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ORIGINAL ARTICLE

CRIMINOLOGY

The dynamics of criminal collaboration: Multiplex ties in mafia networks

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Abstract

This study examines how social embeddedness and multiplex relationships shape criminal collaboration within organized crime networks. Drawing on data from three major investigations into the 'Ndrangheta, we analyze how kinship, clan affiliation, leadership, and prior interactions influence participation in meetings and phone calls. Using relational hyperevent models, we assess the dynamic and multiplex nature of these networks across time and investigations. Results show that kinship, leadership, and shared clan affiliation consistently increase the likelihood of interaction, with stronger effects for face-to-face meetings. Prior joint interactions also predict future collaboration, especially when the mode remains consistent. We find contrasting patterns of closure: meetings resist triadic closure, reinforcing exclusivity and hierarchy, whereas phone calls promote connectivity by bridging structural holes. By modeling multiple relational mechanisms simultaneously and across different networks, this study contributes to research on criminal embeddedness and the structural organization of illicit collaboration.

KEYWORDS
criminal networks, multiplexity, social embeddedness, social network analysis

1 | INTRODUCTION

Why do some members of a criminal organization collaborate more than others? Why do some individuals repeatedly participate in meetings and calls to manage criminal activities or internal disputes, whereas others—equally situated within the organization—do not? These questions lie at the heart of understanding the internal functioning of criminal organizations. They invite us to look beyond aggregated statistics of group activity and focus instead on the micro-dynamics that shape who collaborates with whom, when, and under which conditions. Such questions are not just of theoretical interest: They are crucial for understanding how criminal organizations function, how they resist law enforcement, and how they can be disrupted.

This article investigates the determinants of criminal collaboration within mafia-type organizations, focusing on the Italian 'Ndrangheta. In line with research on the social embeddedness of organized crime networks, we adopt a broad definition of *criminal collaboration* as the set of interactions that enables the coordination of criminal activities within the organization. In doing so, we deploy a definition that incorporates—but is not limited to—the narrower notion of co-offending, which refers to the joint commission of specific crimes. This distinction is especially important in the context of organized crime, where collaboration often extends well beyond formal co-offenses.

Drawing on detailed data from three major investigations—Minotauro, Infinito, and Crimine—we examine whether and how preexisting social ties and organizational elements (kinship, clan affiliation, prior interactions, and leadership roles) shape the likelihood of co-participation in criminal events. We model both meetings and phone calls, capturing different forms of coordination and communication.

We use relational hyperevent models (RHEMs) to analyze co-participation patterns over time, accounting for multiplex social ties (i.e., relationships connecting individuals through multiple types of social or criminal interactions), organizational elements, endogenous network processes, and contextual factors. Our findings reveal consistent patterns across all three investigations: male sex, kinship, clan co-membership, leadership status, and prior collaboration all significantly increase the likelihood of joint action, particularly for meetings. We observe divergent patterns of closure: Meetings are characterized by tendencies against triadic closure, reinforcing hierarchical and exclusive structures, whereas phone calls facilitate connections by bridging structural gaps.

Our study contributes to the literature on criminal networks in three ways. First, we offer a relational and dynamic account of collaboration that goes beyond static attributes or aggregated group-level properties. Second, we apply a novel event-based method—RHEM—that allows us to study multiplex, longitudinal event data with actor-level and dyad-level dependencies. Third, we offer an empirical comparison of co-participation in meetings and phone calls across three separate criminal investigations, thus enhancing the robustness and external validity of our findings.

The rest of the article is structured as follows: We first review relevant theoretical work on embeddedness, multiplexity, and criminal network structure. We then present our data and modeling strategy. Section 4 examines participation patterns across the three networks, followed by a discussion of their theoretical and practical implications. We conclude by identifying key contributions and future directions.

2 | BACKGROUND

2.1 | Social embeddedness and internal organization in organized crime

Social embeddedness, social capital, and trust are often viewed as positive forces that promote cooperation, community cohesion, and economic exchange. Yet a fundamental paradox is frequently overlooked: The same ties that enable legitimate collaboration can also sustain criminal networks, protect illicit activities, and shield wrongdoing from external interference. Granovetter (1985, p. 492) noted that although economic action is embedded in social relations, "force and fraud are most efficiently pursued by teams" built on trust. Portes (1998, p. 18) reinforced this perspective, warning that "sociability cuts both ways," producing not only public goods but also organized crime and corruption. Even trust, as Gambetta (1988a, p. 214) observed, can underlie forms of cooperation—"notably among robbers and murderers"—that society may prefer to dismantle rather than cultivate.

These insights have profound theoretical implications for economic sociology, criminology, and network science. First, they challenge normative assumptions in social capital theory (Coleman, 1988; Putnam, 1993) by demonstrating that strong social ties do not always foster positive outcomes; they can also create resilient criminal enclaves that resist external intervention (Varese, 2011). Second, they complicate rational choice perspectives on crime by showing that criminal cooperation is not merely the result of strategic calculation but is embedded in long-standing social structures (Kleemans & De Poot, 2008; Morselli, 2009). Third, they push network theories of organized crime (Bright & Whelan, 2021; Calderoni et al., 2022) to move beyond simple measures of connectivity and consider how social ties create durable, high-trust criminal collaborations by balancing social processes of closure and brokerage (Bright et al., 2024; Burt, 1992). Recognizing that criminal organizations follow the same principles as legitimate social and economic cooperation forces a reevaluation of how we conceptualize illicit networks, their causes, and their ability to evolve in response to external threats.

In criminology, research on embeddedness has evolved into two partially distinct strands. Studies on *gang embeddedness*, defined as "involvement, identification, and status among gang members" (Pyrooz et al., 2013, p. 243), highlight the increased risk of individual harm, including offending, victimization, and delayed desistance (Charette & Goossens, 2025; Decker et al., 2014; Hagan, 1993; Pyrooz et al., 2013; Sweeten et al., 2013). By contrast, research on the *social embeddedness of organized crime* underscores how general social ties, such as kinship, friendship, work-based relationships, and repeated interaction, enable recruitment into organized crime and durable and coordinated illicit cooperation (Calderoni & Superchi, 2019; Kleemans & De Poot, 2008; Kleemans & Van De Bunt, 1999; Morselli, 2009; Van de Bunt et al., 2014; Calderoni et al., 2025). Although the two are not mutually exclusive—in both cases, social embeddedness shapes behavior within criminal groups—our approach builds on the latter perspective. In the context of organized crime, these ties are actively cultivated and leveraged to build trust, enforce secrecy, and enable sustained collaboration.

Criminal organizations leverage social embeddedness, social capital, and trust to sustain cooperation, regulate resource access, and maintain secrecy. Social embeddedness fosters trust by anchoring illicit exchanges in preexisting relationships, minimizing the risk of betrayal (Kleemans & De Poot, 2008; Kleemans & Van De Bunt, 1999; Reuter, 1983). Social capital strengthens recruitment and organizational resilience, as criminal groups often draw members from kinship

networks and shared social backgrounds, reinforcing loyalty and limiting law enforcement infiltration (Morselli, 2009; Van de Bunt et al., 2014). These mechanisms enable criminal enterprises to function as durable social systems, where trust and secrecy are maintained through deeply embedded ties, mirroring the cooperative dynamics seen in legitimate economic and political spheres (Calderoni et al., 2022; Smith & Papachristos, 2016). Consistent with these theoretical insights, research on the social embeddedness of organized crime has largely emphasized sustained forms of collaboration—such as repeated communication, logistical coordination, and interactions shaped by leadership roles or organizational affiliation—over isolated episodes of co-offending. Although co-offending is certainly documented in investigative records, it represents only the visible tip of a broader collaborative structure. A single criminal act may be preceded and supported by dozens or even hundreds of interactions, which reveal more about how trust, hierarchy, and coordination are maintained within the organization.

Kinship is a fundamental dimension of criminal collaboration, structuring recruitment, hierarchy, and trust within organized crime. Classic ethnographies revealed how mafia groups in Sicily and Italian–American communities were deeply embedded in family networks, where blood ties ensured loyalty and secrecy (Blok, 1974; Ianni & Reuss-Ianni, 1972). More recent research confirmed that kinship fosters network cohesion, tie density, and organizational resilience, making criminal enterprises more resistant to external threats (Berlusconi, 2022; Bright et al., 2024; Campana & Varese, 2013; Malm et al., 2010; Mastrobuoni & Patacchini, 2012; Calderoni et al., 2025). Studies on the 'Ndrangheta showed that interfamily marriages further consolidate alliances, strengthening organizational control (Catino et al., 2022). By reinforcing both trust and obligation, kinship-based embeddedness sustains illicit cooperation, insulating criminal organizations from defection and infiltration. These family-based relations are both *social*—in that they reflect affective and trust-based ties—and *organizational*, as they structure hierarchy and recruitment within the organizations.

Beyond kinship, shared clan, mafia family, gang chapter, or neighborhood ties provide a crucial foundation for criminal collaboration—blending social embeddedness with organizational structure. Many organized crime groups form around territorial bonds: a common hometown, village, or urban neighborhood fostered strong in-group solidarity, even without blood ties. Research on street gangs showed that turf and neighborhood identity shaped cohesion and criminal collaboration (Brantingham et al., 2012; Campana & Varese, 2022; Klein, 1995; Papachristos & Hughes, 2015; Thrasher, 1927; Valasik et al., 2023). In Italian mafias, rituals, oaths, and initiation ceremonies reinforce the authority of the mafia family or clan, which itself is often tied to a specific territory such as a town, village, or urban neighborhood (Battisti et al., 2022; Calderoni et al., 2017; Paoli, 2003). These symbolic practices strengthen loyalty and cohesion within territorially rooted groups, building trust, regulating recruitment, and imposing discipline. Like kinship, these embedded affiliations enhance secrecy and cooperation in illicit enterprises.

Leadership plays a pivotal role in structuring interactions within criminal networks, mediating between internal cohesion and interaction with context. Criminal leaders do more than occupy central positions; they actively regulate information flow, coordinate exchanges, and shape decision-making processes. Mafia leaders are essential in maintaining internal stability while simultaneously managing external ties, ensuring that trust remains contained within tightly knit groups while selectively bridging structural holes to access external resources and opportunities (Calderoni & Superchi, 2019; DellaPosta, 2017; Morselli, 2009). This ability to balance intragroup cohesion with intergroup brokerage strengthens both the resilience and adaptability of criminal networks, allowing them to endure external pressures while maintaining operational flexibility.

In conclusion, criminal collaboration is shaped by both social and organizational factors. Kinship and prior interactions reflect social embeddedness rooted in trust and reciprocity, whereas leadership roles and clan affiliation capture organizational structure and formal authority. These dimensions are not mutually exclusive: Leaders are often relatives, clans emerge from territorially rooted social groups, and repeated interactions build both hierarchy and trust. Viewing social and organizational ties as overlapping and mutually reinforcing allows for a more nuanced understanding of how criminal networks operate and endure.

2.2 | Modes of collaboration, multiplexity, and higher order structures

Criminal collaboration develops over time through repeated interactions that foster trust and cooperation (Bright et al., 2019, 2024; Morselli, 2009). Criminal networks interact in diverse ways—co-offending, criminal or social gatherings, or routine contact—each serving distinct functions. These modes are not interchangeable: Some interactions build cohesion or signal status; others coordinate action or manage risk.

Criminal collaboration takes different forms depending on the mode of interaction. Meetings typically reinforce hierarchy and exclusivity, often involving high-ranking members and serving ceremonial, deliberative, or strategic purposes. They reflect the formal structure of the organization and tend to be more selective in participation (Calderoni & Superchi, 2019). Phone calls, by contrast, tend to be more frequent and operational, facilitating logistical coordination, updates, or informal exchanges across a broader set of actors (Agreste et al., 2016; Calderoni, 2012; Morselli & Petit, 2007). Although meetings mirror institutional authority and internal order, phone calls capture the fluid, day-to-day functioning of the group. These differences imply that the same relational predictors may operate differently across modes and highlight the need to model meetings and calls as complementary but distinct forms of collaboration.

All the mechanisms mentioned above do not operate in isolation; they overlap and reinforce one another, shaping the structure of criminal networks. This overlap is known as *multiplexity*—the condition in which two individuals are connected through multiple simultaneous relationships, such as kinship, clan affiliation, past co-offending, or shared ventures (Battiston et al., 2020; Gómez et al., 2013; Kivelä et al., 2014). In criminal networks, multiplex ties reflect social embeddedness by combining various relational dimensions—like kinship, shared origin, or prior collaboration—between actors. Such ties are typically stronger and more durable than single-stranded ones, as they deepen trust, reinforce loyalty, and raise the social costs of defection (Bright et al., 2015; Campana, 2022; Papachristos & Smith, 2014; Van der Wijk et al., 2025; Wippell & Haynie, 2025, Calderoni et al., 2025). A trafficker who is also a cousin, childhood friend, or business partner has more to lose by betraying the relationship.

Although multiplexity is a recurrent feature of criminal collaboration, its structural implications remain underexplored. Most empirical studies of criminal networks examine single tie types, such as co-offending or meetings—in isolation without accounting for how different relationships intersect, leaving multiplexity's role in criminal collaboration insufficiently understood. Advances from the physical and computational sciences offer promising tools to model such complexity through multilayered networks or hypernetworks—that is, network structures in which ties of different types are represented as interconnected layers or group-level relations rather than simple pairwise links (Battiston et al., 2020; Gómez et al., 2013; Kivelä et al., 2014). Current applications of the multilayered approaches to criminal networks (Bright et al., 2015; Ficara et al., 2021, 2022), so far, have primarily focused on demonstrating the added value of multilayer models

over traditional network analysis—for example, by identifying key actors through cross-layer centrality measures—rather than theorizing how multiplex relational mechanisms shape criminal collaboration itself (for an exception, see Calderoni et al.,2025).

Although empirical evidence remains scarce, existing research suggests that multiplex ties reinforce trust, foster interdependence, and enhance the stability of organized crime networks by providing multiple, overlapping channels of interaction. This layered connectivity raises the cost of defection, as individuals are embedded in relationships that span several domains, thereby strengthening internal cohesion. Campana and Varese (2013), for example, found that kinship and the sharing of information on violent acts significantly increased the likelihood of co-offending. Although multiplex ties are relatively rare, they play a crucial role in linking actors and coordinating activities. In their study of Al Capone's Chicago network, Smith and Papachristos (2016) found that only 10% of connections were multiplex, yet these ties were central in binding the underworld and connecting it to political and economic elites. Similarly, Krebs (2002) and Morselli (2009) showed that multiplex relationships form the critical connective tissue of criminal networks, enhancing their resilience in ways that single-stranded ties cannot.

Social networks are shaped not only by social mechanisms such as kinship, hierarchy, and prior interaction but also by how interactions are structured. Dynamic processes, like closure and brokerage, are common across networks (Burt, 1992; Coleman, 1988). Closure arises when individuals with a shared contact form direct ties, creating tightly knit clusters that reinforce trust and cohesion. Brokerage, by contrast, maintains structural holes between clusters, enabling intermediaries to control information flow and coordinate interactions. Although closure fosters solidarity, brokerage supports flexibility, secrecy, and strategic coordination (Lerner & Hâncean, 2023; Lerner et al., 2021).

These mechanisms are crucial in criminal networks, where balancing cohesion and compartmentalization affects effectiveness and resilience (Bright et al., 2019; Morselli, 2009). Triadic closure enhances trust by linking actors with mutual contacts, reducing risks from unknown collaborators (Bright et al., 2024; Coleman, 1988). In high-risk settings like organized crime, dense connections signal trust and deter infiltration—but excessive closure increases visibility and vulnerability. Criminal groups manage the tension between cohesion and adaptability by assigning brokers to connect subgroups while limiting direct ties (Burt, 1992; Calderoni et al., 2017; Morselli, 2003, 2007, 2009). Brokers control access to information and decision-making (Calderoni, 2012; Calderoni & Superchi, 2019). Understanding closure and brokerage helps explain how criminal networks maintain order and adapt to threats.

2.3 | Empirical gaps and analytical objectives

Despite important insights, prior research has faced key limitations. Most studies are cross-sectional, overlooking the temporal dynamics of trust, social capital, closure, and brokerage. Many focus on a single case, limiting generalizability across contexts. Others examine only one type of tie, neglecting the multiplex nature of criminal networks. Crucially, few studies have explored how different modes of criminal collaboration—such as meetings and phone calls—interact, influence each other, or reflect distinct relational mechanisms. Additionally, the common use of two-mode to one-mode projections—linking actors through shared events—can distort network metrics by inflating closure, especially in large gatherings, and obscure the true structure of interactions. Addressing these issues calls for a longitudinal, comparative, and multiplex approach that captures the complexity of criminal collaboration.

This study aims to examine the social and organizational mechanisms shaping criminal collaboration within meeting and phone call networks, with a particular focus on the multiplexity and social embeddedness of organized crime interactions. By analyzing three major 'Ndrangheta operations—Crimine, Infinito, and Minotauro—through a longitudinal framework, we investigate how different collaboration modes (meetings and phone calls) serve distinct strategic functions within criminal organizations. Furthermore, we explore the role of leadership, kinship, prior interactions, and network closure in shaping criminal collaboration.

To achieve this, we address the following research questions:

- How does the embeddedness of actors within criminal networks—measured through kinship ties, leadership roles, and clan affiliations—affect participation in different forms of interaction?
- How do different types of prior interactions (meetings and phone calls) shape the likelihood of future collaboration in criminal networks?
- How do meetings and phone calls interact, and to what extent does participation in one mode influence participation in the other?
- How do structural mechanisms such as triadic closure and brokerage differ between meetings and phone calls?

3 | METHODOLOGY

3.1 | Data sources

This study draws on three major investigations into 'Ndrangheta-affiliated groups in Calabria, Lombardy, and Piedmont: Operation Crimine (Procura di Reggio Calabria, 2010), Operation Infinito (Tribunale di Milano, 2010), and Operation Minotauro (Tribunale di Torino, 2011). Conducted between 2006 and 2011, these operations led to large-scale trials and the conviction of several hundred individuals. Each was led by specialized anti-mafia prosecutors and police units, with mafia association (Article 416-bis of the Italian Criminal Code) as the main charge. This provision allowed investigators to target not only individual crimes but also the existence, leadership, and internal organization of the groups. As such, the investigations offer rare insight into the 'Ndrangheta's internal dynamics—particularly its formal hierarchies, kinship ties, and patterns of interaction—making them well suited for analyzing participation in meetings and phone calls.[1]

The 'Ndrangheta is structured around kinship and hierarchy (Calderoni, 2014a; Catino, 2019; Paoli, 2003; Sergi & Lavorgna, 2016). Blood ties and marriages form the basis of its smallest units, the families known as *'ndrine*. Several *'ndrine* in a geographic area, a single municipality, or neighborhood combine to form a *locale* (plural: *locali*). The *locale* is an autonomous 'Ndrangheta clan or subgroup that exerts authority over its affiliates and coordinates criminal activities within its area of influence. Its internal governance includes distinct roles such as the *Capo locale* (boss of the *locale*), *Contabile* (treasurer), and *Crimine* (chief of criminal operations).

Data collection relied on pre-trial court orders and judicial documents equivalent to arrest warrants. These documents were manually coded by two researchers. Coding was subsequently

[1] These operations were already studied by several studies (Calderoni, 2014b, 2015; Calderoni & Superchi, 2019; Calderoni et al., 2017; Grassi et al., 2019).

TABLE 1 Descriptive statistics by operation.

Group	Variable	Crimine	Infinito	Minotauro
Actors	Total actors	1056	592	602
	Of which, males	827	549	556
	Of which, leaders	24	25	15
'Ndrangheta locali	Active locali	48	18	17
	Mean affiliates	7.8	16.2	13.3
	Actors in locali (% of total)	35.4	49.2	37.5
Kinship	Maximum ties	32	11	14
	Mean ties	2.8	1.4	1.4
	Median ties	1	0	0
Network structure—meetings	*N* of events	565	550	444
	Components	7	4	3
	Modularity (Louvain)	0.775	0.693	0.589
	Clusters detected	24	17	15
Network structure—phone calls	*N* of events	701	395	1,421
	Components	6	7	5
	Modularity (Louvain)	0.786	0.887	0.803
	Clusters detected	19	24	21

reviewed, updated, and harmonized by a distinct researcher to ensure coherence and accuracy. The first author supervised the process, established a common data collection and coding protocol, and intervened to resolve conflicts or methodological issues when necessary (Procura di Reggio Calabria, 2010; Tribunale di Milano, 2010; Tribunale di Torino, 2011).

For each investigation, we constructed four core datasets. The first focused on individual attributes, including personal information such as name, sex, and year of birth, as well as, when available, *locale* affiliation, office held, leadership status, criminal charges, and other relevant details.[2] The second dataset documented meetings, recording the date, time, location, and list of participants for each observed gathering. The third captured telephone calls, specifying the date, time, and individuals involved in each recorded conversation. Finally, the fourth dataset mapped kinship ties between actors, drawing on explicit references in the judicial documents and inferring additional links when logically possible—for instance, if A and B were identified as brothers, and A and C were also brothers, then B and C were likewise recorded as brothers. Table 1 summarizes the descriptive statistics of the three operations. Figure A1 presents the frequency distributions of events per actor and actors per meeting by operation, whereas Figure A2 displays the quarterly distribution over time by event type and operation. For completeness, Figures A3–A8also provide graphical representations of the actor–event data for meetings and phone calls.

[2] Leaders were identified through direct evidence from wiretaps and surveillance, rather than relying on prosecutors' judgments or network position. Investigators documented conversations in which suspects explicitly outlined the formal hierarchy of 'Ndrangheta *locali*. To focus on active leadership, we included only individuals occupying the two highest formal positions—*capolocale* (boss) and *caposocietà* (deputy)—in the *locali* within the investigation's geographical scope (Calabria, Lombardy, and Piedmont), excluding high ranking individuals affiliated with *locali* outside the investigation's scope or those unable to participate due to imprisonment or death early in the surveillance period were reclassified as non-leaders. This approach ensured that the analysis concentrated on operational leaders within the investigated networks.

Overall, despite differences in the number of individuals indicted, the specific criminal events recorded, and the geographic reach of the groups, the three investigations are comparable in terms of their focus, time frame, and investigative strategy. Each inquiry targeted the structure and functioning of local 'Ndrangheta groups operating within a defined territorial area during overlapping periods between 2006 and 2011. They all relied on similar evidence-gathering techniques—primarily wiretaps and surveillance—and were conducted under the same legal framework with mafia association as the central charge. This comparability ensures that the datasets reflect equivalent organizational contexts and investigatory priorities, making them suitable for the application of consistent analytical methods. As a result, observed patterns in meetings, phone calls, *locale* affiliation, leadership, and kinship ties can be interpreted as indicative of broader regularities in the internal structure and operations of the 'Ndrangheta.

Although the meetings and phone calls analyzed in this study are not necessarily direct indicators of criminal acts (e.g., co-offending), they stem from judicial investigations in which participants were indicted and convicted for mafia association under Article 416-bis of the Italian Criminal Code. This provision targets not only individual offenses but also the existence and functioning of criminal organizations, meaning that the documented interactions were selected precisely for their relevance to the group's criminal infrastructure and operations. These events offer insight into how mafia-type organizations organize, coordinate, and sustain internal cohesion—corresponding to our definition of criminal collaboration.[3]

3.2 | Analytical strategy

To address the research questions with the available data, we selected an analytical approach that allowed us to deal with several challenges.

3.3 | Analytical challenges in modeling relational event data

First, the network ties in the dataset result from time-ordered interaction events where each event can involve any number of participants. Thus, the underlying network is not well represented by a graph in which ties connect pairs of actors at any single time point. Instead, the ties are represented by a hypergraph (Seidman, 1981) whose hyperedges can contain varying and theoretically unbounded numbers of participants. It is well understood that converting hyperedges into collections of dyadic edges—commonly done by projecting two-mode networks into one-mode networks—can lead to information loss, inflated numbers of observations, and structural

[3] Our sources did include information on individual charges and co-charges. In each case, the vast majority of defendants were indicted under a single mafia association charge (Article 416-bis), reflecting their involvement in the functioning of a criminal organization. Additional co-offending charges—typically involving only two to four individuals—were relatively rare, amounting to just a few dozen discrete offenses across cases. By contrast, our dataset contains records of hundreds of meetings and phone calls involving a much larger set of actors. This reflects a broader dynamic in mafia investigations: Although prosecutors must prove the existence and continuity of the criminal organization, they face less incentive and greater difficulty in documenting every discrete offense committed within it. As a result, co-offending charges capture only a small fraction of actual collaboration. Focusing solely on co-offending would be akin to studying academic collaboration by counting only co-authored publications, while ignoring the emails, calls, conferences, and informal exchanges that make such work possible. Our approach therefore centers on the broader architecture of collaboration that sustains criminal enterprises.

artifacts, such as high local density and an abundance of closed triangles (Battiston et al., 2020; Lerner & Lomi, 2023). For example, a meeting event with ten participants would result in 45 dyadic edges and 120 closed triangles. The largest meeting in our data had 79 participants, which would generate almost 80,000 closed triangles in a dyadic representation. Therefore, testing structural patterns, in particular triadic closure (compare RQ4), in dyadic network structures generated from hypergraphs can produce erroneous results. For example, Bright et al. (2024) demonstrated that networks reporting negative triadic closure in hyperevent models can still yield spurious evidence for positive closure when analyzed with models for dyadic graphs.

A second challenge is that observations in our data are longitudinal. An actor's decision to participate in an event with another actor/s at a given point will be influenced by their history of previous interactions (in fact, RQ2, 3, and 4 seek to assess how past interactions shape future interactions). From a statistical perspective, the applied models therefore have to account for endogeneity in the data by estimating the dependence of future interaction events on the history of past interaction.

Third, it is theoretically plausible (and in fact is the content of RQ3) that past meeting events influence not only future meetings but also the tendency to interact via phone calls. Likewise, past phone calls can be expected to have an influence on future meeting events. Therefore, our analytical approach should be able to account for this multiplexity by estimating cross-type interdependencies among the different event types. Other types of ties in our data, in particular kinship and *locale* affiliation, can also impact event participation and are therefore used as further explanatory variables. These types of relations do not change during our observation period.

Last, the employed methods must be able to test and control for various alternatives, and potentially competing, explanations for event participation. To illustrate this, consider the question as to whether an observed interaction provides evidence for or against triadic closure (part of RQ4). The question is tackled by estimating whether actors who have previously interacted with common "third" actors have an increased probability to co-participate in events, therefore closing triangles. However, any model analyzing this question in isolation is likely to be confounded by alternative explanations for event participation. For example, a skewed activity distribution over the actors or a tendency to co-participate in events with kin or with actors from the same *locale* might alternatively explain variation in co-participation probabilities and—importantly—may lead to increased local clustering. In other words, these patterns might yield higher numbers of closed triangles, without any explicit tendency for interacting with those who share a common interaction partner. Such alternative explanations for local clustering may be further emphasized by some (as yet still hypothetical) tendency to repeatedly co-participate with the same set of actors and/or by cross-type interaction between participation in meetings and participation in phone calls.

Due to the methodological challenges outlined above, it would be difficult to tackle our research questions with more "classic" SNA methods, for example, computing clustering coefficients to test for a tendency for or against triadic closure. Although we might compare observed clustering coefficients with a "null distribution" computed over randomized network instances preserving node degrees (i.e., actor-activity and hyperedge-size; compare Battiston et al., 2020), it seems challenging to apply classic SNA methods to simultaneously test and control for a longer list of alternative and potentially competing explanations of event (co-)participation in the given longitudinal data. These more traditional approaches could lead to biased and/or erroneous results as explained above.

3.4 | Relational hyperevent models and their advantages

To tackle the challenges outlined above, we employ RHEM (Lerner & Lomi, 2023; Lerner et al., 2021), a model family that has been recently proposed for longitudinal networks, given by sequences of time-ordered hyperevents.

In this study we use RHEM to explain patterns of participation in events, where "events" are either meetings or phone calls and each event can potentially have a varying number of participants (at least two, theoretically up to any number). Both types of events are considered "undirected" events; that is, in the case of phone calls, we do not distinguish the caller from the other participants. Meeting events do not give rise to any definition of "direction" and are therefore also considered undirected.

Formally, an event is given by a tuple $e = (t,\ I,\ c)$, where t is the time of the event, $I = \{i_1 \cdots, i_k\}$ is the set of participants, and the event type c is "meeting" or "phone call." Although we fit separate models for meetings and phone calls, the participants of an event of one of the two types may be explained by their previous participation in events of the other type. For example, we can test whether actors who more often co-participated in the same (prior) phone calls are more likely to co-participate in future meetings. Thus, we can also test for interdependence across event types, accounting for the multiplexity of the given network data.

RHEM are Cox proportional hazard models (CoxPH) (Cox, 1972; Lerner & Lomi, 2023; Perry & Wolfe, 2013) that specify for each possible set of participants I and each point in time t the predicted relative event rate (also denoted as hazard ratio) as a parametric function of a vector of explanatory variables x in the form:

$$\lambda\,(t,\ I) = \exp\left[\beta_1 \cdot x_1\,(t,\ I) + \cdots + \beta_p \cdot x_p\,(t,\ I)\right]$$

To estimate model parameters, we fit CoxPH models via the R package "survival" (Therneau & Grambsch, 2000; Therneau, 2024). The explanatory variables are computed with the software eventnet[4] (Lerner & Lomi, 2023).

In light of the more informal discussion given above, RHEM obviates the need to convert hyperedges (containing the event participants) into collections of dyadic edges, but they explain the relative probability of the entire set of actors $I = \{i_1 \cdots, i_k\}$ to be the hyperedge of the next event. Moreover, this probability is specified as a parametric function of a whole vector of explanatory variables, allowing us to simultaneously test and control for several alternative explanations for event co-participation. The (potentially time-varying) explanatory variables $x(t,\ I)$ can be functions of actor-level attributes (e.g., sex, age, or rank of the participants of I), dyad-level attributes (e.g., kinship relations among the participants of I), or they may depend on prior events, that is, events that happened before t. This last property means we can test and control for endogeneity in the data in which future interaction may be dependent on the history of previous interaction.

3.5 | Presentation of explanatory variables

We use the following list of explanatory variables, capturing both social ties (e.g., kinship) and organizational elements (e.g., leadership, locale affiliation), in our models. All explanatory

[4] https://github.com/juergenlerner/eventnet

variables are used in the models for meetings as well as in the models for phone calls, so that in the explanations below "event" may stand for "meeting" or for "phone call." The list below uses informal explanations. For formal definitions, see Lerner et al. (2021) and Lerner and Lomi (2023).

- Ratio leader: The ratio of leaders in I; a positive/negative parameter indicates that leaders participate in events at a higher/lower rate.
- Heterogeneity leader: The ratio of pairs of actors i, i', in I such that i is a leader and i' not; a positive parameter indicates that leaders and non-leaders tend to mix in events (heterophily), a negative parameter indicates that leaders tend to co-participate in events with other leaders and non-leaders tend to co-participate with other non-leaders.
- Ratio female: The ratio of females in I; a positive/negative parameter indicates that females participate in events at a higher/lower rate.
- Kinship: The ratio of pairs of actors i, i' in I, such that i is kin of i'; a positive parameter indicates that actors tend to co-attend events with their kin.
- Same locale: The ratio of pairs of actors i, i' in I, such that i and i' belong to the same 'Ndrangheta *locale*; a positive parameter indicates that actors tend to co-attend events with actors from the same 'Ndrangheta *locale*.
- Prior meeting activity: The average number of prior (i.e., before the current time t) meetings over the actors in I; a positive parameter indicates that actors who attended more meetings in the past attend future events at a higher rate.
- Prior joint meetings: The average number of prior co-attended meetings over the pairs of actors in I; a positive parameter indicates that pairs of actors who co-attended the same meetings in the past co-attend future events at a higher rate.
- Prior phone call activity: The average number of prior phone calls over the actors in I; a positive parameter indicates that actors who participated in more phone calls in the past attend future events at a higher rate.
- Prior joint phone calls: The average number of prior co-participations in phone calls over the pairs of actors in I; a positive parameter indicates that pairs of actors who co-participated in the same phone calls in the past co-attend future events at a higher rate.
- Meeting closure: The average weight of indirect connections via joint meetings with common third actors over all pairs of actors in I. Concretely, for a given pair of actors i, i' in I, we search for common third actors j (different from i and i' and not necessarily members of I) that have co-attended prior meetings with i and with i' (note that these prior meetings co-attended by i and j might be different from the meetings co-attended by i' and j). The indirect path $i - j - i'$ is weighted by the minimum number of co-attended events of the two dyads $i - j$ and $j - i'$. These weights are then added over all third actors j. A positive parameter for meeting closure indicates that actors who have stronger connections (via co-attendance to prior meetings) to common third actors co-attend future events at a higher rate. That is, they tend to "close" the two-path indirectly connecting i via j to i'. A negative parameter reveals a tendency not to close such open two-paths, suggesting that brokers have a tendency to maintain their positions (i.e., the actor j in the notation above) (Bright et al., 2024; Lerner et al., 2021).
- Meeting closure over leader: The average weight of indirect connections via joint meetings with common third actors who are leaders over all pairs of actors in I. In the explanation given for "meeting closure" above, the two paths $i - j - i'$ are only considered if j is a leader. If this variable is used together with "meeting closure" in the same model, then a positive parameter indicates that leaders tend to bring together their previous contacts (more than non-leaders),

$$leaders = A, E, \ldots$$
$$kinship = \{D, E\}, \ldots$$
$$locales = \{A, B\}, \{C, E, F\}, \ldots$$

$$e_1 = (t_1, \{A, B, C\}, meet)$$
$$e_2 = (t_2, \{A, B\}, call)$$
$$e_3 = (t_3, \{A, D\}, call)$$
$$e_4 = (t_4, \{C, D, E, F\}, meet)$$
$$e_5 = (t_4, \{C, D, E\}, call)$$
$$\ldots$$

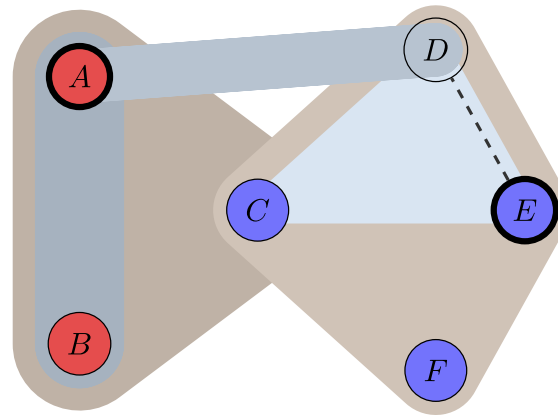

FIGURE 1 Illustrative example of models containing meetings, calls, and additional attributes. [Color figure can be viewed at wileyonlinelibrary.com]

and a negative parameter indicates that leaders tend to keep their previous contacts apart, that is, they typically maintain broker positions more than non-leaders.

- Phone call closure: The average weight of indirect connections via co-participation in phone calls with common third actors over all pairs of actors in *I*. The definition is almost the same as for meeting closure, with the difference that the prior events with third actors are phone calls instead of meetings.
- Phone call closure over leader: The average weight of indirect connections via co-participation in phone calls with common third actors who are leaders over all pairs of actors in *I* (compare "meeting closure over leader" explained above).

Figure 1 illustrates the logic of RHEMs by depicting a sequence of events involving subsets of actors, their roles, and contextual attributes such as leadership, kinship, and shared *locale*. Tables A1–A3 report the distribution of actor- and event-level variables per operation.

Graphical illustration of network data representing time-ordered meeting events and phone call events, alongside exogenous covariates. Event participants are enclosed by shaded areas. Leaders are highlighted with thick borders, kinship ties are indicated by dashed lines, and actors sharing the same *locale* are shown in the same node color.

RHEMs, as estimated in prior work across several social settings, reveal a tendency for the partial repetition of participant lists and a tendency for negative closure. Under these assumptions, the most likely participant lists for upcoming meeting events are subsets of one of the two emergent clusters—namely, {*A*, *B*, *C*} or {*C*, *D*, *E*, *F*}. Subsets of {*C*, *D*, *E*} are particularly likely, as they reflect both prior meeting and phone call interactions. In contrast, meetings that "bridge" the two clusters—such as those involving both *B* and *F*—are less likely, given the absence of previous interactions and the discouraging effect of negative closure on indirect paths like *B*–*C*–*F*. Negative closure thus inhibits the merging of overlapping clusters over time.

Participant lists that include *A* and *D* are more plausible than those including *B* and *F*. Although the negative closure effect reduces the likelihood of *A* and *D* meeting, their prior phone call interaction increases that probability. In addition to such endogenous dynamics, event participation is also shaped by exogenous factors, including leadership roles, kinship ties, and shared *locale* affiliation.

3.6 | Interpretation of results

The general interpretation of any estimated parameter β, associated with an explanatory variable $x(t,I)$ is that a unit increase in $x(t,I)$ implies a multiplication of the predicted relative event rate $\lambda(t,\ I)$ by $\exp(\beta)$. For example, if $\beta = 0.5$ and I and I' are two alternative candidates for the hyperedge of the next event with $x(t,I') = x(t,I) + 1$, then the predicted event rate of I' is that of I times $\exp(0.5) = 1.65$, an increase by 65%. As another example, if $\beta = -0.3$, then a unit increase in the associated explanatory variable implies a multiplication of the event rate by $\exp(-0.3) = 0.74$, a decrease of 26%.

To further clarify the interpretation of parameters, we explain what a "unit increase" means for the various statistics. All exogenous explanatory variables (same locale, ratio leader, heterogeneity leader, ratio female, and kinship) are derived from binary actor-level or dyad-level covariates, which implies a natural scaling, or definition of a unit increase. For example, ratio female(I) is equal to zero if all members of I are male and ratio female(I') is equal to one if all members of I' are female. The estimated parameter for ratio female, thus, reveals the factor relating the predicted event rate of an all-female set of actors to an all-male set of actors. The same interpretation applies to ratio leader, where the estimated parameter reveals the multiplicative increase in the event rate from a no-leader set of event participants to an all-leader set. A hyperedge I takes the value zero in the variable same locale if all members of I are from different *locali* and it takes the value one if all members are from the same locale. A similar interpretation applies for kinship (no members are kin vs. all members are kin of each other).

In contrast to the exogenous variables, the endogenous variables, defined as functions of the history of prior events, are usually skewedly distributed, and previous work recommends transformation with a sublinear function, in our case the square root to attenuate the skewness (Lerner & Lomi, 2023). As the variables don't have a "natural unit," we further standardize them (centering them to mean zero and scaling them to standard deviation equal to one). Thus, in the case of all the endogenous variables, a unit increase means an increase by one standard deviation, which is interpreted as a "typical" increase when comparing two random candidates for the next hyperedge.

4 | RESULTS

4.1 | Meetings

We first focus on the models examining participation in meetings as the outcome variable (Table 2 and Figure 2). The three statistical models, applied consistently across the three operations, increase in complexity, beginning with the simplest structure in Model 1, incorporating closure variables in Model 2, and culminating with the inclusion of the same locale variable in Model 3. Across both the three operations and the three models, the results remained largely consistent, demonstrating robustness in the findings. Notably, both the Bayesian Information Criterion (BIC) and the Akaike Information Criterion (AIC) decreased from Models 1 to 3 across all operations, indicating that the more complex models provided a better fit to the data compared to the simpler ones. In the following, we mainly report results from Model 3, unless differently specified.

The RHEM results for meetings revealed several robust and consistent findings across the three operations—Minotauro, Infinito, and Crimine. First, leadership consistently emerged as a strong predictor of meeting participation, in the sense that groups of individuals having a larger ratio of leaders to non-leaders were significantly more likely to meet. Second, kinship showed a stable and

TABLE 2 Results of relational hyperevent model (RHEM) models.

Variable	1—Minotauro	1—Infinito	1—Crimine	2—Minotauro	2—Infinito	2—Crimine	3—Minotauro	3—Infinito	3—Crimine
Ratio leader	1.42 (0.47)**	2.48 (0.36)***	3.00 (0.46)***	2.73 (0.56)***	2.80 (0.38)***	3.27 (0.48)***	3.41 (0.58)***	3.51 (0.38)***	3.55 (0.39)***
Heterogeneity leader	1.11 (0.24)***	0.47 (0.19)*	0.41 (0.27)	0.94 (0.28)***	0.49 (0.20)*	0.32 (0.28)	0.33 (0.34)	−0.02 (0.21)	0.11 (0.24)
Ratio female	−2.37 (1.14)*	−8.54 (2.78)**	−7.16 (1.07)***	−2.69 (1.16)*	−8.73 (2.84)**	−7.21 (1.06)***	−2.00 (1.23)	−8.30 (2.91)**	−6.52 (1.04)***
Kinship	3.71 (0.43)***	2.91 (0.33)***	3.85 (0.29)***	3.52 (0.44)***	3.17 (0.33)***	3.90 (0.30)***	2.00 (0.44)***	1.49 (0.32)***	2.53 (0.36)***
Prior meeting activity	0.32 (0.06)***	−0.08 (0.08)	0.50 (0.04)***	0.25 (0.07)***	−0.06 (0.09)	0.49 (0.05)***	0.36 (0.07)***	0.06 (0.09)	0.48 (0.05)***
Prior joint meetings	0.33 (0.03)***	0.23 (0.02)***	0.21 (0.01)***	0.62 (0.06)***	0.32 (0.04)***	0.24 (0.02)***	0.52 (0.06)***	0.30 (0.04)***	0.20 (0.02)***
Prior phone call activity	0.09 (0.05)	0.55 (0.09)***	−0.25 (0.05)***	0.08 (0.05)	0.48 (0.09)***	−0.22 (0.06)***	0.09 (0.06)	0.42 (0.09)***	−0.18 (0.06)***
Prior joint phone calls	0.07 (0.01)***	0.06 (0.01)***	0.04 (0.01)***	0.04 (0.01)***	0.05 (0.01)***	0.03 (0.01)*	0.06 (0.01)***	0.04 (0.01)***	0.04 (0.01)**
Meeting closure				−0.60 (0.19)**	−0.37 (0.11)***	−0.12 (0.04)**	−0.82 (0.18)***	−0.62 (0.10)***	−0.16 (0.06)**
Meeting closure over leader				0.03 (0.17)	0.21 (0.09)*	0.00 (0.03)	0.19 (0.16)	0.42 (0.08)***	0.02 (0.03)
Phone call closure				0.07 (0.03)*	0.02 (0.02)	0.06 (0.03)	0.04 (0.04)	0.03 (0.02)	0.04 (0.03)
Phone call closure over leader				0.00 (0.03)	0.05 (0.02)**	−0.07 (0.07)	0.02 (0.04)	0.02 (0.02)	−0.04 (0.06)
Same locale							3.35 (0.30)***	3.12 (0.25)***	2.94 (0.21)***
BIC	3813	4114	4172	3696	4023	4168	3467	3764	3914
AIC	3781	4080	4137	3647	3971	4116	3413	3708	3857
R^2	0.0025	0.0029	0.0029	0.0026	0.0029	0.0029	0.0028	0.0031	0.0031
Max. R^2	0.0053	0.0053	0.0053	0.0053	0.0053	0.0053	0.0053	0.0053	0.0053
Num. events	443	550	565	443	550	565	443	550	565
Num. obs.	1,329,443	1,650,550	1,695,565	1,329,443	1,650,550	1,695,565	1,329,443	1,650,550	1,695,565

Note: Coefficients are shown with standard errors in parentheses. Outcome variable: meetings.

*$p < 0.05$.

**$p < 0.01$.

***$p < 0.001$.

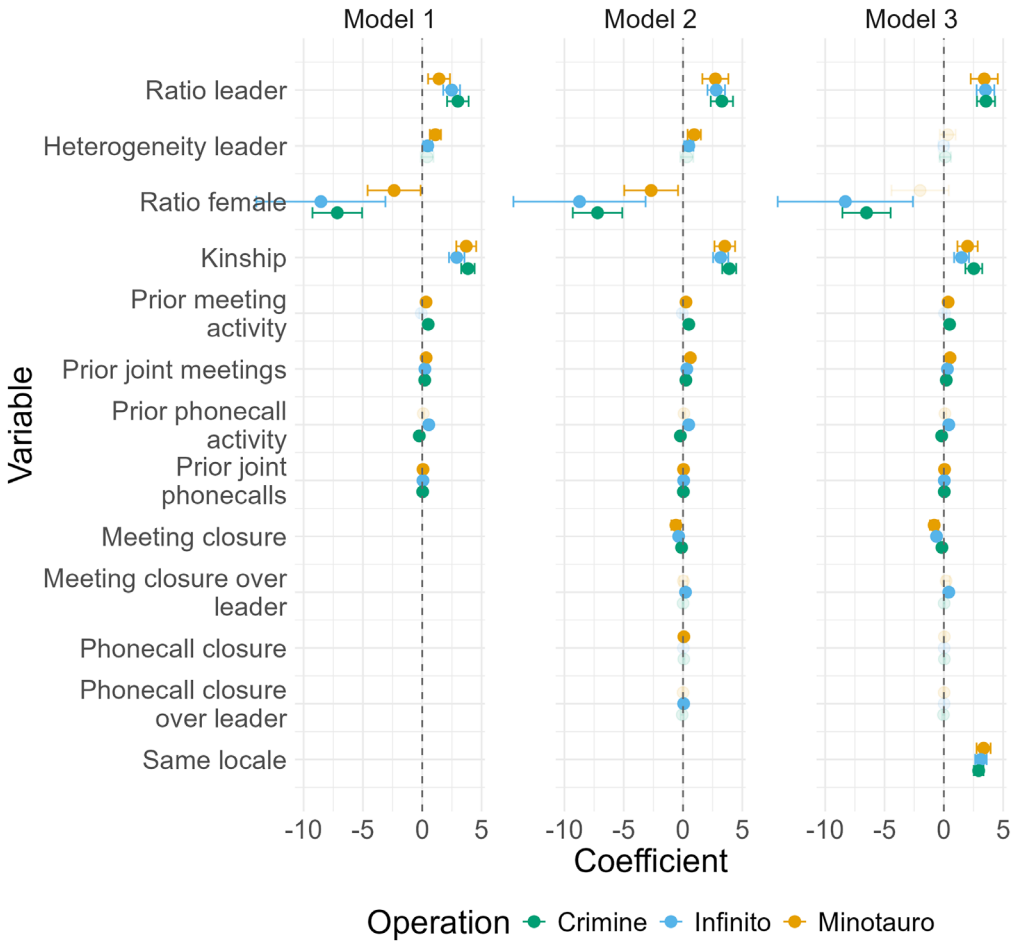

FIGURE 2 Coefficient plot for meeting models. *Note*: Nonsignificant coefficients are shown with increased transparency. Error bars represent 95% confidence intervals (±1.96 × SE).
[Color figure can be viewed at wileyonlinelibrary.com]

highly significant positive association with joint participation in meetings. Third, female actors were less likely to participate in meetings, although this effect did not reach statistical significance for Operation Minotauro in Model 3. Fourth, prior joint meetings and prior joint phone calls, which measure the number of shared meetings or calls between two actors, also showed strong and consistent positive associations across all models and operations, underscoring the importance of prior joint interactions in predicting future meetings. Fifth, meeting closure, reflecting whether future meetings involve pairs of actors having prior meetings with the same third actors, showed a negative association with meeting likelihood. Lastly, the "same locale" variable, introduced in Model 3, consistently demonstrated strong positive effects, indicating that belonging to the same organized crime clan drives meeting participation.

Other variables reported less consistent results. Heterogeneity in leadership, which measures the share of leaders in a set of actors, presented positive associations, particularly in Minotauro and Infinito, but these were not statistically significant in the third model. Prior meetings activity, which captures the cumulative number of meetings an actor has participated in, showed generally positive and statistically significant associations with future meeting participation but

FIGURE 3 Coefficient plot for phone call models. *Note*: Nonsignificant coefficients are shown with increased transparency. Error bars represent 95% confidence intervals (±1.96 × SE).
[Color figure can be viewed at wileyonlinelibrary.com]

not for Operation Infinito. Closure variables other than meeting closure had generally positive but often nonsignificant effects on meeting participation.

Phone call activity reported divergent results across the three operations.

4.2 | Telephone calls

We replicated the same analytical framework using participation in phone calls as the outcome variable (Table 3 and Figure 3). The BIC and AIC showed little to no improvement from Models 1 to 2 and a moderate improvement in Model 3. Overall, the reductions were smaller than for the meeting results, suggesting that the more complex models only marginally improved the goodness of fit.

Robust and consistent predictors of phone call participation included leadership, kinship, prior joint phone calls or meetings among two actors, and prior phone call activity (cumulative number

TABLE 3 Results of relational hyperevent model (RHEM) models.

Variable	1—Minotauro	1—Infinito	1—Crime	2—Minotauro	2—Infinito	2—Crime	3—Minotauro	3—Infinito	3—Crime
Ratio leader	1.61 (0.48)***	0.47 (0.68)	0.98 (0.87)	1.65 (0.47)***	0.72 (0.67)	0.87 (0.88)	1.96 (0.46)***	1.34 (0.58)*	1.56 (0.76)*
Heterogeneity leader	−0.15 (0.25)	0.60 (0.34)	0.48 (0.43)	−0.12 (0.24)	0.57 (0.34)	0.70 (0.43)	−0.28 (0.24)	0.12 (0.30)	0.33 (0.38)
Ratio female	0.06 (0.24)	−4.17 (1.18)***	−2.68 (0.34)***	0.09 (0.24)	−4.24 (1.19)***	−2.63 (0.34)***	0.24 (0.23)	−3.30 (1.18)**	−2.24 (0.33)***
Kinship	2.61 (0.22)***	3.02 (0.31)***	2.19 (0.37)***	2.62 (0.22)***	3.15 (0.29)***	2.19 (0.37)***	2.27 (0.23)***	1.68 (0.27)***	1.30 (0.39)***
Prior meeting activity	0.11 (0.05)*	−0.27 (0.08)**	0.15 (0.04)***	0.12 (0.05)*	−0.28 (0.09)***	0.15 (0.04)***	0.12 (0.05)*	−0.23 (0.09)**	0.14 (0.04)***
Prior joint meetings	0.07 (0.02)***	0.12 (0.02)***	0.10 (0.02)***	0.08 (0.03)*	0.22 (0.06)***	0.09 (0.03)**	0.06 (0.03)	0.18 (0.05)***	0.07 (0.03)*
Prior phone call activity	0.38 (0.03)***	0.93 (0.08)***	0.31 (0.03)***	0.37 (0.03)***	0.92 (0.08)***	0.30 (0.03)***	0.38 (0.03)***	0.89 (0.09)***	0.32 (0.03)***
Prior joint phone calls	0.26 (0.01)***	0.14 (0.01)***	0.24 (0.02)***	0.26 (0.01)***	0.13 (0.01)***	0.22 (0.02)***	0.26 (0.01)***	0.12 (0.01)***	0.22 (0.01)***
Meeting closure				−0.21 (0.12)	−0.49 (0.17)**	−0.03 (0.03)	−0.24 (0.12)*	−0.69 (0.16)***	−0.02 (0.03)
Meeting closure over leader				0.21 (0.11)	0.35 (0.14)*	0.05 (0.03)*	0.22 (0.11)*	0.54 (0.13)***	0.04 (0.02)
Phone call closure				0.03 (0.02)	0.04 (0.02)	0.06 (0.02)***	0.03 (0.02)	0.03 (0.02)	0.05 (0.02)***
Phone call closure over leader				−0.04 (0.03)	−0.01 (0.02)	0.00 (0.02)	−0.04 (0.03)	−0.03 (0.02)	0.01 (0.02)
Same locale							0.99 (0.20)***	2.67 (0.17)***	2.50 (0.21)***
BIC	7821	2945	3357	7836	2923	3332	7803	2688	3206
AIC	7778	2913	3320	7773	2875	3277	7734	2636	3146
R^2	0.0083	0.0065	0.0091	0.0083	0.0066	0.0091	0.0084	0.0072	0.0093
Max. R^2	0.0137	0.0137	0.0137	0.0137	0.0137	0.0137	0.0137	0.0137	0.0137
Num. events	1421	396	701	1421	396	701	1421	396	701
Num. obs.	1,422,022	396,396	701,701	1,422,022	396,396	701,701	1,422,022	396,396	701,701

Note: Coefficients are shown with standard errors in parentheses. Outcome variable: telephone calls.

*$p < 0.05$.

**$p < 0.01$.

***$p < 0.001$.

of calls an actor previously participated in). The "same locale" variable, introduced in Model 3, was also a strong predictor of joint phone calls.

Other variables reported more varied effects. Females were significantly less likely to engage in phone calls, although in Minotauro the coefficients were statistically not significant. The number of prior meetings an actor participated in showed inconsistent effects, with positive and significant results in Minotauro and Crimine but negative associations in Infinito. In Minotauro and Infinito, meeting closure had negative and statistically significant coefficients, and meeting closure over leader was positive and statistically significant, whereas Crimine reported consistent but non-significant coefficients. Conversely, in Crimine, phone call closure displayed positive and statistically significant associations, suggesting that future phone calls often involve actors with mutual contacts, while consistent but scarcely significant results were found for Infinito and Minotauro.

Other variables did not exhibit clear patterns or statistically significant results. Heterogeneity in leadership and phone call closure over leaders showed no significant effects across the models, indicating limited explanatory power in the context of phone calls. Prior meeting activity, measuring the cumulative number of meetings in which an actor participated, showed statistically significant but divergent effects, with positive associations for Minotauro and Crimine and negative association for Infinito.

4.3 | Comparing meetings and phone calls

Although the significance and direction of effects remain consistent across meeting and phone call models, examining their magnitude offers deeper insight. Leadership, clan membership (same locale), and kinship have stronger effects on meetings than on phone calls. Leadership has a greater impact in meeting models (incidence rate ratios or IRR: 4.13–34.8) than in phone call models (IRR: 1.6–7.1). Clan membership also has a stronger effect on meetings (IRR: 18.83–28.5) than on phone calls (IRR: 2.7–14.5). Kinship influences both interaction types but is slightly stronger for meetings (IRR: 4.4–49.2) than for phone calls (IRR: 3.7–23.3). The proportion of females involved in an event is always negatively associated with the likelihood of participation, with a stronger negative effect in meetings (IRR: 0.0002–0.09) than in phone calls (IRR: 0.014–0.106).

Prior activity influences future participation, but its predictive power differs by mode. The number of prior meetings predicts future meetings, whereas their effect on phone calls is inconsistent. Prior phone call activity predicts future phone calls, but its impact on meetings remains unclear. Any prior interaction between two actors increases the likelihood of future interactions, with stronger effects when the mode of prior interaction matches the future interaction. Prior joint meetings predict future meetings (IRR: 1.23–1.85) more than phone calls (IRR: 1.06–1.25), whereas prior joint phone calls are stronger predictors of future phone calls (IRR: 1.10–1.40) than meetings (IRR: 1.03–1.07).

5 | DISCUSSION

Our findings highlighted distinct patterns in how social and organizational structures and prior interactions shaped meetings and phone calls within criminal networks. Being male,[5] leadership,

[5] Although the gender variable (measured as the ratio of female actors) exhibited a consistent negative association with participation in both meetings and phone calls, we do not pursue this finding further, for both empirical and concep-

kinship, and clan membership consistently increased the likelihood of both interaction types, but their effects were stronger for face-to-face meetings than for phone calls. Prior interactions significantly predicted future interactions, with actors tending to maintain the same mode of communication over time. Joint meetings were a stronger predictor of future meetings, whereas joint phone calls more strongly predicted future phone calls. Additionally, although meeting closure reduced the likelihood of direct connections between actors, phone call closure facilitated new links, underscoring the different structural and organizational functions of these interaction modes.

In support of previous research, we found that criminal leaders are essential in structuring criminal interactions. Further, our findings corroborated prior research showing that "Ndrangheta leaders" role was particularly essential in face-to-face meetings, where strategic decisions and coordination occur (Calderoni & Superchi, 2019). 'Ndrangheta leaders also balance intra-clan and inter-clan communications, maintaining ties within their immediate subgroup while acting as intermediaries between clans (Calderoni et al., 2017). Criminal network studies on organized crime consistently highlighted the role of leaders in controlling information flow, reinforcing network cohesion, and regulating access to resources (Bright & Whelan, 2021, 2024; Bright et al., 2015; Morselli, 2001, 2003, 2009; Varese, 2013).

Results on the "same locale" variable confirmed that clan affiliation significantly increases interaction probability, even when accounting for kinship ties. Although shared clan membership fosters criminal ties through territorial, social, and economic incentives (Battisti et al., 2022, 2024; DellaPosta, 2017; Krajewski et al., 2022; Tumminello et al., 2021; Calderoni et al., 2025), these ties often overlap with geographical, ethnic, and kinship proximity. To address this, our models separately include kinship and same *locale* affiliations, demonstrating that clan membership independently influenced interaction.[6] Additionally, the temporal structure of our models reinforced the causal role of clan affiliation, suggesting that it provided a stable framework for collaboration beyond direct kinship ties.

Kinship has long been recognized as a fundamental pillar of criminal networks, particularly within mafia-type organizations. Classical studies highlighted how family ties reinforced organizational structures (Blok, 1974; Hess, 1973; Ianni & Reuss-Ianni, 1972; Kleemans & De Poot, 2008; Paoli, 2003), whereas more recent research demonstrated that kinship fostered network cohesion, increased tie density, and promoted closure, shaping communication and collaboration patterns (Bright et al., 2024; Campana & Varese, 2013; Catino et al., 2022; Malm et al., 2010; Mastrobuoni & Patacchini, 2012; Calderoni et al., 2025). Our findings confirm that kinship significantly increased interaction probability, influencing both meetings and phone calls, independently of other structural factors such as clan membership.

Our results revealed that patterns of prior participation influenced the likelihood of future events (Bright & Whelan, 2021; Von Lampe, 2016). These patterns suggest a clear path dependency in interaction modes. Actors who had participated more frequently in prior meetings were more

tual reasons. Empirically, women constituted only about 10% of the sample. Conceptually, no woman in our data held formal roles within the 'Ndrangheta, was charged with mafia association, or appeared as an active participant in the organization's criminal coordination. Only in Minotauro seven women were charged with other offenses. Although recent scholarship has reconsidered the traditional view of women's marginality in organized crime (Selmini, 2020), our data provide limited analytical ground to engage with these debates. More broadly, the organizational structure of mafia networks—particularly in the Italian context—remains overwhelmingly male-dominated at the aggregate level, a pattern that continues to shape both visibility and participation in criminal collaboration (Savona et al., 2020).

[6] A study of gangs in a Los Angeles neighborhood by Valasik et al. (2023) revealed significant heterogeneity in members' mobility patterns with respect to gang territory. These findings further support our results by showing that group identity can be a powerful driver of criminal collaboration, independently of territorial proximity.

likely to engage in future meetings, but not calls; the reverse held for those active in prior calls. Although this effect may partly reflect baseline activity—that is, actors active in one modality tend to remain active—it also points to underlying differences in roles, access, and structural positioning within the organization. Some members operate predominantly through face-to-face interactions, often signaling higher status or brokerage roles, whereas others rely more on phone calls for logistical coordination (Bright et al., 2024; Campana & Varese, 2013). At the level of shared participation, prior joint interactions increased the likelihood of future interactions of any type, with stronger effects when the mode remained consistent. These findings align with research arguing that repeated exchanges reinforce trust, confidence, and long-term collaboration in criminal networks (Gambetta, 1988b, 2006; Kleemans & De Poot, 2008; Von Lampe, 2016). In illicit environments marked by distrust and law enforcement pressure, actors rely on familiar partners to reduce uncertainty and mitigate risks associated with unknown collaborators (Malm et al., 2010; Mastrobuoni & Patacchini, 2012). Beyond kinship and clan membership, prior interactions provide another mechanism for trust and stability.

Taken together, the results revealed similar patterns in how social and organizational structures and repeated interactions shape participation in both meetings and phone calls in criminal networks. Leadership, same *locale*, and kinship consistently influenced both forms of interaction, with stronger effects for meetings, highlighting the greater role of status and embeddedness in face-to-face contact. Prior interactions reinforced collaboration across both modes, increasing the likelihood of sustained ties. The main difference between the two modes lay in closure effects.

Meeting closure decreased the likelihood of future joint interactions, reinforcing exclusivity and maintaining structural holes. In contrast, phone call closure—though only occasionally statistically significant—was associated with increased collaboration, bridging gaps, and expanding connectivity. This is, to our knowledge, the first study to identify this pattern across multiple groups using dynamic network models. Meeting closure reflects the structured nature of mafia interactions, where attendance—often at weddings, funerals, or criminal gatherings—is selective and shaped by status, hierarchy, and clan ties. Such exclusivity appears to be a strategic effort to regulate access to information and decision-making (Bright et al., 2024; Calderoni & Superchi, 2019; Morselli, 2009). Phone calls, by contrast, facilitate coordination across physical and organizational boundaries. Often used for routine tasks and nonsensitive exchanges, they promote flexibility and expand the network's operational reach. These opposing closure effects highlight how different communication strategies support a balance between secrecy, hierarchy, and efficiency (Bright et al., 2019; Calderoni, 2014b; Morselli, 2010; Morselli et al., 2007; Ouellet et al., 2019).

Our findings contribute to the broader debate on social embeddedness in economic and criminal interactions by showing that kinship, clan affiliation, and prior interactions independently reinforce criminal collaboration and increase the likelihood of future interaction and collaboration. Although sociology and economic sociology have long emphasized how social ties facilitate cooperation and economic action (Burt, 1992; Coleman, 1988; Granovetter, 1985), these mechanisms are often framed as inherently prosocial. In contrast, our results align with perspectives that see embeddedness as a neutral structural condition—one that strengthens collaboration regardless of legality (Gambetta, 2009; Portes, 1998).

Drawing on three law enforcement investigations and modeling both meetings and phone calls, we disentangle the distinct mechanisms shaping each mode of collaboration. Using a dynamic network approach, we find that kinship, clan affiliation, and prior interactions each exert an independent influence, with face-to-face meetings more strongly shaped by social structure and prior interactions reinforcing ties in both modes. Although previous studies highlight the role of social capital in fostering trust and secrecy (Gambetta, 1993; Varese, 2011), few have quantified

the effects of multiple embedded ties within a unified analytical framework. Our findings provide robust evidence that these mechanisms function in parallel—structuring long-term opportunities and sustaining engagement over time. Despite some variation, the most notable finding is the consistency across operations and collaboration modes. Effects of kinship, leadership, prior interactions, and closure recur across contexts and data types—an uncommon result in criminal network research, where the great majority of studies typically focus on a single case and one type of tie. Observed differences likely reflect subtle event-level dynamics that escape quantitative modeling, rather than random noise or case-specific features.

Ultimately, our study shows that complex criminal organizations like the 'Ndrangheta are deeply rooted in social and organizational structures that foster commitment while enabling illicit cooperation. Rather than viewing social ties as inherently prosocial or criminal networks as purely instrumental, our results support a neutral, functionalist understanding of embeddedness: the same social mechanisms that support lawful exchange can also sustain durable criminal collaboration (Kleemans & De Poot, 2008; McCarthy & Hagan, 1995). By integrating structural and dynamic perspectives, our analysis offers a more comprehensive framework for understanding how organized crime networks evolve and endure.

Our study has some limitations that we now enumerate. First, a key limitation concerns the source data and its suitability for constructing criminal networks. Law enforcement case files provide rich detail on interactions in criminal organizations, but their content reflects investigative and prosecutorial priorities. For example, they tend to prioritize information directly relevant to criminal charges, often overlooking more routine or less overtly incriminating forms of interaction that may still be crucial for understanding patterns of criminal collaboration. This selective visibility can underrepresent the full spectrum of relationships and activities that sustain organized crime. However, scholars have developed safeguards to address these biases (Berlusconi, 2013; Bright et al., 2021; Campana & Varese, 2013; Morselli, 2009), which we followed by ensuring long excerpts of conversations were analyzed to reduce misinterpretation and by relying on final convictions that confirmed the accusations in all three operations, reinforcing data reliability. Additionally, our replication across three distinct operations mitigates case-specific biases and enhances external validity, allowing for comparative insights across different criminal organizations. The remarkable consistency of results further supports the robustness of our models and their broader applicability to understanding criminal collaboration.

An important caveat concerns the potential misinterpretation of criminal collaboration as co-offending. Although our analysis focuses on patterns of sustained interaction—through meetings and phone calls—these should not be mistaken for evidence of jointly executed criminal acts. Although criminal collaboration and co-offending are often correlated (Bright et al., 2017; Campana & Varese, 2013; Morselli, 2009), they are conceptually distinct: the former encompasses a wider range of behaviors, such as planning, coordination, and strategic communication, that are central to the operation of organized crime, including facilitating trust, but may not constitute prosecutable offenses. By clarifying this distinction, we aim to prevent conflation and reinforce that our focus is on the relational foundations of organized crime, not on discrete criminal events. Understanding this broader architecture is essential for grasping how criminal organizations coordinate action, maintain internal cohesion, and adapt over time.

A third limitation concerns the generalizability of our findings beyond the 'Ndrangheta and similar mafia-type organizations. Although our multi-case strategy enhances robustness and validity, showing consistency across three independent operations, caution is needed when extending these results to less structured criminal groups. Highly organized organizations, such as mafias, rely on hierarchical control, territorial embeddedness, and long-term social ties, whereas

more fluid or decentralized groups (e.g., drug trafficking networks or ransomware groups) may operate under different interaction patterns. Future research should examine whether similar mechanisms of embeddedness and interaction persistence apply in other criminal contexts.

A further limitation concerns actor turnover during the observation window. The RHEM framework does not explicitly model entry or exit of individuals from the network—such as recruitment, arrests, imprisonment, or death—because it assumes a fixed set of actors across time to maintain a stable candidate set for event participation. In our data, information on actor turnover was limited: For example, only 18 individuals (0.8% of all actors) were known to have died across the three operations, and precise timing of their deaths was unavailable. Although this introduces some noise, its impact is likely minimal due to the small proportion affected. Moreover, RHEM incorporates time-varying endogenous covariates—such as recent participation in meetings or calls—which effectively allocate lower weightings to actors who become inactive during the period. Thus, even without explicitly modeling exit, the influence of disengaged actors is indirectly reduced over time.

6 | CONCLUSIONS

This study examined how multiple social dimensions of social and organizational embeddedness—kinship, clan affiliation, leadership, and prior interactions—shape criminal collaboration through meetings and phone calls. By analyzing three distinct investigations into the 'Ndrangheta using RHEM, we provided a dynamic and comparative assessment of how embedded relational structures and interaction histories influence criminal network formation and persistence. Unlike prior research that typically focused on single tie types or static snapshots, our approach captured the multiplex and evolving nature of illicit collaboration.

Our findings show that both structural and interactional factors independently and consistently increase the likelihood of communication within criminal networks. Kinship and clan affiliation emerged as robust predictors of interaction, confirming the centrality of embedded ties—both social and organizational—in sustaining organized crime. Leadership played a pivotal role, particularly in meetings, reflecting its organizational importance in maintaining hierarchy, managing information, and brokering across subgroups. Prior interactions—especially when mode-consistent—significantly predicted future collaboration, underlining the importance of repeated contact in reinforcing trust and familiarity.

Importantly, our results revealed that although similar mechanisms operate similarly across meetings and phone calls, the network structures they generate differ. Meetings appear more hierarchical and exclusive, shaped by status and embeddedness, whereas phone calls enable more flexible, decentralized forms of interaction. Closure effects highlight this divergence: Meeting networks resist triadic closure, maintaining structural holes, whereas phone call networks more readily form new ties through mutual contacts.

These findings have broader implications for the study of criminal networks. They confirm that criminal collaboration is not solely driven by opportunism or economic rationality but is embedded in multiplex and dynamic relational structures. Our analysis advances the field by demonstrating that multiplexity is not only theoretically relevant but also empirically observable and consequential. By incorporating multiple relational dimensions and their interaction over time, we offer a more comprehensive framework for understanding how criminal organizations sustain cooperation under conditions of risk, secrecy, and constraint.

Future research should extend this dynamic, multiplex perspective to other contexts and criminal formations, including less structured or more transient networks. Further methodological advances could also improve the modeling of tie interdependence and event co-evolution. For policy and law enforcement, our findings suggest that disrupting multiplex ties—particularly those reinforced by kinship and organizational roles—may be more effective than targeting a single type of interaction in isolation.

Our findings have important implications for criminal justice and public policy. Traditional strategies that focus narrowly on disrupting criminal activities or targeting high-ranking individuals—such as kingpin strategies applied against Mexican drug trafficking organizations—often underestimate the embedded and multiplex nature of criminal collaboration. Although removing leaders may produce temporary disruption, it frequently fails to dismantle the overlapping social and organizational ties that sustain criminal networks (Calderón et al., 2015; Estévez-Soto & Lecona Esteban, 2024; Jones, 2016). Our results suggest that actors are embedded in multiple relational dimensions—kinship, clan affiliation, and repeated interaction—which makes criminal networks resilient and adaptive in the face of enforcement.

By contrast, policies and policing strategies that target broader sets of relational ties appear more promising (Bright et al., 2015; Calderoni et al., 2022). For instance, civil gang injunctions applied in Los Angeles and similar legal measures can restrict communication and limit repeated contact between members, potentially disrupting the interactional continuity on which trust and collaboration are built, and ultimately weakening their capacity to coordinate criminal activities and eventually. Although studies reported decline in aggregating offending levels and altered interaction patterns among targeted gang members (Ridgeway et al., 2019; Valasik, 2025), others reported a change in conflict patterns across gangs (Bichler et al., 2019, 2020). In Japan, ordinances targeting the Yakuza have substantially curtailed the organizational and relational leverage of these groups by undermining their ability to maintain offices, recruit openly, and formalize social ties (Baradel, 2021; Hoshino & Kamada, 2021). Similarly, in Italy, personal police injunctions (*sorveglianza speciale*) may inhibit the capacity to convene large-scale, face-to-face meetings, thereby weakening the high-trust interactions central to mafia operations (Calderoni, 2015). These examples point toward a more promising strategy: targeting the relational infrastructure of organized crime, rather than its surface-level criminal acts alone.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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