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The Technology Transfer Network Dynamic in the Information Technology Industry of Yucatan, Mexico

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Abstract

The present paper explores the technology transfer linkages among universities, research centers, and private companies in Yucatan, Mexico's information technology industry. Social network analysis (SNA) was used as a method to identify the structural characteristics of the technology transfer collaborations, and the changes in the patterns of interactions among institutions over the years. Data were obtained from the National Council for Science and Technology repository (CONACYT). Associations formed to enhance technology advancement and innovation practices between 2010 and 2018 were analyzed in this study. Network transitivity, the patterns of triadic configurations, and heterophily were compared to uncover the evolution of the innovation and technology transfer network of Yucatan, Mexico. Results indicate that the number of transitive triads has increased significantly since 2012, suggesting that a greater number of firms are networking with more than one university or research center. The degree of homophily showed a decreasing trend, mainly as a result of the increment in the proportion of associations among universities and research centers. This study aims to provide insights into the technology transfer network dynamics over the past decade that can support future efforts to enhance innovation and technology development in technology-based industries in the region.

Keywords
Technology transfer networks, information technology, network analysis

1. Introduction
Technology transfer refers to the process by which universities, research institutes, or government laboratories transfer research outcomes to private or quasi-private firms in a variety of productive sectors [1]. In these transfer processes, universities and research institutes are seen as valuable sources of knowledge that might accelerate research and development for businesses and industries, can escalate technology innovation, and foster regional economic growth [2]. Extensive technology transfer processes play a critical role in developing technology-based industries in emergent economies [3, 4]. Fostering alliances between academy and industry have become a core component for enhancing innovation capacity in various countries [5]. However, little is known about the nature and patterns of technology transfer in which universities, research centers, and the private sector collaborate for innovation and technology development in emergent economies [6]. Scholars agree that more efforts are needed to understand how technology transfer interactions are formed and developed over time, which can help policymakers to strengthen their systems of innovation [7, 8]. This paper aims to contribute to the literature on technology transfer in emergent economies by investigating networks of universities, research institutes, and government laboratories from the information and technology industry of Yucatan, Mexico. This exploratory study was conducted to understand *how has the technology transfer network structure evolved in the last decade?* Social network analysis was conducted to characterize the transitivity, triadic configurations, and cross-institutional associations in the information technology industry of Yucatan, Mexico.

2. Method

2.1. Research approach

The present study utilizes social network analysis (SNA) to characterize the technology transfer network formed by universities, research centers, and private companies in the information technology industry of Yucatan, Mexico. SNA is a methodology used to understand what influences the formation of relational structures in populations and how those structures affect outcomes at both, individual and group levels [9, 10]. These relational structures are displayed as network graphs composed of ties and nodes. Ties illustrate the interactions between the members of a network (i.e., the flow of information), and nodes represent individuals, organizations, or any entity that is connected with other nodes [9]. Networks may have different properties. The ties connecting nodes in a network can be undirected or directed. Undirected networks show bidirectional relations node to node, whereas directed ties indicate a specific direction in the relationship [11]. Considering the nature of the associations, networks may contain binary or weighted ties. Binary ties indicate whether a relationship exists or not, while weighted ties show the strength of the relationships [9]. This study characterized the networks as undirected and weighted, where nodes were the institutions, and ties indicated the technology transfer among them. Previous studies using SNA to investigate the technology transfer between academia and industry have provided insight into network composition, community relations and structures, key players, and the antecedents and consequences of these structures [5, 8, 12, 13]. This paper is aimed at investigating the technology transfer network's changes over time by focusing on transitivity and heterophily.

2.2. Data acquisition and processing

The present work employs data retrieved from the Mexican National Council for Science and Technology repository (CONACYT), which contains data on collaborative projects to develop innovative technology solutions in Mexico. The dataset includes projects developed in 31 states and about 13 industries such as energy, construction, electronics, and information technology. These projects have received support from CONACYT's sectorial fund "PROINNOVA" during the years 2009 – 2018. Among the different National Council's programs, "PROINNOVA" stands out for being exclusively focused on networking projects oriented to innovation and technology development in which at least two universities, two research centers, or one of each is involved [14]. The data is accessible from the CONACYT web page. All information required for the analysis was obtained from this institution.

This study focused only on a subset of data including projects in the information technology industry of Yucatan dating between 2010 and 2018. Data from 2009 was excluded because it only had one private firm listed. The dataset was then grouped by years and transformed into adjacency matrices, which were required to estimate the network characteristics. Adjacency matrices are node by node tables where the first row and first column represent the institutions -universities, research centers, and private companies-, and cells' entries indicate the transfer associations among institutions through the founded projects. The resulting matrices were weighted and symmetrical, meaning that each cell accounted for the number of times each pair of institutions worked together, and there was no direction in those associations [11]. For instance, consider university i and firm j in an adjacency matrix A = $[i_j]$, $a_{ij} = 2$ would indicate that i and j worked together in two projects, whereas $a_{ij} = 0$ would indicate that there was no association at all. Nine adjacency matrices were generated from this process, one for each year. Thus, each matrix represented the state of the network in a given year. The matrices were loaded into UCINET [15] to estimate the network transitivity, triads configurations, and network heterophily.

The present study focused on transitivity, triads configurations, and heterophily to characterize the technology transfer network. Transitivity is a network-level measure that indicates the extent to which knots of nodes are all interrelated [11]. Transitivity (also called cluster coefficient in undirected networks) is often used in social systems to discover the tendency of nodes to develop associations with the connections of their connections. The measure of transitivity in undirected networks is obtained based on the ratio of triads that are transitive [11]. A triad is a network configuration involving three nodes, which can be transitive or intransitive (see **Figure 1**). Transitive triads occur when the three nodes are fully connected, while intransitive triads have at least two unconnected nodes [16]. Because the networks in this study were undirected, two triad configurations -201 and 300- described in the MAN convention [17] were used to calculate the degree of transitivity. This paper considers transitivity as the number of fully connected triads divided by the sum of transitive and intransitive triads. Homophily refers to the principle stating that nodes with similar attributes tend to form positive relationships [18]. Hence, network homophily indicates that nodes are more likely to form positive ties within boundaries rather than across boundaries [19]. Otherwise, the network displays heterophily. Network homophily index was obtained as the number of ties connecting nodes across categories (E) minus the number of ties connecting nodes in the same category (I) divided by the number of total ties (E+I). Homophily index ranges from -1 to 1, where values of -1 indicate homophily, and values of +1 shows heterophily [15]. To define external or internal ties, institutions were categorized as 1=Private Firms, and 2=University or Research Center.

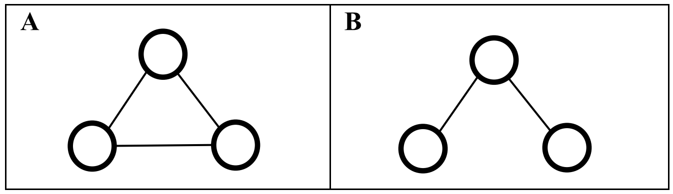

Figure 1: Example figures illustrating a transitive **(A)** and an intransitive triad **(B)** in undirected network graphs. Circles represent nodes, and ties exemplify their relationships.

2.3. Data analysis

Network transitivity, frequencies of transitive and intransitive triads, and network heterophily were analyzed to address the research question. Time series plots were generated to explore the changes of the network structures over time.

3. Results

3.1. Sample characteristics

The dataset for analysis included 64 projects in the information technology industry during the years 2010 to 2018. **Table 1** summarizes the network size (number of nodes), number of projects, number of universities (UNI), research centers (RC), and private firms by year. The data set from 2010 to 2018 included 23 different universities, 3 research institutes, and 35 different firms. About 94% of the companies were micro or small firms.

Table 1. Descriptive statistics of the technology transfer data by year

Year	*Network Size*	*Projects*	*Firms*	*UNI*	*RC*
2010	6	4	4	2	0
2011	8	5	5	3	0
2012	4	4	3	1	0
2013	15	9	9	6	0
2014	22	12	8	12	2
2015	8	4	3	4	1
2016	15	9	8	5	2
2017	15	7	7	7	1
2018	25	11	11	14	0

3.2. Analysis of network changes

Technology transfer networks were generated in UCINET to visualize the adjacency matrices constructed previously. **Figure 2** shows the nine network graphs for each consecutive year. Institutions type 1= Private firm, and 2=University or Research Center; and firm size: 1= Micro, 2= Small, 3= Medium, and 4=Big, were included as node attributes to facilitate networks' visualization.

After 2012, the number of nodes in the network increased significantly, so did the number of universities involved. The biggest networks were formed in 2014 and 2018, both with the same number of universities or research centers (14). The network graphs suggest overall growth in the connections between private firms and universities and RCs. Also, **Figure 2** indicates that firms start in the outer nodes of a network and towards the end of the period they become more central to the network. Overall, the network size and the number of ties increased after 2012, suggesting that a greater number of universities and research centers started providing inputs to private firms for enhancing innovation and developing technology.

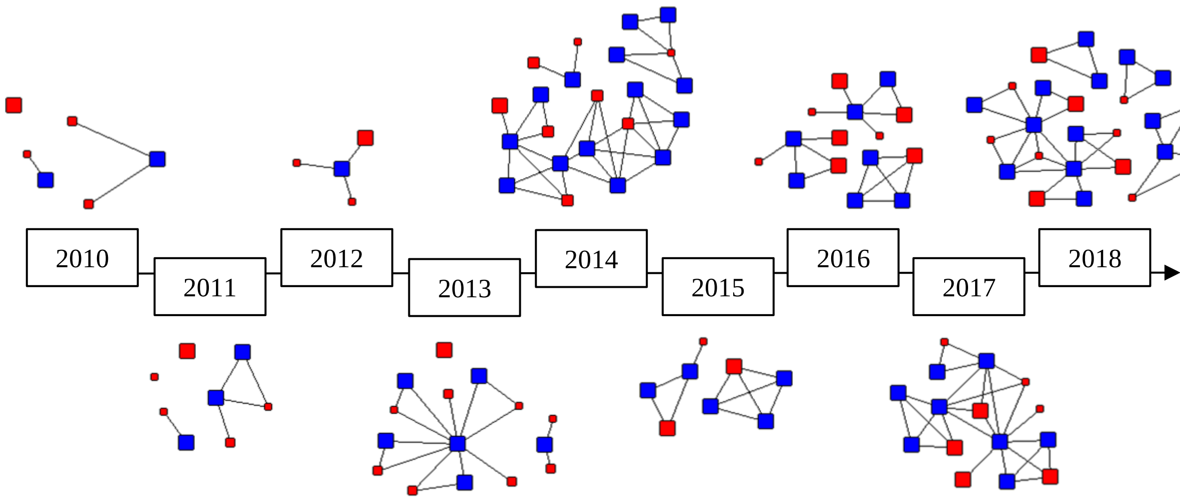

Figure 2: Technology transfer networks by year. Nodes are colored by type: *blue*=UNI or RC, *red*=Firms. The size of the red nodes shows the firms' size. Firm size was coded as 1= Micro, 2= Small, 3= Medium, and 4=Big, so the smallest nodes display micro-companies.

The visual representation of the network changes was complemented with an estimation of network characteristics. Network transitivity, frequency of transitive triads, and intransitive triads were calculated for each year. **Figure 3** shows the time series plot of the transitive triads from 2010 to 2018, and a comparison of the proportions of the two types of triads configurations across periods.

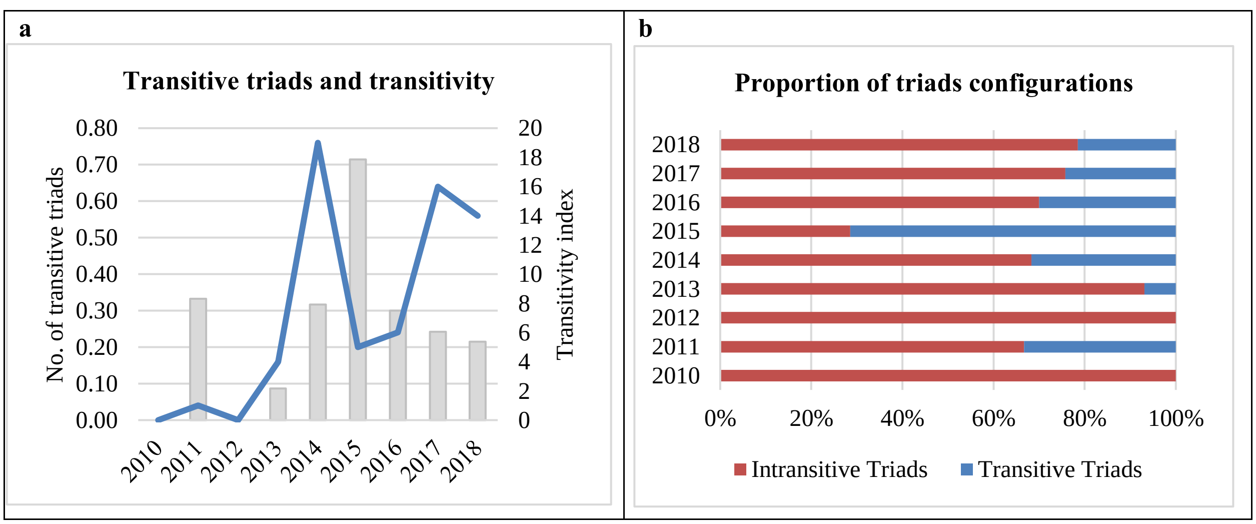

Figure 3: Time series plot contrasting the number of transitive triads and transitivity index **(a),** and the proportion of triads configurations by year **(b)**. In chart **a**, bars illustrate the transitive index, and the tendency line illustrates the trend of the transitive triads.

The number of transitive triads showed a positive tendency, with the maximum frequency of fully connected triads reached in 2014. This indicator coincided with the highest projects' value, which was achieved the same year. It is noticeable that the degree of transitivity did not experience significant changes across years, except for the 2014's index. The plot **b** in **Figure 3** also suggested that the proportion of intransitive triads was higher than the proportion of transitive triads in most periods, which conducted to the small variation in network transitivity. The two types of triads have particular meanings in the context of this study. Fully connected triads suggest that firms networked at least with two other institutions, either universities, research centers, or one of each. Otherwise, intransitive triads account for universities or research centers forming ties with two different private firms.

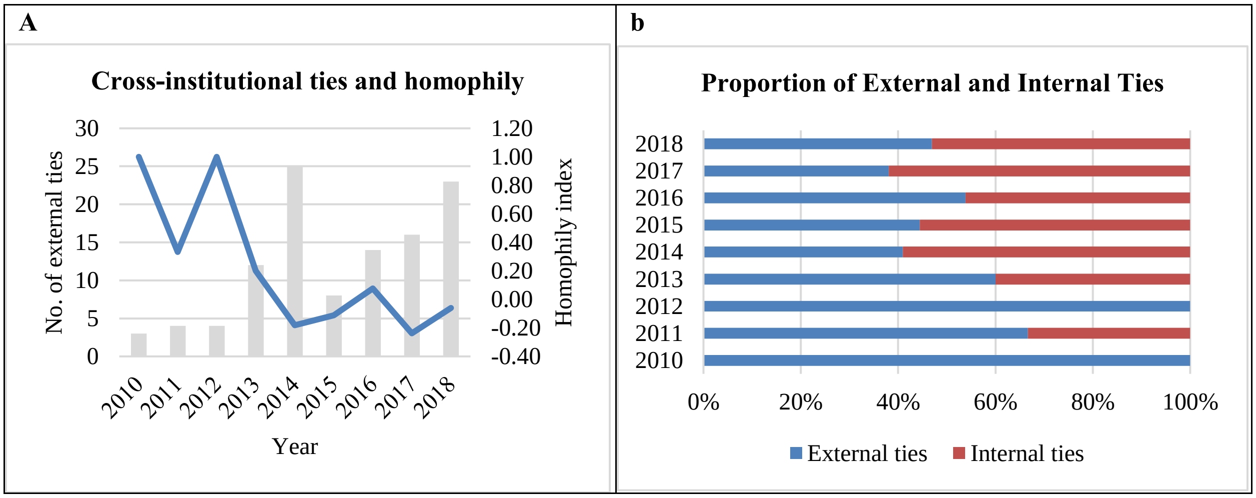

Figure 4: Time series plot contrasting the number of cross-institutional links and the homophily index by year **(a)**, and the proportion of external (E) and internal (I) ties **(b)**. In plot **a,** bars show the number of external ties, and the tendency line indicates the trend of the homophily index. Recall values of -1 indicate homophily, while values of 1 indicate heterophily.

The row counts of the external ties increased over time, as displayed in **Figure 4 (a)**. The trend in the homophily index displays decreasing variations across years, suggesting an increase in the number of ties among similar institutions. The tendency of homophily was mainly due to an increase in the collaborations among universities and research centers, as suggested by the triad configurations. The proportion of external ties, however, slightly increased after 2013, which indicates that firms started having connections with more than one university or research center.

4. Conclusions

Evidence from various nations shows that academia and research centers can help to address the challenge of enhancing industries' innovation capacity through the transfer of knowledge and technology, in a way that the scientific advances generated in these institutions are transformed into new products and solutions for organizations [12]. Strategies to facilitate technology transfer from academia to productive sectors have shown to be successful in fostering innovation and technology development in various nations and industries [1, 3, 5]. In Mexico, diverse funded programs have been established to facilitate academia-research-centers-industry networks. A recent report indicates that firms involved in these associations tend to generate patents more frequently than firms outside of the network, and also tend to introduce new developments into the market [2]. In Yucatan, the efforts to foster innovation and technology development through the university-research centers-private firms' associations have contributed to an increase in the level of innovation, according to the same report. However, the growth was smaller than in other states, locating Yucatan from place 15th in 2010 to the 20th place of the national rank by 2017. The accumulated experience indicates that challenges remain in coordinating the transfer processes between academia, research centers, and the productive sectors [2]. This paper adds insights into the technology transfer practices by looking at the structure and emergence of partnerships across institutions in Yucatan's information technology industry and aims to serve as an antecedent for the study of technology transfer networks in high-impact industries Relying on social network analysis, this study aimed at investigating how did the network transitivity, transitive triads, and network homophily evolve from 2010 to 2018. Results of the analysis suggested that the number of transitive triads showed a positive tendency, with a significant increase after 2012. The tendency of fully connected triads indicated that the number of firms networking with at least two universities, two research centers, or one of each, has increased over time, which might facilitate the technology transfer from diverse institutions to private firms. Intransitive triads have characterized the network across time, which is mainly due to universities or research centers providing inputs to at least two different firms. Over the years, the networks displayed a high level of homophily indicating an increase in the number of ties between similar nodes. This pattern was mainly due to an increase in the number of universities and research centers that jointly provided inputs to private firms. Inherently, this study has some limitations. First, the analysis only included projects developed with the support of CONACYT, whereas other collaborations funded by external sources could contribute to having a complete picture of the technology transfer networks. Second, the data in this study only covered 9 years, from 2010 and 2018. Additional data after 2018 might contribute to support the tendencies of network structures in a longer period. A complementary study should consider the technology transfer networks in other states, and potentially, other industries, so results from this study could be compared. Stochastic oriented models could be used in future studies to investigate the factors that determined the formation and dissolution of ties across institutions and over time.

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