A Deeper Understanding of the Empire of Networks

Tom Kobes, Digital Humanities and Digital Knowledge, 0001036714
Abdul Moqeet, Artificial Intelligence, 0001113225
Chang Sun, Artificial Intelligence, 0001109482

1 Introduction

Building on the "Empire of Networks" study, which examined how the Spanish Crown used privilege distribution as a tool for colonial governance, this project aims to conduct a more comprehensive analysis of influence in this network. While the original research focused on grouping privileges by time and geographic region, our project will explore the internal structure of influence using additional centrality measures, community detection, and role differentiation (hubs and authorities).

To achieve this, we analyze the **monomodal directed network** in which nodes represent individuals, and directed edges indicate the granting of privileges from one person to another. In this way we are able to analyse hierarchical relationships, track the flow of influence, and identify key figures who acted as intermediaries or central authorities in the system. These enhancements will provide a better understanding of how individuals within the network acted as connectors, authorities, or influential community members.

2 Problem and Motivation

Our study seeks to identify the most influential individuals within the privilege network by applying a wide range of metrics to capture both direct and indirect influence. Key questions include:

1. Influence and Centrality: Which individuals held the most power and influence in the network based on centrality metrics?
2. Role of Hubs and Authorities: By differentiating between hubs (nodes that connect to influential figures) and authorities (highly resourceful and influential nodes), we will examine the hierarchical structure and influence flow, identifying key intermediaries.
3. Community Structure: Beyond geographic and temporal groupings, we aim to detect communities within the network, revealing internal groups that might represent power clusters or factions within the colonial administration.
4. Profession and Privilege Type Influence: What impact did different types of professions have on an individual's position and influence within the network?

3 Datasets

The dataset for this study was sourced from the *Visualizing Privileges* project, by Harvard University (histecon.fas.harvard.edu/visualizing/privileges/index.html). This project provides a structured database of privileges granted by the Spanish Crown between 1500 and 1559, derived from the *Cedularios*, a collection of royal decrees.

3.1 Data Preprocessing and Modifications

3.1.1 Cleaning Node and Place Names

Some names contained accents and special characters that caused errors when imported into Gephi. To resolve this, we standardized node names by removing or replacing accented characters (e.g., *García* $\rightarrow$ *Garcia*). Place names were also modified for consistency, ensuring uniform spelling across the dataset.

3.1.2 Adding Profession Categories

The original dataset did not explicitly classify all individuals by profession. We manually categorized each node into one of four types:

- **Merchants** (e.g., traders, bankers)
- **Royal Officials** (e.g., colonial administrators, royal appointees)
- **Local Officials** (e.g., city council members, regional leaders)
- **Other** (e.g., clergy, military personnel, representatives of the Crown)

This classification allowed us to color-code the nodes in Gephi, making it easier to identify the roles of individuals in the privilege network.

3.1.3 Data Formatting

The data was structured into two primary CSV (UTF-8) files to ensure compatibility with Gephi and other analysis tools:
Nodes File: Contained unique IDs, names, professions, and geographic locations.
Edges File: Represented directed connections between privilege granters and recipients, with attributes including:

- **Privilege Type** (Licenses, Benefits, Monopolies)
- **Time Interval** (start and end dates)
- **Weight:** Assigned by the researchers in the original study to reflect the importance of privileges.

3.2 Tools Used

3.2.1 Data Handling and Storage

We used **Python (Pandas, NumPy)** for data processing and manipulation, while **CSV files** were used for structured storage and easy import into network analysis tools.

3.2.2 Computation and Analysis

For the analytical computations, we employed:

- **Gephi** for network modeling and visualization.
- **Centrality Metrics:** Weighted Indegree, Katz Centrality (PageRank), and the HITS Algorithm were computed to analyze influence within the network.
- **Community Detection:** NetworkX for community detection. K-cores analysis helped identify core-periphery structures.
- **Profession Type Analysis:** The dataset was segmented into types of profession to examine changes in privilege distribution according to the profession of the individuals.

4 Validity and Reliability

4.1 Validity: How Closely Does the Model Represent Reality?

The validity of our dataset is determined by how accurately it captures the structure of privilege distribution within the Spanish colonial administration. Our data, sourced from the *Visualizing Privileges* project, is based on the *Cedularios*, a collection of royal decrees that document formally granted privileges. While these records provide a structured account of privilege distribution, they do not fully encompass the informal negotiations, undocumented agreements, or conflicts that also played a role in the power dynamics.

The article *Empire of Networks* acknowledges that historical records such as the *Cedularios* present several challenges when used for network analysis. One key issue is the **heterogeneity of recorded information**—some privileges include detailed descriptions of the grantee's status and responsibilities, while others provide minimal information. Additionally, geographical designations evolved over time, making it difficult to precisely map privilege distribution to fixed territorial boundaries.

To address some of these limitations, we made modifications, including:

- Standardizing names and locations to ensure consistency across records.
- Categorizing individuals into four broad professional groups (Merchants, Royal Officials, Local Officials, Other).
- Using privilege types (privileges, obligations, orders) to differentiate the nature of the documents.

Despite these efforts, our model remains a simplification of historical reality. As the article notes, privilege grants were part of a broader strategy of political control, often influenced by external factors such as factional disputes and economic pressures. Our network analysis captures direct privilege relationships but does not account for indirect influence, lobbying, or power struggles occurring outside the documented privilege system.

4.2 Reliability: How Does Data Treatment Affect Reproducibility?

The reliability of our study is based on the extent to which our dataset and analytical processes can be consistently applied and reproduced. Several characteristics are included that enhance the reproducibility:

4.2.1 Consistency in Data Cleaning and Preprocessing

We followed a structured data cleaning process to ensure that future researchers could replicate our steps. This included:

- Standardizing name formats by removing accents and resolving spelling variations.
- Assigning professional categories.
- Structuring the dataset into separate files for nodes (individuals) and edges (privileges) to maintain clarity in network modeling.

4.2.2 Structured Data Formats

Our dataset is stored in **CSV UTF-8 format**, making it easily accessible for analysis in Python and Gephi. The use of a structured format ensures that the dataset can be reconstructed and reanalyzed under similar conditions.

4.2.3 Computational Reproducibility

We applied standard network analysis techniques to our data using:

- **Gephi** for network visualization and metric computation.
- **Python (Pandas, NumPy)** for data preprocessing.
- **Centrality and Community Detection Measures**, including Weighted Indegree, Katz Centrality, HITS, and K-cores analysis.

4.2.4 Stability and Limitations

Our dataset is based on historical sources that are fixed and static, meaning the core dataset will not change over time. However, as the article *Empire of Networks* already noted, any new archival discoveries or other classifications could affect the interpretation. While our model is reproducible within its current structure, different weighting criteria or alternative privilege classifications could alter certain findings.

4.3 Balancing Validity and Reliability

While our model captures key privilege relationships within the Spanish colonial system, it remains a **structured approximation** of historical reality rather than a definitive representation. The limitations noted in the original article—such as data gaps, evolving geographic boundaries, and missing informal influence structures—apply to the dataset. Nonetheless, the standardization of our methodology ensures that our approach is reproducible, making it a valuable framework for further studies in historical network analysis.

5 Measures and Results

In this chapter, we present the measures and results of our analysis of the social network, where nodes represent individuals and edges represent privileges granted. The original research employed several key measures to assess influence and structure within the network: Weighted Indegree, which quantifies the number and strength of privileges received by individuals; Harmonic Centrality, which evaluates how close individuals are to others in the network; and Rank Prestige, which measures the prestige of individuals based on the status of those who grant them privileges. Additionally, the network was analyzed through subnetworks based on time and place, allowing for a nuanced understanding of how influence and structure varied across different temporal and spatial contexts.

In our study, we build upon these measures and introduce additional techniques to provide a more comprehensive analysis. These measures are organized around the three central themes of our research: Influence and Centrality, which identifies the most powerful and influential individuals in the network; Role of Hubs and Authorities, which examines the hierarchical structure and flow of influence by differentiating between individuals who grant privileges (hubs) and those who receive them (authorities); and Community Structure, which explores the internal groupings and power clusters within the network. Each measure and its results will be explained in the context of these themes, highlighting its relevance and contribution to the original research.

5.1 Measures

5.1.1 Influence and Centrality

This theme focuses on identifying the most influential individuals in the network using centrality measures. The following techniques fit here:

Katz Centrality
Measures influence by considering both direct and indirect connections, with a decay factor for longer paths. It identifies individuals who are influential due to their connections, including indirect ones.
Eigenvector Centrality
Measures importance based on the importance of a node's neighbors. Identifies individuals who are central because they are connected to other central individuals.
PageRank
A variant of Eigenvector Centrality with a damping factor to handle dead-ends. It identifies individuals who are likely to receive influence or privileges due to their position in the network.

5.1.2 Hubs and Authorities

The measures described here, were used to reveal the dual roles of individuals in the network, specifically those who grant privileges (hubs) and those who receive them (authorities). We also identified Bridges that made for critical connection who maintained the flow of influence.

HITS
We applied the HITS algorithm to a directed privilege network to identify the two key types of influential nodes: hubs and authorities. Hubs are nodes that point to many high-quality

authorities, while authorities are nodes that receive many links from hubs. The HITS algorithm assigns two scores to each node in a directed graph:

1. **Hub Score** (h_i): measures the extent to which a node links to authoritative nodes.
2. **Authority Score** (a_i): measures the extent to which a node is linked to by hubs.

The iterative update equations for these scores are:

$$\begin{aligned} a_i &= \sum_{j:(j\to i)} h_j \\ h_i &= \sum_{j:(i\to j)} a_j \end{aligned} \tag{1}$$

where i represents a node in the network, j represents other nodes and $j \to i$ denotes an edge from node j to node i.

Bridge nodes
Bridge nodes are critical connectors that facilitate communication between different parts of a network. In this analysis we use betweenness centrality, which is a measure that quantifies how often a node lies on the shortest paths between other nodes, to identify bridge nodes. Betweenness centrality of a node v is computed as:

$$C_B(v) = \sum_{s\neq v\neq t} \frac{\sigma_{st}(v)}{\sigma_{st}} \tag{2}$$

where σ_{st} is the total number of shortest paths between nodes s and t, $\sigma_{st}(v)$ is the number of these shortest paths that pass through node v and the summation runs over all pairs of nodes (s,t) in the network. A higher betweenness centrality score means the node is frequently on the shortest path between other nodes, acting as a bridge.

5.1.3 Community Structure

Beyond geographic and temporal groupings used in the original research, we aim to detect natural communities within the network, revealing internal groups that might represent power clusters or factions within the colonial administration. For this goal we applied the following methods:

Community Detection with the Louvian Method
We performed community detection using the Louvain method from community package with the combination of NetworkX libraray and obtained several distinct communities. It works in two phases: **(1)** Local Optimization, where each node is assigned to a community that maximizes modularity gain. **(2)** Aggregation, where communities are treated as single nodes and the process is repeated until modularity no longer improves.

K-core Decomposition Analysis
We performed a k-core analysis to understand the structure of our network. In simple terms, a k-core is a group of nodes where each node is connected to at least 'k' other nodes within that group. By progressively removing nodes with fewer than 'k' connections, we can identify these densely connected subgroup. It possibly reveals tightly connected groups of individuals,

which might represent core power structures within communities.

Enhanced K-core Analysis
A refined k-core analysis, in which the weighted sum of the edges within the subgraph are also considered, providing a deeper understanding of node influence.

5.2 Results

5.2.1 Influence and Centrality

PageRank
As seen Table 1 PageRank identified influential figures like García de Lerma and Heinrich Ehinger, consistent with the original study. It also highlighted Bartolomé de las Casas as a key figure due to his indirect but strategically significant connections to influential decision-makers like Cardinal Cisneros. This shows PageRank's effectiveness at capturing both direct authorities and those with indirect influence.

Using weighted edges revealed differences in influence dynamics. García de Lerma and Heinrich Ehinger maintained top positions, reflecting the importance and frequency of their connections. However, Bartolomé de las Casas ranked lower, suggesting his influence relied on diverse but less frequent interactions. Conversely, Alonso de Ojeda and Bartholomaus Welser II ranked higher with weighted edges, highlighting the impact of high-volume connections. This comparison shows that weighted PageRank emphasizes the strength of interactions, while the unweighted version captures strategic positioning

PageRank	**PageRank (weighted edges)**
Bartholome de las Casas	Garcia de Lerma
Garcia de Lerma	Heinrich Ehinger
Bartholomaus Welser II	Bartolome de las Casas
Heinrich Ehinger	Bartholomaus Welser II
Gaspar Mateo	Alonso de Ojeda
Fray Pedro de Cordoba	Fray Pedro de Cordoba
Sabastien Neidhart	Sebastien Neidhart
Alonso de Ojeda	Gaspar Mateo
Alonso Vazquez de Acuna	Alonso Vazquez de Acuna
Pedro de San Martin	Pedro de San Martin

Table 1: Top 10 Nodes for PageRank and PageRank (Weighted Edges)

Eigenvector Centrality
Eigenvector Centrality, shown together with Katz Centrality in Table 2 identified **Hieronymus Sayler** and **Alonso de Ojeda** as influential figures due to their strategic connections within powerful subgroups, despite not receiving the most direct privileges. Their influence was linked to their connections with key figures like **Heinrich Ehinger** and **García de Lerma**, revealing their embeddedness within elite circles. This measure uncovers hidden hierarchies and power networks that were less visible in the original study, highlighting how influence can be exercised through strategic network positioning rather than direct privilege accumulation. This is also confirmed by the community detection.

Katz Centrality
Katz Centrality revealed nodes with indirect influence by highlighting connections to other influential figures. It identified key individuals like **Heinrich Ehinger** and **García de Lerma**, consistent with the original study. However, it also emphasized again **Bartolomé de las Casas**, whose influence was more indirect but substantial through his network ties to powerful intermediaries. This finding shows Katz Centrality's strength in uncovering hidden power structures and indirect influence, revealing a more nuanced picture of power dynamics within the colonial governance network.

Eigenvector Centrality	**Katz Centrality**
Heinrich Ehinger	Heinrich Ehinger
Garcia de Lerma	Hieronymus Sayler
Gaspar Mateo	Alonso de Ojeda
Alonso Vazquez de Acuna	Bartolome de las Casas
Pedro de San Martin	Diego de Ordas
Bartholomaus Welser II	Jeronimo de Ortal
Sabastien Neidhart	Bartholomaus Welser II
Luis Gonzalez de Leyva	Juan de Espes
Alonso de la Llana	Pedro de Heredia
Hieronymus Sayler	Licenciado Marcelo de Villalobos

Table 2: Top 10 Nodes for Eigenvector Centrality and Katz Centrality

5.2.2 Hubs and Authorities

After applying the HITS algorithm from **NetworkX** Python library, we can get the top 10 Hubs in Table 3 and top 10 Authorities in Table 4:

- **Hubs**: the highest hub score is associated with **Charles V**, suggesting that he played a central role in granting privileges to authoritative individuals. Similarly, **Isabella of Portugal** and **Francisco de Santa Cruz** are notable hubs, indicating their significant connections to influential authorities.
- **Authorities**: **Hieronymus Sayler** is the highest-ranked authority, meaning he received the most connections from influential hubs. **Bartholomaus Welser II** and **Anton Welser** follow, indicating their critical roles as authoritative figures.

Table 5 presents the top 10 nodes with the highest betweenness centrality. We can see from the table that:

- **Garcia de Lerma** has the highest betweenness score, meaning he acts as a crucial link between different sub-networks.
- **Hieronymus Sayler** is another important bridge, reinforcing his influence in the network (he was also identified as a top authority).
- **Diego de Ordas**, **Georg Hohermuth** and **Heinrich Ehinger** all have similar betweenness scores, indicating intermediate bridging roles.
- Some nodes (**Juan Garcia de Samaniego** and **Matias Roberto**) have zero betweenness, meaning they do not act as bridges.

Table 3: Top 10 Hubs.

Node id	Name	Hub score	Authority score
227	Charles V	0.775526	-1.377128e-18
231	Isabella of Portugal	0.132781	-1.701713e-18
10	Francisco de Santa Cruz	0.052083	3.997987e-03
225	Joanna of Castile	0.015918	2.715735e-18
123	Diego de Ordas	0.005241	1.149791e-03
93	Pedro de Heredia	0.005241	5.367010e-03
7	Garcia de Lerma	0.003939	6.757452e-03
6	Hieronymus Sayler	0.002568	1.108047e-03
5	Heinrich Ehinger	0.002078	6.401247e-03
17	Georg Hohermuth	0.001336	8.680486e-03

Table 4: Top 10 Authorities.

Node id	Name	Hub score	Authority score
6	Hieronymus Sayler	0.002568	0.110805
15	Bartholomaus Welser ii	-0.000000	0.034091
14	Anton Welser	-0.000000	0.034037
55	Juan Lopez de Arrechuleta	-0.000000	0.025357
62	Martin de Ochandiano	-0.000000	0.015992
19	Nikolaus Federmann	-0.000000	0.015992
9	Alonso Vazquez de Acuna	-0.000000	0.012692
202	Francisco de Castellanos	0.000615	0.012678
220	Luis de Lugo	-0.000000	0.011994
1	Lazaro Nurnberger	-0.000000	0.011994

- **Hieronymus Sayler** is both a top authority and a top bridge, meaning he not only received privileges but also acted as a connector. This suggests that some high-status individuals controlled both direct influence (authorities) and indirect influence (bridges).

5.2.3 Communities

The k-core analysis of the network revealed a maximum k-core value of 3, identifying a tightly connected subgroup in which each node is linked to at least three others within the same group. This subgroup represents the structural core of the network, with its nodes likely playing a central role in maintaining connectivity and robustness. Table 6 lists the nodes within this highest k-core subgroup, which includes well-known influential figures such as Charles V, Isabella of Portugal, and Garcia de Lerma. Notably, the enhanced k-core analysis also identified Juan de Ampies and Diego de Ordas, whose inclusion is significant. Despite their lower individual influence, these nodes contribute substantially to the network's structural cohesion, underscoring their importance in sustaining connectivity and reinforcing the robustness of the network's core.
Further analysis of the network's communities provides additional insights into their functional roles and influence:

- **Community 0**: This community emerges as one of the most influential in terms of ad-

Table 5: Top 10 Bridge nodes.

Node id	Name	Betweenness
7	Garcia de Lerma	0.000074
6	Hieronymus Sayler	0.000055
123	Diego de Ordas	0.000037
17	Georg Hohermuth	0.000037
5	Heinrich Ehinger	0.000037
93	Pedro de Heredia	0.000028
10	Francisco de Santa Cruz	0.000018
202	Francisco de Castellanos	0.000018
154	Juan Garcia de Samaniego	0.000000
141	Matias Roberto	0.000000

Node id	Name
227	Charles V
5	Heinrich Ehinger
6	Hieronymus Sayler
7	Garcia de Lerma
231	Isabella of Portugal
9	Alonso Vazquez de Acuna
10	Francisco de Santa Cruz
15	Bartholomaus Welser ii
93	Pedro de Heredia

Table 6: Nodes in the Highest k-Core Subgroup

ministration and law enforcement. It includes a large number of both local and royal officials, indicating strong governance and regulatory power. The presence of merchants suggests a role in shaping commerce policies, though their influence is likely moderated by the officials. This community is one of the largest, dominated by merchants (blue) and local officials (orange), making it a key hub in the network..

- **Communities 1, 2, and 9**: These communities consist almost entirely of officials, representing specialized administrative or governance roles. Their relatively isolated and focused composition suggests niche functions within the broader network. Community 2, in particular, has a strong presence of royal officials (green), reinforcing its importance in the network's hierarchy.

- **Community 3**: This community combines local officials and merchants, controlling critical local functions such as infrastructure management, taxation, and general governance. Its mixed composition serves as a bridge between upper administration and the broader public, ensuring effective policy implementation and service delivery. While smaller in size compared to Communities 0, 1, and 2, it plays a vital role in connecting different parts of the network.

- **Smaller Communities**: Some individuals are classified as "out of network" (purple), indicating they are less connected or play a peripheral role in the overall structure.

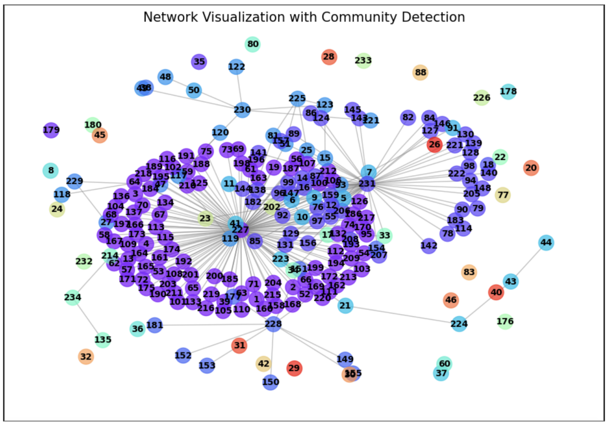

Figure 1: Communtiy Detection

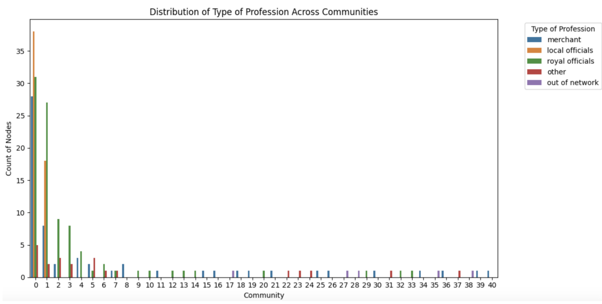

Figure 2: Distribution of Professions Across Network Communities

6 Conclusion

Our follow-up study aimed to build upon the original "Empire of Networks" research by conducting a more comprehensive analysis of the Spanish colonial privilege network. By applying advanced network analysis techniques and measurements, we sought to reveal a deeper understanding of the structure of influence, the roles of key individuals, and the community dynamics within the network. Our findings not only reinforce many of the conclusions drawn in the original study but also provide new perspectives on how influence was distributed and maintained within the Spanish colonial administration.

6.1 Key Findings

6.1.1 Influence and Centrality

Our analysis using centrality measures such as PageRank, Eigenvector Centrality, and Katz Centrality confirmed the importance of individuals like García de Lerma, Heinrich Ehinger, and Hieronymus Sayler, who were identified as central figures in the original study. These individuals held significant influence due to their direct, and as we found also indirect, connections within the network. However, our analysis also highlighted the strategic importance of individuals like Bartolomé de las Casas, whose influence was more indirect but still substantial due to his connections with powerful intermediaries such as Cardinal Cisneros. This suggests that influence in the network was not only determined by the number of privileges received but also by the quality and strategic positioning of connections.

6.1.2 Hubs and Authorities

The use of the HITS algorithm revealed a clear hierarchical structure within the network, with individuals like Charles V and Isabella of Portugal acting as key hubs who granted privileges to authoritative figures such as Hieronymus Sayler and Bartholomaus Welser II. These findings align with the original study's emphasis on the monarchy's role in controlling privilege distribution. However, our analysis also identified bridge nodes like García de Lerma and Diego de Ordas, who played crucial roles in connecting different parts of the network. This highlights the importance of intermediaries in maintaining the flow of influence and information across the colonial administration.

6.1.3 Community Structure

Our community detection analysis revealed distinct power clusters within the network, with some communities dominated by royal officials and others by merchants. For example, Community 0 emerged as a key hub of governance and commerce, while Communities 1, 2, and 9 represented specialized administrative roles. These findings suggest that the network was not homogenous but rather composed of tight groups with specific functions. This complements the original study's focus on geographic and temporal groupings by showing how internal power structures and factions operated within the broader network.

6.2 Implications for the Original Study

6.2.1 Indirect Influence

While the original study focused on direct privilege relationships, our use of centrality measures like Katz Centrality and Eigenvector Centrality revealed the importance of indirect influence. Individuals like Bartolomé de las Casas, who were not the primary recipients of privileges, still held significant influence through their strategic connections. This suggests that the network's power dynamics were more nuanced than previously thought, with influence flowing through both direct and indirect channels.

6.2.2 Hierarchical Structure

The identification of hubs and authorities through the HITS algorithm provides a clearer picture of the hierarchical structure within the network. This supports the original study's argument that the Spanish Crown used privilege distribution as a tool for governance but also highlights the dual roles of individuals who acted as both granters and recipients of privileges. This dual role was particularly evident in figures like Hieronymus Sayler, who was both a top authority and a bridge node, controlling both direct and indirect influence.

6.2.3 Community Dynamics

Our community detection analysis adds a new dimension to the original study by revealing the internal power clusters within the network. These communities, composed of royal officials, merchants, and local administrators, suggest that the network was not just a tool for centralized control but also a space where local power structures and factions operated. This aligns with the original study's emphasis on the polycentric nature of the Spanish Empire but provides a more detailed view of how these local power structures were formed.

6.3 Conclusion

In conclusion, our follow-up study enhances the original "Empire of Networks" research by providing a more detailed and nuanced understanding of the Spanish colonial privilege network. While our findings largely support the original study's conclusions, they also reveal new layers of complexity in the network's structure and dynamics. By uncovering the roles of indirect influence, hierarchical structures, and internal power clusters, our analysis offers a richer picture of how the Spanish Crown maintained control over its colonies through the strategic distribution of privileges.

7 Critique

The goal of our research was to go beyond the original "Empire of Networks" approach and produce a more comprehensive and detailed analysis of influence within the Spanish colonial privilege network, particularly by identifying key individuals, their roles and their community structures. In this regard, our work partially succeeds in solving the aforementioned problems. However, while the network metrics we applied provide robust structural insights, they cannot capture the totality of **political**, **social**, or **economic pressures** that influenced how privileges were granted or withheld. There are some measures we can take to future improve the work:

- **Additional metadata**: such as nodes' extended biographical backgrounds or social ties, would offer a more multidimensional understanding of why certain individuals gained or lost influence.
- **Integration with Spatial Analysis**: Geographic dimension could have been used to visualize cross-regional networks, showing how privileges flowed between the Iberian Peninsula and the Americas.