of relations, interactions, and interdependencies occurring between the socio-technical actors of the economic networks through the prism of the allocation and distribution of information, knowledge, resources, and tasks. The actor-network model is the starting point for further, more advanced research, as well as the operationalisation and validation of the model, which would contribute to the actor-network theory and network theory. In this conceptual form, the presented actor-network model seems to be universal, and its application is possible whenever we can identify actors and the relationships between them. Its implementation in the study of economic networks in any sector is conditioned by the definition of social and technical actors; their relations, roles, and positions in the network affecting the efficiency of the network as a whole.

Key words

actor-network model, economic networks, network efficiency, actor-network theory, network theory, geo-economic context

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Introduction

The opening of markets, the interconnectedness of economies, and the rapid evolution of geo-economic contexts force us to consider economic networks as spatially distributed flows of knowledge, resources, and shared activities. It is the variable geometry of connections and co-interests, networks and relationships which lead to network thinking. These, in turn, affect the world in which we live and their offshoots structure networks, which are becoming one of the main paradigms of our times. Economic networks are becoming increasingly connected and integrated, which leads to the possibility of having universal access to resources, as well as information and knowledge. The current speed of technology research and exploitation cycles (Jabbour et al., 2019), together with the innovation process resulting from the integrated use of existing or emerging technologies and resources, will lead to a more significant acceleration of change. Likewise, the traditional margin of technological superiority held by capabilities for military use has eroded, to the benefit of civilian technologies, where often these are also available at a lower cost, leading to a broader possibility of access to technologies and resources, including more sophisticated ones. This will widen the opportunities for their use by non-state actors against enemies or opponents, significantly diminishing the capacity for prevention and control of the state bodies in charge. It therefore becomes essential to study and understand the present and future relationships of the actors in the geo-economic context and to define a network analysis approach that could be helpful in learning these changes.

Discovering the existing literature and applying it to our modern scenario, the article aims to identify an actor-network model which is useful for synthesising and providing a representation of perception regarding links and relationships between different actors in economic networks. In this way, it is possible to define what we know to analyse the actor in a specific context and what we need to know through the straightforward validation, analysis, and verification of information, with the integration of structured analysis techniques. The conceptual aim of this article is to point out that using the actor-network model helps broaden the knowledge and forecasts of research in the economic networks that consequently presuppose the study of economic interconnection and rapid evolution of the geo-economic contexts.

The research question we attempt to answer through these conceptual considerations is: *RQ: How can network analysis and the identification of network roles in an actor-network model contribute to understanding the complexity of interactions and links between economic network actors?*

In previous research (e.g. Lo Re et al., 2015; Saviotti, 2009), cognitive and predictive goals have been linked to the study and analysis of limited and restricted areas of knowledge. We instead try to outline a reference synthesis that sees network analysis as a natural ally in identifying those critical nodes that are essential to providing a valuable framework for analysing the inevitable centrality of economic-social facts. Based on the last decade of literature on economic networks (among others, see: Fang et al., 2019; Jackson and Wolinsky, 1996; Jin, 2007; Oerlemans et al., 1998; Piccardi and Tajoli, 2018; Schweitzer et al., 2009a; Schweitzer et al., 2009b; Sexsmith, 2009; Xu et al., 2014)1996; Jin, 2007; Oerlemans, Meeus, & Boekema, 1998; Piccardi & Tajoli, 2018; F. Schweitzer, Fagiolo, Sornette, Vega-Redondo, & White, 2009; Sexsmith, 2009; Xu, Zhang, & Wu, 2014, we developed f an actor-network model, thanks to which it has been underlined that network analysis has helped economic and social scientists to approach the theory, methods, and empirical applications.

Our considerations are of a conceptual nature. The proposed actor-network model is a starting point for much more advanced network research. However, its framework bears the hallmarks of a universal approach to studying actors, information, knowledge, resources and tasks from the perspective of a network of relationships, interactions, and interdependencies occurring in a given sector or industry. Then it is up to the researchers to interpret the actors, information, knowledge, resources, and activities in the network of relations.

1. Theoretical background

An economic network is formed by actors (economic agents) acting on the basis of institutionalised forms of cooperation or informal relations based on flows of tangible and intangible resources used in economic exchange (activities). Network actors demonstrate specialisation and bring to the network a unique ability to create value, such as knowledge resources or market access. In these considerations, the assumption of the dependence of the economic network on the social network will prevail. Economic networks create specific rules and norms of economic and social behaviour, which are informal, often based on interpersonal and inter-organisational relations. In the network ecosystem, the decision-making processes of economic entities are connected simultaneously with the norms and principles which are binding in economic and social networks. Valuable theoretical perspectives to create assumptions of the concept of the economic network are actor-network theory and network theory.

1.1. Economic networks in terms of actor-network theory

Actor-network theory (ANT) goes beyond the analysis of social actors and considers the interaction among social and non-social actors, or only among non-social actors (Czarniawska, 2017). An example of such a relationship is the impact of knowledge and resources on performing tasks within economic networks. As in the case of social network analysis, positive or negative changes related to a specific actor (adding/losing a tie and/or an actor) often influence the entire network, its evolution, deterioration, and even destruction. Socio-technical relations (also known as a sociogram and technogram) are visible, for example, when a specific resource is not used by its intended user. This approach is widespread in research related to tourism (Dedeke, 2017; Jørgensen, 2017) or knowledge sharing (Twum-Darko and Harker, 2017). In the case of a sociogram, the analysis of social networks is applicable (Wasserman and Faust, 1994). A technogram includes technical elements (e.g. resources or infrastructure) that are analysed in the context of a given place where relationships between actors take place. Thus, socio-technical networks are interrelated, and should be investigated. Actors and networks are mutually constitutive, creating the dynamics of actors interacting with each other, affecting the network. The network consists of actors who cannot act without the network (Callon and Latour, 1981).

ANT assumes that the inclusion of technical and social actors in a network of relationships is inevitable, meaning that no elements exist outside the network, making all elements of the network-actors, such as roles or functions, interrelated. These relations make the economic networks dynamic. The choice of an actor for which individual actions are analysed affects the involvement of other actors in terms of undertaking assigned roles (e.g. position and influence in a network; using a specific knowledge or resource to perform a task). In this way, the dynamics of relationship-building processes within the emergence and disintegration of economic networks are rendered. The configuration of resources within economic networks occurs in multiple social, socio-technical, and technical relationships. According to ANT, resources are considered volatile because changes in the links between actors or technologies can lead to different resources and interdependencies with other actors (Law, 1992). However, the possibility of considering resources as having their own dynamics is still an open question for discussion. In the context of the economic network, we may observe many relationships, both material and semiotic. Analysis of the economic network requires the recognition of actors, their knowledge, resources, and activities (tasks) that create interacting elements within a given network, forming an actor-network. No actor acts alone for itself but under the influence of a complex material-semiotic network.

1.2. Economic networks in terms of network theory and analysis

Network science grew out of graph theory (Barnes and Harary, 1983), matrix algebra (Shimbel, 1951; Luce and Perry, 1949), and network statistics (Brinkmeier and Schank, 2005), which are used in network analysis. Networks permeate the economy, technology, or business. Economic networks are characterised by a complexity of relationships and connections, creating a system of relationships (Barabási, 2016) and a structure based on the behavioural dynamics of nodes (actors) and links in the network. The behaviour of actors (social and technical) in the network of relationships determines the network models, which are representations of the economic networks of interest in which actors depend on each other. The basic premise of economic network theory is thus to conceptualise an economic network in which a set of multiplicative relationships links technical and social actors, and to understand how they function. The co-sharing of activities, the distribution of resources, the flow of knowledge and information, and the co-creation of value in a chain are basic examples of relationships in an economic network.

Network research focuses on the relationships between actors embedded in a network of interrelated relationships that influence the behaviour of an economic network. The network approach is dominated by a focus on relationships, on structured patterns of interaction, rather than on individual characteristics (attributes) of individual actors (Brass et al., 2004). Network models that focus on the individual actor capture the structural environment of the network that creates opportunities or constraints for the individual actor's action in the network. Also, network models enable the conceptualisation of an economic, social, and even political network structure based on persistent (at least over a certain period of time) and identifiable patterns of relationships among actors.

An economic network consists of nodes (actors) connected by a set of specific ties. Ties can be strong, weak, direct or indirect, which affects the position of an actor in a given network. An actor's position in a network can be measured by centrality measures, which indicate how important or influential an actor is in an economic network (Brass et al., 2004). Tie strength is the frequency and intensity of interactions, the duration of relationships, and the closeness between two actors (Granovetter, 1973). In turn, network density and network integrity (Scott, 2012) determine the properties of the network as a whole. Thus, in an economic network, relationships, the flow and use of resources, information, and knowledge are related to the implementation of activities aimed at the co-creation of value in the network. The essence of the functioning of an economic network is primarily interaction, that is, the continuous exchange of information, knowledge, and resources that occurs between actors who take joint action creating a network structure (Alba, 1982).

Within an economic network, ontology classes (unimodal and bimodal) of node segmentation are created. Given two ontology classes, one or more networks can be distinguished that consist of a given type of relationship between nodes. Most of these economic networks are unimodal, such as social networks, which cover relationships between economic actors. In contrast, bimodal (socio-technical) networks connect network nodes in one ontology class with another (e.g. a resource used by an economic actor). There are also technical networks where social actors (economic actors) are not directly involved (e.g. blockchains). Networks can be interpreted in terms of their ecology, meaning that multiple networks, such as information networks, knowledge networks, resource networks, or task networks, influence each other (Carley, 1999; Ujwary-Gil and Potoczek, 2020). Changes in any part of this network ecology affect all other parts, and the behaviour of the entire system is a function of how these networks are interconnected.

2. Methodological approach

The methodology was based on qualitative research using a narrative literature review, establishing our own point of view on the topics discussed, which does not exclude the identification of the state of knowledge in the subject of research for the creation of new knowledge and the conduct of empirical studies (c.f. Florek-Paszkowska et al., 2021; Gancarczyk and Ujwary-Gil, 2021). The small number of scientific papers devoted to economic networks, indicating that it is still an underdeveloped field of research, argued for the choice of this method. The narrative review allowed us to focus on studies closely related to economic networks and to formulate conclusions by referring to theoretical and empirical studies (van Knippenberg, 2012). The method gives the researcher a certain freedom of action in terms of literature selection, namely which studies should be included and which should be excluded from further analysis. The narrative review allows us to capture qualitative differences between studies, combine different concepts and indicate the context of the problem, go beyond the synthesis of previous studies, make a new contribution in the form of original inference, and indicate fields for further exploration or conceptual elaboration (Jones, 2004; Bryman, 2021). These assumptions reflect the research approach adopted in this article.

For the analysis of the research question identified in the introduction, the papers for the narrative review were selected through a keyword search, inclusion and selection of scholarly studies included in peer-reviewed scholarly journals in the Web of Science and Scopus databases. Despite the relatively small number of results obtained (136 in the Web of Science database; 150 in the Scopus database), closer examination of the abstracts revealed the unsuitability of most studies in the context of the research question posed. To understand the essence of economic networks, the focus was mainly on sources with the phrase “economic networks” in their title. In order to avoid selecting papers that are not closely related to the research area of interest (economic networks), the search results were mainly limited to the title of the articles, which increases the likelihood of accuracy in document selection. There were 136 documents in the Web of Science database (in the period 1960-2020), including 60 articles, 41 reviews, 18 meetings, eight editorials, and nine books. Another 150 documents appeared in the Scopus database (during the period 1969-2020), including 89 articles, 29 conference proceedings, 16 book chapters, five books, seven reviews, and four editorials.

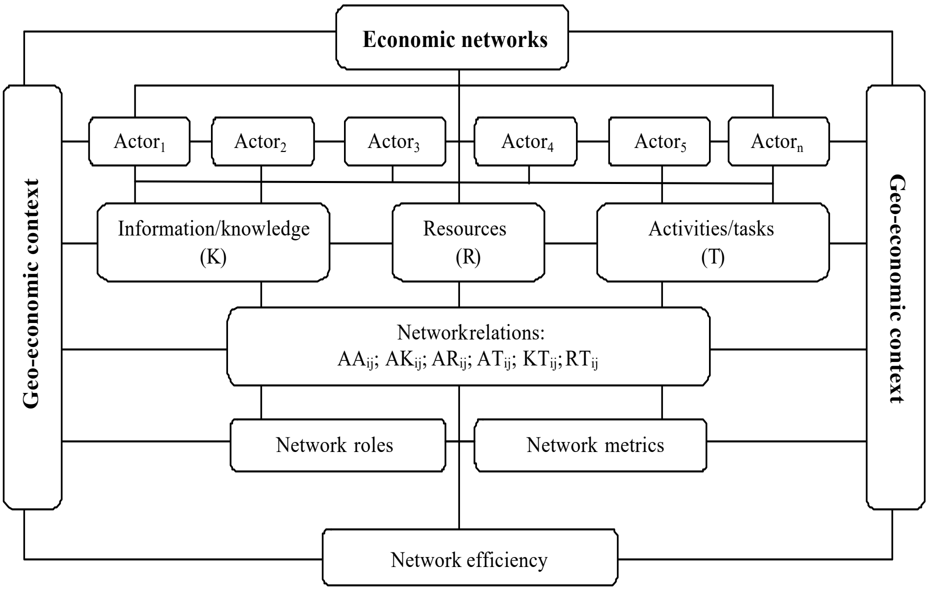
The selected sources were intended to provide a broader theoretical context for the review, consequently formulating research questions for further exploration. We focused mainly on contents in the field of actor-network theory and network theory to develop the concept of an actor-network model and elements of its operationalisation in the form of network metrics. Our narrative approach ends with an indication of research limitations, directions, and questions. The narrative literature review does not cover all published sources, but it provides a good starting point for in-depth systematic literature studies and future quantitative research.

3. Conceptual contribution

3.1. Actor-network model

When studying economic networks where many elements interact in different ways, two approaches are possible. The first is to identify the actors and their intentions, while the second consists of grouping elements into homogeneous sets. The network approach seeks to integrate these two points of view, halfway between the description of individual elements and that of large groups. From the perspective of analytical experimentation, it is appropriate to apply network analysis to assess the economic actor in geo-economic scenarios (Figure 1).

Figure 1. Actor-network model for economic networks



Source: own elaboration

By studying the network structure, the acquired abilities, and the intent of each node, it is possible to understand how that network evolves in time and space. The actor-network model demonstrates a framework from the actor's perspective within a given context, i.e.: the dynamics of the structure in terms of inter-organisational relations; the presence of leaders and roles; internal links; technical and social equipment in terms of human and technological resources; external links; competitive positioning; and activities to external stimuli. The general conceptual framework for analysing economic networks is based on diverse ties that can be established between actors in the system, such as service development or collaborating on a new product, belonging to the same trade value chain, having overlapping board membership, delivering materials, or being linked through a contractual relationship.

3.2. Economic network roles and centrality metrics

Economic actors' positions have specific implications for their network roles. Table 1 presents an overview of the theoretical implications of central nodes with the possible related key centrality metrics.

Table 1. Economic network roles and key centrality metrics

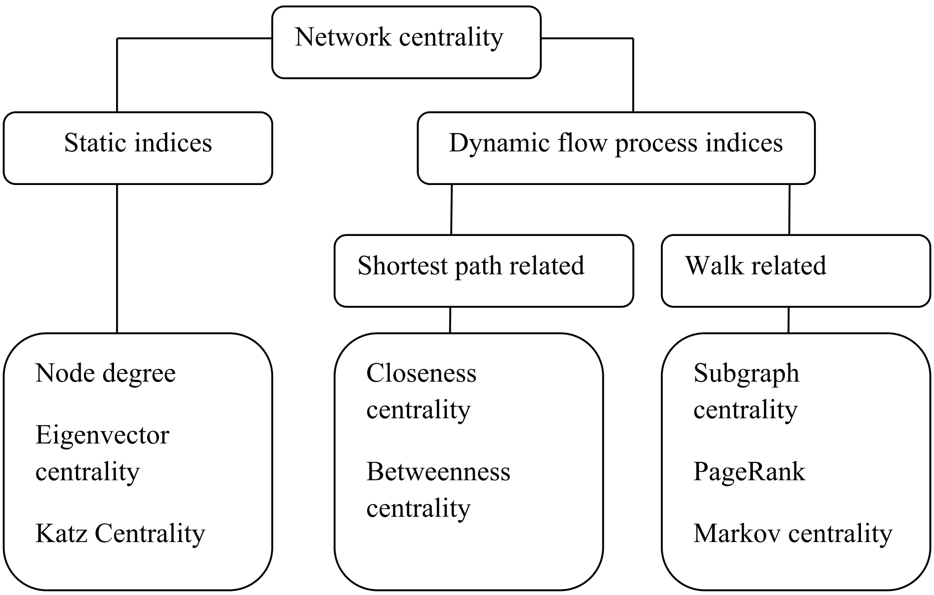
Economic network roles	Description of the key finding	Main centrality metrics
Pivot or strategic actor	To control or facilitate the flows of the system across the whole network.	Betweenness centrality
Broker	To intermediate dealings between actors and turn them to their own advantage.	Betweenness centrality
Headquarters	To take full responsibility for managing all business activities. It denotes the actor or location where most, if not all, of the important functions of a system or organisation are coordinated.	Degree centrality
Coordinator or influencer	To mitigate differences among network participants and come to a compromise.	Degree centrality
Facilitator or spoke	To act as a liaison between actors, stakeholders and information sources with a position within a network or business activities.	Degree centrality
Integrator	To transform different raw materials or parts into a product.	In-degree centrality
Buyer	To acquire, own, benefit, or use goods and/or services under a sales contract; experienced in purchase negotiations, market analysis, supply coordination, bulk purchasing; specialised in a specific group of goods or services.	In-degree centrality
Hub	To connect nodes or segments in a network.	Out-degree centrality
Allocator	To allocate (distribute) restricted resources across multiple customers.	Out-degree centrality
Navigator	To collect, access, and explore various information with greater autonomy in the network.	Closeness centrality

Source: own elaboration

It is worth noting that the meaning of network measures is indicated by the nature of the relationship between nodes. Exploration of the international trade as goods (or information) flows among entities (countries) has been initially proposed in the context of sociology and political sciences (Snyder and Kick, 1979). The network approach in international economic relations has been used to describe the critical geopolitical situation and a possible explanation for economic and social crises (Fagiolo et al., 2010). Network analysis as a general framework provides theoretical support in investigating complex network topology (Boccaletti et al., 2006) and allows us to describe emergent properties of a complex system. Such an analysis can change the point of view from the macro- (the entire network structure) to the micro-scale (node properties) level. In particular, the network centrality indices (Borgatti and Everett, 2006), which describe particular features of single nodes within the network, characterise each component taking interactions of the entire system into account. This is useful in situations in which the single variables of a system cannot be simplified efficiently in a linear model.

A set of particular centrality indices can be chosen in order to study a given problem. In our actor-network model, we divided these indices into two classes: i) describing local interactions among nodes (only directly linked neighbours); ii) describing a more pervasive relation among nodes (taking nodes which are not directly linked into account). The first indices quantify static properties, while the second quantify dynamical properties (Borgatti, 2005)or at least popular interpretations of these measures, make implicit assumptions about the manner in which traffic flows through a network. For example, some measures count only geodesic paths, apparently assuming that whatever flows through the network only moves along the shortest possible paths. This paper lays out a typology of network flows based on two dimensions of variation, namely the kinds of trajectories that traffic may follow (geodesics, paths, trails, or walks. In particular, static indices are useful in a system where links correspond to shared properties among nodes. In this case, a relation between two given nodes cannot transfer to a third node connected to one of them. Conversely, whenever a spreading flow process is possible among nodes, a particular quantity of something can be transferred to other nodes which are not directly connected, then the dynamical indices are indicated to be used. A schema of the previously described subdivision is shown in Figure 2.

Figure 2. A schematic representation of network centrality metrics as a function of the different nature of economic networks



Source: own elaboration

On the left side, centrality indices describe a network in which links correspond to shared properties among nodes; while on the right side, centrality indices describe a network in which links correspond to a spreading flow process among nodes. The static indices concern the node degree, i.e. the sum of links around nodes. This value describes that nodes which have the most connections in the network. Extending this concept to a directed network, the node degree can be split into in-degree and out-degree, indicating node outstanding in- or out-connections. Finally, in the weighted network, such an index is calculated by the sum of node weights. This value is called the strength of a node (in- and out-strength for the directed and weighted network).

An extended version of the previous measure is eigenvector centrality (Bonacich, 1972). This index calculates the influence of a node as proportional to the sum of the centralities of its neighbours. Then, a node has a high value of this index if it is connected to others which themselves have high values (Newman, 2004). In such a way, the influence of a node can be extended from the immediate neighbours (node degree) to the other nodes connecting the node through these immediate neighbours. It is worth noting that such a measure concerns a system in which each node simultaneously affects its neighbours (Bonacich, 1987) and cannot be used as an indicator for a dynamical flow process. While eigenvector centrality can be calculated in both binary and weighted networks, due to a computation problem, such an index could have a misleading interpretation in a directed network. A related measure such as Katz's centrality can be used (Katz, 1953).

As a general remark, in terms of flow process, we propose to rank a node by its ability to be a source, a sink, or a middle-bridge. A source is a node with a high probability of sending something to other nodes; a sink is highly likely to receive something from other nodes; and a middle-bridge is a node passing in most of the trajectories among nodes. Some issues arise in this framework: i) this concept is not applicable in the undirected network since all nodes are interconnected without a clear source. However, the sink and middle-bridge nodes remain possible; ii) the in-degree and out-degree in the directed network can be used to characterise these different node roles. Yet this measure lacks a straightforward generalisation of the entire network spreading process. Then, a new set of indices are introduced to improve node characterisation in the dynamical flow process. In order to understand the following indices, some concepts should be defined: i) a walk is a sequence of links between connected nodes in which the trajectory can pass several times on the same link; ii) a path is a walk in which links are crossed only one time; iii) the shortest path is the path with the lowest value of links in the sequence. In weighted networks, the corresponding values are calculated by the sum of link weights, while in directed networks, the sequence must be composed of links with the same direction. Consequently, the dynamical flow process indices can be divided into two other classes: shortest path-related indices and walk-related indices.

Metrics focusing on the shortest path are helpful in a system. In particular, the path minimises the time-traveling among nodes or the loss of energy in each passage. To understand this concept, it is helpful to visualise a transfer process in which a small amount of transferred quantity is lost at each passage. Then, in such a process, an economic and efficient path to transfer flow is the shortest one. This class is composed of closeness and betweenness centrality. Closeness centrality is defined as the inverse relationship of the sum of the shortest path between a node and all other nodes in the network Betweenness centrality estimates how many times a given node is crossed by the shortest path (Freeman, 1977). Nodes with the highest value of this index play the role of a middle-bridge with the following properties: i) control function of flow (switching among different paths); ii) the efficiency function, since the general integration of the entire network decreases upon removal of these nodes (Motter, 2004).

The second class of dynamical flow process indices can characterise a system with no particular way to pass through nodes. In this case, it is beneficial to study the properties of nodes without the constraint of transferring. The first of these is subgraph centrality (Estrada and Rodriguez-Velazquez, 2005), which is the sum of closed walks of different lengths in the network. Thus, in this case, a node is a source and a sink at the same time. A second index is PageRank centrality (Brin and Page, 2012). This value concerns a Markovian dynamical system in which, starting from any node, the probability of the node itself being an end station is estimated (considering all the possible walks around it). Thus, this index describes the probability of a node being the end-station in a dynamically spreading flow process (sink). Finally, new versions of closeness and betweenness centrality have been introduced. They are called Markov centrality (White and Smyth, 2003) and random-walk betweenness (Newman, 2005) respectively. Research by Blöchl et al. (2011) clarifies their usefulness in terms of an input-output of goods and services flows between different sectors of the economy.

3.3. Multimodal metrics and economic network efficiency

More sophisticated network metrics such as diversity and redundancy come from multimodal networks (Table 2). Knowledge diversity (KD), resource diversity (RD), and task diversity (TD) measure the availability and the even or uneven distribution of knowledge, resources, or tasks in economic networks. Economic network actors share information, knowledge, resources, and tasks, creating cognitive networks based on mutual interactions of actors making choices based on their perception of other actors in the economic network. The flow of knowledge, resources, and tasks is crucial to the efficiency of the economic network (Cai and Szeidl, 2018; Ujwary-Gil, 2019). Knowledge redundancy (KR), resource redundancy (RR), and task redundancy (TR) indicate where there is an excess or shortage of knowledge, resources, or tasks in the economic network and how they can be managed (Altman et al., 2020). Both redundancy and distribution describe the allocation of knowledge, resources, and tasks in economic networks, indicating the percentage of actors with access to the same knowledge, resources, or tasks.

Table 2. Economic network efficiency metrics

Knowledge diversity	Knowledge redundancy
let $w_k = \sum_{i=1}^{\lvert A\rvert} AK(i,k) \text{for } 1 \le k \le \lvert K\rvert$ and $W = \sum_{k=1}^{\lvert K\rvert} w_k$ then knowledge diversity (KD) is: $KD = 1 - \sum_{k=1}^{\lvert K\rvert} (w_k / W)^2$	$KR \in [0, (\lvert A\rvert - 1) * \lvert K\rvert]$
Resource diversity	**Resource redundancy**
let $w_k = \sum_{i=1}^{\lvert A\rvert} AR(i,k) \text{for } 1 \le k \le \lvert R\rvert$ and $W = \sum_{k=1}^{\lvert R\rvert} w_k$ then resource diversity (RD) is: $RD = 1 - \sum_{k=1}^{\lvert R\rvert} (w_k / W)^2$	$RR \in [0, (\lvert A\rvert - 1) * \lvert R\rvert]$
Task diversity	**Task redundancy**
let $w_k = \sum_{i=1}^{\lvert A\rvert} AT(i,k) \text{for } 1 \le k \le \lvert T\rvert$ and $W = \sum_{k=1}^{\lvert T\rvert} w_k$ then task diversity (TD) is: $TD = 1 - \sum_{k=1}^{\lvert T\rvert} (w_k / W)^2$	$TR \in [0, (\lvert A\rvert - 1) * \lvert T\rvert]$

where:

$|K|$ – number of elements in set K (knowledge)

$|R|$ – number of elements in set R (resources)

$|A|$ – number of elements in set A (actors)

$|T|$ – number of elements in set T (tasks)

Source: own elaboration based on Altman et al., (2020); also used by Ujwary-Gil, 2019 and Ujwary-Gil, 2020

A unimodal information network (AA) is comprised of economic network actors (A), contributing to information exchange, social contact, resource control, and task allocation. In the economic network, actor $_i$ (A_i) is related to actor $_j$ (A_j) in the economic network forming a relationship matrix (AA_{ij}) if actor $_i$ transmits or receives information to/from actor $_j$. The bimodal knowledge network (AK) allows for the identification of flows and bottlenecks related to knowledge (K) in the economic network. Information pertaining to the knowledge (K), resources (R), and actions (T) of other actors can be indicators of economic network performance. Actors within a knowledge network (AK) are interconnected through interdependent knowledge flow and transfer, or formalised rules and procedures (Pugh and Prusak, 2013). A knowledge network is defined as a collection of actors that create, deliver knowledge, coordinate, learn, and develop innovations (Bourouni et al., 2015). In such a network, nodes (actors) are both sources and consumers of information and knowledge. Through an economic network, actors can access information, knowledge, or valuable resources. In a knowledge network, an actor occupies a specific position in the network (central, intermediary, or peripheral), which creates different opportunities to access new knowledge needed to perform tasks (Wu et al., 2012). The knowledge network (AK) consequently determines what knowledge the actors in the economic network possess, who uses it, and how. A link in the AK network indicates that actor $_i$ (A_i) is linked to knowledge $_j$ (K_j) if the actor possesses and/or uses knowledge $_j$ (AK_{ij}) in its actions. Similarly, the resource network (AR) can be visualised in the context of access and use. Resources (R) in an economic network are used by actors (A) to perform tasks. Actor $_i$ (A_i) is associated with resource $_j$ (R_j) if the actor accesses or uses the resource in actions (AR_{ij}). Knowledge use (K) is related to a specific task (T) in which knowledge is applied (KT), then there is a relationship KT_{ij}. Tasks (T) are a key element of the economic network (A), which are performed by specific actions of actors involving both resources and knowledge. With a simulation focused on nodes such as the actor, knowledge, resource, or task, it is possible to illustrate how the characteristics of the economic network affect the degree of their utilisation and the coordination of knowledge/resources/task acquisition. An actor-task association (AT_{ij}) occurs if actor $_i$ (A_i) can do or does a given task $_j$ (T_j). Resources ® provide the potential for action (T) by creating a network of resource and action links (RT_{ij}). When resource and task nodes are identified, the value of a resource is defined in terms of its use in an action (Milgrom and Roberts, 1995).

4. Discussion

4.1 Implications for economic networks resulting from actor-network theory and network theory

With actor-network theory, we can better understand why and how economic networks work by analysing the network of influences that shape the behaviour of social and technical actors. Each socio-technical actor is equally important to the network. A comprehensive and multimodal view of the actor-network structure allows us to identify and analyse the performance of the actor-network, taking into account the dynamics of change in this structure (the addition or removal of actors or relationships from the economic network). Combining socio-technical elements (Steen, 2010) encourages a detailed description of specific mechanisms connecting the networks and how specific they are to the context and located within the social relations and dynamism of power. Network heterogeneity analysis can be a way to map the diversity and complexity of knowledge, resources or activities, and their relationships in an economic network. A deeper analysis of socio-technical networks in economic networks can foster future technological development.

The multimodal network perspective used to diagnose and analyse economic networks allows for the identification of networks of resource flows, their allocation, and the optimisation of planned and allocated activities (Tsvetovat and Carley, 2004). Relationships result from complex and multiple interactions between socio-technical actors and formal and informal links in the economic network (Schipper et al., 2015). Network analysis provides a good starting point for measuring the effectiveness of an economic network, including resource efficiency and the ability to model relationships, identify patterns in such networks, and uncover the impact of network and relationship changes on economic network actors.

4.2. Implications for economic networks resulting from the actor-network model in the geo-economic context

Integrating the actor-network model described in a geo-economic context such as an international trade dynamics framework, specific features can be estimated and eventually used as an analytical description of the current and past picture of the international relationships between different countries. As a matter of fact, network modelling makes it possible to manage a large set of data in a unique and analytical approach (Sheng et al., 2020; Dedić and Stanier, 2016; Lohr, 2013; Snijders et al., 2012) or integrate it with other multivariate statistical analyses. It can contribute to crucial knowledge which – if used efficiently – could be a base for the economical and ethical actions of actors in the international market network.

In an international relations framework, actors can be defined as countries with given interactions. Such interactions can be described in relation to international trade as goods (or information) flows and assembled in a network or set of entangled networks (Vernon, 1966). Such an approach originally arose in the field of sociology and political sciences (Snyder and Kick, 1979), and may also be used to explore the import-export relationships in the global trade web (Fagiolo et al., 2009; Nwosa and Fasina, 2020). In this framework, changes in the architecture of international cooperation can be useful in the characterisation of factors underlying certain economic consequences in one or a set of particular countries (for examples in the manufactory industries, see Haraguchi et al., 2017; Lo Re et al., 2015). They considered single countries to be not only independent actors but parties to possible larger international organisations or as an entire ensemble of a unique system. The process of internationalisation of national companies can be related to global economic forces, new legal regulations, as well as tensions between globalisation and protectionism, and it would be appropriate to take these factors into account for a global understanding of the economic system (Rowoldt and Starke, 2016; Hopt, 2014; Aktas et al., 2007). The protectionist political activity of a set of countries and the consequential re-allocation of capital can be analysed in order to understand the possible realignment of changes in the supply chains of large international firms (Ambos et al., 2006; Vernon, 1966), as well as changes in the investment of national industrial systems (Garlaschelli and Loffredo, 2005; De Benedictis and Tajoli, 2011; Jackson, 2010). Moreover, countries are not static actors but can respond to the feedback of the international trade market by means of incoming taxes, the ability to approach potential investors, and purchasing power in relation to the foreign exchange market (c.f., Stoykowa, 2021; Drelich-Skulska and Bobowski, 2021). Using different factors in a geo-economic relations framework, various economic forces can be included in the same network model to estimate properties related to emergent socio-economic phenomena.

Many studies emphasise the role of economic networks in economic development, especially in achieving growth in productivity and GDP (Haraguchi et al., 2017; Andreoni and Chang, 2016; Szirmai and Verspagen, 2015). Policymakers in developed and developing countries alike are seeking measures to foster economic activity and encourage new growth models to increase productivity and employment. China has shifted its focus to technology-driven growth. The One Belt One Road initiative aims to promote economic integration with the rest of the world, which may enhance China's ability to modernise its economic networks. In this sense, the international relations system presents a high degree of complexity due to the interconnection of numerous factors (information, knowledge, tasks, and resources) and actors. This is at the same time an element of dynamism and strength of the system as a whole, but also of vulnerability, because the perturbations and crises propagate easily and quickly.

The current international situation is characterised by widespread and frequent instability, a harbinger of conflicts that are not always limited and catalysed by political, social, economic, environmental, or fideistic factors. The process of the progressive affirmation of a new worldwide balance on a polycentric basis or, according to some, on a centric and regional basis, deriving from the affirmation of new emerging powers, could lead to new political, economic or military challenges in the medium term. Hence the possible emergence of new situations of conflict, perhaps localised, but potentially of significant impact for the country, Europe, and the Atlantic Alliance. On a global level, traditional wars between states for the control of resources or for the reignition of unresolved situations over time could cause a domino effect with an exacerbation of crises.

The current speed of technology research and exploitation cycles, together with the innovation process resulting from the integrated use of existing or emerging technologies, will lead to a greater acceleration of change. The world is becoming increasingly connected and integrated, which leads to the possibility of having universal access to knowledge and information. The particular dependence of the West on a system of computer networks that is functioning, safe and resilient involves the affirmation of a new operational domain, namely the cybernetic one, which must be guarded and defended. The effects of cyber-attacks on computer networks or services can be particularly destructive for Western countries and, if successful, have effects on society comparable to those of a conflict fought with conventional weapons. In this context, developing nations need increasing levels of energy and raw materials to support their growth. Competition for these resources could produce a higher level of international tension with consequent possible conflicts. More serious is the growing scarcity of vital resources, such as water and food, generated by population growth, climate change, and the irrational use of territory. It is the basis of migration phenomena and could lead to strong competition, even armed, for the possession of these resources.

Conclusions

The actor-network model for economic networks represents a theoretical and conceptual framework designed for the elaboration of the information elements of complex systems and understanding problems of an economic nature, which is suitable for studying and having a representation of various economic and social organisations, highlighting the connections between the actors that interact in the context of reference. Referring to our main research question (RQ), we assume that identifying network roles, taking the measurement of actors' centrality into account, contributes to an understanding of the complexity of interactions, connections and interdependencies between the actors of the economic network. On the other hand, the network analysis and its elementary measures of network efficiency, to which we have referred (diversity or redundancy), allow for the measurement of the economic network from the perspective of the allocation and distribution of knowledge, resources, and tasks. The actor-network model is only a starting point for the operationalisation of the elements of the model, which include: the broadly understood geo-economic context; social and technical actors, including information, knowledge, resources, and activities (tasks); relations between socio-technical actors; the roles and centrality of actors; and network efficiency. Thus, our conceptual considerations lead to the definition of the *actor-network model for economic networks as a set of socio-technical elements related by multiplex relations, interactions and interdependencies based on access to information, knowledge, resources and sharing activities in a geo-economic context. In the economic network, entities play a more or less central role, which influences their position in the network. The allocation and distribution of socio-technical actors in the network determine the efficiency of the economic network.*

Therefore, an actor-network model should map the chaotic effects typical of periods of great transformation, interacting non-linearly with the external environment and their components, whose effects are often unpredictable. It is difficult to represent the actor-network model in reduced form without losing a number of properties and at the same time to give informative answers. It will be fundamental to understand up to what level it will be possible to create an abstraction of the interactions and behaviours of the economic actors. Whatever the object of study and the scope of the study, local environments today appear fragmented as well as the objects of analysis. This actor-network model seems to be useful for synthesising and providing a representation of perception regarding links and relationships between different socio-technical actors in the same system. An important concept which is often used when talking about economic networks is that a node is critical if it occupies a strategic position within the network. This change in methodological perspectives of structural analysis poses a cognitive challenge for the search and forecasting of both events in general and economic ones in particular (Lo Re and Veglianti, 2017). Network analysis becomes a natural ally in identifying those critical nodes (see Table 1) that are essential to providing a framework and good tools for intervention and policy in defence of economic, political, and social interests.

Future analyses could be carried out in order to deepen the use of actor-network theory associated with network analysis techniques to draw up a framework which is able to help reclassify and apply research knowledge in practice, thus favouring more in-depth analysis of interconnections and economic interests among actors. Working from this perspective continues to be relevant, considering the current dynamic factors that characterise the modern context, where the interest is to understand the relationship between actors and complex network systems well, thus expanding the scope of possible future research on the subject and above all of the policy implications. This can open new lines of research, thus articulating new approaches to industry analysis, supported by technological developments that change the way we approach the subject by integrating existing tools.

The application of the theoretical network perspective to the geo-economic context is often confronted with the following critical issues: the problem of the perimeter boundary of the network; the incompleteness of the data and the difficulty in finding new data; the dynamic character of economic actors; and the validation of the model. A common problem in practice is that researchers rarely access detailed and complete information on actual data flows (Ducruet and Notteboom, 2012). However, all these limiting aspects represent the strengths of the network paradigm itself (Woo et al., 2012). In fact, in the case of a lack of data, while some methods would not be able to complete the data processing, network analysis is able to face this issue effectively. These problems attempt, even partially, to provide the requested output and even highlight those informative differences that can only be filled later.

Furthermore, it is important to underline that in the activity of detecting ties, whether it is a question of relationships between subjects or relations between economic organisations, in order to obtain a more realistic picture of a network, it is necessary to consider all of the possible links between the nodes. The emergence of techniques for the structured analysis of economic networks constantly highlights the importance of the strategic position of an actor within the context in which it operates, with respect to the scenarios that can be observed. Future developments of this research should broaden the analysis from the study of network relationships to the impact of network externalities on economic networks and model validation. The actor-network model can be applied wherever there are actors and defined relationships, e.g. the circular economy (Shpak et al., 2021), value creation (Gruber, 2021), value chains (Potoczek, 2021), or local self-government (Vaitkienė et al., 2021).

The above conceptual considerations allow us to formulate research questions for further studies that integrate existing achievements:

RQ1. What are the network relationships and the impact of network externalities on economic networks?

RQ2. How can economic network variables be modelled to analyse dynamic network properties and its efficiency?

RQ3. How do relationships between economic entities change over time?

RQ4. How does the importance (influence) of individual entities, roles and their position in the economic network change over time?

RQ5. How are information, knowledge, resources and tasks allocated and distributed throughout the economic network?

RQ6. How may one efficiently catalyse the propagation of information, knowledge, resources and tasks in the economic network?

RQ7. How is the use of new technologies spreading through economic networks?

A feature which has not yet been examined in particular depth is the usage of network analysis as an instrument to monitor the ongoing development and evolution of the interactions between economic actors in economic networks within a given reference context. New paradigms and approaches to industry analysis are increasingly crucial, supported by technology connections that modify the way of thinking in scientific studies.

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