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Preferential Attachment and Fitness in the Evolution of the Brazilian Film Network

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Abstract

This study analyzes the network evolution, specifically that of the Brazilian film network. It examines two generative mechanisms that lie behind the network evolution: preferential attachment and fitness. The starting point is that preferential attachment and fitness may compete to shape the network evolution. We built a novel dataset with 974 Brazilian feature films released between 1995 and 2017 and used PAFit, a brand-new statistical method, to estimate the joint effects of preferential attachment and fitness on the evolution of the Brazilian film network. This study concludes that the network evolution is shaped by both preferential attachment and fitness. However, in the presence of fitness, the effects of preferential attachment on the network evolution become weaker. This means that the node ability to form ties in the Brazilian film network is mainly explained by its fitness. Besides, the preferential attachment assumes a sub-linear form. Costs, communication and managerial capabilities, and node age explain why nodes are unable to accumulate ties at rates proportional to their degree. Finally, preferential attachment and fitness manifest themselves heterogeneously, depending on either the type or the duration of the network. Preferential attachment drives the cast network evolution, whereas fitness is the main generative mechanism of the crew network. Actors and actresses rely on their status, privilege, and power to obtain future contracts (preferential attachment), whereas technical members are selected on the basis of their talent, skills, and knowledge (fitness). Due to node age or exit, preferential attachment becomes stronger in shorter networks.

Keywords: network evolution; preferential attachment; fitness; Brazilian film production industry.

Introduction

Networks are an important topic for organizational studies (Ahuja, Soda, & Zaheer, 2012; Kenis & Raab, 2020), as the literature is vast (Carpenter, Li, & Jiang, 2012; Kirschbaum, 2019). On the one hand, several studies examine the benefits and penalties for organizations embedded in social networks (Benton, 2017, 2019; Burt, 1995; Coleman, 1988). On the other hand, research argues that such benefits and penalties are not perennial but vary as networks evolve (Ahuja et al., 2012), displaying persistence and change (Zaheer & Soda, 2009). This study positions itself into this line of research.

Despite the increasing interest in network evolution (Ahuja et al., 2012; Dagnino, Levanti, & Mocciaro Li Destri, 2016), Abbasi (2016, p. 1) and Clegg, Josserand, Mehra, and Pitsis (2016, p. 281), who are scholars from different knowledge domains, agree that this research topic is not well understood. In this sense, the network microdynamics (Ahuja et al) or the generative mechanisms (Bianconi & Barabási, 2001) that drive the network evolution deserve further attention (Abbasi). Of particular interest are the joint effects of two or more generative mechanisms (Pham, Sheridan, & Shimodaira, 2016). That means understanding how competing generative mechanisms shape the formation, development, and even dissolution of networks (Corbo, Corrado, & Ferriani, 2016; Powell, White, Koput, & Owen-Smith, 2005).

This study looks at two key generative mechanisms of the network evolution (Pham et al., 2016): preferential attachment and fitness. Specifically, it examines how preferential attachment and node fitness compete within network evolution, represented herein by the Brazilian film network.

Previous research shows that either preferential attachment or fitness is operative in creative industries, in particular the film industry, thus affecting the formation and dissolution of ties. For example, Faulkner and Anderson (1987) and Perretti and Negro (2006) suggest the film industry is dominated by an elite (e. g., highly visible directors, famous actors and actresses, and successful technical staff) that has accumulated advantages based on past ties (preferential attachment). Yet, Lutter (2014, p. 2) points out that the film industry is sensitive to "signals of talent" (node fitness). However, research that considers the joint effects of preferential attachment and fitness on the film network evolution, including the Brazilian film network, remains backstage.

Since the Resumption Period, the Brazilian film industry has attracted the attention of organizational scholars (Matta & Souza, 2009; Michel & Avellar, 2012), specially from a relational standpoint (Kirschbaum, 2006; Steingraber, 2013). This study followed this approach including novel dataset with 974 Brazilian feature films released between 1995 and 2017. To provide robust statistical analysis, a brand-new method was used to jointly estimate the effects of preferential attachment and fitness on the network evolution (Pham et al., 2016).

This study contributes to the literature fourfold. First, it shows that both preferential attachment and fitness affect the evolution of the Brazilian film network. Second, it shows that preferential attachment assumes a sub-linear form with fitness reducing the effects of preferential attachment. Third, it presents evidence on the heterogeneity of the Brazilian film network. The pattern of tie formation among the cast is different from that of the crew. Fourth, it shows that preferential attachment is stronger in networks developed in a short amount of time.

Theoretical background

Network evolution

The analysis on networks permits grasping social structures and processes by analyzing nodes (individuals, groups, organizations, and sites) and ties (relationships or links) (Kirschbaum, 2019; Wasserman & Faust, 1994). In organizational studies, such an analysis has been used to understand the social embeddedness of individuals, organizations, and industries (Corbo et al., 2016; McEvily, Jaffee, & Tortoriello, 2012).

Past research points to positive and negative effects of social embeddedness (Lutter, 2013; Soda, Stea, & Pedersen, 2019), depending on node position (Zaheer & Soda, 2009), relationship strength (Granovetter, 1973), the level of collaboration (Soda et al., 2019), node degree (Zhang, Tang, Xiong, Wang, & Zhang, 2019) or the network topology (Uzzi, 2008). For example, in sparser networks, structural holes may bridge disconnected nodes (Burt, 1995), resulting in advantages from non-trivial resources and non-redundant information (Baum, McEvily, & Rowley, 2012). By contrast, in densely connected networks, nodes usually transact with each other. Recurrent contacts foster trust (Uzzi, 1997), decreasing thus transaction costs (Coleman, 1988), as well as favoring the flow of information (Ter Wal, Criscuolo, McEvily, & Salter, 2020; Tortoriello, Reagans, & McEvily, 2012), and resilience (Benton, 2017). However, these benefits come at the cost of over-embeddedness. Over-embeddedness hampers innovation and limits the development of opportunities beyond the network (Uzzi, 1997).

The effects of social embeddedness are not necessarily perennial (Corbo et al., 2016). For example, Soda, Usai, and Zaheer (2004) show that closure and structural holes are related to network performance at different periods. Accordingly, current closure and past structural holes positively affected the current network performance. Baum et al. (2012) show that the benefits that organizations accrue from the network position depend on the age of the ties established by the network. The benefits of closure were positively related to age, whereas the benefits of bridging were negatively related to age. Therefore, the positive or negative effects of social embeddedness identified in past research through cross-sectional studies change over time (Zaheer & Soda, 2009).

These results contribute to a dynamical approach to networks (Ahuja et al., 2012). Accordingly, networks follow an evolutionary process characterized by both persistence and change (McEvily et al., 2012). In this sense, Kilduff, Tsai, and Hanke (2006) propose that organizational networks are close to complex adaptive systems (CAS). Broadly, CAS are composed of interdependent subsystems (Meyer, Gaba, & Colwell, 2005). Weick (1976) suggests that some subsystems are loosely coupled to the extent that, although they are linked, they maintain some degree of separateness. Besides, in CAS, there is an unclear link between means and ends, which favors the creation of project-based teams, such as in the film industry (Orton & Weick, 1990).

Stacey (1996) argues that persistence in networks has its origins in stability sources, whereas change has to with sources that transform the networks. More specifically, persistence means that networks reproduce themselves over time. Due to inertia (Zaheer & Soda, 2009), imprinting (McEvily et al., 2012), or the endurance of the generative mechanisms (Mollica, Gray, & Treviño, 2012), the network structural properties and/or compositional elements remain over time. For example, McEvily et al. show that bridging has an imprinting effect. In the Nashville legal industry, the network benefits produced by the bridging ties were not only long-lasting but also traced back to the formation of these ties.

Networks are also subject to change due to tie content (Ahuja et al., 2012), tie attachment (Hallen & Eisenhardt, 2012), or exogenous factors (Corbo et al., 2016; Rossoni, 2018). For example, Hallen and Eisenhardt suggest that newcomers from internet security ventures developed inducements to form advantageous ties. They developed catalyzing strategies to access superior network outcomes. Corbo et al. show that, after a jolt (09/11/2001), actors entered into new alliance networks. Central actors lost their position and searched for complementary resources in heterogeneous partners, played by peripheral actors. Similarly, Rossoni shows that the introduction of a new online article search platform (Spell) affected the patterns of tie attachment in scientific citations.

This study looks at the generative mechanisms of network evolution (Abbasi, 2016). In doing so, it analyzes the joint effects of preferential attachment and node fitness. With notable exceptions (see, for example, Corbo et al., 2016; Dahlander & McFarland, 2013; Powell et al., 2005), scholars isolate a particular generative mechanism for closer examination. That is problematic because the network evolution may be the result of the coexistence of generative mechanisms (Ahuja et al., 2012). In this sense, generative mechanisms likely compete to drive the network evolution (Pham et al., 2016).

Preferential attachment and fitness

Generative mechanisms are the logics of tie attachment (Powell et al., 2005). Drawing on the knowledge of complex networks (Barabási & Albert, 1999; Bianconi & Barabási, 2001), we believe that network evolution is subject to multiple generative mechanisms (Powell et al.). This study pays attention to two competing generative mechanisms (Pham et al., 2016): preferential attachment and fitness. The main argument is that both highly connected nodes (preferential attachment) and highly fitted nodes (fitness) shape the network evolution even though they may manifest themselves heterogeneously over time. The former is responsible for a path-dependent process, whereas the latter is more associated with a path-breaking process.

In a broad sense, preferential attachment refers to cumulative advantages in which earlier advantages of a node magnify over time (Aguinis, O'Boyle, Gonzalez-Mulé, & Joo, 2016). Perc (2014) suggests that preferential attachment is close to Merton's (1968) Matthew Effect. In this sense, both mechanisms show the "rich getting forever richer" (p. 610). In organizational studies, either mechanism has been used to illustrate status and power in several networks such as the research collaboration (Dahlander & McFarland, 2013), the editorial boards (Rossoni & Guarido-Filho, 2012), and the graduate programs in management (Rossoni & Guarido-Filho, 2009).

Strictly speaking, the preferential attachment means that nodes have different probabilities to form ties, and the probabilities are proportional to the node degree. The higher the degree of a node, the higher the probability of a node to form ties (Barabási & Albert, 1999). Pham et al. (2016) define preferential attachment as "the amount of some quantity distributed among the members of a population increases with the amount of the quantity they already possess" (p. 1).

Preferential attachment is assumed to be linear since the probability of forming ties is linearly proportional to the node degree (Barabási & Albert, 1999). However, in organizational networks, preferential attachment assumes a sub-linear form (Broido & Clauset, 2019). The probability of a node to form ties is proportionally lower than the node degree (Bianconi & Barabási, 2001; Jeong, Néda, & Barabási, 2003). First, forming ties is not cost-free (Dagnino et al., 2016). There are costs that come with searching for potential ties and maintaining current ties (Ahuja, 2000). In this sense, costs limit nodes to form ties indefinitely. Second, nodes have limited managerial and communication capabilities (Dagnino et al.). Dahlander and McFarland (2013) suggest that nodes connected to a large number of ties reduce the amount of attention dedicated to alters, resulting in the brevity of ties. Third, nodes age. Old ties may be less capable of either forming or attracting new ties (Gay, 2012).

Fitness is an inherited or acquired attribute (e. g., talent, skills, and knowledge) that enables a node to form ties regardless of its degree (Bianconi & Barabási, 2001; Ferriani, Cattani, & Baden-Fuller, 2007). The fitness of a node reflects the collective perception of the network participants about the attribute (Madhavan, Koka, & Prescott, 1998; Ramos, Roseira, Brito, Henneberg, & Naudé, 2013). The more the participants rate an attribute, the more the fitness of the node possesses such an attribute.

The implications of fitness for the analysis of the network evolution are fourfold (Barabási, 2016). First, nodes with a similar degree have different probabilities to form ties provided their fitness is distinct (Ganco & Agarwal, 2009). This statement applies to both highly and poorly connected nodes. For example, newcomers, who usually have a similar node degree, can differ in tie efficiency formation (Hallen & Eisenhardt, 2012). As a result, they will likely accumulate ties at different rates. Second, nodes with no degree but above average fitness may form ties. In organizational networks, such nodes may initially form ties with peripheral actors to attract more connected nodes later. Third, nodes with above average fitness can compete for new nodes against highly connected nodes. For example, peripheral yet above average fitted nodes can challenge highly connected nodes by introducing breakthrough innovations, which constitute a platform for building assets and strong network positions (Ahuja, 2000). Fourth, latecomers can become central nodes in networks (Silveira, 2009). Although such nodes enter the network later, their valued attributes enable them to accumulate ties that turn into hubs.

If newcomers with above average fitness have the potential to challenge highly connected nodes and, consequently, become hubs in the networks (Bianconi & Barabási, 2001), newcomers with below average fitness end up occupying peripheral positions in the networks (Cattani & Ferriani, 2008). That happens because these nodes are less likely to bring unique resources to a tie (Bae & Gargiulo, 2004), becoming thus unattractive. In other words, newcomers with below average fitness have more difficulties in maintaining ties because they are more easily substitutable by a competing node (Jones, Hesterly, & Borgatti, 1997). They do not possess attributes that are attractive and valuable to existing nodes (Cattani & Ferriani). What they offer is expertise similarity

(Liu, Mihm, & Sosa, 2018), that is, a set of skills that overlap with that of the alters or is possessed by competitors.

Networks affected by either preferential attachment or fitness tend to show that few nodes concentrate the majority of ties. Over time, these nodes become hubs, that is, "nodes with an exceptionally large number of links" (Barabási, 2016, p. 4). However, the process through which networks go may be rather distinct (ideal-type). On the one hand, networks affected by the preferential attachment mechanism show that pioneers in the networks, "due to dumb luck or optimization" (Perc, 2014, p. 3), reap first-mover advantages, such as contracts, friendships, and referrals. Following a path-dependent process, these advantages accumulate over time through positive feedbacks (Aguinis et al., 2016). As a result, pioneers become more connected (e. g., central nodes), which is akin to be more prestigious (Merton, 1988; Rossoni & Guarido-Filho, 2012) and resourceful (Usai, Marrocu, & Paci, 2013). Thus, the preferential attachment mechanism suggests that the transformation of nodes into hubs is positively correlated with the timing of entry into the network.

On the other hand, networks affected by fitness have two ideal-type paths. First, if the fitted nodes are pioneers, they will attract new nodes based on valued attributes (Aguinis et al., 2016). Over time, some nodes will accumulate more ties based on both attributes and degree, even though it is difficult to distinguish which one has the strongest effect on the network evolution (Barabási, 2016). Second, if the fitted nodes are latecomers, the networks can follow a path-breaking process, thus going through massive transformations (Ke, 2014). For example, fitted nodes may originate new hubs that engage in fierce competition for ties with existing hubs (Silveira, 2009). In addition, peripheral but highly fitted nodes can provoke the disappearance of existing hubs formed by highly connected nodes by introducing breakthrough innovations (Gulati & Gargiulo, 1999).

This study suggests that the knowledge of the network evolution, affected by either preferential attachment or fitness, has progressed considerably, even though such a progress is more visible in complex networks (Barabási, 2016). However, it is still behind in situations in which preferential attachment competes with fitness for network evolution (Pham et al., 2015, 2016). That is, the joint effects of preferential attachment and node fitness are still unclear (Pham et al.). Such a dearth of studies is particularly noticeable in organizational studies (Clegg et al., 2016), providing a fertile ground for further research.

Research setting

The empirical part of this study is based on research carried out in the film production industry. That is the ideal context for examining the joint effects of preferential attachment and fitness on network evolution for the following reasons. The film production industry is based on freelance projects (Kirschbaum, 2006). Each film results from a single, temporary project (Bakker, DeFillippi, Schwab, & Sydow, 2016). The project team is, in turn, usually headed by the film producer and/or director and is formed by individuals from the artistic (e. g., actor and actress) and the technical (e. g., cinematographer) domains. Therefore, the film industry can be viewed as networks formed by individuals with different expertise that participate in film projects (Cattani & Ferriani, 2008). Such networks are close to CAS in which they are composed of loosely-coupled subsystems

(Orton & Weick, 1990), evolve nonlinearly (Stacey, 1996), and have a power-law degree distribution (Amaral, Scala, Barthélémy, & Stanley, 2000).

Professional ties between the film participants are formed and terminated (Kirschbaum, 2006). Some individuals have more permanent network positions, participating in both past and future projects, whereas others will enter and exit the network as new film projects are announced and terminated, respectively (Cattani & Ferriani, 2008; Jensen & Kim, 2020). In this sense, the film network likely persists in repeating past behaviors (Andersen, 2013; Lutter, 2014). However, as new nodes enter the network, some network structural properties may change (Ferriani, Cattani, & Baden-Fuller, 2009). Therefore, the film network enables the researcher to map the network topology as well as identify when nodes and ties have become part of the network (Cattani & Ferriani). That is, it permits analyzing structure and process (Bakker et al., 2016; Stacey, 1996).

The film network is also sensitive to both the time of entry and talent. On the one hand, research shows that nodes that enter the film network earlier might accumulate advantages (Faulkner & Anderson, 1987). Besides, network pioneers tend to form more relationships (Faulkner & Anderson). Such a social capital confers status (Rossman, Esparza, & Bonacich, 2010), access to first-hand information about the announcement of film projects (Faulkner & Anderson), technical and financial resources (Michel & Avellar, 2014), and preference for distributing films (Sorenson & Waguespack, 2006). High-status nodes are also nominated for Oscars more frequently (Rossman et al.).

On the other hand, the film production industry is sensitive to talent (Jensen & Kim, 2020; Lutter, 2014; Rossman et al., 2010). Talented individuals from both the artistic and the technical domains influence the setting of the film industry (Liu et al., 2018; Lorenzen & Täube, 2008). Although they suffer from the liabilities of newness (Baker & Faulkner, 1991), these individuals are highly attractive to existing nodes (Liu et al., 2018). Besides, newcomers yet talented individuals can engage in localized competition, that is, competition with equals before establishing highly connected nodes (Jensen & Kim).

Therefore, the film network evolution can be affected by nodes that enter the network earlier as well as by newcomers yet talented nodes. That means that preferential attachment and node fitness coexist in the film network (Ferriani et al., 2007; Rossman et al., 2010), which allows us to analyze the joint effects of these generative mechanisms on the film network evolution. We believe research on this topic remains backstage, requiring further research on the Brazilian film network.

Data

The dataset contains all Brazilian feature films released between 1995 and 2017, amounting to 974 films. We collected data from 1995 because this year is usually viewed as a "key moment" of the Resumption Period (Gatti, 2005, p. 121), that is, the renaissance of the Brazilian film industry after years of decline (Kirschbaum, 2006). In this sense, the release of Carla Camurati's *Carlota Joaquina: a princesa do Brasil* [*Carlota Joaquina: the princess of Brazil*] in this year is a landmark of the Resumption Period (Biscalchin, 2015; Vasconcelos & Matos, 2012). According to Gatti, "from this year on [2015], the participation of the national production will be steadier about the number of released films per year and market share" (p. 121). Also of note, Michel and Avellar (2014) and

Rocha et al. (2018), who analyze the Brazilian film industry from a relational standpoint, take 1995 as the starting point of the analysis.

The initial input for building the dataset was a list provided by Ancine (Agência Nacional do Cinema, 2018) with all Brazilian feature films released between 1995 and 2017. The list contains the following data: film, director, producer, distributor, country state, film genre, number of movie theaters, box office, and tickets sold. To complement it, multiple data sources were used: online film databases (e. g., Internet Movie Database (IMDb), Cinemateca, Filmeb), the websites of the films, and high-resolution film posters searched through Google Images. Also, past research (Cattani & Ferriani, 2008; Ferriani et al., 2009), documentaries, animated films, and short films were excluded.

The film team used for the empirical analysis of the study comprises the following categories: actor/actress, director of photography, art director, editor, screenwriter, director, and producer. Except for the category 'actor/actress,' which comprises up to four individuals, each category is represented by a single participant. Thus, the team size is up to 10 participants. To validate these categories, not only did we follow previous research (Cattani & Ferriani, 2008), but we also carried out qualitative interviews with a film producer, a film production assistant, and a specialized journalist.

In this study, the nodes are defined concerning the role the participants take on in the film. In this sense, an individual may take on more than one role, such as director and actor. In this example, there is a node between the individual as a director and the individual as an actor. In other words, the network was constructed based on the assumption that individuals and roles must be considered in film projects (Baker & Faulkner, 1991). As a result, the dataset contains 10,540 data entries approximately.

We developed a program called CiNetwork based on Java and SQLLite database to cope with the difficulties of having a large dataset. CiNetwork was used to check and correct data entries, such as typos and inconsistencies of participant names. Also, it generated all the matrixes used for inputs of PAFit.

Data analysis

The data analysis is based on PAFit, which is a nonparametric method that simultaneously estimates the effects of preferential attachment and fitness on the evolution of complex networks (Pham et al., 2015, 2016). Nonparametric estimation methods of network evolution do not make any assumption on the functional form for the node attachment (Ak) (Pham et al., 2015).

According to Pham et al. (2015), PAFit has some advantages over previous estimation methods. First, PAFit does not assume that the network evolution can be driven by a linear form of preferential attachment. Section 2.2 shows that, in organizational networks, the probability of forming ties linearly proportional to the node degree is rare (Broido & Clauset, 2019). Costs (Dagnino et al., 2016), managerial and communication capabilities (Dahlander & McFarland, 2013), and node age (Gay, 2012) impede nodes from forming ties at rates that are linearly proportional to their degree. As a result, the preferential attachment mechanism assumes a sub-linear form (Pham et al., 2015). Second, PAFit can handle large networks. In 2017, the Brazilian film network had 4,818 nodes and 42,702 ties. Last but not least, according to the model proponents, PAFit is "the first ever method in the literature that can do so" (to jointly estimate preferential attachment and fitness). (Pham et al., 2016). The authors go on to say that "even though there are recent works that employ a time-varying PA function or node fitness. . . all of these works assumed the presence of PA and fitness with functional forms imposed a priori, and thus cannot answer the very question about the co-existence of PA and fitness, as well as their true functional forms" (p. 3). Herein, we briefly describe PAFit. To more details, we refer the reader to the conceptual studies that explain the technicalities of the method (please, see Pham et al., 2015, 2016).

To account for the effects of preferential attachment and fitness simultaneously, PAFit establishes that the probability (Pi) of a node (vi) to form a new tie is proportional to a positive function, called attachment (Aki), of the current node degree (ki). If Ak is an increasing function on average, it is said that preferential attachment occurs. That is, the nodes with higher degrees will attract more nodes than those with lower degrees. If Ak = k, it is said that preferential attachment is linear, resulting in a Scale-Free Network (Barabási & Albert, 1999). Ak < k indicates a sub-linear form of preferential attachment and Ak > k points to a super-linear form of preferential attachment. The sub-linear form of preferential attachment results in exponential distributions (Pham et al., 2015).

In PAFit, the higher the attachment exponent (α), the stronger the preferential attachment. Exponents superior to 0.1 indicate that preferential attachment affects the network evolution. According to Tom Pham (e-mail dated 2016, November 23rd), one of the model builders, results superior to 0.50 indicate that the effects of preferential attachment on the network evolution are "strong."

PAFit also considers that nodes can differ in tie formation capabilities (Hallen & Eisenhardt, 2012). In this case, the probability (Pi) of a node (vi) to form a new tie is related to a positive quantity (ηi), which is called fitness. In this case, it is the "intrinsic excellence of node" that determines the attractiveness of the node (Pham et al., 2016, p. 2). Thus, ηi is independent of the node degree. Two nodes with a similar degree may have different patterns of tie formation. In PAFit, the parameter s indicates the variance of node fitness. Since s is inversely proportional to the variance of the fitness distribution (Pham, Sheridan, & Shimodaira, 2017), the higher the parameter s, the smaller the variance of node fitness.

Formally, the simultaneous estimation of preferential attachment and fitness is expressed as follows (Pham et al., 2016):

$$P_i \;\propto\; A_{ki}\; x\; n_i$$

where Pi is the probability, Ak is the function of preferential attachment, and ηi is the function of node fitness.

As mentioned in Section 3.2, CiNetwork generated the matrixes used as inputs for PAFit. Each matrix shows the nodes, the ties formed between a pair of nodes, and the year in which the ties are formed (Pham et al., 2016). The ties are formed between existing nodes and new nodes, as well as between existing but previously disconnected nodes (Ghoshal, Chi, & Barabási, 2013). The first network dates back to 1995, whereas the entire network contains ties formed between 1995 and 2017. Therefore, the Brazilian film network evolution spans 23 years.

In addition to estimating preferential attachment and fitness for the entire network, PAFit was adjusted to estimate both generative mechanisms for network subsets, accounting for variations in the team composition (Packard, Aribarg, Eliashberg, & Foutz, 2016) and time (Newman, 2009). Specifically, Section 2.1 suggests the film network can be viewed as CAS (Kilduff et al., 2006), which comprise several heterogeneous subsystems (Meyer et al., 2005; Stacey, 1996). Hence, a node can be fully linked (tightly coupled) to a particular subsystem (e. g., clique) and more sparsely linked (loosely coupled) to ties outside this subsystem. For example, by splitting the film network into cast (e. g., actor and actress) and crew (e. g., director and cinematographer), Packard et al. (2016) show that that the film network is distributed heterogeneously in terms of embeddedness. Positional embeddedness, the degree to which a node is linked to a highly connected node, was more accentuated in the cast network, whereas the junctural embeddedness, the degree to which a node bridges disconnected nodes, was more prominent in the crew network.

Along with directors, actors and actresses are the most visible members of the film team, some of them reaching what Rossman et al. (2010, p. 37) call "star power," meaning status, prestige, and reputation in the film industry. Besides, stars may influence the commercial success of the film (e. g., the Indian film industry) (Lorenzen & Taube, 2008). Hence, producers seek to have stars in the film team to minimize uncertainty from means (e. g., team composition) and ends (e. g., commercial or artistic success) (Orton & Weick, 1990). Technical members of the film team are, in turn, low profile and less visible to the audience. Even though they can positively influence film critics, Packard et al. (2016) suggest that the effects of the crew members on the commercial success of the film are weaker than those of the cast members.

Inspired by this discussion, we generated a network formed by actors and actresses, the cast network, and a network formed by the other members of the film team, the crew network, to explore the possibility of the Brazilian film network subsets being driven by different generative mechanisms.

Section 2.1 also points out that in organizational networks, age can affect the node capabilities of forming ties (Gay, 2012). These nodes may retire or die, which means that they exit the network. Thus, the preferential attachment mechanism may suffer deviations caused by networks covering long periods (Newman, 2009). Because the Brazilian film network evolution covers 23 years, we generated shorter networks, that is, networks covering shorter periods, to account for the possibility of node exit from the network.

Due to space constraints, this study presents the results of the entire network and three network subsets: the cast network, the crew network, and the shorter network (2008-2017). The shorter network reported herein (2008-2017) is only an example. Results are robust across networks generated at different time intervals. That means that left-censoring bias is not a concern. Additional results are available from the first author upon request.

Results

In the Resumption Period, the Brazilian film industry can be characterized according to various dimensions (Vasconcelos, 2014). For example, both commercial and non-commercial films were released between 1995 and 2017. On the one hand, commercial films are entertaining firms aiming at box office performance (Montoro & Peixoto, 2009). In the Brazilian market, comedies are a popular genre (Ferraz & Cabral, 2019; Oliveira & Rossini, 2016). The dataset shows that more than 60% of the top 50 highest-grossing Brazilian films released in this period are comedies. That is the case of *Se eu fosse você* (If I were you) released in 2009. This film sold 3.6 million tickets. Nine comedies are, in fact, sequels. *Se eu fosse você 2* (If I were you 2) sold more than 6 million tickets. Film sequels point to tie endurance since the crew and cast team members tend to take on similar roles.

On the other hand, non-commercial Brazilian films focus on social, cultural, and political issues. Their directors are said to have more creative freedom (Montoro & Peixoto, 2009). In this sense, there are ties amongst particular producers (Rocha, Bonfim, Citadin, & Gimenez, 2018), ties with distributors that focus on non-commercial films, such as Vitrine (Garret & Oliveira, 2014), and participation in international festivals (Vasconcelos, 2014). In some non-commercial films, the logic of production is different. They are not project-based but organized in film collectives (e. g., Teia and Alumbramento) in which a more permanent group of individuals take on multiple roles (Vasconcelos, 2014).

This study shows that between 1995 and 2017, the Brazilian film network expanded considerably. For example, the network had 107 nodes and 1,586 ties in 1995. Subsequently, new nodes entered the network by forming ties with existing nodes. Yet, existing but disconnected nodes also formed ties, whereas other nodes exited the network. As a result, more than two decades later, 4,818 nodes participated in the Brazilian film network, forming 42,702 ties. Figure 1 shows this network at different time intervals (1995, 2008-2017, and 1995-2017). Note the emergence of hubs represented by the cast and crew members that accumulate a disproportional number of ties due to either preferential attachment or fitness. This topology is close to the Core-Periphery network (Cattani & Ferriani, 2008).

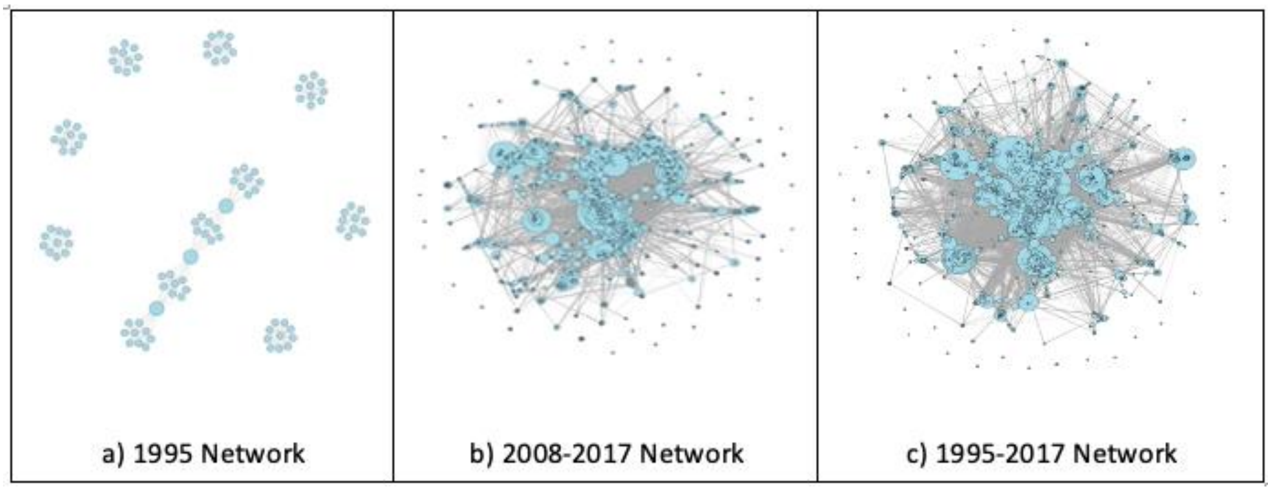

Figure 1. The Brazilian film network evolution

Source: Elaborated by the authors.

Table 1 contains descriptive data about the Brazilian film network evolution showing the degree distribution of nodes. Most nodes in the shorter network (2008-2017) and the entire network (1995-2017) have nine or fewer degrees. Only 26 and 74 nodes have more than a hundred degrees, respectively. This degree distribution, in which few nodes concentrate a large number of ties, persists over the years. That is, even though the Brazilian film network changed the tie composition in the Resumption Period, it shows persistence in terms of the degree distribution of nodes. In other words, the Brazilian film network evolution displays both persistence and change (McEvily et al., 2012; Stacey, 1996). The full list of nodes is available from the first author upon request.

Table 1

Degree distribution

	Nodes		
Degree	**1995**	**2008-2017**	**1995-2017**
≤ 9	104	2,805	3,314
10-36	3	826	1,121
40-99	0	169	309
≥ 100	0	26	74
Total	107	3,826	4,818
Highest degree		252	369

Sources: Elaborated by the authors.

Preferential attachment and fitness

The joint estimation of preferential attachment and fitness for the entire network (1995-2017are $\alpha = 0.04$ (Preferential attachment) and $s = 0.50$ (Fitness). The results suggest that preferential attachment has a near-zero effect on network evolution ($\alpha < 0.1$). However, the parameter s is "low," suggesting that nodes accumulated ties in the network because of their intrinsic attributes (Pham et al., 2016) (see Table 1). Thus, the results suggest the Brazilian film network has been driven by node fitness. That is, the attributes of the nodes are more important for forming ties than their degree.

In other words, the results suggest that fitness outcompetes preferential attachment in the Brazilian film network evolution. Although node attributes such as talent, skills, and knowledge are unquestionably regarded as assets in the film industry (Rossman et al., 2010), recent research has emphasized that preferential attachment lies behind the cumulative advantages of nodes in the film network (Barabási, 2016). In this sense, this study brings fitness back to the fore in the film network evolution analysis (Ferriani et al., 2007).

Table 2

Network 1995 – 2017: PA and fitness joint estimation

	Preferential attachment (*Ak*): *α*	Fitness (*f*): *S*
Entire network	0.04	0.50
Crew Network	0.07	0.23
Cast Network	0.35	1.88

Sources: Elaborated by the authors.

Splitting the network into cast and crew reveals that the results of the crew network are similar to those of the entire network. Fitness affects the evolution of the network constituted by ties from the technical domain. In the Brazilian network evolution that means that directors of photography, art directors, editors, screenwriters, directors, and producers are mostly selected based on either talent or other intrinsic attributes (Ferriani et al., 2007). Therefore, preferential attachment is not a generative mechanism in the crew network evolution (see Table 1). These results offer a finer-grained understanding of the joint effects of preferential attachment and fitness on the network evolution by suggesting that fitness is not only a relevant generative mechanism at the whole network level but also at the network subset level, here represented by the crew network.

The results of the cast network are slightly different. Nodes formed ties based on the preferential attachment rule as well as fitness ($\alpha = 0.35$; $s = 1.88$) (see Table 1). The exponent α, superior to 0.1, suggests that preferential attachment is the strongest generative mechanism in the evolution of the cast network for 1995-2017. That means that the degree of nodes, which were represented by actors and actresses, affects the probability of future tie formation. In the Brazilian film network that means that the more actors and actresses participate in film projects, the more they become visible. The more they become visible, the more they become attractive to the film industry (Kirschbaum, 2006). As a result, these actors and actresses will likely receive more invitations to participate in film projects. Notwithstanding, the results do not rule out node fitness as a generative mechanism in the cast network evolution. Rather, it shows that it loses prominence vis-à-vis preferential attachment.

Figure 2 shows the results of preferential attachment for the entire network (Figure 2a), the crew network (Figure 2b), and the cast network (Figure 2c). Note that in Figures 1a and 1b, Ak is not an increasing function on average. Also, the function is distant from the full line, which hypothetically represents a linear form of preferential attachment (Ak = 1) (Barabási & Albert, 1999). In contrast, Figure 2c shows that Ak is increasing on average, although nonlinearly. That suggests that a sub-linear form of preferential attachment is the dominant generative mechanism in the cast network evolution (Pham et al., 2015), meaning that, in the Brazilian film network, actors and actresses are unable to accumulate ties at rates that are linearly proportional to their degree.

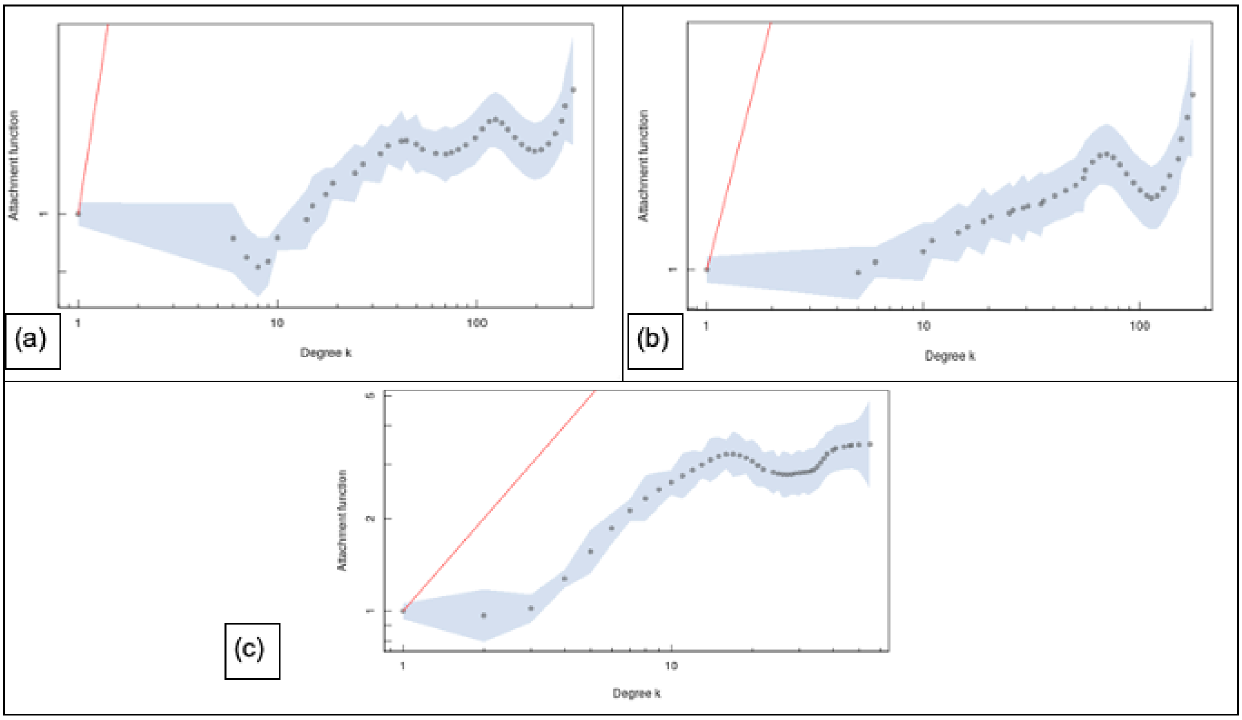

Figure 2. PA in joint estimation with fitness. (a) Entire Network: 1995-2017; (b) Crew Network: 1995-2017; (c) Cast Network: 1995-2017

Sources: Elaborated by the authors.

Figure 3 shows the results of fitness for the entire network (Figure 3a), the crew network (Figure 3b), and the cast network (Figure 3c). When the histogram of estimated fitness is concentrated around the mean value of 1, it is said that the fitness mechanism is weak (Pham et al., 2017). That is because the attributes of the nodes are very similar. The absence of a particular attribute attracting nodes indicates nodes perform averagely. In creative industries, Liu et al. (2018) use the term 'expertise similarity' to suggest that certain nodes have similar experience and, thus, tend to offer similar sets of skills. As a result, the team members become highly substitutable because they do not possess any distinct attributes (Jones et al., 1997). That is the case of the cast network (see Figure 3c), but not of the entire network (see Figure 3a) and of the crew network (see Figure 3b).

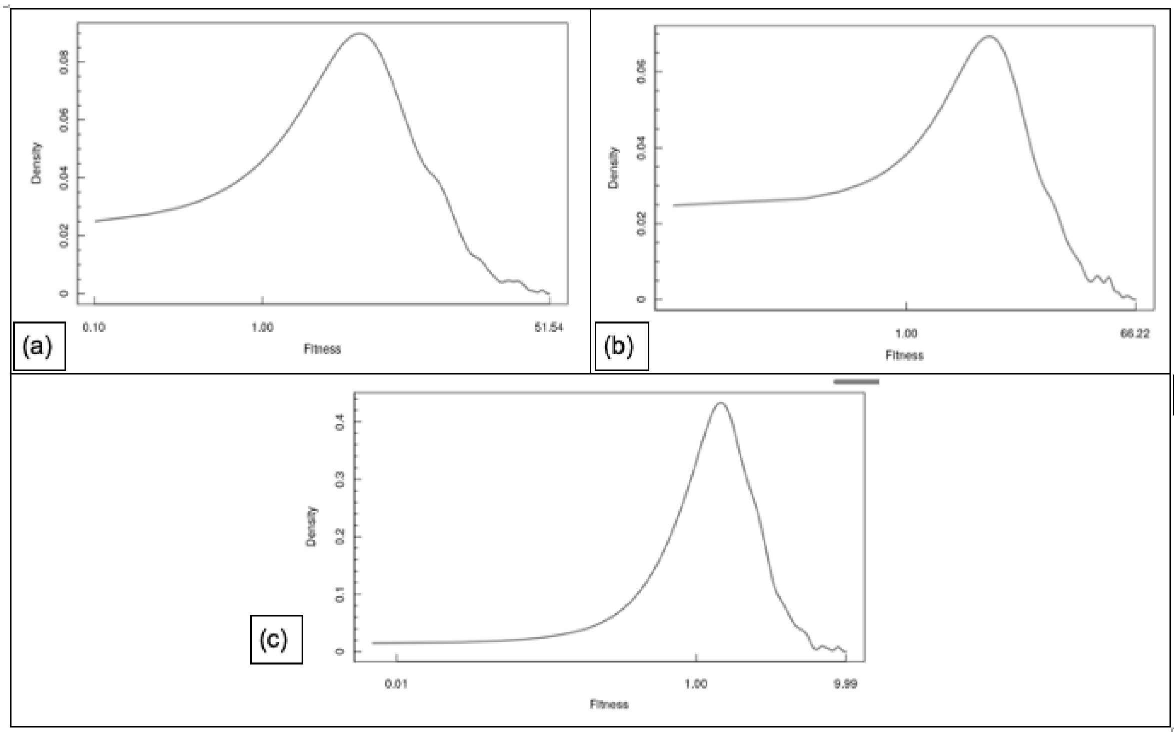

Figure 3. Fitness in joint estimation with PA. (a) Entire Network: 1995-2017; (b) Crew Network: 1995-2017; (c) Cast Network: 1995-2017

Source: Elaborated by the authors.

Analyzing the entire network for 23 years (1995-2017) may favor nodes that have formed relationships in the very beginning of the network evolution but have reduced the tie accumulation rate over the years due to obsolescence, retirement (Gay, 2012), personal choices, amongst other reasons. In such cases, they open room for newer nodes to accumulate ties at rates that are disproportionally higher (Amaral et al., 2000; Baum et al., 2012). To account for the node age effect, preferential attachment and fitness are jointly estimated for the network evolution at the onset of 2008 (see Table 3).

Table 3

Network 2008 – 2017: PA and fitness joint estimation

	Preferential attachment (*Ak*): *α*	Fitness (*f*): *S*
Entire network	0.23	3.75
Crew Network	0.13	0.75
Cast Network	0.67	15.60

Source: Elaborated by the authors.

For the entire network, preferential attachment becomes stronger (α = 0.23). It can be said that it has moderating effects on network evolution. At the same time, fitness becomes weaker (s = 3.75). Therefore, it is plausible to say that both generative mechanisms coexist in the entire network evolution for 2008 and 2017, even though a sub-linear form of preferential attachment stands out.

That is similar to the crew network. The results of this network for the whole period show that preferential attachment has a near-zero effect on it (see Table 2). However, between 2008 and 2017, preferential attachment overcame the threshold of 0.10, slightly affecting the crew network evolution, whereas node fitness became weaker (α = 0.13; s = 0.75) (see Table 3). Therefore, both mechanisms coexist in the crew network evolution at the onset of 2008. That means that the film participants are selected based on both accumulated ties and intrinsic attributes (Pham et al., 2017).

Preferential attachment has a strong effect on the evolution of the cast network for the shorter period (2008-2017) (α = 0.67; s = 15.60). The exponent is superior to 0.5, which points to the prominence of preferential attachment as a generative mechanism in the cast network evolution (2008-2017). The effects of fitness are nearly inexistent.

Altogether these results show that preferential attachment is more relevant in shorter networks (entire network, cast network, and crew networks). As Newman (2009) points out, the preferential attachment mechanism may suffer deviations from networks that cover long periods. This study supports this contention.

In the Brazilian film network, these results suggest that pioneers may have aged, thus affecting their capabilities to form ties. Alternatively, some nodes may have died or alternated roles (Carla Camurati is a nice example, taking on different roles, such as actress and film director). Pioneers may also have opted to change careers for several reasons, such as better salaries or more job opportunities. For example, working on Brazilian film projects still results in lower incomes than those of the publicity industry and television, especially for crew members (Vasconcelos, 2014). Besides, as the film industry in general (Bakker et al., 2016), the Brazilian film industry is based on freelance projects (Kirschbaum, 2006). Thus, it usually offers temporary contracts, whereas other industries may offer more permanent work contracts. That is an additional incentive for nodes to exit the film network. All in all, when the effects of the node age are discounted, preferential attachment becomes a more relevant generative mechanism in the Brazilian film network evolution.

Preferential attachment

To compare the results of this study with those of past research (Barabási, 2016), the preferential attachment was estimated in the absence of fitness. The results of the entire network, the crew network, and the cast network for the whole period are seen in Table 4. The results show that a sub-linear form of preferential attachment manifests itself in the evolution of these networks. The exponents are high, going from α = 0.54 (entire network) to α = 0.71 (cast network). In other words, when node fitness is excluded from the computational analysis, preferential attachment has a stronger effect on the Brazilian film network evolution (entire network, crew network, and cast network).

Table 4

1995-2017: Only Preferential Attachment

	Preferential Attachment (*Ak*) *α*
Entire Network	0.54
Crew Network	0.59
Cast Network	0.71

Source: Elaborated by the authors.

Similar to Section 4.2, we analyzed shorter networks, that is, network evolution at the onset of 2008 (see Table 5). The results show that the exponents are higher than those of the networks for the whole period (1995-2017) (see Table 4). Preferential attachment becomes stronger in the network evolution (entire network, crew network, and cast network).

Table 5

2008-2017: Only Preferential Attachment

	Preferential Attachment (*Ak*) *α*
Entire network	0.59
Crew Network	0.70
Cast Network	0.79

Source: Elaborated by the authors.

Overall, the results presented in this section support the claim of Pham et al. (2017), who argue that the effects of preferential attachment on the network evolution are overestimated in past research because the generative mechanism is analyzed in the absence of a competitive mechanism. The results also suggest that preferential attachment assumes a sub-linear form even in the cast networks (1995-2017; 2008-2017). Thus, in the Brazilian film network, preferential attachment is not invariant to time.

Discussion

The analysis of the Brazilian film network points to a continuous network growth. In this process, few nodes accumulated a disproportionally high number of ties, resulting in various hubs of different sizes. Most nodes ended up with only nine ties. Two generative mechanisms explain the Brazilian film network evolution: preferential attachment and fitness.

On the one hand, preferential attachment explains the existence of hubs constituted by earlier entrants into the network (Barabási & Albert, 1999). They reaped first-mover advantages reproduced over time through positive feedbacks (Aguinis et al., 2016). The more they formed ties, the more they were likely to form new ties. This is a path dependence trajectory in which earlier advantages are magnified over time (Kilduff et al., 2006). On the other hand, fitness explains the existence of hubs constituted by latecomers (Bianconi & Barabási, 2001). Having a near-zero degree, such nodes disrupted the existing evolutionary process of the network by forming ties regardless of their degree. This path-breaking trajectory relies on the excellence of nodes. As some nodes had intrinsic attributes that were highly valuable to network participants, they attracted a higher number of ties than the majority of nodes (Powell et al., 2005). Yet, some of these nodes may have first engaged in localized competition with peripheral nodes to later challenge central nodes (Jensen & Kim, 2020).

This study also presents robust evidence that fitness weakens preferential attachment. When fitness is included in the computational analysis, preferential attachment either declines or becomes irrelevant. Put it differently, without fitness, preferential attachment becomes more powerful. As Figure 1 shows, the Brazilian film network is highly porous. During 1995-2017, many nodes entered and exited this network. On the one hand, family clans, node experience, and status favored network persistence (Vasconcelos, 2014). On the other hand, talented individuals willing to make their way into the film industry favored network change (Jensen & Kim, 2020; Vasconcelos, 2014). These newcomers and/or peripheral nodes may have developed strategies to form ties advantageously (Hallen & Eisenhardt, 2012). What lies behind such a process were nodes with valuable attributes (Powell et al., 2005). They were able to attract not only new but also existing nodes (Corbo et al., 2016). In the Brazilian film network, the latter (tie attachment based on node fitness) was paramount. That is why fitness outcompeted preferential attachment, thus becoming the principal generative mechanism of the Brazilian film network evolution (Ferriani et al., 2007).

In this sense, this study suggests that this evolutionary process is not affected by a single generative mechanism but by the coexistence of competing mechanisms (Corbo et al., 2016; Pham et al., 2017; Powell, 2005). That has an important implication for future research, that is, isolating generative mechanism to analyze the network evolution may amplify the explanatory power of the scrutinized mechanism.

We also suggest that the Brazilian film network evolution is affected by a sub-linear form of preferential attachment (Gay, 2012). That is, the probability of forming ties was proportionally lower to the degree of the nodes. In this sense, the Brazilian film network cannot be viewed as a Scale-Free Network, driven by a linear form of preferential attachment. On the one hand, this result is not in line with past research on the Hollywood film industry (Albert & Barabási, 2002; Barabási, 2016). This discrepancy may be related to the Hollywood film network being analyzed through the lens of preferential attachment. As discussed earlier, this type of analysis may produce inflated results to the extent that it disregards the fact that competing generative mechanisms may weaken the preferential attachment rule (Corbo et al., 2016).

On the other hand, the results support recent studies showing that Scale-Free Networks are indeed very rare in social contexts (Broido & Clauset, 2018; Gay, 2012). Unlike the technological and biological networks, in organizational networks there are limits for the nodes to accumulate ties at rates proportional to their degree (Gay). Such nodes face several constraints that prevent them from forming ties over time (Dagnino et al., 2016). For example, tie formation is costly, which may outweigh its benefits (Andersen, 2012). Likewise, managing a tie portfolio imposes additional communication costs, requiring a set of managerial capabilities to balance different interests and demands (Dagnino et al.). Gay also points out the aging of nodes. With age, nodes are less likely to introduce breakthrough innovations, making room for newcomers. Besides, older nodes may leave the network because of retirement, lack of interest, or even death. These factors may explain why the Brazilian film network evolution is affected by a sub-linear form of preferential attachment.

The results also show that the effects of preferential attachment and fitness on the entire network evolution are different from those of the cast network. The entire network evolution is basically driven by fitness. That is, node attributes such as talent, skills, and knowledge are the drivers of tie formation in the entire network (Ferriani et al., 2007). However, when the cast network evolution is analyzed separately, preferential attachment becomes the major generative mechanism (Barabási, 2016). Some actors and actresses accumulate advantages over time (Rossman et al., 2010), including those that become superstars (Kirschbaum, 2006). Hence, they will likely participate in film projects based on these cumulative advantages reaped from past ties (Rossman et al.).

Put it differently, this study argues that the film network is heterogeneous, formed by members from different domains (Packard et al., 2016): the artistic domain (cast network) and the technical domain (crew domain). Preferential attachment is stronger in the cast network even though it assumes a sub-linear form. Participating in a film team means that an actor or actress may form ties that can be valuable in future projects. Thus, the more they participate in a film, the more likely they will participate in future projects (Kirschbaum, 2006). However, preferential attachment loses prominence in the crew network. The network constituted by technical members such as directors, screenwriters, and producers is best explained by fitness (Ferriani et al., 2007). More relevant than the node degree, it is the intrinsic attributes of the node that are behind the crew network evolution (Pham et al., 2017). These attributes include talent, technical capability, and commitment (Ferriani et al.).

The fact that different generative mechanisms drive the cast and crew network evolution can be explained as follows. Preferential attachment, the main generative mechanism of the cast network, is equivalent to status, prestige, and power (Merton, 1988; Rossoni & Guarido-Filho, 2012). As Rossman et al. (2010) show, these attributes are particularly noticeable in the Hollywood film industry. The authors go on to say, ". . . status for Hollywood actors should be equivalent to star power" (p. 37). Hence, some actors' and actresses' popularity and visibility may attract the audience and facilitate financing (Faulkner & Anderson, 1987; Lorenzen & Täube, 2008). As a result, well-known actors and actresses are not only better paid, but are also more invited to participate in film projects (Baker & Faulkner, 1991; Kirschbaum, 2006). In the Brazilian film network, this is well illustrated in Vasconcelos' (2014) doctoral dissertation. Interview excerpts show the producers' interest in having stars from TV Globo, the largest open channel television.

Fitness, the main generative mechanism of the crew network, highlights that unique talent, skills, knowledge, and creative experiences determine whether a node will be invited to a film project (Ferriani et al., 2007). As the crew members are unknown by the audience (one exception is the film director), there is a looser connection between the composition of the film team and the box office (Packard et al., 2016). Consequently, the selection criterion is based mainly on the crew members' capabilities (Ferriani et al., 2007. That explains why fitness is the dominant generative mechanism in the crew network evolution. Future research on the film industry is needed, specifically on the Brazilian film network, focusing on the differences between the cast and crew networks.

Our study also shows that the film network is not a homogeneous entity, explaining that network subsets can be affected by different generative mechanisms. In this sense, this study contends that the film network is not only differentiated into types of embeddedness (Packard et al., 2016) but also generative mechanisms. The individuals that take on artistic roles have a different pattern of tie formation than the individuals that take on technical roles. The former is closer to “the rich getting forever richer” (Merton, 1968, p. 610) or a rich-get-richer pattern (Barabási & Albert, 1999), and the latter follows a fit-get-richer pattern (Bianconi & Barabási, 2001).

This study makes a final contribution by accounting for the dissolution of ties in the network evolution. PAFit is not well-equipped to deal with either node age (Amaral et al., 2000) or node exit (Ghoshal et al., 2013). It helps correct this deficiency by presenting results of various networks measured in different time periods. We found that the pattern of tie formation in shorter networks is similar to that of the entire network. However, the exponents of preferential attachment are 13% higher on average. Because individuals die, retire, change careers, or are less capable of forming ties (Dagnino et al., 2016; Gay, 2012; Dahlander & McFarland, 2013), they open room for rivals willing to occupy central positions in the networks (Ahuja, 2000). This explains the increase in the exponents of preferential attachment in shorter networks. This study also suggests that future estimation methods of the network evolution should account for both tie formation and tie dissolution.

Our study has some limitations. First, it explains the network evolution based on the Brazilian film network. Thus, caution is needed to generalize the results to other industries and geographical contexts. Second, the dataset excluded documentaries, animated films, and short films. Because the team composition involved in these productions is distinct, the pattern of tie formation may differ (Ferriani et al., 2007). Third, the ties formed in the Brazilian film network are the outcome of the co-participation of nodes in film projects. Thus, ties developed out of this context are neglected. Finally, the study looks at both preferential attachment and fitness. However, organizational networks may be driven by a plethora of generative mechanisms, such as heterophily and geographical proximity (Ahuja et al., 2012). This issue deserves further attention even though its progress depends on the development of robust estimation methods (Kirschbaum, 2019).

Conclusion

This study analyzes the network evolution by examining the joint effects of preferential attachment and fitness. Based on the Brazilian film network, we conclude that both generative mechanisms affect network evolution. Due to costs, communication and managerial capabilities, and node age, preferential attachment assumes a sub-linear form. In addition, fitness reduces the effects of preferential attachment on network evolution. In this sense, the Brazilian film network evolution is explained mainly by the intrinsic attributes of the nodes. The cast and the crew networks display different patterns of tie formation. Preferential attachment is stronger in the cast network, whereas fitness is more prominent in the crew network. In the Brazilian film network, cast members (e. g., actor and actress) form ties based primarily on ties accumulated in the past, which equates to status, privilege, and power. The crew members (e. g., film director and director of photography) form ties based mostly on attributes valuable for other nodes (e. g., talent, skills, and knowledge).

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