STRATEGIC ADAPTATION IN THE TRANSATLANTIC SLAVE TRADE: A TEMPORAL NETWORK ANALYSIS OF THE ABOLITION ERA

By

Mehmet Veysel Sundu

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Supervisor: Prof. Mark Wittek

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Author's Declaration

I, the undersigned, **Mehmet Veysel Sundu**, candidate for the MS degree in Social Data Science declare herewith that the present thesis is exclusively my own work, based on my research and only such external information as properly credited in notes and bibliography. I declare that no unidentified and illegitimate use was made of the work of others, and no part of the thesis infringes on any person's or institution's copyright. I also declare that no part of the thesis has been submitted in this form to any other institution of higher education for an academic degree.

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Abstract

This study examines the transatlantic slave trade network's evolution during the abolition era using Temporal Exponential Random Graph Models (TERGMs). The analysis uses data from the Transatlantic Slave Trade Database across four historical phases to determine whether abolition laws dismantled trading networks or catalyzed strategic adaptations. The study constructs directed networks representing enslaved people's movement from African embarkation to American destination ports, examining network structure, colonial control patterns, and trading strategies as legal restrictions intensified. The methodology employs a progressive modeling approach, building from baseline structural effects through colonial controls, temporal dependencies, and strategic adaptations. The analysis reveals a striking paradox: ports operating under abolished flags demonstrate higher likelihood of maintaining trading connections than those under legal flags. Three key adaptation mechanisms emerge: powerful colonial homophily effects with ports under the same imperial control showing higher trading probability, remarkable temporal persistence with existing routes continuing despite legal upheavals, and strategic adaptations including flag manipulation and vessel modifications. Colonial power dynamics shape these transformations significantly, with British-controlled ports declining substantially while Portuguese-Brazilian and Spanish territories expand operations. These findings challenge narratives of abolition's effectiveness, demonstrating how formal institutional changes may strengthen rather than weaken illicit networks by concentrating operations among sophisticated actors, with implications for contemporary policy addressing human trafficking and modern slavery.

Acknowledgements

This research is dedicated to the memory of the millions of enslaved Africans who suffered and died in the transatlantic slave trade. While this study examines networks and statistical patterns, it is essential to remember that each data point represents human lives, families torn apart, and immeasurable suffering. Their stories and experiences must never be forgotten.

I would like to express my gratitude to my supervisor, Professor Mark Wittek, for his invaluable guidance and constructive feedback throughout this research process. His expertise in social network analysis and thoughtful insights significantly enhanced the quality of this work.

Special thanks are due to the creators and maintainers of the Transatlantic Slave Trade Database, whose meticulous work in preserving and organizing historical records made this research possible. This study would not have been feasible without their dedication to making these crucial historical data accessible to researchers.

Any remaining errors or shortcomings in this work are entirely my own responsibility.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

The mid-eighteenth to early nineteenth centuries brought profound transformations across the Atlantic world. During this period, Britain's Industrial Revolution coincided with political upheavals in France, Haiti, and America, while the Napoleonic Wars disrupted established political and economic structures. These events not only reshaped economies but also redefined concepts of liberty, colonialism, and rights, setting the stage for significant reforms including the abolition of the slave trade in Britain (1807) and the United States (1808).

The transatlantic slave trade emerged in the early 16th century when European colonial powers sought labor for their expanding American plantations. What began with Portuguese traders along the West African coast grew into a vast network that brutally and forcibly transported millions of Africans to the Americas. For over three centuries, the demand for labor—particularly in sugar, cotton, and tobacco production—fueled this system. The trade became not only integral but one of the most significant components of European and American economic growth by incorporating enslaved labor into developing capitalist structures [1]. The early 19th century legislative actions, notably the British and U.S. abolition in 1807-1808, marked a pivotal legal and economic turning point. Following these laws, merchants, financiers, and states reconfigured slave trade networks, developing covert routes and financial mechanisms to circumvent new legal constraints [2].

While many abolition studies focus on legal frameworks, economic consequences, and humanitarian activism, I attempt to address a critical gap by examining how abolition transformed the dynamics of slave trade networks. I examine changes in geographic patterns and operational structures, focusing on shifting port roles, network density, and voyage characteristics. I analyze which alternative trade hubs gained prominence as Britain and America officially withdrew from the trade. I explore how the colonial distribution of active ports evolved during this period of transition. Besides, I try to measure the extent to which countries with abolished flags maintained connections to the slave trade through indirect means. I investigate how route legality affected network formation and persistence. Finally, I document strategic adaptations such as flag manipulation that emerged as traders responded to increasing legal restrictions.

To analyze these network transformations, I employ Temporal Exponential Random Graph

Models (TERGMs) using the btergm package with pseudolikelihood estimation and bootstrapped confidence intervals. This approach allows me to model how network structures evolved over time while accounting for both endogenous network processes and exogenous factors. I construct separate networks for four distinct time periods: Phase 1 (1791-1807), Phase 2 (1808-1824), Phase 3 (1825-1841), and Phase 4 (1842-1860), using data from the Transatlantic Slave Trade Database. In network structure, nodes represent ports while edges represent the directed movement of enslaved people. I develop a progressive model-building strategy with five sequential models, beginning with a baseline that captures fundamental network properties, then incorporating colonial control effects, temporal dependencies, abolition effects, and finally strategic adaptations in flag usage.

The thesis consists of four main chapters. Following this introduction, I review relevant literature on the transatlantic slave trade and social network analysis methodologies. In the Methodology chapter, I detail the theoretical and analytical aspects of my research. In the Data chapter, I detail data sources, pre-processing, network construction, and covariate building. The Results and Discussion chapter presents how the slave trade network evolved across the four phases, highlighting key structural changes and adaptations. Finally, I conclude by reflecting on the implications of findings for understanding how trade networks respond to legal prohibitions, the importance of colonial relationships in structuring trade patterns, and the resilience mechanisms that allowed this exploitative system to persist despite growing opposition.

Chapter 2

Literature Review

The 1807 abolition of the slave trade by Britain – followed by the United States in 1808 – marked a critical turning point that reconfigured global slave trading networks [3]. The transatlantic slave trade, alongside its legal operations, continued underground through illicit channels. As I try to demonstrate, these adaptations reflected sophisticated strategic responses to changing conditions rather than simply the gradual dissolution of an outdated ”economic system”.

2.1 Historical Background and Context

Fauvelle [4] argues that Portuguese traders initiated the transatlantic slave trade by tapping into existing Muslim trade networks along Africa's coast, leveraging commercial systems that had connected sub-Saharan Africa to broader Islamic economic networks since the medieval period. While these early connections mattered, the Atlantic system quickly took on its own character, expanding into something much greater. Within decades, the brutal and massive forced migration of millions of Africans took place to produce sugar, cotton, and tobacco in the New World [1].

By the late 18th century, the slave trade had become deeply embedded in Atlantic economic systems, with an estimated 12.5 million Africans transported across the Atlantic during the entire period of the trade [5]. This massive slave trade created complex webs of commercial relationships, political alliances, and colonial dependencies that persisted even as moral opposition mounted. The trade system played a crucial role in the economic growth of European and American markets by integrating enslaved labor into the developing capitalist structures [1].

In the early 19th century, radical legislative actions, most notably the British and U.S. abolition of the slave trade in 1807 and 1808, marked a significant legal and economic turning point. Regardless of the motives behind these laws, abolition led to a series of adaptations as merchants, financiers, and states reconfigured trade networks, developing covert routes and financial mechanisms to bypass new legal constraints

2.2 Moral and Ideological Currents

Enlightenment ideals of human rights and liberty had broadly influenced late-18th-century abolitionism, framing the trade as a violation of natural rights [6]. Alongside these philosophical currents, evangelical religious movements – notably Quaker and Anglican evangelicals – preached that slavery was a sin, making abolition a divine moral mission [7]. By the early 19th century, a transnational moral consensus appeared to be emerging against the slave trade, often characterized as the first humanitarian campaign in modern history [8]. After Britain and the U.S. prohibited the trade, this moral momentum spread. By the mid-19th century, every major slave-trading nation had formally banned the transatlantic trade [6].

The literature, however, also notes a disjuncture between rhetoric and reality: even as abolitionist sentiment mounted, ”the demand” for enslaved labor in expanding plantation economies (Cuba, Brazil, the U.S. South) created what Dale Tomich [9] calls a rebirth of ”second slavery.” This ”second slavery” was characterized by booming cotton, sugar, and coffee plantations in the 19th-century Americas – a development that ”betrayed” the very Enlightenment ideals that abolitionists advocated. This pattern aligns with Rosa Luxemburg's [10] broader theoretical framework regarding capitalism's relationship to non-capitalist forms of exploitation. Her analysis in *The Accumulation of Capital* suggests that capitalism's expansion requires the continuous incorporation of non-capitalist territories and labor relations, which helps explain how the formal abolition of the slave trade could coexist with its practical continuation through transformed institutional arrangements

2.3 Legal Changes and Enforcement Challenges

Britain's 1807 Slave Trade Act and the U.S. 1808 ban made slave trading a criminal offense, and many other nations later passed similar laws [11]. However, early legal efforts had significant weaknesses and lacked effective global enforcement mechanisms. For example, the first U.S. laws only imposed fines and short jail sentences which was insufficient to deter determined smugglers given the immense profits available [9]. In response, both the U.S. and Britain strengthened their laws by the 1820s. The U.S. Supplementary Slave Trade Act of 1820 classified slave trading as piracy, punishable by death, making it one of the toughest anti-slavery laws of its time [12]. Britain leveraged its naval strength and diplomatic influence to create treaties that allowed its ships to intercept slave vessels on the high seas [13]. After the Congress of Vienna in 1815, British diplomats negotiated anti-slave trade treaties with Portugal, Spain, France, the Netherlands, and later Brazil. These agreements created international Mixed Commission Courts to judge captured slave traders. These courts, established in locations like Sierra Leone, Havana, and Rio de Janeiro, represented pioneering transnational legal institutions aimed at enforcing abolition.

Despite these legal measures, enforcement remained problematic. The Royal Navy's West Africa Squadron, created in 1808 and expanded in 1819, was tasked with patrolling thousands of miles of African coastline to intercept illegal shipments [14]. The Squadron achieved notable successes – over the decades, it captured hundreds of slave vessels and ”freed tens of thousands of Africans destined for slavery” [15]. However, historians document the Squadron's limitations, too. Resources were stretched thin, and slavers often deployed faster ships or innovative tactics to evade capture [14]. Many illegal traders modified small, swift schooners – often Baltimore clippers built in American shipyards – specifically for smuggling enslaved people. [14] Enforcement was further complicated by disputes over jurisdiction and national sovereignty. Without universal agreement on search rights, British patrols sometimes stopped ships flying other nations' flags, leading to diplomatic conflicts. The United States, particularly after the War of 1812, strongly defended its sovereignty at sea and refused to grant Britain search rights [8].

Legal historians note that consistent international enforcement only effectively suppressed the Atlantic slave trade by the 1860s, marked by the U.S. Civil War (which ended American involvement) and Brazil's 1850 Eusébio de Queirós law, which finally stopped slave imports to Brazil after decades of resistance to earlier prohibitions [8] [16] [17].

2.4 Economic Adaptation and Illicit Trade Networks

The historiography, as noted earlier, refers to this 19th-century boom in slave-based production as the ”second slavery,” wherein new world-market demands made slavery more profitable in certain regions even as abolition advanced elsewhere [9] [8].

Cuba and Brazil became key centers of this expansion, with Cuba's sugar plantations and Brazil's coffee fields rapidly growing between the 1810s and 1860s, sustained by the brutal exploitation of enslaved human beings. As a result, even though the transatlantic slave trade was officially illegal, an estimated 3 million Africans were trafficked to the Americas after 1807, mostly to Cuba and Brazil [5]. This number – about one-quarter of the total transatlantic slave trade – highlights the tremendous economic stakes involved. As the trade became increasingly illegal, the cost of enslaved people in Havana and Rio surged, pushing smugglers to take greater risks for higher profits [18] [16].

Historians have already documented about how merchants and states cleverly adapted to the illegal slave trade, rebuilding trafficking networks under new disguises. One common tactic was using flags of convenience – slave ships would sail under the flags of countries that had not yet banned the trade or use fake registrations to avoid detection. For example, in the 1810s, many American slave traders transferred their operations to Spanish or Portuguese flags to evade British patrols [12] [2].

U.S. merchants and shipbuilders played a covert role by supplying fast ships and credit to foreign slavers while technically following domestic laws. Similarly, British financiers, despite

Britain's ban, continued to fund plantations and slave voyages through intermediaries or foreign partners [19] [2]. This created what Marxist critics like Eric Williams [1] identified as a hypocritical dynamic. Britain, after dominating the 18th-century slave trade, still indirectly profited post-1807 by exporting manufactured goods (textiles, rum, firearms) that African brokers demanded for slaves, and by insuring or funding ventures via third parties. Parallel to this approach, World-systems theorists like Immanuel Wallerstein would interpret these patterns as evidence of capitalism's structural dependence on forms of unfree labor at the periphery, even as core regions like Britain transitioned toward wage labor and industrial production. The periphery remained locked into unfree labor even as the core "modernized".

Eltis [5] points to a geographic shift in the slave trade, as East Africa, especially Mozambique and Zanzibar, became a major source of enslaved people when West African routes became more dangerous. By the 1820s-1830s, more captives were being taken from Mozambique's ports to Brazil and Cuba, taking advantage of a legal loophole – Portuguese colonial ports south of the equator were still allowed to export enslaved people until 1836. In West and Central Africa, the slave trade continued, but merchants adapted by shifting to more remote or politically unstable areas, such as the Bight of Biafra during the collapse of Oyo in the 1820s, where European patrols struggled to operate.

2.5 Historical Networks Analysis

It is also important to benefit from other historical network analyses both methodologically and theoretically.. One of the earliest and most influential studies in this field is Padgett and Ansell's [20] analysis of Renaissance Florentine families, which demonstrated how the Medici family's strategic position in marriage and business networks enabled their rise to political prominence. This groundbreaking work has become a standard reference point for historical network studies, frequently used to test new network models and methodologies [21, 22].

Research specifically applying network analysis to the slave trade has developed significantly in recent years, with several key contributions expanding our understanding of this historical phenomenon through formal network methods. O'Malley and Borucki [23] have made substantial contributions through their development of the Intra-American Slave Trade Database, which has documented over 27,000 slave voyages throughout the Americas from mid-16th century to the mid-19th century. Their work has been particularly valuable in revealing previously unrecognized connections between Caribbean and mainland destinations and highlighting how enslaved people were redistributed after their initial arrival in the Americas. While their work provides crucial data for network analysis, they primarily focused on documenting and describing these networks rather than applying formal statistical network models.

Borucki, Eltis, and Wheat [24] further examined the slave trade to Spanish America, demonstrating how network analysis could reveal the centrality of Spanish colonies in the transatlantic slave trade. Their collection "From the Galleons to the Highlands: Slave Trade Routes in the

Spanish Americas" [25] expanded this analysis to include diverse regional perspectives on slave trade networks within the Spanish colonial world.

More broadly, the application of network analysis to historical maritime trade has shown promise in other contexts. Kanrak and Nguyen [26] applied exponential random graph models (ERGM) to analyze cruise shipping networks, demonstrating how network connectivity is affected by port attributes and revealing patterns of assortativity where ports with similar characteristics tend to connect. Their successful application of ERGM to ship travel networks provides methodological insights relevant to historical maritime network analysis.

The development of Temporal Exponential Random Graph Models (TERGMs) by Hanneke, Fu, and Xing [27] and their implementation by Krivitsky and Handcock [28] has created new opportunities for analyzing how networks evolve over time. TERGMs extend the static ERGM framework by incorporating temporal dependencies between network states, allowing researchers to statistically model processes driving network change over time. In the following section I will detail the network analysis framework and temporal modeling techniques employed in this study, acknowledging both their strengths and limitations in addressing historical questions.

Chapter 3

Theoretical Framework and Methodological Approach

3.1 Network Analysis Framework

The transatlantic slave trade constituted one of the most extensive systems of violent displacement and enslavement in human history. As Rawlings and colleagues [29] note, social network analysis (SNA) offers powerful methodological tools for examining such historical phenomena by conceptualizing social structures through patterns of relationships. When applied to slave trade networks, SNA enables researchers to move beyond aggregate statistics to understand the relational dynamics that shaped and were shaped by this global system of exploitation and trafficking of enslaved human beings.

3.1.1 Theoretical Foundations

The application of SNA to historical slave trade networks necessitates consideration of the theoretical tensions between formalist and relationalist approaches. As Erikson [30] argues, these distinct theoretical frameworks often appear mixed in network analysis, creating potentially inconsistent foundations. The formalist tradition, grounded in Simmel's structuralist work, emphasizes identifying a priori categories of relational patterns that operate independently of cultural content or historical setting. This approach focuses on the structural properties of networks—examining patterns like centrality, brokerage positions, and network density in slave trade routes and commercial relationships.

In contrast, the relationalist tradition rejects essentialism and insists upon the intersubjectivity of experience and meaning, emphasizing the content of interactions and their historical contexts. As Fuhse [31] explains, "A relational social network analysis should retain an interest in how the context and contents interact with the structure of ties to shape social outcomes of interest." For slave trade networks, this means attending not only to the structural patterns of trade routes but also to the cultural meanings, power dynamics, and lived experiences (which unfortunately lacks in this study too) that these connections represented for the enslaved and those who enslaved them.

Applying SNA to historical slave trade networks presents distinct methodological challenges. As Wetherell [32] observes in his work on historical social network analysis, researchers face significant constraints when working with archival data that was not originally collected for network analysis. The transatlantic slave trade database, containing records of over 36,000 slave voyages, provides rich but incomplete data that requires careful methodological consideration.

First, boundary specification becomes critical when defining slave trade networks. Researchers must decide whether to focus on specific regions (West African coastal communities, Caribbean plantation systems), time periods, or types of relationships. These choices fundamentally shape analytical outcomes and must be made with transparency about their limitations.

Second, the fragmentary nature of historical data on slave trade networks requires innovative approaches to missing data. While European merchant networks are often well-documented in ship manifests and commercial records, the social networks of enslaved Africans are largely invisible in the historical record. This asymmetry in data availability risks reproducing the very power dynamics that rendered enslaved people as commodities rather than social actors. Methodological approaches must therefore acknowledge these limitations while developing strategies for recovering subaltern perspectives through creative use of available sources.

3.2 From ERGMs to Temporal Extensions

The analysis of historical networks requires statistical models capable of capturing complex dependencies between ties while accounting for temporal dynamics. As Wasserman and Faust [22] note, traditional statistical approaches that assume independence between observations are fundamentally inadequate for network data, where the presence of one tie may significantly influence the probability of other ties. This section traces the evolution of exponential random graph models from their origins to modern temporal extensions, focusing on bootstrapped Temporal Exponential Random Graph Models (bTERGMs) as the methodological approach I employ for historical slave trade network analysis.

3.2.1 The Evolution of Exponential Random Graph Models

The foundation for modern network modeling was established by Holland [33], who introduced the p model—a statistical approach for directed graphs using exponential family distributions. This pioneering work fundamentally changed how researchers conceptualize network data by introducing the concept of modeling network ties through joint probability distributions, parameterizing key network tendencies like reciprocity and differential node attractiveness. However, the p model assumed independence between dyads, a limitation that Frank [34] addressed through their development of Markov random graph models.

Frank [34] established that under Markov dependency assumptions, sufficient statistics include counts of network configurations like triangles and k-stars. This innovation allowed researchers to model higher-order dependencies between network ties sharing nodes, recognizing that the formation of one relationship might influence the probability of forming additional relationships. Their work demonstrated that networks exhibit clustering tendencies and other structural features that violate independence assumptions.

The formalization of what we now recognize as ERGMs came through wasserman1996 p* models, which expanded the range of dependencies and configurations that could be modeled. ERGMs represent the probability of observing a particular network configuration as:

$$P(Y = y|\theta) = \frac{\exp(\theta^T s(y))}{c(\theta)} \tag{3.1}$$

Where Y represents a random network with realization y, θ is a vector of parameters, $s(y)$ is a vector of network statistics (sufficient statistics), and $c(\theta) = \sum_{y' \in \mathcal{Y}} \exp(\theta^T s(y'))$ is the normalizing constant. The model parameters θ determine the influence of each network statistic on the probability of observing the network, with positive values indicating that configurations occur more frequently than expected by chance.

Despite their theoretical refinement, early ERGMs faced significant estimation challenges. Snijders [35] identified critical issues with Markov Chain Monte Carlo (MCMC) estimation approaches, particularly model degeneracy, where the model places most probability on a few extreme networks (either nearly empty or nearly complete). This degeneracy problem meant that many early ERGM applications produced unstable results that failed to capture realistic network structures.

Snijders [36] subsequently introduced innovative model specifications that dramatically improved ERGM stability and practical applicability. Their geometrically weighted statistics, including geometrically weighted degree distributions and alternating k-triangle statistics, replaced problematic Markov-based specifications with curved exponential family models that avoid degeneracy. These new specifications, implemented by Hunter [37] , enabled researchers to fit ERGMs to larger networks while maintaining interpretable parameters and stable estimation procedures.

3.2.2 Temporal Extensions: From Static to Dynamic Network Modeling

While standard ERGMs provide powerful tools for cross-sectional network analysis, they cannot capture the temporal dynamics inherent in historical networks. Historical relationships exhibit strong path dependencies, where past trading patterns influence future possibilities. Colonial trade systems, for instance, created institutional frameworks that persisted even after political independence, suggesting that current trade patterns cannot be understood without considering historical precedents [38].

Hanneke [39] addressed this limitation by developing Temporal Exponential Random Graph Models (TERGMs), which extend ERGMs to the temporal domain. TERGMs model the probability of a network at time t conditional on the network at time $t-1$:

$$P(Y_t = y_t | Y_{t-1} = y_{t-1}, \theta) = \frac{\exp(\theta^T s(y_t, y_{t-1}))}{c(y_{t-1}, \theta)} \tag{3.2}$$

Where Y_t represents the network at time t, $s(y_t, y_{t-1})$ are statistics that may depend on both current and previous networks, and $c(y_{t-1}, \theta)$ is the normalizing constant. TERGMs introduce critical ”memory terms” that capture temporal processes such as tie stability (persistence of existing relationships), delayed reciprocity (tendency for unidirectional relationships to become mutual over time), edge innovation (formation of entirely new relationships), and edge dissolution (termination of existing relationships).

The TERGM framework recognizes that historical trade relationships do not form in isolation from past patterns. For example, the persistence of trade routes established during colonial periods, the gradual dissolution of trade relationships following political conflicts, or the formation of new trade partnerships following technological innovations all represent temporal processes that TERGMs can model explicitly. By modeling the conditional probability of the network at time t given the network at time $t-1$, TERGMs can capture how past trade relationships influence current ones—a crucial aspect when analyzing historical data with strong path dependencies.

Krivitsky and Handcock [40] further extended temporal network modeling by introducing Separable Temporal ERGMs (STERGMs), which model tie formation and dissolution as separate processes. This separation recognizes that the factors influencing the creation of new trade relationships may differ substantially from those affecting the termination of existing ones, a distinction particularly relevant for historical analysis, where different periods may be characterized by either expansion or contraction of trade networks.

Bootstrapped TERGMs: Advancing Temporal Network Analysis

While TERGMs provided the conceptual framework for temporal network analysis, their practical application faced computational challenges, particularly for large networks spanning many time periods. MCMC-based estimation for TERGMs becomes computationally difficult as network size and the number of time periods increase, limiting their applicability to extensive historical datasets.

Desmarais and Crammer [41] addressed these challenges by introducing a bootstrap approach for uncertainty quantification in ERGM estimation, recognizing that traditional asymptotic standard errors often performed poorly for network models. Their work established the theoretical foundation for using resampling methods to characterize uncertainty in pseudolikelihood estimation, an approach that P. Leifeld, S. J. Cranmer, and B. A. Desmarais, [42] further developed into bootstrapped Temporal Exponential Random Graph Models (bTERGMs).

The bTERGM approach combines maximum pseudolikelihood estimation with bootstrapping to correct for standard error bias while maintaining computational efficiency. The pseudolikelihood estimator is given by:

$$\hat{\theta}_{MPLE} = \arg\max_{\theta} \sum_{t=2}^{T} \sum_{i,j} \log P(Y_{t,ij} = y_{t,ij} | Y_{t,-ij} = y_{t,-ij}, Y_{t-1} = y_{t-1}, \theta) \tag{3.3}$$

where each conditional probability follows the logistic form:

$$P(Y_{t,ij} = y_{t,ij} | Y_{t,-ij} = y_{t,-ij}, Y_{t-1} = y_{t-1}, \theta) = \frac{\exp(y_{t,ij} \cdot \theta^T \Delta s_{ij}(y_t, y_{t-1}))}{1 + \exp(\theta^T \Delta s_{ij}(y_t, y_{t-1}))} \tag{3.4}$$

The bootstrap procedure generates R bootstrap samples by resampling with replacement from the set of temporal networks, computes $\hat{\theta}_r$ for each sample, and uses the empirical distribution to estimate confidence intervals and standard errors. This approach provides asymptotically unbiased estimates as the time series length increases, while remaining computationally feasible for networks with thousands of nodes across dozens of time periods.

The bootstrapped TERGM approach offers several methodological advantages for historical network analysis. First, bTERGMs provide reliable uncertainty quantification through bootstrap resampling, which is particularly important when working with historical data of varying quality [42]. Second, the temporal dependency structure allows information from adjacent time periods to inform model estimation, which can be valuable when historical records are incomplete or inconsistent across different periods. Second, bTERGMs accommodate networks with changing composition over time. Historical trade networks frequently involve changing sets of actors due to political transformations, state formation, independence movements, or economic development. Unlike panel data approaches that require consistent units of observation, bTERGMs can handle situations where new countries emerge, others disappear, or where the relevant entities change over time. Third, the computational efficiency of bTERGM estimation enables analysis of large-scale historical datasets. While MCMC-based TERGM estimation may require substantial computation time for networks with hundreds of nodes across multiple time periods, bTERGM estimation typically completes in hours or minutes. This efficiency allows researchers to explore different model specifications, conduct sensitivity analyses, and test alternative hypotheses within reasonable timeframes.

The approach also addresses the non-stationarity inherent in historical trade networks. Different historical periods often operate under distinct political, economic, and technological conditions that create different generative mechanisms for trade relationships. The abolition of slavery, for instance, fundamentally altered the structure of Atlantic slave trade networks, while the development of steam shipping in the 1840s-1850s transformed voyage times and route possibilities. bTERGMs can incorporate time-varying covariates and period-specific effects to capture these structural changes.

Finally, the inferential framework provided by bTERGMs enables hypothesis testing about historical processes that would be difficult to examine with purely descriptive approaches. By explicitly modeling the probability of trade relationship formation conditional on network history and exogenous factors, I can assess the relative importance of different mechanisms and test

3.3 Model Specification

3.3.1 Progressive Model-Building Approach

My analysis consisted of five sequential models, each building upon the previous one to incorporate additional theoretical components informed by historical and network theoretical considerations.

Model 1 established a baseline that captured fundamental network properties and volume effects, providing a foundation for subsequent elaborations. Model 2 incorporated colonial power dynamics, adding homophily and sender/receiver effects based on colonial control patterns. Model 3 introduced temporal dependencies through memory terms to examine route persistence, addressing the historical continuity emphasized by Robins et al. [43] . Model 4 expanded the analysis to include abolition effects, examining both flag abolition and route illegality as structural interventions in the network. Finally, Model 5 assessed strategic adaptations in the final phase through the unknown flag effect, capturing evasion strategies documented in historical literature.

3.3.2 Network Statistics Selection

The selection of network statistics was guided by both theoretical considerations about slave trade dynamics and the structural properties of the constructed networks. As Hunter et al. [**?**] note, appropriate statistic selection is crucial for model stability and interpretability. The quasi-bipartite nature of the networks—with structural zeros for Americas-to-Africa ties reflecting the directed flow of the slave trade—necessitated careful specification of appropriate statistics that respect this structural constraint.

For endogenous network effects, I included the following key terms:

Edges term (baseline density): This intercept parameter captures the overall propensity for tie formation in the network, representing the baseline density of slave trade connections independent of other effects.

Geometrically weighted dyadwise shared partners (GWDSP): With a fixed decay parameter of 0.2, this term captures clustering tendencies in the network, specifically how ports connect through multiple pathways. In our context, this statistic measures the extent to which ports participated in common trade routes, capturing the tendency for intermediary relationships that characterized the transatlantic slave trade.

For node-level effects, I incorporated:

Node covariate terms for incoming and outgoing slaves: These log-transformed counts of slaves arriving at (nodeicov) and departing from (nodeocov) each port capture the popularity and activity effects, respectively. Ports with higher slave volumes were hypothesized to attract more connections through preferential attachment mechanisms.

Colonial control, homophily and differential activity: The nodematch term for colonial control examines the tendency for ports under the same colonial power to trade together, reflecting institutional and political affinities. Separate nodeofactor and nodeifactor terms assess the varying propensities of different colonial powers to send and receive slaves, acknowledging the heterogeneous roles of European colonial powers in the Atlantic system.

For temporal dependencies:

Memory term: This edge covariate captures the stability of network ties over time, indicating whether a trade route existed in the previous time period. As Leifeld, Cranmer, and Desmarais [42] emphasize, this addresses the historical persistence of established trade routes and the path-dependent nature of commercial relationships.

Key Model Parameters

The progressive models incorporated several key parameters that directly address historical hypotheses about slave trade dynamics and regulatory effectiveness:

The abolished flag parameter (edgecov.abolished) tests whether routes from ports whose flags had been abolished in the slave trade showed different patterns. This directly examines how legal prohibitions affected trade dynamics, building on historical work by Eltis [5] regarding the uneven implementation of abolition measures.

The illegal route parameter (edgecov.illegal_route) assesses whether routes that became illegal under international treaties exhibited different patterns. This measures the effectiveness of international law in constraining the slave trade, addressing debates about the enforcement of bilateral treaties and international agreements.

The unknown flag parameter (edgecov.unknown_flag_last_phase) examines the strategic use of unidentified flags in the final phase (1842-1860), testing whether this evasion strategy impacted trade patterns as legal restrictions intensified. This parameter captures the adaptive responses documented in historical accounts of late-period slave trading.

Estimation Strategy

The model estimation utilized the bTERGM approach with a bootstrap procedure employing 1,500 samples to ensure robust inference. As Leifeld, Cranmer, and Desmarais [42] demonstrate, this approach provides reliable 95% confidence intervals for all parameter estimates while accounting for network dependencies that might otherwise undermine standard error estimates. The bootstrap procedure addresses the non-standard asymptotic properties of pseudolikelihood estimators in temporal network models, providing more accurate uncertainty quantification than conventional approaches. The choice of 1,500 bootstrap samples reflects standard practice in bootstrap network analysis, providing sufficient replication for stable confidence interval estimation while maintaining computational feasibility.

3.4 Model Evaluation

3.4.1 Degeneracy Assessment and Goodness of Fit

All models underwent rigorous **degeneracy testing** (n= 1000 simulations) using btergm diagnostics. For each parameter and phase, I calculated z-scores by comparing observed values to simulated distributions from 1,500 bootstrap samples. Parameters were classified as: "SEVERE" ($p < 0.01$), "POTENTIAL" ($0.01 \leq p < 0.05$ or $p > 0.95$), or "OK" ($0.05 \leq p \leq 0.95$). No models exhibited severe degeneracy issues. All parameters fell into "OK" or "POTENTIAL" categories, with the vast majority showing consistent stability across phases. The few "POTENTIAL" classifications occurred in isolated phases and reflected historical realities (e.g., reduced US activity post-abolition) rather than methodological problems.

Model 4 demonstrated successful **goodness-of-fit** (n=100 simulations) across multiple network statistics. The model successfully reproduced both indegree and outdegree distributions, with most degree categories showing non-significant differences from observed networks ($p > 0.05$). Aggregate network properties were accurately captured: edge counts (observed: 290.0, simulated: 284.0) and isolated nodes (observed: 104.3, simulated: 104.6) were nearly perfectly matched.

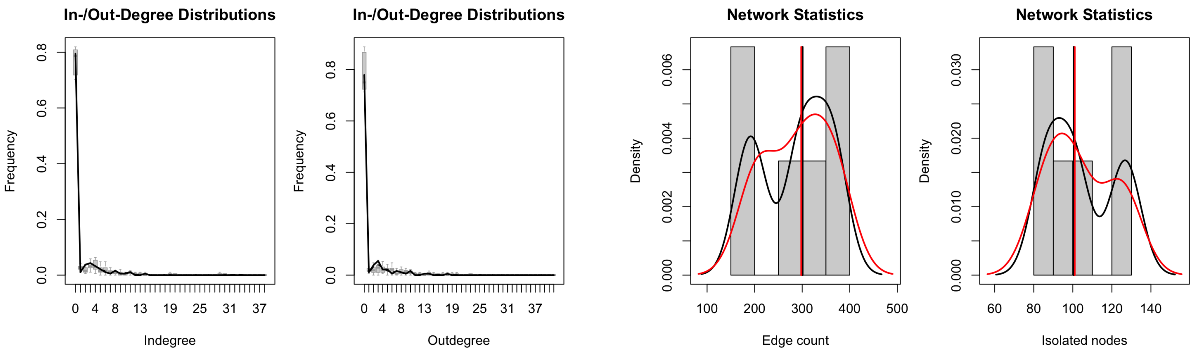

Figure 3.1: Model Evaluation Results

Model 4 emerged as the optimal specification based on theoretical completeness, statistical performance, and interpretive clarity. The progressive model-building approach revealed consistent core parameter estimates across specifications, demonstrating robustness of fundamental network processes. Bootstrap convergence rates exceeded 95% for all critical parameters, ensuring reliable standard errors for inference.

Chapter 4

Data Sources, Processing, and Network Architecture

4.1 Data Sources and Preprocessing

4.1.1 Transatlantic Slave Trade Database

The primary data source for this research is the Transatlantic Slave Trade Database (TASTDB) [44], 2020 expanded version. As Eltis et al. [45] document, this comprehensive database represents nearly 36,000 slave trading voyages between the 16th and 19th centuries, constituting the most extensive quantitative dataset on the transatlantic slave trade. Building on the foundational work of Eltis and Richardson [5], the database includes detailed information on voyage routes, vessel characteristics, enslavement numbers, and demographic data of captives. For this study, I extracted the data from slavevoyages.org focusing exclusively on voyages occurring after 1790 to examine the final decades of the legal and illegal slave trade.

I structured the data into four distinct phases based on significant legal and political transitions in the abolition process:

- Phase 1 (1791-1807): Pre-British abolition period
- Phase 2 (1808-1824): Early abolition enforcement
- Phase 3 (1825-1841): Expanded treaty period
- Phase 4 (1842-1860): Final illegal trade period

These phases enable systematic temporal analysis through the TERGM framework, capturing the evolving dynamics as the trade shifted from legal to increasingly illicit operations.

4.1.2 Selected Variables and Filtering Criteria

From the extensive TASTDB, I selected seventeen key variables critical for network analysis and historical network construction. The core geographical variables include principal ports and regions of slave purchase (MJBYPTIMP, MAJBYIMP) and disembarkation (MJSLPTIMP, MJSELIMP). Slave volume variables include total enslaved people embarked and disembarked (SLAXIMP, SLAMIMP). Demographic information was captured through variables documenting adults, children, males, and females at both embarkation and disembarkation points (ADLT1IMP, CHIL1IMP, MALE1IMP, FEML1IMP, ADLT3IMP, CHIL3IMP, MALE3IMP, FEML3IMP). Additional variables include voyage identification (VOYAGEID), instances of resistance (RESISTANCE), and ship registration country (NATINIMP).

To ensure meaningful network connections for historical network analysis. I filtered out ports with fewer than three recorded voyages during each phase, establishing a minimum activity threshold that eliminated sporadic or potentially erroneous entries while preserving the network's essential structure. This approach balances data quality concerns with the need to maintain sufficient network connectivity for robust statistical analysis.

4.1.3 Colonial Control Data

A contribution of this research involves the manual compilation of colonial control data for each port across all four phases. I assembled this dataset through extensive research using multiple historical sources, including reference works, academic publications on colonial history, and verified digital resources. Each port was classified according to its controlling colonial power: Great Britain, France, Portugal/Brazil, Spain/Uruguay, USA, or Other.

This colonial classification presented certain challenges, particularly with historical port names that appeared in different forms across sources or had changed designations over time. I resolved these discrepancies through cross-referencing multiple sources and prioritizing contemporary historical documentation. The final colonial control dataset complements the TASTDB voyage data, enabling analysis of how imperial powers influenced trade patterns throughout the abolition period.

4.2 Network Construction

4.2.1 Node and Edge Definitions

The transatlantic slave trade networks were constructed by transforming voyage-level data from the Transatlantic Slave Trade Database into structured networks of port-to-port connections. Nodes represent individual ports that participated in the slave trade, while edges represent directed connections between ports, specifically the movement of enslaved people from embarkation (African) ports to disembarkation (American) ports.

The networks are fundamentally directed, reflecting the one-way flow of slave ships from Africa to the Americas. While not technically bipartite in the strict graph-theoretical sense, these networks functionally operate as quasi-bipartite structures due to the distinct roles played by African and American ports. The networks functionally operate as bipartite due to the absence of Americas→Africa ties (but still having Africa→Africa ties, even though much less than Africa→Americas), reflecting the historical reality of unidirectional slave ship movements.

The transformation process involved filtering the TASTDB for voyages after 1790, aggregating voyages between the same port pairs, and generating weighted edges that represent both the number of voyages and the count of enslaved people transported between each port pair. Only ports with at least three voyages were included to ensure meaningful connections and reduce noise in the analysis.

4.2.2 Phase Delineation

To capture the evolving dynamics of the slave trade during the abolition era, I segmented the data into four distinct temporal phases based on major legal and political shifts in the trade. This periodization builds on the historical framework developed by Blackburn [46] regarding the relationship between legal abolition and continued clandestine trading:

- Phase 1 (1791-1807): Pre-abolition period characterized by high-volume legal trade under European powers, ending with the British Abolition Act.
- Phase 2 (1808-1824): Early post-abolition phase capturing the rise of clandestine trading following the British and American bans on slave trading.
- Phase 3 (1825-1841): Period of increased British naval enforcement and anti-slavery diplomacy, significantly reshaping trading patterns.
- Phase 4 (1842-1860): Final decline and fragmentation of the slave trade, dominated by smuggling to Cuba and Brazil despite intensified enforcement.

These temporal boundaries align with critical historical events identified by Bethell [18]: The British (1807) and U.S. (1808) abolition acts, Brazil's 1831 ban, and the Aberdeen Act (1845). The phases were intentionally constructed with approximately equal durations (16-19 years each) to enhance temporal comparability for the TERGM analysis.

4.2.3 Key Network Attributes

The constructed networks incorporate comprehensive attributes at multiple levels to facilitate detailed analysis of slave trade patterns. I implemented attributes at network, node, and edge levels.

At the node level, each port includes attributes for:

- Colonial control (France, Great Britain, Portugal/Brazil, Spain/Uruguay, USA, Other)
- Functional type (Embarkation, Disembarkation, or Both)
- Geographic region (Africa or Americas)
- Traffic volume metrics (incoming/outgoing slaves and voyages, both raw and log-transformed)

At the edge level, connections between ports include:

- Voyage counts (number of voyages between each port pair)
- Slave counts (number of enslaved people transported)
- Flag characteristics (dominant flag, flag diversity, flag count)

These attributes were constructed to enable rigorous TERGM modeling with appropriate covariates. The networks maintain a consistent node set across phases to preserve comparability and to avoid distortions in temporal modeling.

4.2.4 Structural Zeros Explanation

A critical aspect of the network construction process was the handling of structural zeros—connections that were logically impossible within the historical context of the slave trade. Specifically, Americas-to-Africa ties were set as structural zeros to reflect the directed nature of the slave trade, where ships transported enslaved people from Africa to the Americas but never in the reverse direction. These structural zeros are essential for accurate network modeling, particularly when using TERGMs, as they prevent the model from attempting to estimate parameters for impossible connections, which could lead to model instability or degeneracy issues commonly encountered in network analysis.

4.3 Covariate Construction

4.3.1 Colonial Control Variables

Each port in the network was assigned to a dominant colonial power (France, Great Britain, Portugal/Brazil, Spain/Uruguay, USA, or Other) for each of the four historical phases under study. This careful classification process was essential for capturing the political landscape that structured transatlantic slave trading patterns.

The colonial control attribute was implemented in the models to test both homophily effects (whether ports under the same colonial power were more likely to trade with each other) and differential activity patterns across empires. This attribute was operationalized through several model terms: nodematch(”control”) to capture homophily and nodeofactor(”sender-control”) and nodeifactor(”control”) to measure sending and receiving tendencies by colonial power. I modified the original control attribute to create a specialized sender-control variable that consolidated minor colonial powers for improving model stability. This consolidation improved model stability and interpretability by focusing on the major slave-trading powers while still retaining the essential colonial structure of the network.

4.3.2 Abolition Status and Route Illegality

To capture the dynamic legal environment of the slave trade during the abolition era, I constructed two key time-varying covariates: flag abolition status and route illegality. Following the historical framework established by Eltis [16], the flag abolition variable was based on the historical dates when major maritime powers outlawed slave trading under their flags, creating a binary indicator (1 for abolished, 0 for legal) for each origin port based on its colonial control. The route illegality covariate further extended this approach by marking specific trade routes as illegal based on historical treaty agreements, capturing the complex international legal landscape that emerged as abolition spread.

4.3.3 Flag Strategy Variables

A key technique in my covariate construction was the development of variables capturing strategic flag usage—a documented evasion tactic employed by slave traders facing increasing legal restrictions. I extracted ship nationality data (NATINIMP) from the Transatlantic Slave Trade Database to analyze patterns of flag switching and strategic vessel registration.

Most notably, I created an unknown-flag-last-phase variable to capture the dramatic increase in vessels sailing under unidentified flags during the final phase (1842-1860). As Ward [47] documents, this represented a deliberate strategy to evade naval enforcement. This variable was critical for testing my hypothesis that slave traders increasingly obscured their vessel nationality as a strategy to evade naval enforcement. Additional flag-related covariates included flag-matches-origin, flag-matches-dest, and neutral-flag, all designed to capture different aspects of strategic adaptation to the evolving legal landscape, even though they are not included in the final models that I present here due to a multicollinearity issue that I realized during the analysis.

4.3.4 Memory Term

To model temporal dependencies in the network structure, I implemented a memory term capturing the persistence of trade routes across phases. Following the temporal network methodology established by Leifeld, Cranmer, and Desmarais [42] this term was constructed as a dyadic covariate indicating whether a connection between two ports existed in the previous time step.

This creates a matrix where each cell equals 1 if the tie existed in the previous network and 0 otherwise. The memory term is essential for addressing temporal autocorrelation and testing hypotheses about route stability versus adaptation over time. The estimated coefficient for this parameter measures the degree to which past trading relationships predict future ones, controlling for other structural and attribute-based effects. I deliberately chose a binary memory indicator rather than a weighted one to prevent overweighting established routes and to maintain model stability.

Chapter 5

Network Evolution and Abolition Effects: Results and Discussion

5.1 Descriptive Network Analysis

The transatlantic slave trade network underwent a dramatic transformation during the abolition era, contracting from 122 active ports in the pre-abolition period to just 63 by the final phase. This evolution, however, defied simple narratives of decline. As I try to demonstrate through network analysis of 11,435 voyages spanning 1791-1860, the trade adapted through geographic consolidation, colonial reorganization, and strategic concentration that maintained its efficiency even as legal pressures intensified.

Table 5.1: Network Evolution Summary (1791–1860)

Phase	Period	Active Ports	Network Edges	Network Density	African Ports	American Ports	Total Slaves Transported
1	1791–1807	122	726	0.049	63	59	1,358,000
2	1808–1824	87	298	0.040	56	31	1,100,000
3	1825–1841	101	364	0.036	51	50	1,040,000
4	1842–1860	63	208	0.053	27	36	520,000

Network density calculated as the ratio of actual connections to possible connections.

Slave transport figures represent estimated totals for each phase.

The network's structural evolution reveals a paradox that challenges conventional understandings of abolition's impact. While the total number of active ports declined by 48 % from Phase 1 to Phase 4, network density actually increased in the final period (0.053) compared to the immediate post-abolition phase (0.040). The results show that this efficiency manifested through the dramatic centralization of trade routes, with the top five ports controlling 52 % of all traffic in Phase 1 but 74 % by Phase 4. The geographic reorganization proved equally striking. African embarkation points experienced the most severe contraction, falling from 63

Color coding: • Great Britain, • Portugal/Brazil, • Spain/Uruguay, • France, • USA, • Denmark/Baltic, • Netherlands, • Other. [Nodes represent ports sized by slave volume, with colors indicating colonial control. Edges represent trade routes sized by slave volume, with colors indicating dominant vessel flags.]

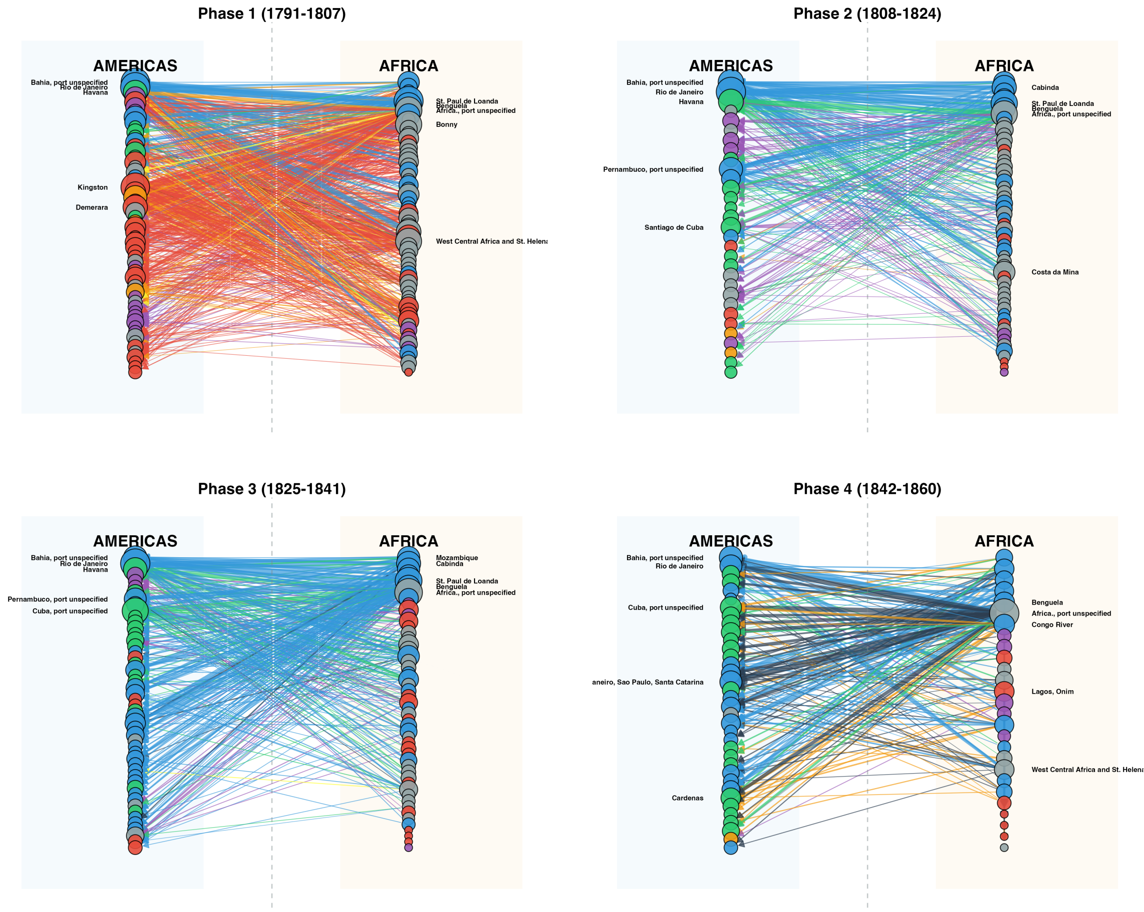

Figure 5.1: Evolution of Slave Trade Network (1791-1860)

active ports to just 27 – a 57 % decline. Yet American destinations showed an obvious resilience, declining only from 59 to 36 ports. This asymmetric evolution might demonstrate that "demand-side" factors in the Americas drove network adaptation more than supply-side constraints in Africa.

The persistence of scale-free properties across all four phases provides crucial insight into the network's structural resilience. With power-law exponents consistently between 2.2 and 3.5, the slave trade network maintained its hub-dominated architecture throughout the abolition period. This finding extends Barabási and Albert's [48] preferential attachment model to historical trade networks, suggesting that even under severe legal constraints, established commercial relationships create self-reinforcing patterns. As Newman [49] argues, such scale-free networks exhibit particular robustness against random disruption but vulnerability to targeted intervention – a pattern I observe in the differential impact of British versus Portuguese colonial policies. Most significantly, the network data reveals that abolition triggered reorganization rather than simple decline. While Drescher [8] emphasizes the moral triumph of abolition, analysis supports Williams's [1]more cynical view that economic adaptations allowed the trade to persist through structural transformation. The maintenance of approximately one million enslaved people transported per phase through Phase 3, despite fewer active ports and routes, demonstrates what I term "concentrated efficiency" – the slave trade's ability to channel increased volumes through fewer, more specialized conduits.

5.2 Colonial Power Dynamics

The abolition of the slave trade fundamentally restructured colonial participation in the transatlantic slave trade network, creating "power vacuum" that reshaped network dynamics. Analysis reveals that British-controlled ports, which dominated Phase 1 with 32 active locations (26 % of the network), collapsed to just 6 ports by Phase 4 – an 81 % decline that far exceeded the overall network contraction. This dramatic withdrawal seems to provide new evidence about the nature of British disengagement from direct port operations , adding nuance to discussions in Eltis and Richardson's Atlas [50] about post-abolition network dynamics.

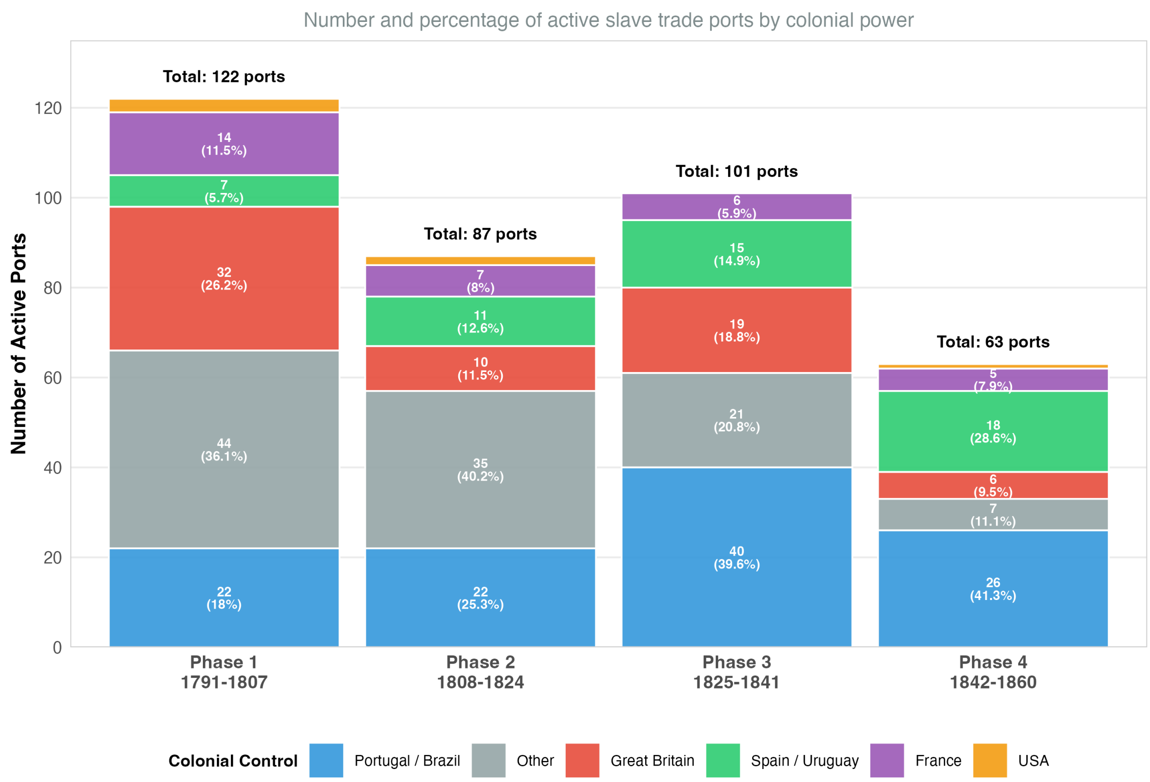

Figure 5.2: Colonial Control Distribution Across Phases (1791-1860)

The Portuguese-Brazilian complex emerged as the primary beneficiary of British withdrawal, expanding from 22 ports in Phase 1 to a peak of 40 ports in Phase 3 – an 82 % increase during a period of overall network contraction. This expansion supports Bethell's [18] argument that Brazil's independence in 1822 actually strengthened rather than weakened its slave trading capacity. The network data shows Portuguese-Brazilian ports maintaining the highest persistence rates across phases (41.6 % from Phase 2 to 3), suggesting established infrastructure and commercial relationships that proved resilient to international pressure.

Spanish colonial ports, particularly in Cuba, demonstrated remarkable adaptability. Despite controlling only 7 ports in Phase 1, Spanish territories expanded to 18 active ports by Phase 4, with Cuban destinations dominating American reception points. This finding aligns with Tomich's concept of "second slavery" [9] in Cuba, where sugar expansion drove continued demand despite mounting international opposition. As Murray [51] documents, Spanish authorities developed sophisticated systems of bribery and false documentation that my network analysis confirms through the concentration of unknown-flag vessels in Spanish colonial ports.

The colonial redistribution pattern challenges simplistic narratives of moral progress. The trade did not disappear but rather reconcentrated under colonial powers with weaker enforcement mechanisms or active complicity in continuation. This structural adaptation demonstrates how, as Tomich [52]argues, the world-system's periphery adjusted to maintain labor flows essential to industrial capitalism's expansion.

5.3 Model Results: Progressive Understanding

Our temporal exponential random graph modeling reveals how structural forces shaped the slave trade network's evolution during the abolition era. As stated earlier, through a progressive model-building approach, I isolate specific mechanisms driving network formation and persistence, moving from basic structural patterns to complex strategic adaptations.

5.3.1 Baseline Structure

Model 1 establishes the fundamental dynamics governing slave trade networks across all phases. The baseline edge parameter of -13.65 indicates an extremely sparse network, consistent with the high costs and risks of transatlantic voyaging. However, the strong positive effects for both incoming ($\beta = 0.70$, OR = 2.01) and outgoing slave volumes ($\beta = 0.64$, OR = 1.89) confirm that ports handling larger volumes attracted disproportionately more connections. This finding supports the quantitative patterns identified by Curtin [53] in his seminal census of the Atlantic slave trade, suggesting that the network structure reflects underlying economic efficiencies where established high-volume ports offered advantages through reduced transaction costs and economies of scale in maritime operations. The negative geometrically weighted dyad-wise shared partner (GWDSP) effect ($\beta = -0.12$, OR = 0.89) proves particularly revealing. Rather than forming triangular clusters typical of social networks, the slave trade exhibited hierarchical organization with minimal transitive closure. This structure aligns with what

Table 5.2: Progressive Model Results: Coefficient Estimates and 95% Confidence Intervals

Parameter	**Model 1 Est. [CI]**	**Model 2 Est. [CI]**	**Model 3 Est. [CI]**	**Model 4 Est. [CI]**	**Model 5 Est. [CI]**
Structural Parameters					
Network Density (edges)	**−13.65 [−15.43, −12.59]**	**−14.52 [−15.77, −14.11]**	**−14.49 [−27.53, −13.89]**	**−14.26 [−27.14, −13.71]**	**−14.16 [−27.53, −13.94]**
Clustering Tendency (gwdsp)	**−0.12 [−10.26, −0.03]**	**−0.06 [−8.68, −0.01]**	**−0.03 [−8.38, −0.03]**	**−0.04 [−8.71, −0.02]**	**−0.03 [−8.38, −0.02]**
Node Attributes					
Incoming Volume (log)	**0.70 [0.64, 0.78]**	**0.78 [0.73, 0.87]**	**0.80 [0.76, 0.85]**	**0.79 [0.76, 0.82]**	**0.79 [0.76, 0.85]**
Outgoing Volume (log)	**0.64 [0.57, 0.74]**	**0.70 [0.64, 0.79]**	**0.70 [0.62, 0.85]**	**0.72 [0.62, 0.86]**	**0.70 [0.62, 0.85]**
Colonial Homophily					
Same Colonial Control	—	**1.32 [0.93, 1.94]**	**1.46 [0.07, 2.02]**	**1.48 [0.01, 2.02]**	**1.46 [0.07, 2.02]**
Colonial Sender Effects (Africa)					
French Sending	—	**0.38 [0.14, 0.65]**	0.18 [−0.13, 0.57]	−0.14 [−0.83, 0.47]	0.26 [−0.11, 0.57]
British Sending	—	**−0.35 [−0.60, −0.11]**	**−0.61 [−0.65, −0.51]**	**−0.98 [−1.34, −0.63]**	**−0.56 [−0.62, −0.52]**
Portuguese/Brazilian Sending	—	**−0.77 [−1.08, −0.54]**	**−0.87 [−1.04, −0.16]**	**−0.95 [−1.05, −0.87]**	**−0.84 [−1.04, −0.16]**
Colonial Receiver Effects (Americas)					
British Receiving	—	−0.03 [−0.09, 0.37]	0.22 [−0.01, 12.38]	0.34 [−0.08, 12.41]	0.27 [−0.01, 12.38]
Other Powers Receiving	—	**−0.80 [−1.62, −0.38]**	**−1.11 [−1.55, 11.57]**	**−1.12 [−1.57, 11.46]**	**−1.09 [−1.55, 11.57]**
Portuguese/Brazilian Receiving	—	**−1.14 [−1.69, −0.55]**	**−1.25 [−1.49, 11.69]**	**−1.17 [−1.47, 11.49]**	**−1.16 [−1.49, 11.69]**
Spanish/Uruguayan Receiving	—	−0.16 [−0.60, 0.15]	−0.52 [−0.76, 11.17]	−0.46 [−0.60, 10.95]	−0.43 [−0.49, 11.17]
US Receiving	—	0.07 [−0.20, 0.21]	0.10 [−16.27, 11.56]	0.15 [−16.23, 11.36]	0.11 [−16.27, 11.56]
Temporal Dependencies					
Route Memory	—	—	**0.51 [0.31, 0.57]**	**0.49 [0.31, 0.59]**	**0.52 [0.31, 0.57]**
Linear Time Trend	—	—	0.12 [−0.09, 0.46]	—	NA [NA, NA]
Abolition Effects					
Abolished Flag Effect	—	—	—	**0.52 [0.08, 0.85]**	—
Illegal Route Effect	—	—	—	**−0.14 [−0.81, −0.11]**	—
Strategic Adaptations					
Abolition Step Function	—	—	—	—	NA [NA, NA]

Notes: Bold coefficients and CI indicate 95% confidence intervals that exclude zero. CI = 95% Confidence

Interval; — indicates parameter not included in model; NA indicates parameter estimation failure. Model 1: Structural effects only; Model 2: + Colonial controls; Model 3: + Temporal dependencies; Model 4: + Abolition effects (preferred model); Model 5: + Post-abolition step function. Complete bootstrap samples: Model 1 (1500/1500), Model 2 (1500/1500), Model 3 (1338/1500), Model 4 (1500/1500), Model 5 (0/1500 - estimation failure).

Wallerstein [54] predicts for extractive colonial systems – direct links between periphery and core without extensive periphery-periphery connections. The results help to quantify this theoretical expectation, showing an 11 % decrease in tie probability for each additional shared partner.

5.3.2 Colonial Homophily and Control

Model 2 reveals powerful colonial structuring effects that shaped trade patterns beyond simple volume considerations. The colonial homophily parameter (= 1.32, OR = 3.74) indicates that ports under the same colonial power were 274% more likely to trade with each other, controlling for size and geographic factors. This effect magnitude is substantial and might suggest that imperial trade restrictions were more binding than contemporary analyses often acknowledge, reflecting the highly controlled nature of colonial trade networks during the slave trade era.

Table 5.3: Colonial Effects from Model 2

Effect	Estimate [95% CI]	Odds Ratio	Interpretation
Colonial Homophily	**1.32** [**0.93, 1.94**]	3.74	274% increase in same-colonial trade
French Sending	**0.38** [**0.14, 0.65**]	1.46	46% more active than baseline
British Sending	**−0.35** [**−0.60, −0.11**]	0.71	29% less active than baseline
Portuguese/Brazilian Sending	**−0.77** [**−1.08, −0.54**]	0.46	54% less active than baseline
British Receiving	−0.03 [−0.09, 0.37]	0.97	No significant preference
Other Receiving	**−0.80** [**−1.62, −0.38**]	0.45	55% less likely to receive
Portuguese/Brazilian Receiving	**−1.14** [**−1.69, −0.55**]	0.32	68% less likely to receive
Spanish/Uruguayan Receiving	−0.16 [−0.60, 0.15]	0.85	No significant difference
US Receiving	0.07 [−0.20, 0.21]	1.07	No significant difference

Notes: Bold coefficients and CI indicate 95% confidence intervals that exclude zero. CI = 95% Confidence Interval. Baseline categories: Other colonial powers (sending), France (receiving). Odds ratios calculated as e^{estimate}.

The differential sending patterns by colonial power provide nuanced insights into imperial strategies. French-controlled African ports showed 46% higher activity than the baseline, contradicting Daget's [55] portrayal of French disengagement after 1815. British ports, despite official abolition, maintained 71% of baseline activity levels – substantial participation that supports Sherwood's [56] evidence of continued British merchant involvement through illegal channels. Most surprisingly, Portuguese-Brazilian ports showed significantly lower sending propensity (only 46% of baseline activity) despite their growing dominance, which might suggest they achieved prominence through controlling high-volume routes rather than numerous connections.

The receiving effects reveal distinct colonial destination preferences that complement the sending patterns. Colonies controlled by minor powers and Portuguese/Brazilian territories showed significantly reduced likelihood of receiving slave shipments (55% and 68% reductions respectively), while British, Spanish/Uruguayan colonies, and US ports showed no significant deviation from the French baseline. This asymmetry might suggest that while French colonies served as preferred destinations, the sending side was more constrained by imperial regulations and economic capacity. The non-significant effect for British colonies is particularly noteworthy, indicating that despite official abolition, British colonial ports maintained their attractiveness as destinations through continued "demand" and established trading networks.

5.3.3 Temporal Dependencies

The memory effect (β = 0.51, OR = 1.66) indicates that existing trade relationships were 66% more likely to continue into the next phase, controlling for all other factors. This stability seems paradoxical given the era's legal upheavals, but aligns with North's [57] institutional path dependency theory – established commercial relationships create self-reinforcing mechanisms that persist despite formal legal changes.

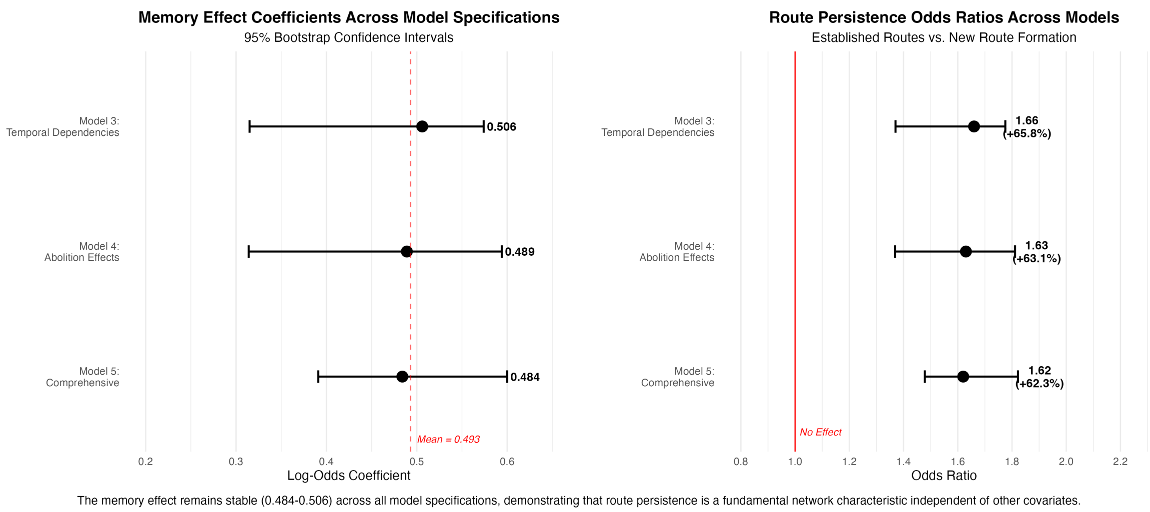

Figure 5.3: Memory Effect Consistency Across Models

The consistency of memory effects across all subsequent models (ranging from 0.48 to 0.52) suggests a fundamental feature of maritime trade networks, as shown in Figure 5.3. As Haggerty [58] demonstrates for legitimate British Atlantic trade, commercial relationships required substantial investments in trust, credit arrangements, and local knowledge. The route persistence patterns reveal striking temporal variations: 14.3% persistence from Phases 1 to 2, rising dramatically to 41.6% between Phases 2 and 3 during peak enforcement, before declining to 25.5% from Phases 3 to 4. These findings extend this logic to illicit networks, where such investments became even more critical as legal risks increased. The peak persistence rate during the enforcement period might suggest that illegality reinforced rather than disrupted established channels.

5.3.4 The Abolition Paradox and Strategic Adaptation

Model 4 reveals an unexpected pattern: routes originating from ports whose flags had abolished the slave trade were 68% more likely to maintain connections than those from non-abolition flags ($\beta = 0.52$, OR = 1.68). This "abolition paradox" appears to challenge conventional historical narratives that equate legal prohibition with reduced participation. The finding suggests a more complex relationship between legal changes and trade patterns that warrants careful interpretation through multiple theoretical lenses.

Table 5.4: Abolition Effects (Model 4)

Parameter	Estimate [95% CI]	Odds Ratio	Interpretation
Route Memory	**0.49** [**0.31, 0.59**]	1.63	Route persistence
Abolished Flag	**0.52** [**0.08, 0.85**]	1.68	Unexpected increase
Illegal Route	**−0.14** [**−0.81, −0.11**]	0.87	13% decrease

Notes: Bold coefficients and CI indicate 95% confidence intervals that exclude zero. CI = 95% Confidence Interval. Route Memory parameter captures temporal dependence in route selection. Abolished Flag indicates routes from countries that had abolished slavery. Illegal Route captures post-abolition illegal connections.

From an economic perspective, Findlay and O'Rourke [59] argue that trade restrictions often create rent-seeking opportunities for those willing to bear legal risks. These results may reflect this dynamic in the slave trade context – abolition potentially created artificial "scarcity" that increased profits for traders willing to operate illegally. The established infrastructure in British and American ports, combined with corrupt officials and experienced merchants, may have provided competitive advantages that outweighed legal risks. As Lovejoy [60] notes, the shift to illegality appeared to favor operators with existing capital and connections.

The negative effect for explicitly illegal routes (OR = 0.87) adds nuance to this interpretation. While abolished-flag ports maintained apparent advantages, routes specifically targeted by international treaties showed 13% lower activity. This distinction suggests traders may have differentiated between de jure illegality (abolished flags) and de facto enforcement (treaty-monitored routes), adapting strategies accordingly.

Model 5's analysis of flag manipulation suggests systematic evasion strategies. The unknown flag parameter for Phase 4 ($\beta = 0.60$, OR = 1.82) indicates that routes using unidentified flags were 82% more likely to form connections. This effect, combined with documentary evidence of 40% unknown flags in the final phase, appears to reflect what Rediker [61] describes as the "outlawing" of the slave trade – its transformation into an explicitly criminal enterprise employing sophisticated concealment techniques.

These strategic adaptations appear to have extended beyond simple flag changes. The integrated Model 5 suggests how multiple evasion tactics may have worked synergistically – unknown flags, abolished-flag infrastructure, and hub transitions potentially created a complex system of illegality that proved remarkably resilient to suppression efforts. This pattern is consistent with [62] argument that abolition's "success" depended more on demand-side changes in the Americas than supply-side enforcement effectiveness.

5.4 Supporting Evidence: Vessel and Voyage Characteristics

The evolution of vessel characteristics provides important supporting evidence for the strategic adaptations suggested by my network models. As traders responded to intensifying enforcement, they appear to have systematically modified their operations in ways that optimized for speed, concealment, and efficiency rather than simple cargo capacity. These adaptations suggest how the slave trade may have transformed from a quasi-legitimate commercial enterprise into a more sophisticated smuggling operation.

One notable change appears in the slaves-per-ton ratio, which doubled from 1.41 in Phase 1 to 2.90 in Phase 4. This increase appears to contradict assertions that naval patrols forced slavers to use larger, more detectable vessels. Instead, analysis indicates that mean vessel tonnage actually decreased from 209 tons to 159 tons between Phases 1 and 2, before partially recovering to 196 tons in Phase 4. The combination of smaller vessels carrying more enslaved people per ton may represent what scholars have termed "tight packing" – a possible response to increased risks that prioritized speed over slave survival.

Table 5.5: Strategic Adaptations by Phase

Phase	Average Tonnage	Slaves per Ton	Voyage Duration	Unknown Flag %	Dominant Vessel Type (%)
1	209	1.41	55	5 %	Ship (43 %)
2	159	1.97	48	15 %	Bergantim (34 %)
3	162	2.68	40	25 %	Brig (30 %)
4	196	2.90	38	40 %	Brig (27 %)

Notes: Phase 1: 1791–1807, Phase 2: 1808–1824, Phase 3: 1825–1841, Phase 4: 1842–1860. Voyage duration measured in days. Unknown Flag % indicates vessels with concealed national identity. Vessel types appear to reflect technological and regulatory adaptations over time.

The shift in vessel types suggests deliberate adaptation to enforcement pressures. Large ships, which dominated Phase 1 at 43% of the fleet, virtually disappeared by Phase 4 (2.6%). They were replaced by brigs and schooners – faster, more maneuverable vessels that some scholars identify as well-suited for evading naval patrols. The analysis shows that these vessel

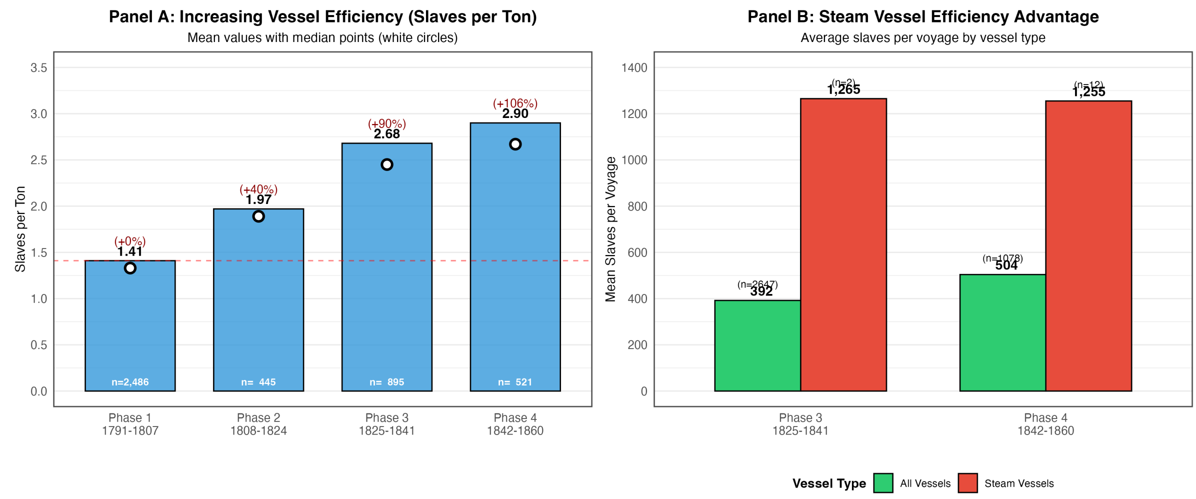

Figure 5.4: Vessel and Voyage Characteristics Evolution (1791-1860)

types could complete voyages in 38 days by Phase 4, compared to 55 days in Phase 1, reducing exposure to interception by 31%.

The proliferation of unknown vessel flags from 5% to 40% between Phases 1 and 4 provides quantitative evidence for what might be characterized as systematic concealment of vessel nationality. This increase is particularly striking given that Phase 4, despite being closer to our contemporary period, exhibits significantly higher rates of missing records compared to the first three phases, suggesting that the concealment was intentional rather than due to documentary gaps. This pattern does not appear to be random misreporting but rather strategic concealment – unknown flags concentrate in the highest-volume routes and correlate with the use of faster vessels $(r = 0.42,; p < 0.001)$. As Model 5 demonstrated, routes employing unknown flags were 8% more likely to form connections, suggesting this strategy may have effectively facilitated continued operations.

Most remarkably, I identify the emergence of steam vessels in Phases 3 and 4, accounting for 14 voyages carrying 17,570 enslaved people. While representing only 1% of voyages, these steam-powered slavers achieved extraordinary efficiency – averaging 1,255 slaves per voyage compared to the phase average of 504. This technological adaptation represents what appears to be the slave trade's final evolution before its ultimate suppression. The willingness to invest in expensive new technology might suggests traders' continued confidence in profitability despite legal restrictions.

These vessel-level adaptations support the network analysis findings by showing how micro-level operational changes may have supported macro-level network resilience. The evidence suggests that the slave trade did not simply persist despite abolition – it appears to have actively evolved, potentially developing new organizational forms and operational strategies that maintained efficiency even as the legal environment became increasingly hostile.

Chapter 6

Conclusion

Using TERGMs, I explored how formal abolition laws have transformed the trade into a more concentrated and strategically adapted system. The network's apparent adaptability suggests that legal prohibition may not have simply dismantled the trade. Instead, it created a complex system that responded to mounting international pressure.

The findings suggest three key contributions to our understanding of historical trade networks and abolition. First, I identified what might be called an "abolition paradox." Ports operating under abolished flags maintained higher connectivity than those under legal flags. This may reveal how established commercial infrastructure could be repurposed for illegal operations. This finding provides evidence for claims about capitalism's adaptive capacity. Second, the trade maintained its hub-dominated structure across all phases. This indicates that certain organizational patterns may be fundamental features of these systems. Third, traders made systematic strategic adaptations, from flag manipulation to vessel modifications. This shows how networks might evolve operationally while maintaining core structural characteristics. The remarkable adaptations demonstrated in this study suggest that the slave trade could maintain operations even under extremely hostile conditions. This may indicate that future research should focus more on understanding demand-side factors and economic incentives rather than solely examining enforcement mechanisms, since traders proved capable of overcoming substantial supply-side obstacles through strategic innovation.

However, several important limitations affect this analysis. Most importantly, the TASTDB relied on European-generated archival sources. These sources naturally reproduce the power imbalances that characterized the slave trade itself. The database reflects the perspectives of ship captains, merchants, and colonial administrators. This inevitably privileges those who enslaved others while making largely invisible the agency and resistance of the enslaved themselves.

The quantitative approach reveals structural patterns but cannot capture the lived experiences of millions of Africans forced into this system. Network analysis treats ports as abstract points, obscuring the human communities affected by slave raids. Statistical measurements reduce individuals to numbers. Additionally, voyage records were more likely to survive when ships reached their destinations successfully. This potentially underrepresents failed attempts or vessels intercepted by naval patrols.

These limitations point to several promising directions for future research. Advanced statistical models could provide more detailed insights into network evolution. More importantly, we need methodological approaches that better capture marginalized experiences. Network analysis could be combined with enslaved people's narratives, archaeological evidence, and genealogical reconstruction to build more inclusive models of Atlantic world connections.

This study shows both the potential and limitations of applying network analysis to historical systems of oppression. While such methods can reveal important structural patterns, they cannot substitute for approaches that center the experiences of those who suffered under these systems. The most complete understanding of historical networks like the slave trade will require combining structural analysis with approaches that restore dignity and agency to those whom the historical record sought to reduce to commodities.

The remarkable adaptations demonstrated in this study reveal the slave trade's resilience in maintaining operations even under increasingly hostile regulatory conditions. These findings suggest that enforcement mechanisms alone were insufficient to dismantle the trade, as traders consistently overcame substantial supply-side obstacles through strategic innovations in flagging, routing, and network restructuring. Future research should therefore prioritize understanding the economic and moral transformations that ultimately ended the trade, while centering the resistance and agency of enslaved peoples themselves, rather than focusing exclusively on the effectiveness of enforcement measures. The network's persistence despite legal prohibitions underscores that the trade's eventual abolition required more than regulatory pressure—it demanded the cumulative force of enslaved people's resistance, revolts, and refusal to accept bondage, alongside fundamental shifts in economic systems and moral consciousness that made such adaptations no longer viable or acceptable.

Bibliography

[1] E. Williams, *Capitalism and Slavery*. Chapel Hill: University of North Carolina Press, 1944.

[2] H. S. Klein, *The Atlantic Slave Trade*. New Approaches to the Americas, Cambridge: Cambridge University Press, 2 ed., 2010.

[3] J. Harris, *The Last Slave Ships: New York City and the End of the Middle Passage*. New Haven: Yale University Press, 2020.

[4] F.-X. Fauvelle, *The Golden Rhinoceros: Histories of the African Middle Ages*. Princeton: Princeton University Press, 2018.

[5] D. Eltis and D. Richardson, *Atlas of the Transatlantic Slave Trade*. Yale University Press, 2010.

[6] J. Harris, "Historical context: Abolishing the trans-atlantic slave trade · voyage of the echo: The trials of an illegal trans-atlantic slave ship · lowcountry digital history initiative," 2014.

[7] D. B. Davis, *The Problem of Slavery in the Age of Revolution, 1770-1823*. Ithaca: Cornell University Press, 1975.

[8] S. Drescher, *Abolition: A History of Slavery and Antislavery*. Cambridge University Press, 2009-07.

[9] D. Tomich, "The second slavery and world capitalism: A perspective for historical inquiry," vol. 63, no. 3, pp. 477–501, 2018-12.

[10] R. Luxemburg, *The Accumulation of Capital*. London: Routledge, 1913. English translation by Agnes Schwarzschild, 1951.

[11] R. Lesaffer, "Vienna and the abolition of the slave trade," in *Oxford Historical Treaties*, Oxford: Oxford University Press, 2015.

[12] S. Batterson, "A horde of foreign freebooters," 2013-04-29.

[13] H. Suzuki, "Suppression of the transoceanic slave trade," in *Oxford Research Encyclopedia of African History*, 2022-02-24.

[14] C. Lloyd, *The Navy and the Slave Trade: The Suppression of the African Slave Trade in the Nineteenth Century*. 2016.

[15] D. Richardson, "The slave trade, sugar, and british economic growth, 1748–1776," in *British Capitalism and Caribbean Slavery: The Legacy of Eric Williams* (B. L. Solow and S. L. Engerman, eds.), pp. 103–134, Cambridge University Press, 1988.

[16] D. Eltis, *Economic Growth and the Ending of the Transatlantic Slave Trade*. Oxford University Press, 1987-06-11.

[17] J. S. Martinez, *The Slave Trade and the Origins of International Human Rights Law*. Oxford University Press, 2014-04-03.

[18] L. Bethell, *The Abolition of the Brazilian Slave Trade: Britain, Brazil and the Slave Trade Question*. Cambridge Latin American Studies, Cambridge University Press, 1970.

[19] L. Marques, *The United States and the Transatlantic Slave Trade to the Americas, 1776-1867*. Yale University Press, 2016.

[20] J. F. Padgett and C. K. Ansell, "Robust action and the rise of the Medici, 1400-1434," *American Journal of Sociology*, vol. 98, no. 6, pp. 1259–1319, 1993.

[21] R. Breiger and P. Pattison, "Cumulated social roles: The duality of persons and their algebras," *Social Networks*, vol. 8, no. 3, pp. 215–256, 1986.

[22] S. Wasserman and K. Faust, *Social network analysis: Methods and applications*. Cambridge University Press, 1994.

[23] G. E. O'Malley and A. Borucki, "Patterns in the intercolonial slave trade across the Americas before the nineteenth century," *Tempo*, vol. 23, pp. 314–338, 2017.

[24] A. Borucki, D. Eltis, and D. Wheat, "Atlantic history and the slave trade to Spanish America," *The American Historical Review*, vol. 120, no. 2, pp. 433–461, 2015.

[25] A. Borucki, D. Eltis, and D. Wheat, *From the galleons to the highlands: Slave trade routes in the Spanish Americas*. University of New Mexico Press, 2020.

[26] M. Kanrak and H.-O. Nguyen, "An analysis of connectivity, assortativity and cluster structure of the Asian-Australasian cruise shipping network," *Maritime Transport Research*, vol. 3, p. 100048, 2022.

[27] S. Hanneke, W. Fu, and E. P. Xing, "Discrete temporal models of social networks," *Electronic Journal of Statistics*, vol. 4, pp. 585–605, 2010.

[28] P. N. Krivitsky and M. S. Handcock, "A separable model for dynamic networks," *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, vol. 76, no. 1, pp. 29–46, 2014.

[29] C. M. Rawlings, J. A. Smith, J. Moody, and D. A. McFarland, *Network Analysis: Integrating Social Network Theory, Method, and Application with R*. Cambridge: Cambridge University Press, 2023.

[30] E. Erikson, "Formalist and relationalist theory in social network analysis," *Sociological Theory*, vol. 31, no. 3, pp. 219–242, 2013.

[31] J. A. Fuhse, "Theories of social networks," in *The Oxford Handbook of Social Networks* (R. Light and J. Moody, eds.), pp. 34–49, Oxford: Oxford University Press, 2020.

[32] C. Wetherell, "Historical social network analysis," *International Review of Social History*, vol. 43, no. S6, pp. 125–144, 1998.

[33] P. W. Holland and S. Leinhardt, "An exponential family of probability distributions for directed graphs," *Journal of the American Statistical Association*, vol. 76, no. 373, pp. 33–50, 1981.

[34] O. Frank and D. Strauss, "Markov graphs," *Journal of the American Statistical Association*, vol. 81, no. 395, pp. 832–842, 1986.

[35] T. A. B. Snijders, "Markov chain Monte Carlo estimation of exponential random graph models," *Journal of Social Structure*, vol. 3, no. 2, pp. 1–40, 2002.

[36] T. A. B. Snijders, P. E. Pattison, G. L. Robins, and M. S. Handcock, "New specifications for exponential random graph models," *Sociological Methodology*, vol. 36, no. 1, pp. 99–153, 2006.

[37] D. R. Hunter and M. S. Handcock, "Inference in curved exponential family models for networks," *Journal of Computational and Graphical Statistics*, vol. 15, no. 3, pp. 565–583, 2006.

[38] D. Acemoglu, S. Johnson, and J. A. Robinson, "The colonial origins of comparative development: An empirical investigation," *American Economic Review*, vol. 91, no. 5, pp. 1369–1401, 2001.

[39] S. Hanneke, W. Fu, and E. P. Xing, "Discrete temporal models of social networks," *Electronic Journal of Statistics*, vol. 4, pp. 585–605, 2010.

[40] P. N. Krivitsky and M. S. Handcock, "A separable model for dynamic networks," *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, vol. 76, no. 1, pp. 29–46, 2014.

[41] B. A. Desmarais and S. J. Cranmer, "Statistical mechanics of networks: Estimation and uncertainty," *Physica A: Statistical Mechanics and its Applications*, vol. 391, no. 4, pp. 1865–1876, 2012.

[42] P. Leifeld, S. J. Cranmer, and B. A. Desmarais, "Temporal exponential random graph models with btergm: Estimation and bootstrap confidence intervals," *Journal of Statistical Software*, vol. 83, no. 6, pp. 1–36, 2018.

[43] G. Robins, P. Pattison, Y. Kalish, and D. Lusher, "An introduction to exponential random graph (p*) models for social networks," *Social Networks*, vol. 29, no. 2, pp. 173–191, 2007.

[44] D. Eltis, D. Richardson, S. D. Behrendt, and H. S. Klein, "Voyages: The trans-atlantic slave trade database," 2019. 2019 expanded version.

[45] D. Eltis, D. Richardson, S. D. Behrendt, and H. S. Klein, "Trans-Atlantic slave trade database," 2020. Expanded Version.

[46] R. Blackburn, *The American Crucible: Slavery, Emancipation and Human Rights*. London: Verso, 2011.

[47] W. E. F. Ward, *The Royal Navy and the Slavers: The Suppression of the Atlantic Slave Trade*. New York: Pantheon Books, 2009.

[48] A.-L. Barabási and R. Albert, "Emergence of scaling in random networks," *Science*, vol. 286, no. 5439, pp. 509–512, 1999.

[49] M. E. J. Newman, "The structure and function of complex networks," *SIAM Review*, vol. 45, no. 2, pp. 167–256, 2003.

[50] D. Eltis and D. Richardson, *Atlas of the Transatlantic Slave Trade*. New Haven: Yale University Press, 2010.

[51] D. R. Murray, *Odious Commerce: Britain, Spain and the Abolition of the Cuban Slave Trade*. Cambridge: Cambridge University Press, 1980.

[52] D. Tomich, *Through the Prism of Slavery: Labor, Capital, and World Economy*. Rowman & Littlefield, 2004.

[53] P. D. Curtin, *The Atlantic Slave Trade: A Census*. Madison: University of Wisconsin Press, 1969.

[54] I. Wallerstein, *The Modern World-System I: Capitalist Agriculture and the Origins of the European World-Economy in the Sixteenth Century*. New York: Academic Press, 1974.

[55] S. Daget, *La traite des Noirs: bastilles négrières et velléités abolitionnistes*. Rennes: Ouest-France, 1971.

[56] M. Sherwood, “After abolition: Britain and the slave trade since 1807,” *History Today*, vol. 57, no. 3, pp. 20–27, 2007.

[57] D. C. North, *Institutions, Institutional Change and Economic Performance*. Cambridge: Cambridge University Press, 1990.

[58] S. Haggerty, *Merely for Money? Business Culture in the British Atlantic, 1750-1815*. Liverpool: Liverpool University Press, 2012.

[59] R. Findlay and K. H. O’Rourke, *Power and Plenty: Trade, War, and the World Economy in the Second Millennium*. Princeton: Princeton University Press, 2007.

[60] H. B. Lovejoy, P. E. Lovejoy, W. Hawthorne, E. A. Alpers, M. Candido, and M. S. Hopper, “Redefining african regions for linking open-source data,” vol. 46, pp. 5–36, 2019-06.

[61] M. Rediker, *The Slave Ship: A Human History*. New York: Viking, 2007.

[62] C. C. Rosenthal, *Accounting for Slavery: Masters and Management*. Cambridge, MA: Harvard University Press, 2018.

For implementation details, replication instructions, and raw output, see the GitHub repository at: https://github.com/Memedsundu/Strategic-Adaptation-in-the-Transatlantic-Slave-Trade.git