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Structural characteristics of collaboration networks among Chinese online film production companies—a comparison with theatrical films

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Abstract. This study examines online films ranked 1–40 in the annual revenue-sharing box-office rankings for 2020–2025 recorded by Maoyan Pro, with the 2025 Youku ranking collected through rank 38, and theatrical films ranked 101–200 in the annual box office rankings over the same period. After data cleaning and deduplication, 488 online films and 564 theatrical films were retained. Collaboration networks were constructed based on shared production credits. The results show that, when isolated nodes are retained, the online film sample has a higher average degree and a larger proportion of nodes in the largest connected component. After isolated nodes are removed, however, the ranking of the two networks by network density is reversed. Both samples contain many entities involved in only one sampled film, with a higher proportion observed in the theatrical film sample. In both networks, the maximum *k*-core consists of entities credited on a single film and therefore cannot be taken as evidence of an industry core. The number of communities is affected by isolated nodes, while modularity varies with the weighting scheme. The weighted betweenness centrality rankings of entities appearing in both samples reflect only their positions within their respective networks. These differences are confined to the structures of the sampled networks and cannot be attributed to distribution channels or used to infer capital control or cross-market channels.

Keywords: online films, theatrical films, production companies, collaboration networks, social network analysis

1. Introduction

Online films and theatrical films differ in their distribution channels, revenue realization mechanisms, and modes of platform participation. However, these differences are intertwined with film scale, genre, sample selection, and the disclosure of production credits. This study compares the production-credit networks of the two types of film samples to describe structural differences under a clearly defined methodological framework, rather than attributing those differences to distribution channels.

This study treats shared production credits on the same film as observable evidence of project collaboration. The definitions of network entities and relationships follow the conventional framework of Social Network Analysis (SNA) [1, 2]. Publicly available production credits generally do not disclose

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complete information on capital contribution ratios, contractual arrangements, or revenue distribution. They can therefore be used only to characterize participation relationships and network positions within the samples, rather than to determine capital control or project leadership.

Existing studies have examined the relationship between creators' network positions and creative performance [3], co-production relationships in the film industry [4], the competitiveness of film production companies [5], and the spatial distribution of film enterprises and their industrial network connections [6]. This study applies consistent procedures for film deduplication, name normalization, the treatment of isolated nodes, and collaboration weighting to address three questions: How do the connectivity structures of the two samples differ? How are the results for maximum *k*-core and communities affected by individual projects and methodological choices? Do entities appearing in both samples occupy similar intermediary positions in their respective networks? The conclusions are limited to the samples collected for this study.

2. Literature review

Social network analysis takes relationships, rather than isolated individuals, as its starting point and provides tools for measuring sustained or temporary collaboration in film projects [1, 2]. Cattani and Ferriani examined the relationship between creators' network positions and creative performance in Hollywood from a core–periphery perspective [3], while Miller compared co-production relationships in films with high box-office revenues and those with high critical acclaim [4]. These studies suggest that network positions may be associated with creative or market performance. However, the nodes, relationships, and outcome variables differ across studies. Findings on collaboration networks among principal creative personnel cannot be directly transferred to networks of production companies without qualification, and dense connections within a network do not necessarily imply control relationships between enterprises.

Research on the Chinese film industry has examined the competitive structure of film production companies from a social network perspective [5]; compared the spatial distribution and industrial network connections of theatrical film and online film enterprises [6]; analyzed collaboration networks in comedy films [7]; and investigated the shift in film production from professional logic toward capital logic through the collaborative relationships between producers and directors [8]. In the online audiovisual sector, Xiao Yuqin and Guan Xin analyzed the capital structures and traffic performance of Chinese online drama series [9]. The present study focuses exclusively on networks formed by production companies and their shared credits, without testing the relationship between network positions and box-office revenue or online traffic.

When the production companies credited on the same film are connected pairwise, the companies listed for that film form a complete subgraph, or clique. Consequently, the clustering coefficient, *k*-core, and community structure are all affected by the size of the production team credited on each film. Their interpretation therefore requires reference to the underlying film credits. This study reports *k*-core, degree centralization, and communities identified using the Louvain community detection algorithm [10]. These measures are not equivalent to the classical core–periphery model, nor do they inherently represent institutional blocs or platform affiliations.

3. Research design

3.1. Sample sources and film deduplication

The online film sample was drawn from the annual revenue-sharing box-office rankings recorded by Maoyan Pro for iQIYI and Tencent Video from 2020 to 2025, covering ranks 1–40 each year, as well as Youku's annual

rankings for 2020–2024, covering ranks 1–40, and its 2025 ranking, covering ranks 1–38. This yielded 718 raw records. The theatrical film sample was drawn from ranks 101–200 in the annual mainland China box-office rankings recorded by Maoyan Pro over the same period, comprising 600 records. Revenue-sharing box-office figures were used solely to select the online film sample and were not used to calculate collaboration edge weights.

Previous studies of film networks have examined co-production relationships among high-grossing films, the competitiveness of production companies, and collaboration among principal creative personnel [3-5, 8]. The theatrical comparison group was selected from films ranked 101–200 in the annual box-office rankings to extend the analysis of production-credit networks beyond top-ranked films and provide a structural comparison with the online film rankings from the same period. Both samples were selected on the basis of rankings, but they were not matched by budget, genre, or audience size. Nor does a box-office ranking range constitute a uniform measure of investment scale. Accordingly, this study compares the production-credit networks of two contemporaneous, non-random samples. Observed differences are not interpreted as channel effects, and the findings are not generalized to all theatrical or online films.

Film deduplication was based on standardized film titles. Records with the same title across platforms and years were consolidated, and the year in which a film first entered the scope of data collection was used as its sample year; this year does not necessarily correspond to its premiere year. Title identification may still be affected by different films sharing the same title, translated titles, and re-release records. The sources of individual records were retained, and an additional robustness test excluded projects with identical titles across different years. When the consolidated entity sets from multiple records for the same film were identical, the film was retained. When one entity list was a subset of another, the larger list actually recorded in the source data was used rather than combining the lists to create a new one. When the lists did not contain one another and the available materials were insufficient to determine which was correct, the film was excluded from the main analysis. This procedure reduced the risk of generating collaboration edges unsupported by any individual record through the merging of different lists.

Under these rules, the theatrical records yielded 581 deduplicated entries, while the online film records yielded 496. After entries without valid production entities and those with incompatible credit lists were further excluded, 564 theatrical films and 488 online films were retained for the final analysis (Table 1). Some entries excluded for lacking valid production entities were actually film festival or screening events. Therefore, the number of deduplicated entries does not equal the number of valid films.

Table 1. Sample processing and composition of the main analysis

Processing stage	Theatrical films	Online films
Number of raw records, 2020–2025	600	718
Entries after deduplication by standardized title	581	496
Entries excluded for lacking valid production entities	12	4
Entries excluded due to incompatible production-credit lists	5	4
Number of films in the main analysis	564	488
Films with one entity after consolidation	408	80
Films with multiple entities after consolidation	156	408

Note: Films are classified as having one or multiple entities according to the number of distinct entity labels after consolidation. Redundant records arising from cross-platform and cross-year duplication are reflected in the difference between the number of raw records and the number of deduplicated entries.

3.2. Network construction and weighting

Let k_p denote the number of production entities credited on film p after consolidation. Let i and j denote two distinct production entities, and let P_{ij} be the set of films on which both entities are credited. Three weighting schemes are defined as follows (Equations (1)-(3)):

$$c_{ij} = |P_{ij}| \tag{1}$$

$$w_{ij} = \Sigma_p \in P_{ij}\, 1/(k_p - 1) \tag{2}$$

$$w'_{ij} = \Sigma_p \in P_{ij}\, 2/[k_p(k_p - 1)] \tag{3}$$

Here, c_{ij} is the frequency weight, representing the number of films on which two production entities jointly receive credit. w_{ij} is the fractional weight, obtained by summing the allocated weights of each undirected collaboration edge. w'_{ij} is an alternative weighting scheme under which the total weight contributed by each film equals 1. Under the allocation scheme in Equation (2), each production entity receives a fractional strength contribution of 1 from a film with multiple production entities, while the film contributes a total weight of $k_p/2$ across all collaboration edges. All three weighting schemes are applied to the same set of collaboration edges. They do not change the number of edges, the number of collaborators for each production entity, or the conventional *k*-core structure, nor can they eliminate the complete subgraphs formed by pairwise connections.

Production and co-production entities were consolidated by name and represented by entity labels. Within each film, the same label was counted only once. Unmatched names were retained as separate labels. The figures reported in this study therefore represent counts of entity labels, not counts of independently verified legal entities. The film–production entity relationships constitute a two-mode affiliation network, which was subsequently transformed through a one-mode projection into an undirected production-entity network in which the initiating party of a collaboration is not distinguished. Every pair of distinct production entities appearing on the same film was connected by an edge. Films involving only one production entity contributed a node but no edge. A node appearing only in single-entity films, with no other collaboration ties, was classified as an isolated node.

3.3. Metrics and comparison strategy

The overall structural metrics include the number of entity labels, the number of undirected collaboration edges, network density, average degree, the number of connected components, and the average clustering coefficient. Network density is defined as $(2m/[n(n-1)])$, and average degree as $(2m/n)$, where both are calculated on the binary network. The average clustering coefficient is calculated across all nodes, with a value of zero assigned to nodes with degree less than 2. The proportion of nodes in the largest connected component uses the total number of nodes as its denominator. Average path length is calculated using unweighted shortest paths within the largest connected component only; it does not imply that every pair of nodes in the entire network can reach one another.

K-core is calculated on the binary network. A node's *k*-core level is the highest value of (k) for which it belongs to the corresponding *k*-core. The maximum shell consists of nodes whose *k*-core levels equal the maximum value in the entire network. Degree centralization is calculated as the sum of the differences between each node's degree and the maximum degree, divided by $((n-1)(n-2))$. Fractional strength is defined as the sum of the fractional weights of a node's adjacent edges. Community detection using the Louvain algorithm is performed with fractional weights and a resolution parameter of 1. The random seed for the main analysis is set to 42, with robustness checks using seeds 0, 1, 7, and 99. Each isolated node is

counted as a separate community, and the number of communities containing collaboration edges is also reported.

Weighted betweenness centrality is calculated using the reciprocal of the number of jointly credited films, $1/c_{ij}$, as the edge distance, with normalization by the total number of nodes in the network. Node pairs that cannot reach one another are excluded from shortest-path calculations. Unweighted betweenness centrality is also calculated for verification. Rankings use descending competition ranking, with differences no greater than 10^{-12} treated as ties. Consequently, entities with a weighted betweenness centrality value of zero share the same rank. An overlapping entity is defined as an entity label appearing in both samples. Its weighted betweenness centrality and rank are calculated separately within each network and do not constitute a measure of cross-market pathways.

The main analysis compares the pooled networks for all six years, with annual networks also reported according to the year in which each film first entered the sample. Sensitivity analyses examine alternative specifications, including retaining or removing isolated nodes, using the three weighting schemes, excluding films with the largest production teams, retaining only projects with consistent production-credit lists, excluding projects with identical titles across different years, excluding projects involving zero-amount records, and retaining unmerged production-credit labels. All calculations were performed using the Python network analysis package NetworkX 3.7 [11], with node and project ordering held fixed.

4. Comparison of the overall structures of the collaboration networks in the two samples

4.1. Network size and connectivity structure

When isolated nodes are retained, the theatrical film sample contains 683 entity labels and 963 undirected collaboration edges, while the online film sample contains 1,703 entity labels and 10,285 undirected collaboration edges (Table 2). The proportions of films with multiple entities after consolidation are 27.66% and 83.61%, respectively. These proportions reflect only the information recorded in the available credit lists. They should not be interpreted directly as actual co-production rates, nor does the absence of a recorded collaboration necessarily mean that no such collaboration existed.

Table 2. Key metrics for the pooled networks covering six years

Metric	Theatrical films	Online films
Number of entity labels	683	1,703
Number of undirected collaboration edges	963	10,285
Number of isolated nodes	246	35
Network density	0.0041	0.0071
Average degree	2.8199	12.0787
Average fractional strength	0.8111	1.6888
Number of connected components	324	83
Number of nodes in the largest connected component	211	1,457
Proportion of nodes in the largest connected component	30.89%	85.55%
Average path length in the largest connected component	3.5271	3.4116
Average clustering coefficient	0.4484	0.8423

Table 2. Continued

Maximum *k*-core level	12	18
Average *k*-core level	2.3602	8.5390
Number of entities in the maximum shell	13	19
Degree centralization	0.0841	0.1300
Number of communities, including isolated nodes	332	105
Number of communities containing collaboration edges	86	70
Modularity	0.8528	0.7351

Note: Except for average fractional strength, the number of communities, and modularity, all structural metrics in this table are calculated on the binary networks. The number of communities and modularity are calculated using fractional weights. Path length is calculated only within the largest connected component. Decimal values are rounded.

The average degree is 12.0787 in the online film sample, compared with 2.8199 in the theatrical film sample. The largest connected components contain 1,457 and 211 nodes, respectively, accounting for 85.55% and 30.89% of all nodes in the corresponding networks. Under the available credit records and consolidation rules, more entities in the online film sample belong to a single connected component, whereas the theatrical film sample contains more isolated nodes and small connected components. The average path lengths within the largest connected components are 3.4116 and 3.5271, respectively. Because these values are calculated over different subsets of nodes, they cannot be used to determine the overall efficiency of information flow in the two markets.

In the theatrical film sample, 586 entities appear in only one sampled film, accounting for 85.80% of all entities. The corresponding figure for the online film sample is 1,269 entities, or 74.52%. The numbers of entities participating in at least five films are 23 and 64, accounting for 3.37% and 3.76%, respectively. The theatrical film sample has a higher proportion of entities with only one recorded participation, while the proportions participating in five or more films are similar. Therefore, the current results do not support characterizing the distribution of entity participation in the online film sample as having a more pronounced long tail.

4.2. Annual differences and data completeness

At the annual level, the proportion of nodes in the largest connected component is higher in the online film sample than in the theatrical film sample in all six years, although the annual values vary considerably. From 2020 to 2023, the proportions range from 72.80% to 84.65%, before falling to 27.44% in 2024 and 26.04% in 2025 (Table 3). The results for the pooled networks covering all six years cannot substitute for the annual results.

The numbers of theatrical films with multiple entities in 2020 and 2021 are 71 and 55, respectively, compared with 9, 2, 5, and 14 from 2022 to 2025. Notably, in 2023, only two of the 95 retained theatrical films had credit lists containing multiple entities after consolidation. This change must be assessed in light of the completeness of production-credit disclosures. Accordingly, this study reports only the observed annual structures and does not directly interpret the increase in single-entity credit lists in later years as a genuine decline in collaboration in the theatrical film market.

Table 3. Sample sizes and connectivity by year of first inclusion in the sample

Year	Theatrical films / films with multiple entities	Online films / films with multiple entities	Proportion in the largest connected component: theatrical films	Proportion in the largest connected component: online films
2020	94/71	116/104	43.02%	72.80%
2021	96/55	100/93	9.94%	84.65%
2022	89/9	73/65	6.25%	78.24%
2023	95/2	61/56	10.53%	73.45%
2024	94/5	58/48	21.28%	27.44%
2025	96/14	80/42	7.41%	26.04%

Note: In each pair, the second number represents the number of films with at least two distinct entity labels after consolidation. The year refers to the first year in which a film entered the collected sample, not its premiere year. Separate networks were constructed for each year.

4.3. Scope of comparison under different specifications

Table 4. Main sensitivity analyses

Specification	Theatrical film density	Online film density	Proportion in the largest connected component: theatrical films	Proportion in the largest connected component: online films
Main analysis	0.0041	0.0071	30.89%	85.55%
Collaboration subnetworks only	0.0101	0.0074	48.28%	87.35%
Excluding films with the largest production teams	0.0039	0.0071	30.28%	85.52%
Consistent credit lists only	0.0042	0.0071	30.63%	85.54%
Excluding projects with identical titles across different years	0.0042	0.0071	30.46%	85.55%
Excluding projects involving zero-amount records	0.0041	0.0072	30.89%	85.94%
Unmerged production-credit labels	0.0034	0.0057	21.22%	80.99%

Note: The "consistent credit lists only" specification retains films with only one valid credit list and excludes films for which the largest nested list was used. "Unmerged production-credit labels" uses the original production-credit names before consolidation and does not represent a verified list of legal entities.

In the main analysis, network density is 0.0071 for the online film sample, higher than the 0.0041 recorded for the theatrical film sample. When isolated nodes are removed and the comparison is restricted to

subnetworks containing collaboration edges, density is 0.0101 for theatrical films and 0.0074 for online films, reversing the ranking of the two samples (Table 4). This indicates that network density depends not only on the number of collaboration edges but also on which production entities are included in the network. When a network contains many isolated nodes, density cannot be directly interpreted as a measure of willingness to collaborate or the maturity of collaborative relationships.

Under all specifications reported in Table 4, the online film sample has a higher proportion of nodes in the largest connected component than the theatrical film sample. When production-credit labels are left unmerged, the respective proportions are 21.22% and 80.99%, indicating that name consolidation affects connectivity without reversing the direction of the comparison. After the 12 online films involving zero-amount records are excluded, 476 films remain in the sample, and the proportion of nodes in the largest connected component rises to 85.94%.

Changing the weighting scheme does not alter the binary network metrics reported above. Under frequency weighting, modularity is 0.7842 for the theatrical film sample and 0.7190 for the online film sample. Under the alternative scheme in which each film contributes a total weight of 1, the corresponding values are 0.9065 and 0.7873. The theatrical film sample has higher modularity under both weighting schemes, although the values change with the weights assigned. Modularity measures the extent of within-community connectivity relative to a random baseline under a given partition. It cannot, on its own, establish the existence of distinct alliance boundaries or the exclusivity of collaborative relationships.

5. Maximum *k*-core, community structure, and overlapping entities

5.1. Project origins of the maximum shell

The theatrical film sample has a maximum *k*-core level of 12, an average *k*-core level of 2.3602, and 13 entities in the maximum shell. The corresponding figures for the online film sample are 18, 8.5390, and 19 entities. Degree centralization is 0.0841 for the theatrical film network and 0.1300 for the online film network. The *k*-core level, the number of entities in the maximum shell, and degree centralization describe different structural properties. The *k*-core level reflects the hierarchical level at which a node is embedded in the *k*-core structure; the number of entities in the maximum shell counts nodes that attain the highest *k*-core level in the network; and degree centralization reflects the extent to which the degree distribution is concentrated. None of these measures represents the result of fitting a classical core–periphery model, nor does any provide evidence of capital contribution shares.

A film-by-film examination of the maximum-shell members shows that all 13 members of the theatrical film network appear in the production credits for *Only Green*, including China Film, Alibaba Pictures, New Classics Media, Lian Ray Pictures, China Media Group, and eight other entity labels. Similarly, all 19 members of the online film network appear in the production credits for *Exterminate Evil: Biker Gang*, including Qishu Youyu, Zhongguang Tianze, and Jingying Media, among others. After these two films are excluded, the maximum *k*-core levels of the two networks fall to 9 and 17, respectively, while the numbers of entities in the maximum shell change to 10 and 50. All 10 members of the new maximum shell in the theatrical film network are drawn from the production credits for *Emergency Rescue*. The number of entities reaching the maximum shell is directly affected by the complete subgraphs formed by individual films and therefore cannot serve as evidence of the size of a stable industry core.

5.2. Community structure and its interpretive limits

Under fractional weighting, the theatrical film network is divided into 332 communities, of which 246 consist exclusively of isolated nodes, leaving 86 communities containing collaboration edges. The online film network is divided into 105 communities, of which 35 consist exclusively of isolated nodes, leaving 70 communities containing collaboration edges. The modularity values are 0.8528 and 0.7351, respectively. The theatrical film sample has both a larger number of communities and higher modularity, while also containing more connected components and isolated nodes. Community counts or modularity values alone cannot establish whether organizational blocs are more clearly delineated or collaborative relationships are more exclusive.

Across the five random seeds, the number of communities in the theatrical film network ranges from 331 to 332, with modularity ranging from 0.8475 to 0.8533. For the online film network, the number of communities ranges from 103 to 107, with modularity ranging from 0.7346 to 0.7380. The slight variations across seeds indicate that the partition is not unique. This study does not assign platform affiliations to all nodes or test assortativity by platform label; consequently, it does not determine whether the communities are divided along platform-based institutional lines.

5.3. Differences in the network positions of entities shared by both samples

The two networks share 55 entity labels. Table 5 includes Alibaba Pictures, iQIYI, Tencent Pictures, China Film, and Maoyan, together with Enlight Media and Qishu Youyu, whose rankings differ substantially between the two networks. These seven entities were not selected as a uniformly defined "top seven" according to a single metric. Alibaba Pictures, iQIYI, and Tencent Pictures all rank among the top 10 in weighted betweenness centrality in both networks. China Film ranks first in the theatrical film network and 232nd in the online film network; Maoyan ranks 11th and 263rd, respectively; Enlight Media ranks 7th and 396th; and Qishu Youyu ranks 56th and 5th.

Table 5. Within-network weighted betweenness centrality of selected entities shared by both samples

Entity label	Weighted betweenness centrality: theatrical films	Rank: theatrical films	Weighted betweenness centrality: online films	Rank: online films
Alibaba Pictures	0.042656	2	0.215128	1
iQIYI	0.009590	5	0.110664	6
Tencent Pictures	0.020589	3	0.072338	10
China Film	0.048445	1	0.000039	232
Maoyan	0.005120	11	0.000017	263
Enlight Media	0.009504	7	0.000000	396
Qishu Youyu	0.000000	56	0.121249	5

Note: Edge distance is defined as the reciprocal of collaboration frequency. Weighted betweenness centrality is normalized by the total number of nodes in each respective network, and values are reported to six decimal places. Ranks are calculated using unrounded values, with tied entities assigned the same rank. Enlight Media has a weighted betweenness centrality of zero in the online film network and shares rank 396 with other entities having zero values. Qishu Youyu has a weighted betweenness centrality of zero in the theatrical film network and shares rank 56 with other entities having zero values.

Weighted betweenness centrality in each network measures the position of an entity on shortest paths within that network. Absolute values and rankings are not cross-network metrics. Maoyan is treated as an

online ticketing platform, and its entity type does not change with its network ranking. The presence of an overlapping entity indicates only that the same label appears in both samples. The available results do not establish that such entities constitute the principal channels connecting the two markets, nor do they support inferences about their motivations for cross-market operations.

6. Conclusion and discussion

Following the same procedures for data cleaning, name consolidation, deduplication, and network construction, this study compares production-credit records from online film rankings for 2020–2025 with theatrical films ranked 101–200 in the annual box-office rankings over the same period. When isolated nodes are retained, the online film sample has a higher average degree and a larger proportion of nodes in the largest connected component. After isolated nodes are removed, the ranking of the two networks by density is reversed. Both samples contain many entities that participate in only one sampled film, and the proportion of such entities is higher in the theatrical film sample.

In both networks, the maximum shell can be traced to the complete subgraph formed by a single film. It therefore cannot be taken as evidence of long-term alliances or a core of industry power. Community counts are affected by isolated nodes and network fragmentation, while modularity varies with the weighting scheme. Neither measure can be directly interpreted as evidence of institutional communities. The weighted betweenness centrality rankings of overlapping entities reflect only their positions within their respective networks. Assessing their cross-market functions requires the construction of a pooled or multilayer network.

Both networks were constructed and their structural metrics calculated using the same rules for processing production credits. However, sample selection, film budgets, genres, and the disclosure of production credits may still affect the results. Accordingly, the findings characterize collaboration structures within the sampled films and do not support attributing the observed differences to distribution channels, revenue-sharing arrangements, or the degree of platform control.

The scope of interpretation is further constrained by the available production-credit data and entity identification. Multiple-entity credits are rare in the 2023 theatrical film sample, and the observed annual changes may partly reflect differences in credit disclosure. The entity labels obtained after name consolidation include both group names and unmatched entity names. Historical ownership relationships, as well as the identification of films with identical or translated titles and re-releases, may also alter network boundaries. Shared production credits reflect project participation but do not provide information on capital contribution ratios, contractual arrangements, or control relationships.

Future research could improve the identification of entities and relationships by incorporating end credits, corporate group relationships at the time each project was undertaken, and more complete film identifiers. Subsequent analyses could then conduct stratified comparisons by year, genre, budget, or production team size and incorporate comparable performance and contractual data.

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