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## Phonological Rule Change: The Constant Rate Effect

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### 1. Introduction

The detailed quantitative study of language change, as found in studies such as Labov (1994) and Kroch (1989), has raised two central questions for linguistic theory. The first is an issue in the theory of language change itself, namely: do changes in different components of the grammar progress in the same way? The second question addresses the relationship between the study of change and the development of synchronic linguistic theory: can quantitative, diachronic data help to choose between alternative analyses of synchronic facts? This paper addresses both of these questions with the case study of the loss of word-final stop fortition (frequently termed “devoicing”) in the history of German, and concludes that the answer to both questions above is “yes”.

Kroch (1989), followed by Pintzuk (1991), Santorini (1992), *inter alia*, showed conclusively that when a new syntactic variant begins to enter the grammar, its use may be more or less favored in different contexts, but it increases in frequency in every context at the same rate over time (the “Constant Rate Effect”). This shows that the different contexts express the same underlying change, a single incoming rule which is unspecified for context. The differing frequencies in each context, then, are orthogonal, additive, and extragrammatical, or at least grammatically inert. With the case of final fortition in German, this paper shows that the Constant Rate Effect holds in phonology as well, demonstrating that phonological change and syntactic change progress in precisely the same way, and that the different contexts for final fortition express a change in a single underlying rule in the grammars of German speakers.

Expanding upon the study of Middle High German final stop fortition in Glaser (1985), we present a quantitative study of the Bonn Early New High German Corpus (*Das Bonner Frühneuhochdeutschkorpus*, Diel et al. 2002) which shows in detail how the rule of German final stop fortition was gradually lost between the years of c. 1300-1700 in a number of High German dialects. The fortition rule was lost at the same rate in various phonological contexts, proving that the “Constant Rate Effect” (CRE) found in syntactic change also applies to changes in the phonological grammar. Furthermore, we show that while the specific course of the change was not identical in each geographical dialect region

of High German, the CRE nevertheless shows up in each dialect we studied. This also confirms that the change in final fortition was the loss of a single, abstract phonological rule, and not the product of sound change diffusing across individual lexical items, nor can it be attributed to mere orthographic variation in Middle and Early New High German texts. In particular, the empirical results we present below are difficult to account for in terms of purely usage based approaches to phonology such as Exemplar Theory (Pierrehumbert 2002; Bybee 2002), and indeed, such approaches would find the robust appearance of the Constant Rate Effect in a change like this one to be highly unexpected.

The remainder of the paper is organized as follows. Section 2 below provides some historical background concerning the loss of final stop fortition in Middle and Early New High German, and discusses some earlier approaches to this topic in the literature. Section 3 presents our quantitative study from the *Bonn Corpus* of the change in final fortition in 10 High German dialects, and shows by modeling the change with the logistic that the Constant Rate Effect applies here, just as in Kroch (1989)'s original demonstration of the CRE in syntactic rule change. In section 4 we discuss the implication of these results for both synchronic phonological theory and the theory of language change. Finally, we close with some conclusions and directions for future research in section 5.

## **2. The Loss of Final Stop Fortition in German**

Our study in phonological rule change will focus on the loss of word final fortition in Early New High German. The phenomenon is called “devoicing” in Modern German, but we will refer to the process as “fortition” here to avoid making any claims about its phonetic quality or the phonological involvement of the [voice] feature (Mihm 2004; Iverson and Salmons 2007).

There is considerable evidence that final fortition was lost in Early New High German, and the final devoicing observed in the modern language was the result of a second, later change. Evidence for this comes in two forms: direct evidence of loss as found in Early New High German texts (1) – (3) (Glaser 1985), and the testimony of contemporary grammarians (Mihm 2004). We will focus mainly on the orthographic evidence here, as it serves as the basis for our quantitative analysis.

- (1) ‘highway robbery’
  - a. *ʃtrazraup* (Nom. sg.) *ʃtrazreube* (Gen. pl.); manuscript date: 1276
  - b. *ʃtraßraúb* (Acc. sg.) *ʃtraßraúbe* (Gen. pl.); manuscript date: 1523
- (2) ‘counsel’
  - a. *rat* (Acc. sg.) *rade* (Dat. sg.); manuscript date: 1276
  - b. *rad* (Acc. sg.) *rade* (Dat. sg.); manuscript date: 1523
- (3) ‘day’
  - a. *tak* (Acc. sg.) *tage* (Acc. pl.); manuscript date: 1276
  - b. *tag* (Acc. sg.) *tage* (Acc. pl.); manuscript date: 1483

There are a number of reasons to conclude that the orthographic patterns we observe truly represent a phonological change rather than a shifting scribal tradition. Firstly, spelling remained quite variable up until around 1600, leaving ample opportunity for a scribe's idiolect to influence the written language. If the change over time from word final ⟨k⟩ to ⟨g⟩ represented orthographic standardization of some sort, there is no intrinsic reason why the standardization should insist on representing only underlying forms. For example, Dutch orthography represents voicing alternations in fricatives: *ik geef* ~ *geven*.

Secondly, another known sound change in Early New High German is represented orthographically in these same texts: the apocope of schwa. Glaser (1985) found the spelling variations in (4) and (5) in her study of four copies of the same manuscript made at different times (the *Augburger Stadtbuch*).

- (4) *tage* 'days' (Acc. pl.)  
*tage* ~ *tag*; \**tac*
- (5) *tag* 'day' (Acc. sg.)  
*tac* ~ *tag*

Lastly, the interaction between apocope and fortition further lead us to conclude that the orthographic variation is evidence of fortition's loss. As the data in (4) suggest, ⟨*tac*⟩ for *tage* is unattested by Glaser (1985). The orthographic variation between ⟨g⟩ and ⟨k⟩ did not occur for just any word final velar stop, but specifically with those that never had a final schwa. It is data from forms like these in (5) that will be the focus of our study here.

Thus, we conclude that the variation in (4) represents the opaque underapplication of devoicing after apocope, and the variation in (5) represents the phonological fortition rule loss. It was probably the opaque underapplication of final fortition introduced by apocope that initially triggered the loss of fortition. However, this question will not be directly addressed here. Having established the fact that the loss of fortition actually occurred, we focus exclusively on the dynamics of that change, and what it can tell us about the nature of the grammar which changed.<sup>1</sup>

### 3. The CRE Emerges in a Quantitative Study

Our study of the loss of final fortition in Early New High German consists of a quantitative analysis of two sets of data. For both sets of data, the analysis is identical, so we will briefly describe it here. The dependent variable of observation is binomially distributed, that is, a series of categorical applications or non-applications of the final fortition rule. Our research question is specifically one about the *rate* of change in application of the final fortition rule over time, so the appropriate statistical analysis is a logistic regression (see also esp. Kroch 1989 and Santorini 1993, for other examples of applying logistic models

<sup>1</sup>For more extensive discussion of the significance of orthographic variation in studying linguistic, including phonological, variation in pre-modern texts, see Milroy (1992); Elmentaler (2003).

to linguistic change). A logistic regression will try to predict the logistic transform of the probability,  $p$ , of fortition application given the terms (described below the equation).

$$\text{logit}(p) = (\lambda + \beta_i) + (\delta + \gamma_i)\text{Year}$$

$\lambda$  = Intercept

$\beta_i$  = Modulation of the intercept by the  $i^{\text{th}}$  segment

$\delta$  = Slope of the function, or rate of change

$\gamma_i$  = Modulation of the slope by the  $i^{\text{th}}$  segment

If  $\beta_b = \beta_d = \beta_g = 0$ , then the intercepts for all three segments are the same. Of particular interest to this study, if  $\gamma_b = \gamma_d = \gamma_g = 0$ , then the slopes of all three segments are the same.  $\gamma_i$  represents the Segment:Year interaction term in the logistic regression model, so if this interaction term is significant in an Analysis of Deviance of the model (i.e. leaving the ‘‘Segment:Year’’ term out of the model significantly worsens the model’s fit to the observed data), then we can conclude that the rate of change for one or more segments has a significantly different slope from that of the others. On the other hand, if the model continues to fit the data well without the Segment:Year interaction term, then it is plausible that the decline in the application of fortition proceeded at the same rate for each of the segments.

We performed our first analysis on the data originally gathered by Glaser (1985). Again, the cases relevant to this study are the ones which *never* had an underlying final schwa, like (5). Here, the voiced final stop does not represent the *opaque* underapplication of the fortition rule, but rather its unconditioned failure to apply, which we take to be evidence for its loss. It is these cases which we will be considering in our analysis.

Table 1 displays the data gathered by Glaser (1985), and Figure 1 plots the proportion of fortition per segment over time. The data show that fortition is decreasing over time in a mostly monotonic fashion. Deviations from monotonicity are probably due to sparse data.

Year	/b/			/d/			/g/		
	Fortition	Non	$p$	Fortition	Non	$p$	Fortition	Non	$p$
1276	18	0	1.00	29	0	1.00	54	19	0.74
1373	10	8	0.56	24	5	0.83	17	59	0.22
1483	2	16	0.11	2	22	0.08	0	78	0
1523	2	14	0.12	3	6	0.33	0	73	0

Table 1: Data from Glaser (1985)

We fit a logistic regression to this data, and Table 2 presents the results of an Analysis of Deviance of that that model. The Segment:Year interaction term is not significant, meaning that the rate of change for all segments is plausibly identical. This is a confirma-

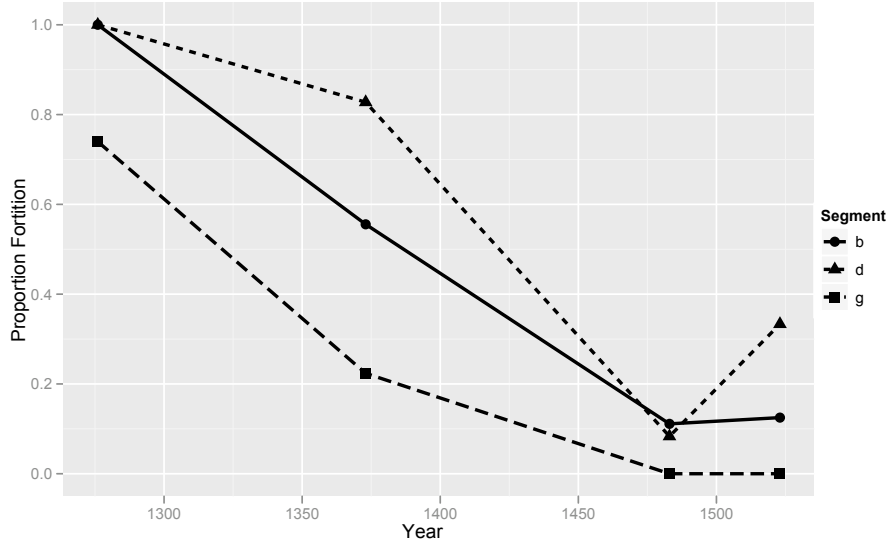


Figure 1: Data from Glaser  
Segment:Year Interaction Not Significant

tion of the Constant Rate hypothesis.

	Df	Deviance	Resid. Df	Resid. Dev	P(> Chi )
NULL			11	330.78	
Segment	2	52.47	9	278.31	<0.0001
Date	1	262.40	8	15.91	<0.0001
Segment:Date	2	0.71	6	15.20	0.7007

Table 2: Analysis of Deviance table based on a logistic regression on data from Glaser (1985)

Our next analysis focused on data collected from the Bonn Early New High German Corpus (Diel et al. 2002). The Bonn Corpus has data from ten New High German Dialects with four texts from different time points for each dialect. We examined every word ending with ⟨b,p,d,t,g,k⟩, and collected the data for words which actually had /b,d,g/ underlyingly (as annotated in the corpus), excluding those words and morphological forms which had a final schwa before apocope. If the word was spelled with ⟨p,t,k⟩, we coded the token as having undergone fortition, and if it was spelled with ⟨b,d,g⟩, we coded it as not having undergone fortition. In total, we collected 8078 tokens from the corpus, with between 500 and 1200 tokens per dialect.

It is immaterial to our investigation whether or not the loss of fortition progressed in the same way in each dialect, as long as the rate of change is the same across segments within dialects. In fact, given different sociolinguistic conditions in different geographical regions of the German-speaking area, it is likely that any given change might spread in a somewhat different way in different speech communities. In contrast, we predict that

the grammar specifies a relationship between the different contexts for the application of fortition (i.e. the segments), and so if the fortition rule is lost, its frequency should change in lock-step across segments in any particular speech community. For this reason, we performed our statistical analyses on a dialect by dialect basis.

Of the ten dialects surveyed in the Bonn Corpus, the loss of fortition appears to have gone to completion in the three southern dialects: Swabian, East Swabian, and Central Bavarian. This makes sense given the data from Glaser (1985), which also came from a southern dialect, but starting about 150 years earlier than the Bonn Corpus. Since the change had completed in these dialects, we cannot use their data in our analysis.

Of the seven remaining dialects, the loss of fortition progresses monotonically in five, as shown in Figure 2. For each of these five dialects, we fit a logistic regression to its data with the same predictors as above, and performed an Analysis of Deviance of the model. The Segment:Year interaction term was not significant for any of these dialects, meaning that the rate of change for each segment within a given dialect is plausibly the same. Again, this is confirmation of the Constant Rate hypothesis.

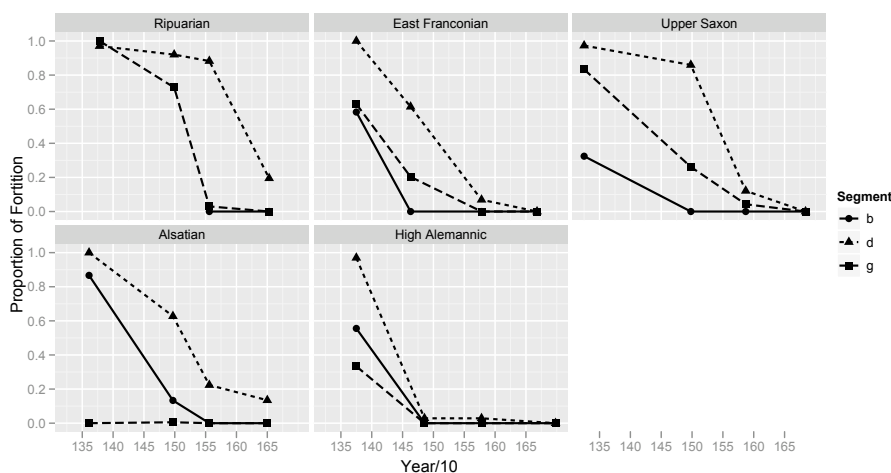


Figure 2: Bonn Corpus dialects with monotonic change  
Segment:Year Interaction Not Significant

For the remaining two dialects, the change in final fortition is strongly non-monotonic (see Figure 3). We don't have a hypothesis as to why there is a rise in fortition before its eventual fall in these dialects, but importantly, this is not disconfirmation of the Constant Rate hypothesis. What is significant for the CRE is that the relative change for all segments be the same, even if the overall shape of the change is erratic. Although we can't model the data from these dialects with the logistic function (it would be inappropriate given their non-monotonicity), it's clear that all segments share the same shape of change. We take the fact that all three segments move in lock-step through the erratic shape of change as further confirmation of the Constant Rate hypothesis. In a sense, this is even stronger confirmation of the CRE than the data from the more well-behaved dialects: it shows that the grammati-

cal relationship between the three contexts for rule-application is so strong, that even when the change is erratic, it is erratic in the same way in every context.

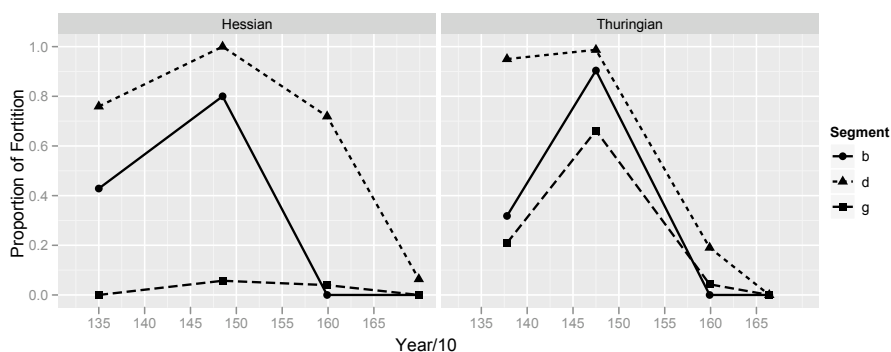


Figure 3: Bonn Corpus dialects with nonmonotonic change

In summary, our hypothesis about the nature of the grammar which produces final fortition makes a strong prediction about how we should observe that grammar change: all contexts affected by the same grammatical process should change at the same rate. We have examined data from eight dialects where this change occurred, and in all eight, the data is in line with our hypothesis.

#### 4. Implications for Phonological Theory and the Theory of Language Change

The demonstration of the Constant Rate Effect in phonological change has the effect of narrowing the range of possible hypotheses about how language change progresses and what phonological grammars must look like. The repeated discovery of the Constant Rate Effect in syntactic change has constituted important evidence that the emergence of a new syntactic system is preceded by a long period of variation between the new system and some old system, and that these variants competed in the minds of speakers at an abstract level of the grammar (e.g. at the level of the parameter setting that separates OV from VO languages). This competition between abstract, underlying grammatical variants is observable in terms of how the two variants' relative frequencies of use changed over time in a number of different syntactic contexts, and the constant rate of change over time in all of the contexts shows that the competition was always between the same two abstract variants, regardless of which context you happen to be observing the variation in at any given time. In other words, the variation was not between some different set of variants in each context, which are understandable only in terms of the specific context. Two clear consequences of this finding are: first, there is empirical evidence for the existence of abstract underlying syntactic structures (or parameter settings), and secondly, that individual speakers are “bidialectal” during periods of syntactic change; speakers acquire both parameter settings natively, but because the settings are in conflict, this situation is not stable diachronically and ultimately results in change (see Kroch (1994) for an in-depth discussion).

To our knowledge, this study is the first demonstration of the Constant Rate Effect in phonological change, and so it is the first piece of evidence that the mechanism of phono-



logical change is the same as syntactic change: grammar (or rule) competition. The rule of final fortition was gradually replaced in all contexts where it had originally applied, and so the loss of final fortition must be defined in terms of the competition between two abstract grammatical variants, just as in the case of syntactic change. In the case of fortition, a new grammar without the fortition rule must have been innovated or introduced in the relevant speech communities at some time, and then it proceeded to compete with, and ultimately win out over, the old fortition rule in all of the contexts where the old rule applied. Therefore, the same two findings that were established for syntactic change also apply here: first, the phonology must be organized such that the old fortition rule was stated without regard to place or articulation or lexical item, and secondly, individual speakers must have acquired both a “fortition-grammar” and a “non-fortition” grammar during the period of variation, with the “non-fortition grammar” gradually replacing the “fortition-grammar” more and more over time.

In this way, diachronic data can also help adjudicate between different theories of phonological representation and process. Specifically, many usage based accounts of phonology, like Exemplar Theory (Pierrehumbert 2002; Bybee 2002), are not amenable to the data presented here for two primary reasons. Firstly, the fact that the loss of final fortition was a possible phonological change *at all* demands rather abstract phonological representations before the change began. Secondly, the way in which the change progressed, at a constant rate in all contexts, is evidence for the cognitive reality of a phonological process, rather than the analogical generalizations of usage based models.

How was it possible for fortition to be lost? Taking the accusative plural of “day” for example, what was pronounced [tak] before the change was pronounced [tag] after the change. However, not all words which were pronounced with a final [k] before the change were pronounced with a final [g] afterwards. It was just those words which had a [k] ~ [g] alternation that underwent the change (Mihm 2004), see example (6) *cf.* (5) (Diel et al. 2002). Under normal assumptions of a generative phonology, learners would posit an underlying /g/ and a process of final fortition given the alternation. As fortition was lost, the underlying /g/ began to surface as [g]. A similar analysis under a usage based account would be much more difficult. Under many formulations, there is no “underlying form” *per se*, just generalizations over surface distributions. These analogical generalizations would have to be ensured to be very robust in order for us to observe the same change begin in eight out of eight dialects investigated.

(6) “strong”

- a. stark (Uninflected) starkes (Neut. Nom. Sg.); manuscript date: 1375
- b. stark (Uninflected) starken (Masc. Gen. Sg.); manuscript date: 1668

The loss of fortition in most of the dialects observed here exhibit a very typical “S-shaped curve.” This shape of change is predicted under models of grammar or rule competition (Kroch 1989), and in fact, the S-shaped logistic curve is the characteristic shape of *any* evolutionary competition between two variants in a population with finite resources (Nowak 2006: 12). By definition, we could not have rule competition if there was no cog-

nitive reality to the phonological rules in question outside of their token applications, and it is precisely this cognitive reality that strong usage based models dispute. More importantly, usage based models make the wrong prediction about the shape of the change. A model of phonological change, like that proposed by Bybee (2002),<sup>2</sup> predicts an *exponential* rate of change, as demonstrated by Fruehwald (2008), not a S-shaped curve.

However, the most important piece of evidence for theories of grammar presented here is the Constant Rate Effect. The fact that the rate of change in fortition is the same for all segments means that we did *not* observe three different competitions in each dialect: [p]~[b], [t]~[d], and [k]~[g]. Rather, we observed a *single* change of an abstract, phonological rule, unspecified for specific segments in competition with its non-application: FORTITION ~  $\emptyset$ . The Constant Rate Effect would be very unexpected under a usage based model since, again, there is no abstract, unspecified rule per se. If the locus of competition and change was on the word or segment level, we would expect to find a different rate of change for every segment. This is not what we observed.

We are not suggesting that it is impossible for the rates of change to be the same under a usage based account, just highly unlikely. Many exemplar theorists have proposed that some segment level analogical generalizations may occur. We assume that within an exemplar theoretic account, there is some probability that within some dialect that fortition would generalize to all voiced segments. Then, as the change progresses, there is some probability that every subsequent generation would make the same analogical generalization to every voiced segment. This would result in the rate of change across all segments being the same.

What is the probability of this chain of events? Given just that it has some probability  $p$ , the probability of observing this chain of events in eight out of eight dialects we investigated would be  $p^8$ . Figure 4 plots the probability that a usage based phonology might produce proper analogical generalizations across all generations in any given dialect against the subsequent probability of our findings. In order for our findings just to be just more likely than not, a usage based model would have to predict the probability of the proper generalizations occurring just once at  $\sqrt[8]{0.51} = 0.92$ . That is, the particular series of analogical generalizations, which may even be unlikely depending on the specifics of the model, would actually have to be nearly guaranteed to occur in order for a usage based model to account for our findings.

The discovery of the Constant Rate Effect in phonological change is perfectly expected under normal generative theories of phonology when the mechanism of change is grammar or rule competition. In order for a usage based model of phonology, like Exemplar Theory, to account for our data, stipulations and promissory notes must be heaped on to the point that it doesn't look much different from our generative assumptions, and its explanatory power as a theory is almost entirely eliminated.

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<sup>2</sup>Even more unfortunately for the usage based models, the phenomenon explored by Bybee (2002) was *not* a change in progress, but stable variation.

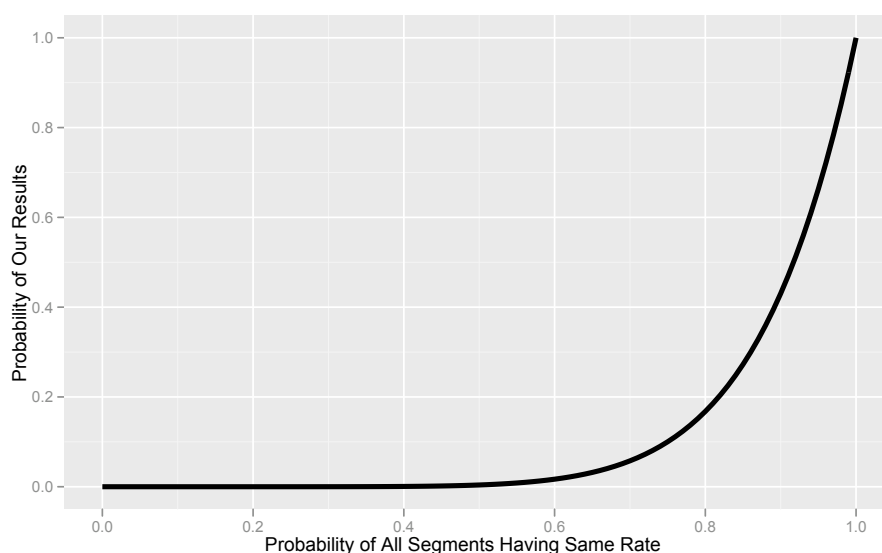


Figure 4: Probabilities of equal rates within one dialect against the resulting probability of our results

## 5. Conclusions and Directions for Further Research

In this paper, we explored the the loss of final fortition in Early New High German in quantitative detail, and showed that it progressed at a constant rate. To these authors' knowledge, this is the first demonstration that the Constant Rate Effect also holds in phonological change. Thus, we conclude that the mechanism of language change in both the syntactic and phonological modules of the grammar is the same: grammar competition. We then showed that this result can adjudicate between two theories of phonological grammar, concluding that the results fall out naturally from normal generative assumptions, and are quite unexpected under usage based approaches. Taking a step back, this type of result shows that synchronic linguistic theories can make specific, quantitative predictions about diachronic data, and so diachronic data is frequently directly relevant to linguistic theory as a whole, beyond just the study of language change itself.

For future research, we hope to identify more cases of the Constant Rate Effect in phonological change. The apocope that initially triggered the loss of fortition may be an excellent candidate. We would also like to explore the implications of the Constant Rate Effect for sound change more broadly construed. Neogrammarian sound change is not typically construed as occurring within the phonological component of the grammar, but rather in phonetic implementation. However, the observed regularity of sound change (Labov 1994) is a promising indication that similar notions of the Constant Rate Effect and competition may be applied there too.

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