Network pathways of peripheral firm entry: Empirical evidence from the global airline industry

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A B S T R A C T

Previous research on interfirm collaboration indicates that networks tend to be structurally stable due to path dependence and embedded firms' incentives to preserve their positional advantages. As a result, industry networks often resemble a core-periphery structure where peripheral firms seem to have little or no opportunity to access the core. Yet, under certain conditions, peripheral firms do manage to cross over to the industry center. In this paper, we examine one such condition: a sudden and unexpected change in the external environment. More specifically, we examine the relationship between the occurrence of an industry-level disruptive event and the dynamics of tie formation/dissolution facilitating or inhibiting peripheral firms' progress toward the center of the industry network. We substantiate our investigation by using longitudinal data on the alliance activities of 258 airlines and applying Stochastic Actor-Oriented Models (SAOM). We integrate our statistical analysis with interview material and descriptive network analysis. The findings reveal a variety of patterns of network entry, contributing novel insights to theories on network dynamics, innovation, as well as policy and practice.

1. Introduction

In the realm of social network theory, the significance of an actor's centrality – or its embeddedness within networks – becomes readily apparent. Centrality furnishes actors with distinct advantages, including power (Bonacich, 1987), access to novel opportunities (Granovetter, 1974), status (Lin, 1999), and timely information (Freeman, 1979). However, a question that continues to intrigue scholars is the trajectory by which peripheral actors navigate to these central positions. In the management domain, proponents of the structural embeddedness perspective have consistently highlighted the strategic dividends accruing to firms highly embedded in interorganizational alliances (Granovetter, 1985). Such embeddedness affords firms several distinct benefits: it facilitates superior informational access regarding prospective alliance partners, acts as a signal of organizational reliability, and amplifies the firm's desirability among potential stakeholders (Pfeffer et al., 1987; Gulati, 1995; Ahuja, 2000). Yet, prevalent within this

perspective, is also the finding that embeddedness is self-reinforcing that is, alliance networks tend to reproduce themselves over time (Gulati and Gargiulo, 1999) because established players behave in ways that produce persistent organizational resistance to changing existing industry configurations (Baum and Ingram, 2002; Baum and Silverman, 2004; Kim et al., 2006; Milanov and Shepherd, 2013), thereby ensuring central actors continued positional advantages while constraining firms that are not as well connected to remain marginal to the network.[1]

While the self-perpetuating tendency of interfirm alliance networks and the core-periphery stratification that stems from it are well-established findings within the network research on interfirm collaboration, even cursory observation of all but the most mature industries suggests that firms do sometimes navigate their way from the periphery to the center of industry networks despite striking initial disadvantages. To illustrate, consider the case of Qatar Airways and its swift rise to prominence in the context of the worldwide airline industry, as summarized by its CEO:

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[1] Core-periphery interorganizational networks – i.e., networks displaying a definable core of densely connected nodes that encompass a vast majority of the relevant social action – are a common structural manifestation of this pervasive stratifying force across industries as diverse as industrial automation (Gulati and Gargiulo, 1999), steel (Madhavan et al., 1998), computer (Sytch and Tatarynowicz, 2014), motorcycle (Lipparini et al., 2014), wine (Giuliani, 2013), and chemical industry (Polidoro Jr. et al., 2011).

My statements were being taken by my industry peers with a pinch of salt. In particular, both Emirates and Gulf Air used to think that I was a joker when I mentioned my plans - even though I was very modest when I said that we would have only 35 aircrafts and 35 destinations and that people should not get very worried about Qatar Airways. Things are very different now. We have become a major global carrier in a short span of just over 10 years, and we are going to be even stronger and most certainly will be in the league of airlines that are very profitable.

(Qatar Airways CEO, quoted in Flight Global, 2011)

Qatar Airways CEO's emphasis on the company's evolution from modest beginnings to global presence and exceptional profitability is not an overstatement considering that starting in 2001, and in less than a decade, Qatar Airways moved up from 35 to almost 120 aircrafts and an annual turnover of approximately 25 billion US dollars. The explanation for this formidable trajectory, while multifaceted, is inherently tied to the airline's dynamic repositioning within the broader network structure of the aviation industry. Qatar Airways, in a relatively brief timeframe, significantly enhanced its network embeddedness through the development of several pivotal code-sharing agreements. These agreements encompassed partnerships with both globally recognized carriers – granting the airline coveted international status and a significantly extended global reach – as well as less prominent airlines, which presented Qatar Airways with an opportunity to address overcapacity issues by accessing secondary markets (Chiambaretto and Wassmer, 2019). As a result, in just three years, from 2002 to 2005, Qatar Airways's number of alliances quadrupled when compared to the previous three-year period, allowing the airline to move from the margins to the core of the airline industry network.

This transition from the periphery to the center of the alliance network, what we label "network pathways of peripheral firm entry," is illustrative of the more general phenomenon we intend to unpack in this study. Unfortunately, prior studies' overwhelming emphasis on core, central, or more generally highly embedded actors and the relations among them (e.g., Gulati and Gargiulo, 1999; Corrado and Zollo, 2006; Gulati et al., 2012), has favored the development of an endogenous perspective of network change that struggles to "make substantive predictions about how firms that are not advantaged by the current network structure are able to break into networks" (Rosenkopf and Padula, 2008, p. 671) thereby forcing a theoretical concession over the role of peripheral network players as drivers of network change. The purpose of this paper is, therefore, to investigate general mechanisms that can explain some of these real but seemingly unlikely network pathways, a topic that has received much less attention in prior studies (Hu et al., 2021). Shedding light on such mechanisms not only has the potential to inform the scholarship on network dynamics, but it also has important normative implications as a rigid core-periphery structure offering no entry opportunities would be undesirable from a societal point of view "as it could impede the emergence of novel actors" (Ahuja, 2000, p. 323).

To investigate how and under what conditions peripheral players enjoy opportunities to form ties with central players and thus become more embedded in the network, we draw on the literature concerned with how patterns of network affiliation change in response to environmental conditions triggered by disruptive events. These events, also known as environmental jolts, are often turning points in the evolution of an industry and play a key role in raising awareness of possible new logics of action (Meyer, 1982), thereby unlocking opportunities for industry entry and progression (Madhavan et al., 1998; Sine and David, 2003; Fligstein and McAdam, 2012). For example, jolts have been shown to catalyze the mobilization of peripheral actors who can advance their

position in the industry (Sine and David, 2003) or precipitate the entry of innovative outsiders into an organizational field (Cattani et al., 2017). Revisiting our earlier example, it should then not come as a surprise that Qatar Airways's meteoric rise to the heart of the airline alliance network occurred in the wake of the large-scale disruptions caused by September 11, 2001, terrorist attacks. Still, this kind of network transition remains sorely understudied, perhaps because the occurrence of external shocks is by itself unlikely to reveal the mechanisms underpinning it (Croidieu and Kim, 2018). Hence the question we seek to address with this study: what network mechanisms enable peripheral players' successful transition toward the center of an industry's alliance network in the aftermath of a shock?

In response to this question, we advance the proposition that the entry of peripheral firms is channeled through dyadic and triadic network mechanisms, anchored upon the two most fundamental dynamics of affiliation in the network literature (Borgatti et al., 2022; Milo et al., 2002; Wasserman and Faust, 1994). At the dyadic level, we postulate that these firms gain foothold by establishing relationships with prominent partners – a mechanism we define as expansive ties. At the triadic level, we argue that transitive closure involving core and periphery airlines – a mechanism we define as hybrid closure – operates as a key embedding mechanism. Building on the well-established idea that contextual forces shape patterns of changes in networks (Chen et al., 2022), we test these network mechanisms of peripheral firms' transition toward the core in the aftermath of a large-scale disruptive event.

As with other studies developing context-specific hypotheses, we conducted several interviews to gain a deeper understanding of our research context. Empirically, we rely on the largest longitudinal dataset on the worldwide airline alliance network ever assembled to substantiate our arguments on peripheral firm entry. The use of strategic alliances in the form of code-sharing agreements is common in the airline industry and a crucial determinant of competitive advantage, thus making this industry an appropriate empirical setting for the study. The quantitative analysis based on stochastic actor-oriented models (SAOMs; Snijders et al., 2010) lends credence to the argument that the embedding of peripheral players via expansive ties and hybrid closure increases after an exogenous shock.

The study makes three main contributions. First, by zooming in on network pathways and unpacking their dynamics pre- and post-disruption, the study advances research on interfirm network evolution, which has so far remained somewhat silent on the mechanisms responsible for attenuating the self-reproducing character of interorganizational networks. Relatedly, the study also extends network-oriented management scholarship attending to the strategies that poorly embedded firms may follow to work their way into the center of industry networks. Second, while it is relatively unproblematic to note that exogenous shocks may create opportunities for peripheral actors to break into the core of an industry, very little evidence exists to suggest how such a transition occurs. We contribute to this literature by providing granular evidence on the dyadic and triadic micro-mechanisms undergirding the core-periphery hybridization that often results from discontinuous events that dramatically alter an environment's competitive and operating conditions. In so doing, we echo a more general move in the social sciences to analyze momentum, turning points, and transitions (see Abbott, 2001 for a general overview). Finally, albeit indirectly, our work also contributes to the innovation management literature. To the extent that poorly embedded actors often represent untapped opportunities and novel ideas while central actors have the power and legitimacy to leverage those opportunities, and insofar as innovation requires both novelty and legitimacy, our study offers a general framework for understanding when and how the bridging

between those two complementary ends of the network continuum is more likely to occur.

2. Theoretical background

2.1. Peripheral firm entry

The attractiveness of a firm strongly depends on its relational capital, which determines its network embeddedness (Ahuja, 2000). It follows that for firms that are poorly embedded, the understanding of how they manage to form linkages and advance into the industry network is theoretically relevant. Based on our literature analysis, we identified two main lines of empirical research focusing on how peripheral organizations break through the center of a given industry via networks: (1) actor-focused research and (2) events-focused research.[2] Working at different levels of analysis, each of these approaches has led to important insights into this question. Nevertheless, each approach confronts limitations arising from its specific theoretical and methodological concerns.

Actor-focused research emphasizes the mechanisms and initiatives through which organizations occupying peripheral positions may gain industry prominence. This research is premised on the basic idea that peripheral firms can overcome network inertia (Kim et al., 2006) and enhance their visibility by pursuing strategic collaborations with highly embedded firms (Ahuja, 2000; Rosenkopf and Padula, 2008). For instance, it has been suggested that peripheral firms that are loosely connected can overcome the constraints that their structural position imposes by using a "*creeping* strategy of working one's way toward the center of the network" (Ahuja et al., 2009, p. 942) by linking up to their more embedded counterparts. To accomplish this goal, peripheral firms may offer favorable terms of trade to entice central allies into an exchange relationship. There are mutual benefits in forming such relationships as peripheral firms access valuable resources that typically reside in the industry center while central firms obtain non-redundant insights, as in the case of collaborations between young firms and industry incumbents (e.g., Polidoro Jr. and Yang, 2021), and diversify and expand their alliance portfolio. Focusing on investment syndication networks, Fund et al. (2008) developed a process model of centrality development for peripheral firms, which they illustrate through the journey form the periphery to the core of two venture capital firms. Within the same context, another study (Keil et al., 2010) found that the rigid structure of venture capital syndication networks was permeated by a more peripheral class of investors – corporate venture capitalists (CVCs). CVCs were able to move to more central positions in syndication networks by offering valuable resources, not typically available to peripheral traditional VCs. Other studies suggest that peripheral firms can try to capitalize on the attainment of prestigious awards that boost their

visibility to move to more central alliance-network locations (Soh et al., 2004). Related literature suggests the notion of "insurgent partnering" to indicate a strategy in which peripheral firms improve their visibility by allying with other peripheral firms (Baum et al., 2003).

The set of explanations associated with events-focused research hinges on rare disruptive events as enablers of peripheral firm entry into the industry. These events can take multiple forms, including technological shocks (Schilling, 2015), regulatory changes (Madhavan et al., 1998), economic crises (Wan and Yiu, 2009), and terrorist attacks (Llussá and Tavares, 2011). Organizations that unexpectedly experience such events are faced with immediate adaptation needs that may tip them into embracing new logics of action and interaction that, in turn, may create industry entry opportunities for players otherwise confined to its margins. Although such events generate uncertainty and represent a challenge to those experiencing them, they also "offer propitious opportunities for introducing unrelated changes" (Meyer, 1982, p. 515). Consider Sine and David's (2003) analysis of the US electric power industry in the aftermath of the oil crisis when a wave of entrepreneurial agency resulted in "increasing access for peripheral actors to central policy makers" (Sine and David, 2003, p. 203). Similarly, regulatory and technology shocks in the global steel industry in the mid-1980s "created opportunities for peripheral firms to acquire a more favorable position in the network" (Koka et al., 2006, p. 723). A more contemporary example is the portable music industry following the abrupt transition from analog to digital music (Burgelman and Grove, 2007), with marginal players, such as Napster, gaining an increasing foothold in the industry (Hensman, 2003). Importantly, the findings from this scholarship suggest that jolts may curb the characteristically self-reinforcing dynamics of interorganizational networks, where poorly embedded firms struggle to make significant changes to their peripheral status, thereby increasing receptiveness to strategic options that would be foreclosed in more stable or less dynamic environments (Cattani et al., 2017).

Each of these streams of research has yielded important insights into peripheral firms' entry. However, their largely autonomous pursuit has, at the same time, limited inquiries into questions concerning the relations between actor-based and event-based explanations of network change. By emphasizing the general agency of organizational actors in finding ways to obtain resources, actor-based explanations run the risk of relying too much on teleological categories, such as exceptional skills in generating breakthrough innovations, claiming unique identities, or forging strategic ties, and fall short of explaining the circumstances that precipitate these actors to work their way from the sidelines to the center of an industry. Event-based explanations emphasizing shocks, on the other hand, illuminate the external conditions that may prompt peripheral organizations to cross over to the center but do not exhibit much analytical leverage in explaining the mechanisms by which such transitions occur.

As the positions actors occupy as a result of the relationships they hold within an industry are crucial to understanding the structuration of an industry (Powell et al., 1996, 2005), we argue that actor- and event-focused perspectives can be fruitfully bridged by relying on the intuition that patterns of network affiliation are helpful for understanding periods of change triggered by disruptive events. Establishing such bridge allows the researcher to achieve a more balanced view between "the extreme image of a 'heroic' network architect and a completely deterministic environment" (Koka et al., 2006, p. 721). Madhavan et al. (1998) were among the first to foreshadow this idea by sharing evidence indicating variation in alliance patterns in response to regulatory and technological shocks (defined by the authors as "exogenous structure-loosening events") which overturn the established order, ultimately leading to a shuffling of relationships among previously disconnected firms. Schilling (2015) advanced detailed arguments as to why firms may respond to shocks by forming new alliances that extend beyond their typical alliance partners (for a similar perspective see also Arslan and Tarakci, 2020). Focusing on interorganizational responses to periods of

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[2] The review is based on an extensive search of the literature on peripheral firm entry. We searched for articles published in leading academic journals in the business field between 1990 and 2022 in Scopus using the terms "peripher*", "outsider", "network*", "center", "core", and "entry" in their title, abstract or keywords. We limited our search to contributions published in academic journals in the business area and in English. This initial query yielded 357 results. We further restricted our search to articles published in top academic journals (i.e., ABS 3 and above by the Chartered Association of Business Schools) in the areas of entrepreneurship, innovation, organization, and strategy. We then searched for articles analyzing the entry and associated strategies of peripheral firms and excluded those that dealt with the entry of peripheral individuals (rather than firms) as well as articles that mentioned our search terms but did not look at the core-periphery divide through a network lens. Two parallel streams include research looking at core and periphery through a geography-based lens (e.g., Power and Collins, 2021) and research adopting a resource partitioning perspective that is typical of the organizational ecology tradition of studies (e.g., Verhaal et al., 2017). This procedure led to a refined database of 28 empirical articles. From these articles we identified the two main classes of explanations summarized in Table 1.

uncertainty, Collet and Philippe (2014) echoed a similar point, suggesting that firms may respond to uncertainty by initiating heterophilous ties if risk is positively valenced. Withers et al. (2018) too offered evidence on the relationship between regulatory change and change in firm-level mechanisms of partner selection, such as reciprocity, multiplexity, and transitivity in board interlock networks. In sum, not only has this line of work shown that industries characterized by dynamic environments differ from stable ones with respect to the network structure they exhibit (Tatarynowicz et al., 2016), but also such differences are often the manifestations of network dynamics triggered by unexpected events.

Our aspiration is similar to this scholarship's desire to understand *if* and *how* collaboration changes in response to external perturbations. But while this stream of work typically assumes network change to be an invariant process that radiates out evenly across nodes, we are interested in exposing potential heterogeneity in nodal-level affiliation dynamics across the core-periphery spectrum - an important yet undertheorized aspect in extant interorganizational network research. Two exceptions to this general observation are Powell and Owen-Smith's (2012) study on the evolution of the biotech industry network in the face of abrupt changes and Corbo et al.'s (2016) analysis of the transformation of the worldwide airline alliance structure in the aftermath of 9/11. Both works present distinctive ideas that we seek to leverage and limitations that we attempt to address. While Powell and Owen-Smith (2012) alluded, albeit indirectly, to ways in which shifting patterns of affiliation at the core may render the network more (or less) permeable to peripheral players, because they focused solely on the most connected players within the main component, parallel arguments on peripheral or isolated nodes can only be speculative at best. Corbo et al. (2016) managed to detect changes in generalized logics of partner affiliation during the pre- and post-jolt periods. Yet, because their analysis is at the whole network level and focuses on the degree centrality of the actors (i.e., the number of ties in which each actor is involved), it remains unknown which specific affiliation patterns underlie peripheral players' progression toward the industry core.[3]

2.2. Network pathways of peripheral firm entry

From the analysis of the literature on peripheral firm entry, we conclude that the question of how poorly embedded firms navigate their way toward the industry core has only been partially explored, leaving room for additional investigation of both the theoretical and empirical viability of such a mobility strategy (Ahuja et al., 2009; Hu et al., 2021). To appreciate how firms that are not advantaged by the current network structure can break into these networks, we build on well-established network concepts at the dyadic and triadic levels of analysis. Dyads and triads are indeed the bases of the most basic micro-mechanisms that govern the structure and the dynamics of networks of any type (Borgatti et al., 2022; Milo et al., 2002; Wasserman and Faust, 1994). While on one hand the formal and quantitative character of such network structural micro-mechanisms will allow the statistical testing of our hypotheses, on the other hand we will endow their formalism with the contingent meaning they take in our empirical context by supplementing their network formalism with qualitative evidence. First, at the network level, peripheral players' embedding efforts operate via dyadic

connections to other firms. In principle, in the aftermath of an exogenous shock, such efforts could focus inward by forming connections with similarly positioned others or outward by linking with more remote or central actors. For instance, peripheral players establishing inward connections could create the conditions for the emergence of a new cohesive cluster at the margins, potentially challenging the industry core (Baum et al., 2003). Outward ties, instead, could help peripheral players increase their influence by obtaining the "relational imprimatur of existing elites" (Powell and Owen-Smith, 2012, p. 468). We use the term *expansive tie* to define an outward tie between a peripheral and a core player and the term *segregating tie* to indicate an inward tie among members of the periphery (or members of the core).

Besides direct dyadic connections, indirect connections could also shape peripheral players' embedding efforts. In particular, a given focal peripheral player could become more embedded in the industry network via triadic closure, where at least one of the members of the triad is a core player. We define this embedding mechanism as *hybrid closure*. For the sake of illustration, consider the case where ego (the focal actor) is a peripheral player that is maintaining ties with two unconnected alters. As shown in Fig. 1, different stylized forms of triadic closure are possible, depending on whether the alters are themselves peripheral or core network members. The triadic closure in panel 1a reflects a situation where the two alters are both core members.

In contrast, the triadic closure in panel 1b reflects a situation where one alter is a core member of the network, and the other is a peripheral player. Because these core-periphery closures differ in the extent to which peripheral actors become entangled in relationships with core members, we further differentiate the core-periphery closures in panels 1a and 1b as "strong" and "weak" hybrid closures, respectively. Note that hybrid triadic closures might take place following a shock in order to promote mutual collaboration and collectively oriented norms, thereby minimizing opportunism (Coleman, 1990; Granovetter, 1985; Uzzi, 1997), a condition that may be particularly sought after in times of uncertainty (Romero et al., 2016). To illustrate this idea in our context, consider a triad that involves two alters, which are core airlines and an ego that is a peripheral airline; if such a triad closes, the peripheral carrier could benefit by "feeding" the respective hub airports of the core airlines on code-shared flights between them, thereby offering additional routes to its customers, which can be an especially valuable solution in the post-shock period. Conversely, the triadic closure in panel 1c describes a situation where the two alters are themselves peripheral players. We label this embedding mechanism *segregating closure* because it increases network stratification, preventing peripheral actors from migrating toward the core. This mechanism is nonetheless interesting to the extent that, by turning on one another, peripheral players may potentially sow the seeds of a new cohesive cluster that may someday coalesce against the elite. Broadly, we view these different dyadic and triadic embedding efforts as *network pathways* that actors pursue as they strive to either improve or consolidate their position within the industry.

To explore such pathways, we adopted the following research design. First, in line with pressing calls for more "contextual sensitivity as a basis for theoretical contribution" (Bamberger, 2008, p. 844; but see also Filatotchev et al., 2022; Stahl et al., 2023) to capture the increasing volatility of the environments in which firms operate, we used field evidence and descriptive network analysis to develop a thick, detailed appreciation of the way in which airlines reconfigured their networks following the 9/11 disruption. As noted by Bamberger (2008, p. 842): "The insights gained from these context-rich descriptions can provide important hints as to, if not grounded hypotheses regarding, how context directly shapes particular outcomes or conditions particular relationships". We thus leveraged our preliminary findings to inform the development of two context-specific hypotheses about dyadic and triadic network mechanisms of entry into the network. Second, we analyzed a unique dataset containing the alliance records of 258 airlines and then used stochastic actor-oriented models to test our predictions on

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[3] Corbo et al. (2016) documented a general movement of peripheral actors toward the center of the airline industry's alliance network, which translated into a more even degree distribution after the 9/11 shock. Our work extends and builds on Corbo et al.'s findings by delving deeper into this general tendency to tease out the network micro-mechanisms of entry into the core (which we term "*network pathways*"). Accordingly, not only do we account for the sheer number of alliances (i.e., network degree) in which each actor is involved, but more importantly we examine with whom those alliances are established (i.e., how those alliances are distributed between core and peripheral alters).

Table 1
Selected evidence on peripheral firm entry modes.

Mode	Exemplary studies	Empirical setting	Main results
(1) Actor-focused research			
Offering access to new-to-the-network technology via distant shortcuts	Rosenkopf and Padula (2008)	US cellular industry	Nonembedded firms are more likely to be admitted to the network when offering access to novel technology
Acceptance of unfavorable terms of trade in asymmetric partnerships	Ahuja et al. (2009)	Chemical industry	Poorly embedded firms manage to form partnerships with densely embedded firms by offering better terms of trade in relationship governance
Creating connections to prominent actors	David et al. (2013)	Consulting industry	Outsiders form ties to prominent authorities outside of the field and influential individuals to obtain legitimacy for a new organizational form they introduce
Offering innovative ideas to access key technological knowledge	Kudic et al. (2015)	German laser industry	The transition from peripheral to core positions is influenced by the strength of a firm's commercial and business-related orientation
Partnering with moderately high-centrality firms	Hu et al. (2021)	Japanese joint ventures in foreign countries	Low-centrality firms partnering with firms that have moderately higher centrality obtain more durable alliances and progress to more central network positions
(2) Event-focused research			
A structure-loosening event taking the form of a technology shock	Madhavan et al. (1998)	Steel industry	Peripheral players exploit structure-loosening events to improve their position into the industry network
An environmental jolt taking the form of an oil crisis	Sine and David (2003)	US electric power industry	An exogenous shock grants peripheral actors access to central players in the field, creating opportunities for entrepreneurial action
An exogenous shock caused by a terrorist attack	Corbo et al. (2016)	Airline industry	Industry-wide sudden events open up opportunities for marginal firms to join the network core
The recent global financial crisis of 2007–2008 resulting in institutional and regulatory reforms	Redert (2022)	European Supervisory Authorities	An external event generating opportunities for the participation of new interest groups in the lobbying networks of the European Supervisory Authorities

the dataset.[4] In the sections below, we describe each of these elements of the study and discuss the results.

3. Empirical context and hypotheses

We developed our predictions by engaging with contextual evidence and well-established literature on network-evolution mechanisms. Following other studies that develop context-specific hypotheses (e.g., Washington and Zajac, 2005; Lee and Lounsbury, 2015; Cancellieri et al., 2022), we conducted a series of interviews which we integrated with archival material and descriptive analyses to gain a deeper understanding of our context (Wry et al., 2014; Taeuscher et al., 2021), and to inform our predictions (see Table 2 for details on data sources). Our goals during this stage were to probe the rationale for establishing or discontinuing alliances in a context of extreme uncertainty, such as 9/11, and to ascertain how these relational choices emerge. The interviews took place between 2014 and 2018. The interviewees were C-level executives of airlines and alliance constellations who identified themselves as responsible for their organizations' alliance strategies. When possible, we asked personal contacts to make introductions to airline executives to ensure both elite and less prestigious firms were represented in the sample. Half of our interviews resulted from such introductions, while the other half resulted from cold calls to airlines meeting our criteria.

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[4] The use of context theorizing, or the direct integration of the richness of context into the framing of theoretical arguments, is especially recommended for the development of theories in which time is the contextual dimension (i.e., pre- and post-disruption) and the focus is on explaining the period-contingent nature of such relations (i.e., the temporal contingencies shaping the dynamics of network entry). As discussed by Filatochev et al. (2022, p. 1037): "To capture the increasing complexity, volatility, and uncertainty of the external environment, and gain a better understanding of how firms can address these challenges and deal with the environmental discontinuities associated with them, management scholars need to adopt […] more context-dependent perspectives". For quantitative researchers, this typically implies relying on context-oriented qualitative research in the early stages of the research as a way to better appreciate the situational or temporal contingencies shaping the phenomenon of interest. The insights so gleaned might then result, for instance, in developing context-oriented hypotheses or specifying a model to include cross-level effects to better account for situational or temporal constructs' influence (Bamberger, 2008).

Overall, we conducted 13 interviews that lasted between 20 and 70 minutes; one of the authors conducted all the interviews. Table A.1 summarizes the characteristics of our respondents, Table A.2 includes the interview protocol, while Table A.3 in Appendix A compiles the most representative quotes from our informants (see Appendix A).

The study's context is the worldwide airline alliance network in the wake of the terrorist attack of September 11, 2001, an event that has produced an enormous global economic and social impact. On that day, 19 militants associated with the terrorist group Al Qaeda hijacked four airplanes and carried out suicide attacks against targets in the United States. Two planes were flown into the towers of the World Trade Center in New York City, another plane hit the Pentagon just outside Washington, DC, and a fourth plane crashed in a field in Pennsylvania. The attacks resulted in extensive death and destruction, triggering major initiatives in the United States and elsewhere to combat terrorism. It has been estimated that over 3000 people lost their lives in the 9/11 attacks.

In addition to directly causing a temporary but complete shutdown of the commercial aviation system, the attacks caused many travelers to reduce or avoid air travel, wary of a newly-perceived risk associated with flying (Ito and Lee, 2005). Since September 11, 2001, numerous airlines, both in the United States and abroad, have been experiencing a financial crisis unlike any in modern aviation history. To illustrate the point, consider the following paragraph from the report produced for the US Congress after the attacks:

> Most Wall Street analysts were projecting an overall financial loss for the industry in the range of $1–2 billion for 2001. Industry losses for the full year were instead over $7 billion. … It now appears that the events of September 11 changed the airline industry in some fundamental ways that are not yet fully understood.
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> (Makinen, 2002)

The impact of 9/11 was so severe that well-reputed players experienced immediate losses that were impossible to remediate, and numerous carriers had to engage in dramatic cost-cutting programs. Within months of the attacks, large US carriers such as United Airlines and US Airways filed for bankruptcy under Chapter 11; many other historical carriers outside the United States, such as Sabena and Swissair, went bankrupt and ceased operations. In the aftermath of the shock, traffic fell by 26 % in the North Atlantic, >10 % in Europe, and >17 % in the Far East. Moreover, European and North American carriers reduced
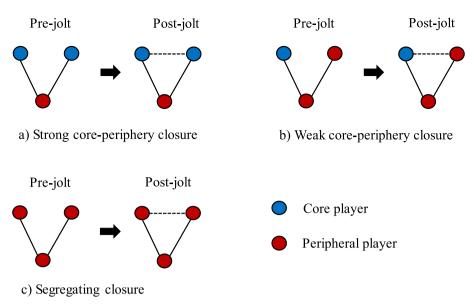
Fig. 1. Triadic mechanisms of peripheral firm embedding: hybrid and segregating closure.

Table 2
Data sources.

Type	Source	No. of documents/ interviews	No. of pages[a]
Industry associations	International Air Transport Association (IATA)	6	9
Specialized press	Airline Business; Brough (2015); Flight Global; Travel Trade Gazette	31	84
General press	Australian Financial Review; Financial Times; Forbes; New York Times; South China Morning Post; The Australian; The Montreal Gazette	18	18
Technical reports	Booz & Co.; Directorate General for Mobility and Transport; Makinen (2002)	3	148
Academic papers	Blunk et al. (2006); Gillen and Lall (2003); Goll and Rasheed (2011); Hatty and Hollmeier (2003); Ito and Lee (2005)	5	27
Interviews	C-level executives of airlines and airline constellations	13	69
Total		63 (+11)	355

[a] The numbers represent the pages from each document containing valuable information for our research. Recordings from 2 interviews are not available per our informant's request.

their capacity by 10–20 % with similar adjustments made on international routes (Airline Business, 2002).

Our data indicate that the 9/11 shock generated a spike in alliances in the airline industry. For instance, in 2002, 148 new code-sharing agreements were initiated by the airlines in our sample, representing an increase of almost 29 % over the number of such arrangements initiated in previous years. One alliance executive explained to us the pivotal role of 9/11 in this increase in alliance activity in the airline industry:

> The industry was already in bad waters before 9/11. However, 9/11 accelerated such problems and clarified the need for change for everyone in the industry. Companies reacted differently depending on the region where they were operating. In general, 9/11 acted as a game-changer for the whole world, not only for the air transport industry. Airlines started realizing the increased importance of cooperation. Those were the times when Continental, Delta, and Northwest deepened their relationships or KLM and Air France started talking to each other again
>
> (Vice President Sales #9)

Another interviewee stressed the importance of alliances and networks as a means to cope with exogenous shocks such as the 9/11 even further:

> You need to be prepared in this industry, any event that happens has an immediate effect on this industry … And you really should use

your alliance network to handle, to deal with this smoother. Alliances are the only way we have to manage such crises, if we try to handle it on our own there is no chance we can succeed
>
> (Head of emergency response process management #10)

Prior research and qualitative evidence thus suggest that exogenous shocks lead to the fragmentation of the system (Gulati et al., 2012), and generate alliance spikes in which more marginal players increase their chances of being involved in new alliance formation. Drawing on network literature (Borgatti et al., 2022; Milo et al., 2002; Wasserman and Faust, 1994) we focused on the two most fundamental network evolution mechanisms at the dyadic and triadic levels to develop our hypotheses on peripheral firm entry.

3.1. Dyadic network pathways

We now turn our attention to mechanisms of peripheral entry via dyadic relationships. Anchoring to the observation that disruptions triggered by unforeseen events serve as turning points in industry evolution (Meyer, 1982), acting as occasions for network structuring (Madhavan et al., 1998), we expect that the 9/11 shock will increase a peripheral airline's chance of forging new ties with central airlines. Various studies suggest that exogenous events provide an impetus for action, unlocking opportunities for otherwise marginalized players to improve their prominence within the network (Koka et al., 2006). Conversely, once a shock strikes in, core firms may find themselves

Table 3
Core and periphery partition (%).

Player type	Pre-shock (1998–2001)	Post-shock (2002–2005)	Change
Core	17	22	+5
Semi-marginal	55	57	+2
Marginal	28	21	−7

constrained in their ability to quickly adjust their network as they are already invested in a large number of ties, which limit their 'degrees of freedom' as a result of path dependency and the inherent complexity of managing a larger number of relationships, thereby leaving peripheral firms' greater freedom to maneuver (Madhavan et al., 1998; Corbo et al., 2016). Our descriptive data is supportive of this idea, indicating that firms that are located outside of the industry core tend to create, on average, more expansive ties in the post-shock period, which, as a result, allows some of these firms to move relatively quickly closer to the center of the network. The increase in expansive ties in the post-shock period is mirrored by a decrease in segregating ties between members in the periphery. This can be best appreciated by aggregating our data into two sub-periods representing the pre- (1998–2001) and post- (2002–2005) shock periods. Table 3 shows that the percentage of airlines in the core increased from 17 to 22 % during the post-shock era, while the percentage of actors in the periphery decreased from 83 to 78 %. The increase in 'mixed' dyadic agreements was also confirmed by one of our informants:

> … the alliances have changed over time. The partnerships became much more…let's say much more various, so basically you have a bigger combination of bigger and smaller carriers in all the alliances
> (Head of alliances and international relations #3)

Turning now to the composition of the periphery, it can be noted that until 2001, there was a significant chasm between those who occupied a position between the core and the periphery – which we labeled "semi-marginal" – and the purely peripheral airlines – which we labeled "marginal".[5] During the post-shock period, however, this difference decreased considerably. Specifically, in the aftermath of the attacks, the percentage of marginal players decreased from 28 to 21 %, while the percentage of semi-marginal players increased from 55 to 57 %. Fig. 2 shows that especially expansive ties increased, whereas segregating ties remained pretty stable or decreased. This can be analytically appreciated by looking at the trends of bipartite densities, i.e., the count of the ties that are observed as a percentage of those that might exist, given the number of airlines. This is to account for both the decreasing number of airlines over time in our sample (from 239 in 1998 to 179 in 2005) and the changing size of the core and the periphery.

In the tumultuous period following the 9/11 terrorist attacks, new alliance constellations were built by core players and increasingly joined by peripheral airlines that opened up new, previously overlooked opportunities by acting as feeders for the large airport hubs enabling passengers from such hubs to travel to peripheral regions (Iatrou and Oretti, 2007). The Star Alliance constellation, for example, expanded rapidly in the convulsive climate of the early 2000s, enlisting a number of peripheral members such as Croatia Airlines and Adria Airways. To illustrate the increased visibility of smaller, peripheral airlines, a Star Alliance senior executive, commenting on their shift of strategic attention following 9/11 noted:

> We've realized that there are parts of the world that can't be reached or aren't reached by the major networks, and in those cases, it would make sense to partner up with a regional airline.

(The Gazette, 2003)

This evidence does not imply that standard drivers of affiliation, such as centrality and status, cease to function as means of sorting alliance partners—but it does suggest that airlines are less reliant on those mechanisms in periods of increased uncertainty. In other words, peripheral firms can also leverage their value in dyadic relationships with more embedded partners (Hu et al., 2021). Consequently, a greater number of airlines that were previously shut out of alliancing opportunities can access more embedded partners. Overall, this evidence supports the results of previous research indicating that firms respond to periods of turmoil by increasing their alliance activity (Schilling, 2015; Arslan and Tarakci, 2020)—albeit for only a short period of time in our setting—but is also indicative of changes in the nature of collaborations, with peripheral actors' expansive ties largely responsible for such an increase. Accordingly, we posit:

Hypothesis 1. *Compared to the period before the 9/11 shock, peripheral airlines' movement toward the industry core is likely to be facilitated by an increase in expansive ties and a concurrent reduction in segregating ties in the period after the exogenous shock.*

3.2. Triadic network pathways

We further assessed peripheral airlines' network pathways by examining the changes in alliance activity within triads (i.e., subsets of three actors and the possible ties among them). Triads play a key role in relating micro-structural tendencies with macro-structural patterns, sitting at the intersection of ties between pairs of actors (i.e., dyads) and entire networks. Although micro-level mechanisms of triadic closure and the associated macro-level pattern of network clustering have long been documented in a variety of settings (Madhavan et al., 2004; Ferriani et al., 2013; Zhelyazkov, 2018), few studies have explored how exogenous shocks affect triadic closure tendencies (e.g., Romero et al., 2016). Work that does so by accounting for the different structural statuses of the actors included in the triads is even rarer.

Here, we address this issue by examining triadic changes involving core and peripheral players.[6] Fig. 3 shows the average number of open triads where the focal node was a peripheral company – as previously conceptualized in Fig. 1 – which became closed triads during the post-shock period. First, note that, on average, segregating triadic closure activity – that is, the creation of cohesive subgroups in the network's periphery – decreased during the post-shock period. Conversely, hybrid closure increased, both in its weak and strong form, with a sharper increase in the strong one. Hybrid closure as a mechanism for marginal airlines to become more embedded in the airline industry after 9/11 was also emphasized by one of our interviewees:

> From the standpoint of multilateral alliances there have been status gains for smaller airlines, if I am Java [a peripheral airline] and I join a multilateral alliance I do it not only for traffic but also for status because I put myself on the main stage

(Vice President sales #9)

The benefits of triadic closure, which include trust and commitment, have been widely studied in the network literature (Coleman, 1990; Kilduff and Tsai, 2003). As an industry becomes more established, these network structures typically become more prominent and drive inertial network evolution (Ter Wal, 2014). There is also some evidence suggesting that networks become more cohesive in response to shocks

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[5] We categorize a firm as "marginal" if it doesn't hold any tie to a core firm and "semi-marginal" if it holds one or more connections to core firms. We provide a more detailed definition of such categorization, as well as of its construction, in the "Econometric analysis" section below.

[6] We analyzed triadic configurations by using the ego network change routine implemented in UCINET 6 (Borgatti et al., 2002). For each period between two consecutive observations of the network, this routine counts the number of triads that change from a certain configuration in the starting observation time to another configuration in the next observation time while enabling the actors in the triad to be partitioned according to a categorical attribute.
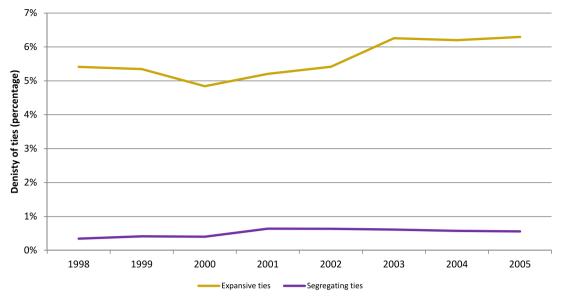
Fig. 2. Annual bipartite densities of expansive and segregating ties, full sample.
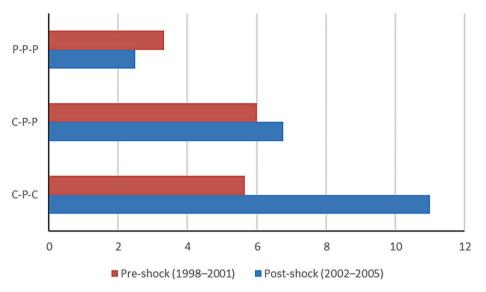

Fig. 3. Triadic embedding of peripheral players during the pre- and post-shock periods (C: core; P: peripheral) **Note:** P-P-P, C-P-P, C-P-C on the *y* axis represent segregating closures, weak hybrid closures, and strong hybrid closures respectively. The *x* axis is the average count of triadic closures where ego is a peripheral firm.

(Romero et al., 2016). Yet, limited scholarly attention has been given to the nexus between shock-induced changes in triadic network structures and the characteristics of the actors that make up a specific triad. While generally consistent with extant research, our evidence also suggests that those triads are more likely to close when they entail both peripheral and core network members. We surmise that these hybrid triads carry two concomitant advantages that are particularly beneficial in periods of turmoil. First, they offer a diversity advantage because, through hybrid triads, core and peripheral players can obtain access to new, non-redundant resources. In our context, hybrid triads grant the involved airlines access to non-redundant routes or geographical areas, whereas segregating triads are much more likely to exhibit a higher overlap of shared resources. At the same time, the presence of a common third-party increases trust and encourages the parties to spend time and effort on the collaboration (Ter Wal et al., 2016). For these reasons, we expect that segregating closure will diminish while hybrid triads will increase. This leads to the following hypothesis:

Hypothesis 2. *Compared to the period before the 9/11 shock, peripheral*

airlines' movement toward the industry core is likely to be facilitated by an increase in the formation of hybrid triads and a concurrent reduction in segregating closures in the period after the exogenous shock.

4. Econometric analysis

Our econometric analysis relies on worldwide airline data compiled from the Airline Business magazine, the International Air Transport Association (IATA), and the International Civil Aviation Organization (ICAO). Network alliance data covering 258 airlines worldwide revealed 1188 unique ties between 1998 and 2005. Contrary to most previous studies employing alliance data from the global airline industry based on significantly smaller samples (Gimeno, 2004; Lazzarini, 2007; Corbo et al., 2016; Wassmer et al., 2017), we used data for the whole population of airlines from 132 countries. Aiming for a complete census of the population was primarily motivated by the advantages of overcoming at once both issues of boundary specification and sampling rather than aiming at greater statistical power. This is especially important in our study because we rely on a fully structural approach in order to be able

to tease out the "network pathways". There appears to be no other database of airline alliances ever used in prior research that approaches the comprehensiveness of our dataset.

We defined an alliance tie as any code-sharing agreement between two airlines since joint route operations through these agreements represent the most important cooperative activity of global airline alliances (Gimeno, 2004). Code-sharing agreements are bilateral alliances in which two airlines combine routes and offer a single composite product to customers (Lazzarini, 2007). Code-sharing is the most prevalent collaborative practice in the airline industry because it is less binding than mergers or joint ventures but enables carriers to access new markets and supply a viable service when traffic volume does not justify individual operations by two airlines (Iatrou and Oretti, 2007).[7] We organized these code-sharing agreements into eight 258×258 binary and symmetric matrices, one for each year in our observation period (1998–2005). We assigned the ij^{th} entry (which is the same as the ji^{th} entry) of the matrix for a given year a value of 1 if a code-sharing agreement was observed between the ith and j^{th} airline in that year, and 0 otherwise.[8] We then partitioned the network coded in these adjacency matrices into a core and a periphery, according to the well-established approach discussed by Borgatti and Everett (1999). To add nuance to this analysis, we further differentiated within the periphery between extreme and less extreme forms of peripherality, by considering those ties that span across the core and periphery subsets and that are at first ignored by the main core-periphery partition: we label 'marginal' those firms that are located at the extreme periphery (Scott, 2013) as they belong to the periphery and do not hold any tie to members of the core, while in keeping with Wilde (2004, p. 598) we use the label 'semi-marginal' to refer to firms that are peripheral but not too peripheral by virtue of one or more connections to core players. While our general focus is on peripheral firms, this more refined categorization enabled us to explore potential variations in the network pathways that operate at the periphery. As a matter of fact, we did not observe any direct transition between the extreme periphery and the core of the network. The airlines that shifted membership from one period of observation to the next only flowed between the semi-marginal and core subsets or between the marginal and semi-marginal subsets; they did never shift directly between the marginal and core subsets. Semi-marginal firms do indeed occupy a peculiar position because they effectively straddle both the resource and identity space of the periphery and the core of the network (Cattani and Ferriani, 2008), which could result in idiosyncratic relational patterns in the aftermath of the shock.

4.1. Measures

Networks with a core-periphery structure can be partitioned into two subsets of nodes, such that the core subset is internally cohesive (high density of ties) and its members hold many ties with each other; the periphery subset has low internal density because it includes nodes with a lower number of ties, mainly with members of the core. Although no standard methodology for partitioning networks into core and periphery has emerged thus far (Rombach et al., 2014), one of the most widely

used approaches was developed by Borgatti and Everett (1999). They implemented it in the software UCINET 6 (Borgatti et al., 2002), introducing a genetic algorithm that maximizes cohesion in the core and minimizes it in the periphery. While this approach is indifferent to the density of the ties between the core and the periphery and is concerned with a split of the network into just two subsets, a core and a periphery, Borgatti and Everett (1999) recognize the interest in detecting multiple cores, and discuss a variety of core-periphery patterns that could be distinguished based on the density of core-periphery ties. More recent research (Gallagher et al., 2021) notes the value of detecting a more articulated hierarchy of subgroups instead of just a core and a periphery. To offer a more nuanced view of the periphery, we moved a step in this direction while remaining consistent with the overall approach suggested by Borgatti and Everett (1999).

First, we partitioned the network into a core and a periphery, and then we further partitioned the periphery subset into a group of nodes with at least one tie to nodes in the core (*semi-marginal*) and a group of nodes without any such tie (*marginal*). Both the general core-periphery approach and our further split of the periphery are based on both the number of ties (alliances) each actor (airline) maintains and the core or peripheral nature of its alters. This resulted in a partition of the network nodes into *core*, *semi-marginal*, and *marginal* players for each of the eight years in the observation period of 1998–2005. Hence, our approach allows a simple extension of the basic core-periphery distinction to a more articulated classification into three groups, consistent with the core-periphery ordering of the actors and based on those ties between core and periphery that are at first neglected when using Borgatti and Everett's original core-periphery algorithm. Indeed, it is important to stress that semi-marginal players are peripheral players involved in those ties between the core and the periphery that do not affect the primary core-periphery split but are potentially important for better characterizing peripheral firms' dynamics of affiliation. As we did not observe direct jumps from a marginal position to the core, we performed our SAOM estimations by focusing on the entry into the core of semi-marginal airlines instead of peripheral airlines at large. We relied on the above partition to operationalize the two main independent variables.

Segregating ties. This variable captures the tendency toward tie formation between airlines that are semi-marginal, and between airlines that are core, as well as a tendency against ties across the semi-marginal-core divide. A positive coefficient indicates the propensity of actors to establish inward ties to other similarly located actors, while a negative coefficient indicates a preference for expansion through outward ties that connect peripheral (semi-marginal) and core actors.

Hybrid closure. This variable gauges the extent to which two actors i and j that share a common contact h tend to establish a tie, where i and h belong to the same category (i.e., they are either both core or both semi-marginal), which differs from that of j. Triadic closure is a key micro-level network mechanism that has pervasive macro-structural consequences, namely the clustering of network actors in more or less exclusive cohesive subgroups: a positive estimate of the hybrid closure coefficient indicates a tendency toward the involvement in such micro-level affiliation dynamics of airlines from different core-periphery strata, while a negative estimate would indicate that micro-level subgroups tend to involve either only core companies or only peripheral (semi-marginal) companies.

To analyze the network pathways during the post-shock period, we estimated the interactions between the two main effects and the dummy, *2002–2005*. Our decision to consider the period 2002–2005 as a post-shock period was motivated by several factors. First, after the 9/11, the airline industry was hit by other, albeit less severe, shocks such as the SARS pandemic and the war in Iraq in 2003, which affected the industry's recovery. Second, several airlines reported a performance improvement only toward the end of our study period. The former CEO of British Airways, Rod Eddington, explained the carrier's situation in the post-shock period as follows:

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[7] For example, there were only four active joint ventures in our database for 2004. While these agreements represent deeper forms of airline cooperation, they nonetheless do not exclude the possibility to included code-sharing practices between two partner airlines. We thank an anonymous reviewer for this suggestion.

[8] In order to deal with the changing composition of our sample across the period of observation, we followed the approach proposed by Ripley et al. (2023) based on structural zeros. In cases where the ith or the jth airline was inactive in a given year, the corresponding entry of the matrix was coded as a structural zero and was not used in the computations. In cases where both the ith and j^{th} airlines were active in a given year, and we had no information about whether or not a code-sharing agreement existed between them, we coded the corresponding entry of the matrix as missing.

Being in the most comfortable deckchair on the Titanic was still not a good place to be. To relax would be fatal, absolutely fatal.

<div align="right">(Financial Times, 2005)</div>

To control for possible alternative explanations, we included a variety of network and firm-level controls. *Degree (density)* controls for the baseline propensity to maintain ties net of the inducements captured by the other parameters. *Transitivity* controls for the extent to which there is a structural tendency toward closed triads in the airline industry network. *Northern* is a dummy variable that captures differences in tie formation propensity between airlines located either in the Northern or the Southern hemisphere. We also controlled for airlines' experience measured as the *age* of the airlines (i.e., years since foundation). To control for *size*, we used the size of the fleet, an often utilized proxy that captures a company's dimension in the airline industry. Beyond dyadic alliances, the evolution of industry networks can also be influenced by companies' membership in multi-partner alliances or constellations (Gomes-Casseres, 1996). As this is a common phenomenon in the airline industry, we operationalize *constellation* membership as a dummy variable taking the value of 1 if an airline belongs to an alliance constellation (Gomes-Casseres, 1996). Last, we include a measure of operational performance, *load factor*, which measures an aircraft's capacity utilization and is generally considered a more reliable measure of performance compared to financial results and widely used in the airline industry (Lazzarini, 2007). Table 4 provides a summary of the key effects estimated in this analysis.

4.2. Estimation strategy

To test the two hypotheses, we employed stochastic actor-oriented models (SAOM) for network dynamics (Snijders et al., 2010). A well-known general characteristic of the network approach is the ability to link micro and macro levels by connecting aggregate structural patterns to local relational configurations – e.g., cohesive patterns at the network level and closed triads among triples of actors. SAOMs fully embrace and leverage this general feature of the network approach because of their dynamic character and actor orientation; by modeling actors' relational preferences, they trace macro-structures back to their micro-level

Table 4
Summary of key measures for the analysis of the airline network.

Variable	Description
Parameters of interest	
Segregating ties	The tendency of peripheral (semi-marginal) and core actors to be tied to other peripheral (semi-marginal) and core actors, respectively
Hybrid closure	The extent to which two actors *i* and *j* that share a common contact *h* tend to establish a tie, where *i* and *h* belong to the same category (i.e., they are either both core or both peripheral), which differs from that of *j*
Control variables	
Density	The proportion of possible linkages present in a network, which is equal to the total number of ties divided by the total number of possible ties
Transitivity	The propensity for two actors *i* and *j*, which share a common contact *h* to establish a tie
Northern	Dummy variable identifying the region of origin of an airline, which equals to 1 if the airline is from a region in the Northern hemisphere (i.e., Asia-Pacific, Europe, and North America) and 0 if the airline is located in the Southern hemisphere (i.e., Africa, Central and South America, and the Middle East)
Age	Age of the airline (years since foundation)
Constellation	Dummy variable taking a value of 1 if the airline was a member of an alliance constellation, and 0 otherwise
Fleet	Number of aircrafts possessed by the airline
Load factor	The measure of how much of an airline's passenger carrying capacity is used. It is calculated as passenger-kilometers flown as a percentage of seat-kilometers available

behavioral antecedents. SAOMs model network dynamics as driven by actors' tie creation or termination choices. These choices are guided by an objective function that actors try to maximize, constructed as a linear combination of a set of components (*effects*) that represent features of the network as viewed from each actor's perspective. Hence, specifying a model for network evolution involves selecting the effects included in the objective function. The parameters associated with the effects are estimated by simulating the evolution of the network between consecutive observations. During this iterative process, a provisional parameter vector is used to initiate a simulation. This vector is updated by correcting it in the direction suggested by comparing the simulated and the observed network, then it is used to initiate another simulation, and so on, until convergence (if at all) is achieved to a final vector of parameter estimates. Based on these parameter values, another series of simulations is performed, producing an estimate of the standard errors.[9]

5. Results

We now report the results of the SAOM estimations. A correlation matrix and SAOM estimates are presented in Tables 5 and 6, respectively. Model 1 in Table 6 includes the control variables. Models 2 and 3 add the dyadic and triadic effects of interest, respectively, to Model 1. Model 4 estimates the interactions of both the dyadic and triadic effects with the time-dummies used to assess the time-heterogeneity of the model testing hypotheses 1 and 2. Convergence was very good for all models.

In all of our models (and in SAOM models in general), *Degree (density)* is negative and significant due to the implied costs of maintaining a tie per se (e.g., $\beta = -1.417$ and SE $= 0.023$ in Model 1). Evidence of a different propensity to maintain alliances between airlines from the Northern or the Southern hemisphere is found only in Model 3 ($\beta = 0.147$ and SE $= 0.061$).[10] The data reveal evidence of a higher propensity to maintain alliances among more experienced companies (*age*) (β between 0.009 and 0.01 and SE lower or equal to 0.002 in all models). Evidence of a higher propensity to form alliances by companies that already belong to an alliance constellation (*constellation*) is found in Models 3 ($\beta = 0.560$ and SE $= 0.170$) and 4 ($\beta = 0.368$ and SE $= 0.128$). No significant impact on the airlines' involvement in alliances was found for size, as measured by the number of aircrafts (*fleet*) or operational efficiency (*load factor*). *Transitivity* controls for the baseline tendency of the airlines to cluster in groups with a high internal density of alliances. Our models attest to the existence of this tendency among airlines worldwide; indeed, the estimates are positive and significant in all models (e.g., in Model 4, $\beta = 0.170$ and SE $= 0.036$), with the exception of Model 3.

We estimated separately the dyadic effect of segregating ties and the triadic effect of hybrid closure in Models 2 and 3, respectively, before joining them in Model 4. We did so to tease out the theorized dyadic and triadic embedding mechanisms for both the whole and the post-shock periods. The estimates in Model 2 indicate a negative propensity to

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[9] SAOM simulations address the key inferential issue about network structure (i.e., the analytical form of the sampling distribution of the parameter estimates remains unknown). This is because modeling the network structure is equivalent to modeling the form of interdependence in the network data; this radically precludes the standard assumption of observation independence required to determine the sampling distribution of the estimates.

[10] In order to help make sense of the magnitude of the effects let's take as an example the Transitivity parameter, which, as estimated in Model 4 of Table 5, is positive (0.170) and highly significant (p < 0.001). This reflects a preference of the companies for those ties that increase the number of closed triangles in their ego-network. The magnitude of such preference is grasped by translating such parameter estimate in terms of probabilities: all else being equal, the probability of a company to extend a tie that adds one new closed triangle to its ego-network is 19 % higher (because the value of $e^{0.170}$ is 1.19) than the probability to extend a tie that does not add any new closed triangles.

Table 5
Correlation matrix.

		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1.	Density											
2.	Northern	0.039										
3.	Age	0.145	0.371									
4.	Constellation	0.189	−0.061	−0.099								
5.	Fleet	−0.038	−0.177	−0.188	−0.139							
6.	Load Factor	0.076	−0.061	−0.004	−0.054	−0.164						
7.	Transitivity	−0.311	−0.149	−0.27	−0.455	−0.031	−0.011					
8.	Segregating Ties	−0.479	−0.035	−0.178	−0.122	0.051	−0.015	0.293				
9.	Segregating Ties × 2002–2005	−0.1	−0.085	−0.111	−0.141	0.048	−0.049	0.272	0.401			
10.	Transitivity × 2002–2005	−0.118	−0.024	−0.045	−0.207	0.072	−0.053	0.249	0.251	0.258		
11.	Hybrid Closure	0.148	0.104	0.196	0.389	0.038	−0.025	−0.879	−0.418	−0.324	−0.285	
12.	Hybrid Closure × 2002–2005	0.141	0.03	0.066	0.21	−0.055	0.045	−0.321	−0.324	−0.515	−0.884	0.349

Table 6
Results of SAOM analysis.

		Model 1 Controls				Model 2 Controls Segregating Ties				Model 3 Controls Hybrid Closure				Model 4 Controls Segregating Ties Hybrid Closure			
		Estim.		SE	p-value	Estim.		SE	p-value	Estim.		SE	p-value	Estim.		SE	p-value
1.	Density	−1.417	***	0.023	0.000	−1.341	***	0.027	0.000	−1.481	***	0.026	0.000	−1.378	***	0.029	0.000
2.	Northern	0.113	†	0.058	0.053	0.086		0.060	0.153	0.147	*	0.061	0.017	0.103		0.063	0.101
3.	Age	0.009	***	0.002	0.000	0.009	***	0.001	0.000	0.010	***	0.002	0.000	0.009	***	0.002	0.000
4.	Constellation	0.196	†	0.106	0.063	0.145		0.104	0.163	0.560	***	0.170	0.001	0.368	**	0.128	0.004
5.	Fleet	0.001		0.000	0.211	0.000		0.000	0.453	0.001		0.001	0.243	0.000		0.001	0.424
6.	Load Factor	0.652		0.557	0.242	0.771		0.539	0.153	0.620		0.552	0.261	0.714		0.542	0.188
7.	Transitivity	0.345	***	0.016	0.000	0.379	***	0.017	0.000	0.071		0.052	0.175	0.170	***	0.036	0.000
8.	Segregating Ties					−0.288	***	0.048	0.000					−0.323	***	0.057	0.000
9.	Segregating Ties × 2002–2005					−0.185	*	0.079	0.019					−0.144		0.110	0.189
10.	Transitivity × 2002–2005									−0.252	**	0.086	0.003	−0.207	**	0.065	0.001
11.	Hybrid Closure									0.869	***	0.129	0.000	0.667	***	0.090	0.000
12.	Hybrid Closure × 2002–2005									0.453	*	0.220	0.040	0.386	*	0.184	0.036

† p < 0.1.
* p < 0.05.
** p < 0.01.
*** p < 0.001

segregation (or a positive tendency to form expansive ties) (*segregating ties*: β = −0.288 and SE = 0.048), which is strengthened in the post-shock period (*segregating ties × 2002–2005*: β = −0.185 and SE = 0.079).[11] This would seem to indicate a reinforcement of the tendency to form ties between core and semi-marginal actors in the periphery in the post-shock period, which lends tentative support to the idea that peripheral firms in semi-marginal structural positions may enjoy new entry pathways after the shock. However, while the signs of the estimates are confirmed in the full model, only the main effect is significant (β = −0.323 and SE = 0.057), while the reinforcement in the post-shock period is not significant (β = −0.144 and SE = 0.110), suggesting that the tendency of the formation of ties between semi-marginal and core actors was not significantly different after the shock. All in all, these results provide mixed support for our hypothesis 1.

We observed above that airlines tend to cluster in groups with a high

internal density of alliances (*transitivity*). Given core companies' higher propensity to form alliances, this might suggest the prevalence of homophilous triads in which core companies cluster with other core companies. However, this is not the case in our empirical context. Model 3 shows an overall tendency toward forming hybrid core-periphery (semi-marginal) triads (*hybrid closure*: β = 0.869 and SE = 0.129). This trend strengthens during the post-shock period (*hybrid closure × 2002–2005*: β = 0.453 and SE = 0.220). Results are similar for the full model (Model 4).[12] It is worth noting that, when estimated together with hybrid transitivity, the general transitivity effect weakens: although hybrid closure increased during the post-shock period, general transitivity decreased after the shock that perturbed the airline network, as indicated by the negative estimate of its interaction with the post-shock dummy (Model 4, β = −0.207 and SE = 0.065). These results support our second hypothesis and suggest that hybrid closure was the main driver toward closure in our network after the shock. The loss of significance of the negative estimate of *segregating ties × 2002–2005* when estimated together with hybrid closure further reinforces the prevalence of hybrid closure rather than expansive ties as the main embedding

[11] A similar result is also found in our sensitivity analysis that accounts for the geographical width of operations of the airlines, where the variable *Generalists* identifies those companies that serve destinations outside their region of origin. Also, in those analyses, the interaction *segregating ties × 2002–2005* was found to be negative and significant (β = −0.294, SE = 0.135). These analyses also confirm the results of the full model (see Appendix B).

[12] Sensitivity analyses using an alternative measure of triadic closure generated similar results and are available from the authors upon request.

mechanism after the shock.[13]

6. Discussion and conclusion

Extreme events such as natural disasters, pandemics, and terrorist attacks represent turning points in the history of humanity and often affect hundreds of thousands of people. However, for all their dramatic effects on the economy and human affairs, these shocks are also an extraordinary catalyst for change and adaptation (Chakrabarti, 2015). The catalytic role of exogenous shocks on peripheral firms can be likened to the impact of earthquakes on buildings. Just as "seismic tremors often disclose hidden flaws in the architecture and construction of buildings" (Meyer, 1982, p. 515), exogenous shocks can expose the limits and the fallacies of industry structure and create a unique window of opportunity for less embedded actors to move toward the core of the industry. The link between disruptive events and network embeddedness represents an important extension to network literature as firms need to revise their strategy and adapt to remain or become successful as industries evolve (de Vaan, 2014).

Building on the intersection between the literatures on peripheral firm entry adopting a network analytic lens (Ahuja, 2000; Ahuja et al., 2009; Rosenkopf and Padula, 2008), and on disruptive external events as drivers of change (Sine and David, 2003; Markard and Truffer, 2006), we theorized dyadic and triadic embedding mechanisms through which peripheral firms can break through the industry network in the wake of an exogenous shock. Analytically, we conceptualized and examined two types of affiliations at the dyadic level: "expansive ties" and "segregating ties". At the triadic level, we focused on the formation of core-periphery clusters by analyzing the evolution of "hybrid closures," that is, tie formation/termination dynamics that link core and peripheral actors in closed triads. Our quantitative tests indicate, as suggested by our qualitative field evidence, that following the 9/11 attacks, peripheral firms – semi-marginal firms in particular – managed to cross over to the center of the network through a pronounced increase in hybrid triadic closures that narrowed the core-periphery divide. Some evidence of peripheral firm entry through increased direct expansive ties linking semi-marginal players to the core and a corresponding reduction in segregating ones was also found. Taken together, these findings contribute to our understanding of the mechanisms by which peripheral firms can increase their industry prominence and offer a variety of theoretical as well as practical insights.

6.1. Theoretical insights

Vast research on interfirm collaboration indicates that networks tend to be structurally stable due to path dependence (e.g., Giuliani, 2013) and established players' strong incentives to behave in ways that ensure their continued positional advantages (Kim et al., 2006). As a result, industry networks often resemble a core-periphery structure where highly embedded firms have disproportionately larger and better networks than their poorly embedded counterparts. Unfortunately, the empirical emphasis on core firms in interorganizational networks combined with the prevalence of centrality-oriented network analytic

approaches (often premised on the elimination of "inconvenient" data points such as isolates) has encouraged the development of an endogenous perspective of network change that has trouble elucidating how poorly embedded firms are able to break into networks (Rosenkopf and Padula, 2008). Within such a perspective, peripheral actors, if conceptualized at all, are typically viewed as responding passively to central players' moves and decisions. Yet, peripheral actors do sometimes manage to cross over to the center. The findings in this study shed light on the role of exogenous and impactful disruptions on the dynamics of peripheral firm entry. While a few previous studies have raised the possibility that networks become more permeable to the entry of poorly embedded firms because of revolutionary events outside the existing network (Madhavan et al., 1998; Corbo et al., 2016), little has been said about the way (i.e., the type of ties) in which such entries occur following disruptive events. Directly addressing this shortcoming, our study contributes to the literature on peripheral entry by offering a richer understanding of how entry effectively takes place and by expounding the change in affiliation mechanisms occurring in pre- and post-shock periods.

Our work also contributes to innovation-oriented management scholarship. Peripheral organizations are often assumed to be key carriers of novelty due to their limited assimilation into dominant institutional norms and standards (Leblebici et al., 1991). Yet, it is hard to imagine an organizational theory of periphery-driven innovation without a broader framework for understanding how such novelty can reach into the core of the network where the crucial sources of legitimacy lie (Cattani and Ferriani, 2008). We have attempted to stimulate the development of such a framework by suggesting that complementary to the question of whether peripheral actors are more likely to innovate is how they progress within the network, despite their seemingly unsurmountable structural disadvantages. Unpacking these network pathways is central to the mission of strategy and innovation scholars because it helps to understand which firms accrue differential positional advantages, getting at the heart of heterogeneity in competitiveness and innovation. Future work examining the type of ties that are instrumental in sustaining the legitimation and recognition of peripheral firms' innovative efforts represents a promising research avenue.

Finally, we propose a simple yet novel approach for detecting actors who are located between the core and the periphery in a manner that is consistent with the classic core-periphery approach of Borgatti and Everett (1999). This latter approach exploits a genetic algorithm that maximizes the density of the ties in the core and minimizes it in the periphery. While valuable, this network partitioning method neglects the ties between the core and the periphery, and divides the network into just two subsets, even though Borgatti and Everett (1999) recognize the interest in detecting multiple cores, and more recent research (Gallagher et al., 2021) emphasizes the value of detecting a more articulated hierarchy of subgroups. By further partitioning the periphery, we move a step in this direction with an approach that complements Borgatti and Everett's (1999) analytical framework and is consistent with it. That is, we partition the periphery into semi-marginal and marginal subsets by exploiting those core-periphery ties that are at first ignored in the network split. This approach is flexible and can be easily extended to other empirical settings.

6.2. Management and policy insights

The entry of peripheral firms into an industry's network is typically challenging for several reasons, including a lack of resources and support from those who act as industry gatekeepers. The results of this study suggest that under changing industry conditions, peripheral firm entry is more likely to take place, despite such barriers. The instability generated by exogenous shocks may increase the likelihood of non-local partner search. It follows that peripheral firms should be especially alert to tie-formation opportunities in the aftermath of such events. In the wake of unforeseen shocks, the trajectories of once-marginal entities can

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[13] It is helpful to note that the same expansive ties may at once contribute to both the dyadic and the triadic effects. So, for example, a tie between airlines i and j, one in the core and the other in the semi-marginal periphery, i.e., an expansive tie, contributes negatively to the estimate of the *Segregating Ties* effect; that same tie also contributes positively to the *Hybrid Closure* effect if i and j share a contact h belonging to the same category of i. In other words, the ties that contribute to the *Hybrid Closure* effect are a subset of the expansive ties that contribute to the Segregating Ties effect. The results of Model 4 indicate that the increase of expansive ties in the post-shock period was mainly induced by the closure of hybrid triads involving the expansive ties mentioned above, which helps explain why the dyadic effect loses statistical significance.

dramatically shift, as seen beyond just the airline sector. Take BioNTech, for example. Virtually unknown, outside the small world of European biotechnology start-ups, it vaulted to prominence by pioneering a Covid vaccine (Cnbc, 2021). In the aftermath of the pandemic's upheaval, BioNTech didn't just weather the storm – it seized an opportunity, partnering strategically with pharmaceutical titan Pfizer. This alliance granted BioNTech not only credibility but also unparalleled access to Pfizer's vast development expertise and infrastructure (The Wall Street Journal, 2020). The Covid-19 era witnessed a surge in such collaborations, with nimble biotech startups partnering with industry behemoths like Pfizer, Fosun Pharma, and Regeneron. This phenomenon underscores the dynamic nature of network pathways, which can rapidly evolve post a significant external jolt. Alliance managers, armed with this knowledge, can astutely navigate and capitalize on these transformative moments, brokering partnerships that might have once seemed out of reach.

The findings of our study also carry policy implications. Exogenous shocks hit airlines severely, often pushing affected carriers toward bankruptcy or extinction. Since interorganizational collaborations are a strategic resource in this industry, a better understanding of the structural impact of policy decisions in the aftermath of exogenous shocks could help to inform the formulation of policies more conducive to 'healthy' interorganizational networks. As Madhavan et al. (1998, p. 456) aptly put it, studying network change offers a lens to evaluate the ripple effects of regulatory interventions. For antitrust regulators, this means a fresh perspective: evaluating the network positions of alliance members and using such knowledge to inform decisions to grant or withdraw antitrust immunity to code-sharing agreements. When a peripheral player is involved, especially in the turbulent wake of a shock, concerns over monopolistic or collusive tendencies may diminish compared to when only central carriers join forces. Such nuanced insights, derived from our study, can complement traditional market evaluations, ensuring policies are more holistic, informed, and effective.

6.3. Limitations and extensions

As with every study, the generalization of the findings presented in this paper should be approached with caution. First, as with every industry that is highly cyclical, external events impact the airline industry significantly, as air travel demand and profitability are highly correlated with income level and demographics, as well as with world energy demand, supply, and prices (Iatrou and Oretti, 2007). Additionally, the airline industry is, to a large extent, a mature industry, with established technology and little product differentiation among competitors. When exposed to an exogenous shock, firms often choose to adapt to the fast-changing environment by altering their resources and capabilities through mergers and acquisitions rather than through alliances (Wan and Yiu, 2009). However, in the airline industry, regulatory constraints have often prevented cross-border mergers and acquisitions, leaving alliances as the only alternative to organic growth. While these factors make the airline industry a formidable setting in which to analyze how and under which conditions peripheral firms use network-based mechanisms to advance toward the industry center, they may also limit the generalizability of our findings to settings that exhibit similar characteristics (e.g., aerospace and defense, logistics, shipping). Therefore, it would be interesting to replicate this study's research design in industries in other stages of the lifecycle, in contexts where technical standards have not yet emerged or where technology is a major source of uncertainty, and in industries characterized by looser regulatory constraints. Is peripheral firm entry more likely to occur through alliances or deeper forms of collaboration (e.g., mergers and acquisitions) following a major shock? What is the role of diminished financial and resource strength of the core players that may lead peripheral firms to establish more favorable terms? What is the 'price' that peripheral players pay to achieve such goal?

The network lens adopted in this study can also be useful for exploring peripheral firm entry, and core-periphery dynamics more broadly, at an ecosystem level (Shipilov and Gawer, 2020). In some respects, ecosystems resemble core-periphery structures, with a group of peripheral organizations often trying to get a stronger foothold into the ecosystem (Cozzolino et al., 2021) and a narrower set of organizations assuming the role of platform leaders (Gawer and Cusumano, 2002) who ensure the stability of the ecosystem. Technological disruptions or other shocks, however, may question such leadership and break established relationships within the ecosystem (Ozalp et al., 2018), offering peripheral firms the opportunity to dislodge an existing power structure. Since "most companies today inhabit ecosystems that extend beyond the boundaries of their own industries" (Iansiti and Levien, 2004, p. 70), and cross-industry alliances have been shown to improve a firm's bargaining position with respect to more central firms in their own (primary) industry (Xia et al., 2016), an interesting extension of this study would be to explore whether peripheral firm entry in the primary industry is related to the establishment of alliances *across* industries within an ecosystem's boundaries.

An additional extension of this study is to examine how network-entry dynamics vary with the risk profile of contexts affected by an exogenous event. According to Hällgren et al. (2018), three main types of contexts have been explored in the literature: risky, emergency, and disrupted contexts. Terrorist attacks such as 9/11 lead to disrupted contexts since they do not usually allow for preparation (Lanzara, 1983) and typically catch firms off-guard (Hällgren et al., 2018). In contrast, risky and emergency contexts are characterized by near-constant exposure to potentially extreme events that might increase firms' preparedness and adaptability. We leave the examination of network pathways across contexts of varying risk profiles to future research. Finally, while our study has focused on network pathways of peripheral firm entry, there is evidence that analogous relational dynamics operate at the individual level of analysis. An example is the work of Padgett and McLean (2006), which traces the genesis of the partnership systems in Renaissance Florence and studies the inclusion of peripheral players into the ruling elite in the wake of the Ciompi revolt. While exogenous changes, such as revolutions or political crises, carry the power to subvert an existing equilibrium and open up space for alternative views and the ascendance of peripheral individuals, we know little about the network mechanisms promoting such individuals' rise to prominence. We invite future research to address this and related questions.

CRediT authorship contribution statement

Leonardo Corbo: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Raffaele Corrado:** Methodology, Software, Validation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing. **Simone Ferriani:** Conceptualization, Methodology, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

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