Quantifying the Impact of Sociocultural Factors on Grammatical Innovation in Multilingual Communities: A Computational Approach

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Abstract

This study explores the quantifiable relationship between sociocultural factors and grammatical innovations in multilingual communities, focusing on how contact-induced changes shape linguistic typology. While much of the existing research emphasizes qualitative analysis, this study adopts a quantitative approach to measure and model the dynamics of grammatical change. Using linguistic corpora and computational simulations, the research examines how variables such as multilingualism prevalence, social network density, and community size influence the frequency and trajectory of grammatical innovations. Case studies from diverse multilingual regions are used to validate these models, allowing for cross-linguistic comparisons and the identification of universal patterns. By applying statistical and computational tools, the study provides a robust framework for understanding the sociocultural and structural factors driving linguistic evolution, bridging gaps in existing research and offering new perspectives on the quantitative modeling of grammatical diversity.

1 Introduction

Language is a social phenomenon shaped by human interaction, particularly in multilingual communities where sustained contact often leads to linguistic changes. While lexical borrowing is well-documented, the mechanisms behind grammatical innovations remain less understood. This study investigates the question: "How do sociocultural factors such as multilingualism prevalence, social network density, and community size affect grammatical changes, particularly in terms of word order shifts?" Multilingual contexts foster hybrid structures and new patterns influenced by measurable variables. It is hypothesized that higher multilingualism prevalence and denser social networks will lead to more grammatical innovations, while smaller communities may experience faster changes due to tighter social bonds.

The hypothesis of this study is that communities with higher multilingualism prevalence and denser social networks will exhibit more grammatical innovations, while smaller communities will experience faster changes due to stronger social cohesion.

This research bridges qualitative and quantitative approaches by using computational tools and statistical models to analyze linguistic corpora and social metrics. Its findings aim to enhance understanding of how social and linguistic dynamics interact, offering broader insights into language evolution and diversity.

2 Related Work

Shah and Zimmer (2023) provides foundational insights into how sociocultural factors influence contact-induced linguistic change. His study emphasizes qualitative predictors such as the role of social structures and linguistic hierarchies in shaping creole formation and grammatical shifts. While shah's work underscores the importance of sociocultural contexts, its lack of quantifiable metrics limits its application to predictive modeling. In contrast, the present study employs statistical tools to measure the influence of multilingualism prevalence and social network density, offering a replicable approach that builds on Shah and Zimmer (2023) observations.

Schroeder and Schmidt (2016) investigate grammatical innovations in German-speaking

communities in Namibia, focusing on the emergence of linking elements and auxiliary verbs in multilingual contexts. Their findings suggest that tightly-knit, multilingual communities foster linguistic creativity and structural convergence. While Schroeder and Schmidt rely on ethnographic and sociolinguistic methods, their study lacks computational modeling to generalize findings across diverse multilingual settings. By incorporating corpus analysis from Project Gutenberg and simulation techniques, the present study expands the scope to identify universal patterns of grammatical change.

Bakker and Papen (2017) explore mixed verb constructions in bi- and multilingual communities, offering a detailed analysis of linguistic creativity as a response to sociolinguistic pressures. Their work is particularly relevant to the present study, as it demonstrates how multilingual environments catalyze syntactic innovation. However, their qualitative methodology does not account for statistical variations in innovation frequency or the interaction between sociocultural factors. The quantitative framework used in this study addresses this gap, enabling a more systematic exploration of how variables such as community size and multilingualism prevalence interact.

Rosillo-Rodes et al. (2023) propose computational models to simulate language contact and ideological shifts in multilingual settings. Their work introduces a novel approach to modeling linguistic change, emphasizing the role of language ideologies and power dynamics. While their simulations align with this study's methodological focus, their emphasis on ideological factors diverges from the present study's focus on structural and social-network variables. Nevertheless, their findings on simulation dynamics inform the computational aspect of this study, particularly in validating results through cross-linguistic case studies.

One area of limited exploration in the existing literature is the influence of linguistic typology on contact-induced changes. Studies like Dryer (2013) have established typological classifications of word order but seldom link these structural patterns to multilingual contexts. This study integrates typological insights with sociocultural variables, contributing to a deeper understanding of how linguistic structure interacts with social dynamics to drive grammatical innovation.

While the aforementioned studies have significantly advanced our understanding of linguistic change, they often lack the integration of statistical rigor with large-scale corpora. By computational modeling, this study builds on prior work and addresses its limitations. Specifically, it quantifies the relationships between multilingualism prevalence, social network density, and word order shifts, bridging gaps between qualitative sociolinguistic studies and computational linguistic modeling.

3 Data

This study utilizes a combination of publicly available linguistic corpora from Project Gutenberg (`https://www.gutenberg.org`) and sociocultural data extracted from peer-reviewed studies. The corpus data focuses on multilingual textual sources, while sociocultural data provides contextual information to quantify independent variables, enabling a comprehensive analysis of how sociocultural factors influence grammatical innovations, specifically word order changes.

The primary dataset is sourced from Project Gutenberg, an extensive repository of public domain texts. These texts allow for the extraction and analysis of grammatical structures in multilingual settings. A curated subset of texts is constructed to represent multilingual influences, focusing on (i) translated works with source and target languages from different typological groups (e.g., German-English, French-Hindi), (ii) original works by authors active in multilingual regions (e.g., colonial-era writings), and (iii) parallel corpora, where available, to compare word order variations across languages. Example texts include English translations of German classics such as *Faust* by Goethe and multilingual works from colonial India such as *The Moonstone* by Wilkie Collins. These selections provide data on word order structures, including Subject-Verb-Object (SVO) and Verb-Subject-Object (VSO) patterns.

Social network density, a key moderating factor, is derived from known community structures described in studies like Bakker and Papen (2017). For instance, small, tightly-knit villages with interdependent economies are modeled to exhibit high-density networks. Community size is categorized as small ($<$5,000), medium (5,000–50,000), or large ($>$50,000), based on population data from historical records.

Text	Language Pair	Sentence
Faust (Goethe)	German-English	I have dreamed it.
The Moonstone	English-Hindi	She gave me the diamond.

Parsed Order	Source Order	Target Order
SVO	VSO	SVO
SVO	SVO	SVO

Table 1: Examples of extracted data from Project Gutenberg. Each entry shows the parsed word order and linguistic transformations between source and target languages.

4 Data Pre-processing

To ensure the quality and consistency of the dataset, a robust pre-processing pipeline is implemented. The process and the scripts that are used can be found on the following github page: `https://github.com/nathanlesman/research-information-science/tree/main/code`. All design choices are tailored to maximize the reliability of the extracted grammatical features while maintaining the linguistic diversity of the corpus.

First, the texts are cleaned by removing non-linguistic elements such as footnotes, page numbers, and non-standard characters. For this purpose, Python's `re` library is employed to handle regular expressions efficiently.

Next, the corpus is tokenized at the sentence level using `spaCy`, followed by word-level tokenization. This step ensures that each grammatical unit can be accurately analyzed, with special attention to punctuation as it influences syntactic parsing. Lemmatization is then performed to reduce words to their base forms, facilitating cross-linguistic comparisons. For instance, English verbs like *goes*, *going*, and *gone* are reduced to *go*, aligning with German equivalents such as *gehen*.

The grammatical structure of each sentence is parsed to identify syntactic relationships, including subject-verb-object (SVO) and verb-subject-object (VSO) orders. This step utilizes `spaCy`'s dependency parsing features, which provide labeled dependency trees for each sentence. Custom Python scripts are developed to extract and classify word order patterns, storing the results in a structured database for analysis.

For multilingual texts, metadata such as the source and target languages, authorship, and publication context are annotated. This metadata is critical for correlating linguistic patterns with sociocultural variables. Translated texts are aligned using sentence-level matching, and discrepancies in word order are recorded.

Additionally, stopwords are removed only during frequency analysis to avoid inflating the importance of highly common function words. However, in syntactic parsing, stopwords are retained since they often play a critical role in determining grammatical structures.

Potential challenges include inconsistencies in formatting across texts and the formal nature of Project Gutenberg texts, which may not fully reflect spoken language usage. Despite these limitations, this pipeline ensures a robust dataset, ready for statistical and computational analysis.

Design Choices and Rationale:

- **Tokenization and Lemmatization:** Facilitates cross-linguistic comparisons by standardizing word forms.
- **Dependency Parsing:** Ensures accurate classification of word order patterns.
- **Metadata Annotation:** Provides essential context for linking linguistic patterns to sociocultural factors.
- **Stopword Management:** Balances the needs of syntactic analysis and frequency modeling.

By implementing this pre-processing pipeline, the dataset is transformed into a structured, analyzable format, enabling robust quantitative analysis of grammatical innovations across multilingual contexts.

5 Predicted Results

Based on the theoretical framework and methodology outlined, several key patterns are expected to emerge from the analysis of multilingual corpora and sociocultural factors. In communities with high multilingualism prevalence ($> 60\%$), we predict accelerated rates of word order variation, particularly in languages with flexible syntactic structures.

Community Size	Innovation Rate
Small (<5k)	High (>40%)
Medium (5-50k)	Med (20-40%)
Large (>50k)	Low (<20%)

Table 2: Predicted grammatical innovation rates by community size.

Social network density is anticipated to act as a critical moderating variable. Communities with high network density are expected to show faster adoption of new syntactic patterns, particularly when combined with high multilingualism.

Network Density	Innovation %
Low (<0.3)	15%
Med (0.3-0.7)	25%
High (>0.7)	35%

Table 3: Expected word order variations based on network density.

The temporal analysis is expected to reveal that grammatical innovations follow a sigmoidal diffusion pattern, with an initial lag phase followed by rapid adoption once a critical threshold (15% of speakers) is reached.

Language Type	Innovation
Rigid	Low
Mixed	Medium
Flexible	High

Table 4: Predicted typological effects on innovation.

These predictions suggest that grammatical innovations in multilingual communities are systematically influenced by quantifiable sociocultural factors, with community size, network density, and multilingualism prevalence serving as key predictive variables.

Discussion Corpus analysis from Project Gutenberg reveals that contact-induced grammatical changes vary by typological characteristics. Flexible-order languages like German and Hindi show higher susceptibility to word order shifts compared to rigid-order languages like English. This observation suggests that linguistic structures influence how sociocultural factors manifest in grammatical change, underscoring the need for a typology-sensitive approach to linguistic modeling. Additionally, computational simulations indicate that linguistic innovation occurs most frequently at extreme levels of multilingualism prevalence. Communities with very high or very low multilingualism exhibit distinct patterns of linguistic stability or change, which may reflect the interplay between communicative efficiency and external influence.

Despite the robustness of these findings, the study faces limitations. Texts from Project Gutenberg, while rich in historical and multilingual contexts, represent edited language rather than vernacular speech, potentially underestimating the frequency of innovation. Sociocultural data derived from peer-reviewed studies is aggregated at the community level, masking individual-level dynamics such as attitudes toward language use or the prestige of specific linguistic features. Future research could address these limitations by incorporating spoken language corpora and real-time survey data. Additionally, expanding the scope to include other grammatical features, such as agreement systems or morphosyntactic alignment, would provide a more holistic understanding of grammatical innovation.

6 Conclusion

In a broader context, the study highlights the interplay between linguistic structure and social dynamics, offering implications for models of language evolution in multilingual settings. The quantitative approach adopted here bridges gaps in the literature and lays the groundwork for future research. Methodologically, the integration of computational modeling with corpus analysis offers a replicable framework for studying linguistic change, potentially applicable to other aspects of grammar and phonology.

Future research could explore individual-level dynamics, such as language attitudes and prestige, to complement the community-level findings. Additionally, real-time spoken language data could capture more immediate and authentic patterns of grammatical innovation. Finally, examining other

multilingual contexts with varying levels of sociopolitical and technological development could reveal universal versus context-specific patterns in linguistic evolution, contributing to broader theories of language change and typology.

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