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Exploring the effect of semantic diversity on boundary permeability in verb/noun heterosemy using deep contextualized word embedding

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Abstract: This study investigates the relationship between semantic diversity and boundary permeability in verb/noun heterosemous words in English. Using sense data from the Oxford Dictionaries API and the Corpus of Historical American English enhanced by contextualized word embedding, we quantified semantic diversity using Shannon entropy and measured boundary permeability as the relative proportion of verb/noun uses. Results reveal a significant positive effect of overall semantic diversity on boundary permeability, i.e., words that have more senses or balanced sense distributions show greater cross-categorical flexibility. Furthermore, we find asymmetric effects between noun and verb semantic diversity: noun-sense diversity positively affects permeability, while no meaningful effect was detected for verb-sense diversity. This asymmetry, combined with our finding that higher permeability is driven by increased verb usage, provides strong quantitative evidence for a directional preference in English conversion from noun to verb. To our knowledge, this study offers the first large-scale empirical support for theoretical accounts of directionality in English conversion, demonstrating that semantic diversity functions as a critical indicator of a word's conceptual flexibility.

Keywords: conversion; heterosemy; contextualized word embedding; semantic diversity; noun and verb

1 Introduction

Nouns and verbs are basic lexical categories in English (Ježek 2016). Traditional Aristotelian approaches have depicted these categories as discrete “islands” that cannot make contact. However, contemporary linguistic evidence increasingly challenges this rigid separation. A key example is conversion, a process where words shift from one lexical category to another without formal changes. For instance, *Google*, the noun originally referring to a search engine, developed into the verb *to google*, meaning ‘to search for information online’. Such instances illustrate the permeability of category boundaries, suggesting a more dynamic interplay between nouns and verbs in English.

The boundary permeability hypothesis (Berg 2014) offers a typological parameter to understand this phenomenon. Based on prototype theory (Rosch 1973; Taylor 1995), this hypothesis proposes that category boundaries are fuzzy rather than absolute. In other words, languages may vary in how strict or soft their boundaries between categories are. Languages with strict boundaries resist categorical extensions, while those with soft boundaries facilitate broader applications of linguistic units across boundaries. Through detailed crosslinguistic comparison of grammatical categories, Berg (2014) demonstrated that English typically exhibits soft boundaries while German maintains stricter categorical distinctions. This analysis consisted of various linguistic dimensions including units (e.g., nouns vs. verbs), properties (e.g., count vs. mass), and levels (e.g., phonological vs. morphological). Berg

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(2014) attributed these differences primarily to inflectional morphology: German's moderately robust inflectional system reinforces categorical distinctions, while English's relative lack of inflections allows greater categorical flexibility. Berg (2023) further substantiated this distinction by examining the functional ranges of the English verb *to be* and its German counterpart *sein*, finding that *to be* operates across a significantly wider semantic terrain than *sein*, consistent with the soft-boundary characterization of English.

While Berg (2014, 2023) established boundary permeability as a synchronic typological parameter, Shao et al. (2024) extended this to diachronic analysis. Examining 877 heterosemous words in Recent English, they tracked changes in verb/noun heterosemy over the past century. Heterosemy, as defined by Enfield (2006: 297), refers to cases "where the different but related meanings of a given morpheme are associated with distinct grammatical contexts". This concept encompasses what linguists have variously termed as conversion, zero-derivation, or functional shift – a productive word-formation process. Essentially, heterosemy describes words that function across word classes while maintaining semantic, derivational, and etymological connections. For instance, *charge* functions as both a verb meaning 'to cause a body to receive electric charge' and a noun meaning 'an accumulation of electricity stored in a battery or capacitor'. This example exemplifies heterosemy through its consistent morphology and semantically related meanings across different grammatical contexts.

Shao et al. (2024) found that verb/noun heterosemous words increasingly develop toward more balance over time, with weakening associations to either specific word class. They attributed this evolution to the historical loss of inflections in English – the same factor Berg (2014) identified as central to boundary permeability. Thus, boundary permeability, initially conceptualized as a crosslinguistic typological parameter, was applied by Shao et al. (2024) as a measure of language-internal diachronic change, reflecting whether grammatical categories within a language become increasingly rigid or more flexible over time. While Shao et al. (2024) effectively demonstrated the diachronic increase in boundary permeability of English verb/noun heterosemy as a whole, a crucial gap remains in understanding why individual heterosemous words exhibit varying degrees of permeability at any given time point. The overall trend toward increased flexibility across heterosemous words obscures the substantial variation that exists among individual words. This variation raises an important question: what internal linguistic factors might account for differing levels of boundary permeability among heterosemous words?

Given that categorical shifts inherently involve semantic extensions (Bybee 2010; Traugott and Dasher 2001), semantic diversity – a property closely tied to the polysemous nature of words – emerges as a potential explanatory factor. Semantic diversity, defined as the range of meanings or conceptual domains a word encompasses, is crucial for understanding a word's conceptual flexibility and cognitive adaptability (Divjak and Gries 2008; Evans and Green 2006; Geeraerts 1989, 1997; Gries 2007). Prototype theory further suggests that semantically diverse words can more readily extend their meanings through metaphorical or metonymic processes (Lakoff and Johnson 1980; Langacker 1991; Rosch 1978). Accordingly, high semantic diversity may facilitate the creation of senses across categorical boundaries, thereby softening these boundaries and promoting balanced categorical use. Building on these theoretical motivations, the present study investigates how semantic diversity affects boundary permeability in verb/noun heterosemous words. Specifically, we empirically examine two primary research questions:

- (1) To what extent does semantic diversity affect boundary permeability in verb/noun heterosemous words in English?

We hypothesize that words with greater semantic diversity will exhibit higher boundary permeability due to enhanced conceptual flexibility.

- (2) Do noun semantic diversity and verb semantic diversity differentially affect boundary permeability in heterosemous words?

This question explores potential asymmetries in how noun-sense and verb-sense diversity might contribute to categorical flexibility.

By investigating these questions, this study aims to illuminate an under-explored area of linguistic variability within English, offering insights into how semantic diversity shapes the permeability of lexical category boundaries.

2 Methods

2.1 Sense data

The lexical semantic information for this study was derived from the diachronic sense dataset created by Hu et al. (2019). This dataset contains detailed semantic annotations for polysemous words from the Corpus of Historical American English (COHA; Davies 2012), covering the years 1810–2009.

To construct this dataset, Hu et al. (2019) first created a sense-embedding dictionary for 3,220 polysemous words selected according to two criteria: (i) each word occurred at least 10 times per year for at least 50 consecutive years in COHA between 1810 and 2009, and (ii) each word had delineated sense entries in the Oxford Dictionaries API. The Oxford Dictionaries API was chosen for its programmatic access to extensive English usage definitions and examples. Each sense was represented as a sense-embedding vector derived by averaging the contextual embeddings of illustrative sentences provided in the Oxford Dictionaries API. Hu et al. (2019) processed at most 10 example sentences per sense through the BERT language model (Devlin et al. 2019) to ensure computational feasibility and consistency across senses with varying numbers of available examples. This process yielded fine-grained sense embeddings for a total of 13,805 distinct senses across 3,220 polysemous words. Subsequently, all sentences containing these polysemous words in COHA were extracted, and contextual embeddings for each occurrence of the target words were computed using BERT. Each contextualized occurrence was then automatically assigned to the most similar dictionary sense embedding, creating a rich diachronic dataset that tracks sense proportions across different time periods. Figure 1 shows the processes for constructing this dataset.

There are three primary advantages of employing this particular dataset in our study. First, it demonstrates a high level of reliability. Hu et al. (2019) validated their sense-labeling approach, reporting an accuracy of 92.3 % on a separate test set of 2,000 sentences from the Oxford Dictionaries API. Second, it substantially overlaps with the heterosemous words investigated in Shao et al. (2024). Specifically, 607 out of the original 877 heterosemous words (approximately 70 %) analyzed by Shao et al. (2024) are represented within this dataset. These 607 words form the basis of the current investigation, providing a sufficiently large and robust sample for evaluating the relationship between semantic diversity and boundary permeability. Third, because this dataset provides detailed sense definitions and proportions for each word across decades, it allows for a direct investigation into how semantic diversity influences verb/noun boundary permeability.

Ultimately, we obtained a sense dataset containing diachronic semantic annotations for the 607 heterosemous target words spanning from the 1810s to the 2000s. To ensure consistency with Shao et al. (2024), whose heterosemous word list was constructed using COHA data from the 1920s to the 2010s, we restricted our analysis to the overlapping period from the 1920s to the 2000s.

2.2 Boundary permeability index

To quantify the boundary permeability of heterosemous words, we calculated a permeability index defined as follows:

$$\text{Permeability index} = 1 - |p(n) - p(v)| \quad (1)$$

In Formula 1, $p(n)$ represents the total proportion of occurrences of the noun form for a given heterosemous word, while $p(v)$ indicates the total proportion of its verb form. The logic behind this measure is straightforward: an index close to 0 indicates that the word is predominantly associated with either noun or verb use, signifying low boundary permeability. Conversely, an index approaching 1 indicates balanced use across both noun and verb uses, thus reflecting high permeability.

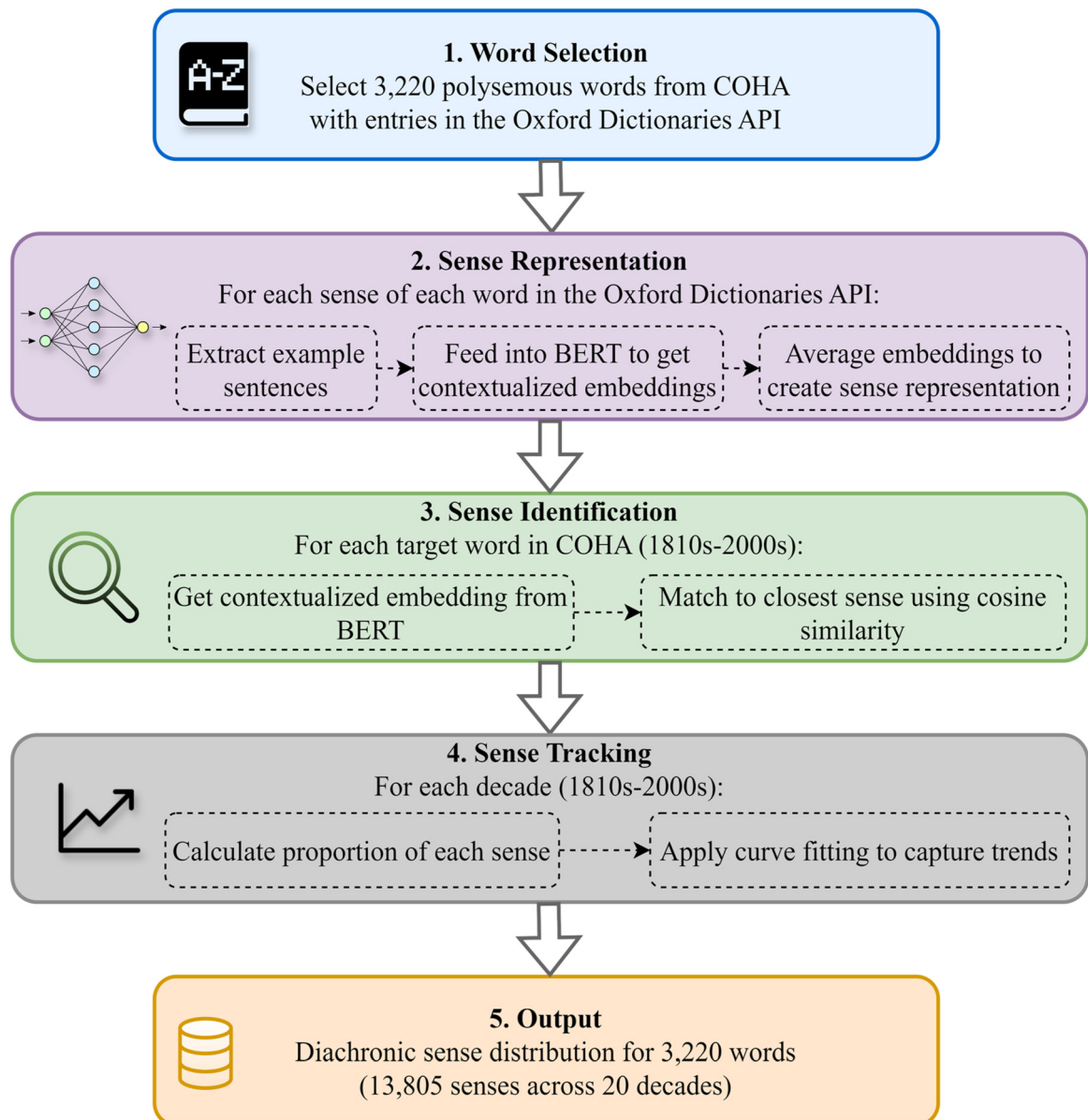


Figure 1: Procedures for constructing the diachronic sense dataset.

2.3 Semantic diversity

Semantic diversity in this study is defined along two key aspects: the number of senses a heterosemous word possesses and the distribution of these senses. Specifically, we operationalized semantic diversity using Shannon's entropy as a quantitative measure. This index has been adopted in diverse contexts, including biodiversity (Allen et al. 2009; Dickman 1968) and lexical diversity (Jarvis 2013; Shi and Lei 2022), because it captures both the richness (i.e., number of categories) and the evenness (i.e., relative distribution) of a given system. We apply this measure to quantify semantic diversity using the following formula:

$$\text{Semantic diversity } (X) = -\sum p(x) * \log_2(p(x)) \quad (2)$$

In this formula, X represents a given heterosemous word, x is a specific sense of the word, and $p(x)$ indicates the proportion of occurrences of sense x relative to all occurrences of word X . Thus, higher entropy values correspond to greater semantic diversity, arising either from a larger number of senses or a more balanced frequency distribution among the existing senses.

For instance, a heterosemous word with three senses distributed as 0.4, 0.3, and 0.3 has higher semantic diversity compared to a word with three senses distributed 0.9, 0.05, and 0.05. Similarly, a word with five senses, each equally represented at 0.2, demonstrates even greater diversity. Thus, higher entropy indicates either a greater number of senses or a more balanced sense distribution. This entropy-based approach offers a precise, quantitative way to compare semantic diversity across heterosemous words, capturing both sense quantity and their distributional evenness.

It is worth noting that in addition to calculating the overall semantic diversity of each heterosemous word, we computed semantic diversity separately for its noun senses and verb senses. This allowed us to investigate whether noun and verb semantic diversity have distinct effects on boundary permeability.

2.4 Data analysis

For RQ1, examining the effect of overall semantic diversity on boundary permeability, we employed a linear mixed-effects model. The boundary permeability index served as the dependent variable, while semantic diversity was included as a fixed predictor. To control for potential temporal effects and account for the overall linear trend previously identified in Shao et al. (2024), decade was included as a covariate. Additionally, logged normalized frequency of each heterosemous word was included as another covariate to control for differences in corpus size across decades and potential frequency effects. Logged normalized frequency was calculated by dividing each word's raw frequency by the corpus size for the corresponding decade and then applying a logarithmic transformation. The log transformation was used due to the skewed distribution of normalized frequencies, ensuring suitability for linear modeling. Collinearity diagnostics showed minimal correlation between semantic diversity and logged normalized frequency, confirming the appropriateness of including both variables in the model. Heterosemous pairs were set as random intercepts to account for the non-independence of observations within each pair across decades and to control for pair-specific variation in baseline boundary permeability levels.

For RQ2, investigating the separate contributions of noun and verb semantic diversity to boundary permeability, we used another linear mixed-effects model. Here, the boundary permeability index again served as the dependent variable, but semantic diversity was split into two separate fixed predictors: semantic diversity of noun senses and semantic diversity of verb senses. Decade and logged normalized frequencies of noun and verb forms were included as covariates. Similar to the previous model, heterosemous words were included as random intercepts to account for word-specific variability across time points.

It is worth noting that both semantic diversity and boundary permeability are calculated from the same underlying sense frequency data, creating a potential for spurious correlations. Specifically, words with more evenly distributed senses may automatically tend to have more balanced verb/noun usage simply due to the mathematical properties of frequency distributions, regardless of any genuine linguistic relationships. To validate that our findings reflect substantive linguistic patterns rather than such statistical artifacts, we conducted permutation tests for both research questions. For each test, we randomly reassigned verb/noun labels to senses within each word-year combination while preserving the original sense frequency structure. This procedure maintains each word's semantic diversity while disrupting the specific noun/verb categorizations. We repeated this process 1,000 times, refitting our statistical models to each permuted dataset. The proportion of permuted results equaling or exceeding our observed effects provides an empirical p value for testing whether our findings could arise from chance relationships between our measures.

3 Results and discussion

3.1 Effect of overall semantic diversity on boundary permeability

As shown in Table 1, our results reveal a significant positive relationship between overall semantic diversity and boundary permeability ($\beta = 0.356$, $SE = 0.008$, $t = 43.2$, $p < 0.001$). This finding strongly supports our hypothesis: heterosemous words possessing either a greater number of senses or a more balanced distribution of these senses exhibit higher boundary permeability. This increased permeability enables greater flexibility in the words' ability to function interchangeably as nouns or verbs.

To address potential circularity concerns between our semantic diversity and boundary permeability measures, we conducted a permutation test. As illustrated in Figure 2, none of the 1,000 random permutations produced a coefficient as large as our observed effect (observed $\beta = 0.3562$ vs. mean permuted $\beta = 0.2018$, $p < 0.001$). The distribution of simulated coefficients clusters tightly around 0.20, while our observed coefficient lies far beyond the range of any permuted result. This confirms that the positive effect of overall semantic diversity on boundary permeability reflects a genuine linguistic relationship rather than a mathematical artifact.

Table 1 also shows a significant positive effect of decade ($\beta = 0.0003$, $SE = 3.9e-05$, $t = 8.0$, $p < 0.001$), which aligns with the findings of Shao et al. (2024). They found a significant increase in boundary permeability in verb/noun heterosemy from the 1920s to the 2010s in Recent English. Notably, when comparing coefficient magnitudes, the effect of semantic diversity (0.3562) substantially outweighs that of decade (0.0003). This indicates that while boundary permeability in heterosemous words has indeed increased over time, the overall semantic diversity of a word remains a far stronger predictor of its permeability, even after controlling temporal trends.

Additionally, we observed a significant positive effect of normalized frequency ($\beta = 0.0087$, $SE = 0.0042$, $t = 2.087$, $p = 0.0369$). This result indicates that heterosemous words occurring more frequently tend to exhibit greater boundary permeability. This frequency effect likely reflects Zipf's (1949) Law of Meaning Distribution, which predicts that high-frequency words develop more meanings over time. Because heterosemous words with more senses tend to have both higher semantic diversity and more opportunities for balanced noun/verb usage, higher-frequency words would be expected to show greater boundary permeability. Although this frequency effect is relatively modest compared to the effect of semantic diversity, it provides further evidence that overall usage patterns play an important role in the development of categorical flexibility.

These findings collectively demonstrate that while Recent English is indeed undergoing diachronic shifts toward increased boundary permeability, the semantic structure of individual heterosemous words, especially the diversity and distribution of their senses, serves as a more powerful predictor of their ability to function flexibly across word classes.

3.2 Effect of noun and verb semantic diversity on boundary permeability

Table 2 reveals an intriguing asymmetry in how semantic diversity affects boundary permeability depending on word class. Our analysis shows a significant positive effect of noun-sense semantic diversity on boundary

Table 1: Statistical results for the effects of overall semantic diversity on boundary permeability.

Effect	Variables	Estimate	Std error	t-Value	df	p-Value
Fixed	(Intercept)	−0.7064	0.0772	−9.149	5,690.2	<0.001***
Fixed	Entropy	0.3562	0.0082	43.216	5,369.0	<0.001***
Fixed	Decade	0.0003	3.9e−05	7.966	5,437.0	<0.001***
Fixed	Log_normed_freq	0.0087	0.0042	2.087	6,048.7	0.037*

Entropy indicates the overall semantic diversity. Log_normed_freq indicates the logged normalized frequency. * $p < 0.05$. ** $p < 0.01$.

*** $p < 0.001$.

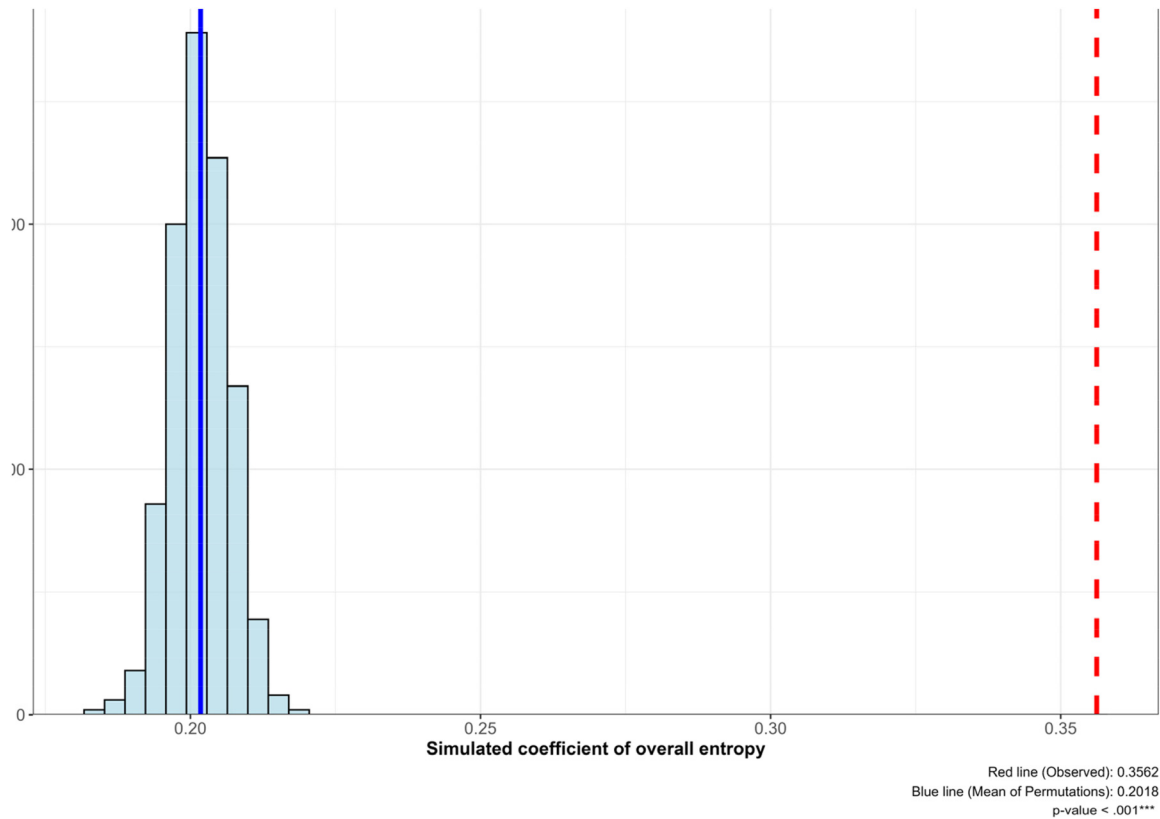


Figure 2: Distribution of simulated coefficients of overall semantic diversity based on 1,000 permutations.

permeability ($\beta = 0.0307$, $SE = 0.009$, $t = 3.4$, $p < 0.001$). In contrast, verb-sense semantic diversity exerts a significant negative effect ($\beta = -0.0396$, $SE = 0.009$, $t = -4.45$, $p < 0.001$).

To validate these asymmetric findings, we conducted the same permutation test approach for the noun/verb semantic diversity effects. Figure 3 illustrates the results of this analysis, which revealed that random noun/verb assignments produce consistently negative coefficients for both predictors.

As shown in the left panel of Figure 3, the permutation test provides strong evidence for a genuine positive effect of noun semantic diversity. The observed coefficient ($\beta = 0.0307$, red dashed line) is robustly positive, standing in stark contrast to the consistently negative distribution generated by random assignment (mean simulated $\beta = -0.1539$; $p < 0.001$). This indicates that the positive influence of noun semantic diversity represents a genuine linguistic phenomenon that operates counter to the mathematical tendencies inherent in our measures.

Table 2: Statistical results for the effects of noun and verb semantic diversity on boundary permeability.

Effect	Variables	Estimate	Std error	t-Value	df	p-Value
Fixed	(Intercept)	-0.2510	0.0868	-2.893	5,675.7	0.0038**
Fixed	N_entropy	0.0307	0.0090	3.392	3,623.6	<0.001***
Fixed	V_entropy	-0.0396	0.0088	-4.475	4,675.4	<0.001***
Fixed	Decade	0.0003	4.4e-05	7.837	5,544.7	<0.001***
Fixed	Log_normed_n	-0.0424	0.0044	-9.654	5,779.8	<0.001***
Fixed	Log_normed_v	0.0781	0.0032	24.418	5,796.6	<0.001***

N_entropy indicates semantic diversity of noun senses. V_entropy indicates semantic diversity of verb senses. * $p < 0.05$. ** $p < 0.01$.

*** $p < 0.001$.

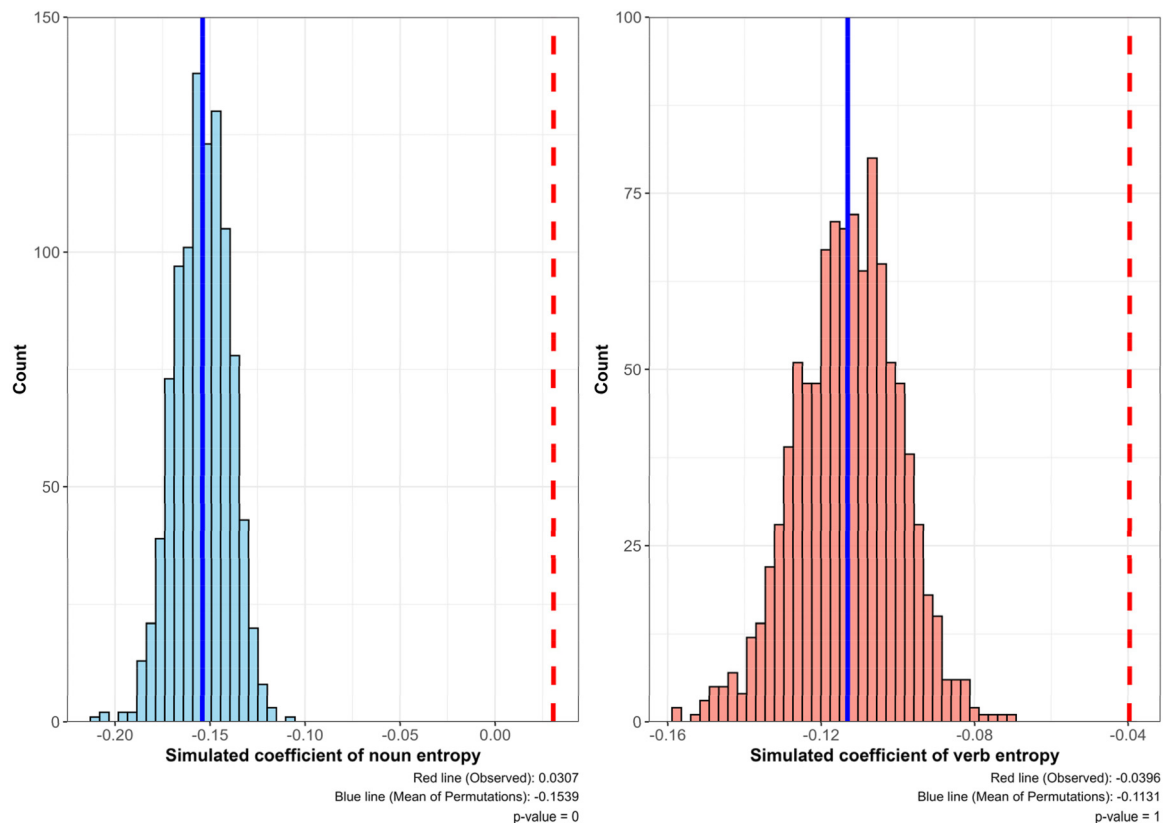


Figure 3: Distribution of simulated coefficients of noun/verb semantic diversity based on 1,000 permutations.

However, the analysis for verb semantic diversity yields a different conclusion. The right panel of Figure 3 shows that while our observed coefficient ($\beta = -0.0396$, red dashed line) is statistically significant in the original model, it falls within the same directional pattern as the null distribution (mean simulated $\beta = -0.1131$). Since both the observed effect and the simulated effects are negative, we cannot definitively determine whether the observed negative effect reflects a genuine linguistic pattern or residual mathematical artifact.

In short, these results indicate that noun semantic diversity exerts a robust positive effect on boundary permeability, while the negative effect of verb semantic diversity remains uncertain and requires further investigation to establish its authenticity.

To interpret these findings, we must first consider what our permeability index represents. A higher score reflects more balanced usage between noun and verb forms, indicating greater flexibility. However, the index itself does not specify the direction of this shift. The positive correlation we find is between noun semantic diversity and this state of balance. The critical question, as raised by our analysis, is how this balance is achieved.

Our model provides a clear answer through the effects of word-class frequency. As shown in Table 2, boundary permeability is positively affected by verb frequency ($\beta = 0.0781$, $p < 0.001$) and negatively affected by noun frequency ($\beta = -0.0424$, $p < 0.001$). This pattern provides direct evidence for the direction of change. Given that heterosemous words in our dataset are predominantly noun-like (approximately 65 % noun usage), achieving greater balance (i.e., higher permeability) requires an increase in verb usage relative to noun usage. Our frequency predictors capture this dynamic precisely: permeability increases as verb frequency rises and noun frequency falls.

By synthesizing these findings, we can draw a more robust conclusion. The fact that noun semantic diversity positively predicts a state of balance, and that this balance is achieved through a shift toward verbal usage, provides strong quantitative support for a directional preference in English conversion. It is the semantic flexibility within the noun category that facilitates the extension into the verbal domain. This result offers a novel

explanation for the well-documented productivity of noun-to-verb conversion (Bauer 1983; Biese 1941; Marchand 1969), grounding it in the semantic structure of the words themselves. Our findings thus support prior theoretical proposals on the directionality of English conversion (e.g., Balteiro 2007; Plag 1999), while providing a new empirical perspective on the semantic mechanisms that may underlie this asymmetry. Nevertheless, our conclusions are based on a sample of 607 heterosemous words; further research with broader datasets would help validate these patterns and explore the cognitive and linguistic principles that shape this directional preference.

4 Conclusions

The present study examined the boundary permeability hypothesis from within-language dynamics. Specifically, we investigated how semantic diversity affects boundary permeability in verb/noun heterosemous words using sense data from the Oxford Dictionaries API and COHA corpus, enhanced by deep contextualized word embeddings.

Our findings revealed a significant positive relationship between overall semantic diversity and boundary permeability. This result confirms that semantic diversity functions as a critical indicator of a word's conceptual flexibility and cognitive adaptability. At the word-class level, we found a crucial asymmetry. Noun semantic diversity robustly predicts higher boundary permeability, while no meaningful effect was detected for verb semantic diversity. By examining the effect of word-class frequencies on permeability, we demonstrated that this increased permeability is achieved specifically through an increase in verb usage relative to noun usage. This combination of findings provides strong quantitative evidence for a directional preference in English conversion from noun to verb, showing that semantic flexibility in nouns is a key mechanism enabling their functional shift. To our knowledge, this represents the first large-scale quantitative study to document this phenomenon.

These findings operate within and complement the broader inflectional morphology framework established by Berg (2014). The inflectional morphology account provides the fundamental explanation for boundary permeability patterns: languages with rich inflectional morphology maintain strict categorical boundaries, while those with impoverished inflection (like English) develop softer boundaries. Our results demonstrate that within this soft-boundary context created by English's historical loss of inflections, semantic diversity emerges as a significant predictor of word-level variation in categorical flexibility. Thus, morphological impoverishment creates the structural preconditions that allow semantic factors to influence boundary permeability, with these two accounts targeting complementary levels of linguistic explanation – system-wide typological patterns versus individual word behavior within a given language type.

Several limitations warrant consideration. First, our analysis focuses on Recent English (1920s–2000s), potentially limiting generalizability to earlier periods. Future research could investigate semantic diversity effects using sense data from before the twentieth century to validate our findings across different historical contexts. Second, we used the Oxford Dictionary API as our sense repository, which primarily covers modern senses. Consequently, senses that disappeared before compilation or emerged recently might not be captured, potentially affecting our semantic diversity calculations for words with significant sense change during our study period. Future research using historical dictionaries like the *Oxford English Dictionary* could provide more complete coverage, though this would require different methodological approaches given API limitations. Third, our exclusive focus on verb/noun heterosemy in English raises questions about crosslinguistic patterns. For example, Chinese has been claimed to favor verb-to-noun conversion (Shen 2010) – a proposition that has yet to be verified through rigorous quantitative analysis. The methodological framework developed in this study offers a valuable template for exploring similar phenomena across languages, potentially revealing both universal tendencies and language-specific variations in boundary permeability dynamics.

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