HOW TO FORMALIZE VARIATION: STOCHASTIC OT MODELS AND /s/ DELETION IN SPANISH[1]

Keelan Evanini
University of Pennsylvania

The existence of variability, i.e., when multiple surface forms correspond to a single underlying representation, is a significant problem for many formal theories of phonology, which are often treated as strictly deterministic. Many theorists simply regard the different surface forms as *free variants* and use *optional rules* to formalize the variation (see Chomsky & Halle 1968). Others argue that the choice of surface variants is a performance phenomenon, and has no place in a model of grammatical competence (e.g., Bickerton 1971).

However, following Labov's early work (e.g., his 1969 article on the copula in AAVE) which demonstrated that the choice of surface variants is conditioned in a consistent and probabilistic manner by several factors, most variationist sociolinguists have assumed *inherent variability* in the grammar. That is, a speaker's grammatical competence contains knowledge of all of the surface variants, as well as knowledge of how frequently they occur. While variationists working under this paradigm do not always attempt to formalize their empirical findings, when they do, the model they use most commonly is the *variable rule* (see Labov 1969 and Cedergren & Sankoff 1974 for early formulations).

The locus of variation in a speaker's grammar has remained a contentious issue to the present day (see, for example, the exchange between Newmeyer 2003 and Bybee 2005). Recently, however, many phonologists, especially those working within the framework of Optimality Theory (OT), have begun to explore ways in which to extend their formal models to account for variation. Some of the formalisms that have been proposed are Partially Ordered Grammars (Anttila 1997), Floating Constraints (Reynolds 1994, Nagy & Reynolds 1997), Constraint Competition (Zubritskaya 1997), and Stochastic OT (Boersma 1997, Boersma & Hayes 2001). Anttila (2002) and (*In press*) provide good general overviews of these various formalisms and how they relate to each other. Significantly, all of them assume that at least some knowledge of variation is located in a speaker's grammatical competence, and thus depart from more traditional phonological formalisms that have attributed variation solely to performance. In this regard, they come closer to the model of inherent variability espoused by many variationists. However, they are still limited in that they usually focus only on providing a model that generates the raw output frequencies of the surface variants, and cannot adequately account for all of the factors that condition the variation.

In this paper, I apply the formal model of variation that has received the most attention in recent years, namely Stochastic OT, to the phenomenon of /s/ deletion in Spanish, one of the most widely studied sociolinguistic variables. I show how this formalism is not adequate to provide a complete model of the phenomenon, and propose changes to it that enable it to take into account the empirical findings from variationist studies. Finally, I compare this modified Stochastic OT formalism with the variable rule model, and demonstrate that the two are functionally equivalent. This finding represents an advance for both phonological and sociolinguistic theory, and should lead to greater collaboration between the two fields.

1 /S/ DELETION IN SPANISH.

/s/ deletion in Spanish is one of the most widely studied sociolinguistic variables, and has been documented for several dialects, including Puerto Rican (Ma & Herasimchuck 1971, Poplack 1980), Panamanian (Cedergren 1973), Colombian (Lafford 1982), and Chilean (Cid-Hazard 2003). The fact that so many quantitative analyses of /s/ deletion have been carried out, and that they have consistently shown the same conditioning factors to have significant effects on the choice of variants, means that it is an ideal variable for testing the formal phonological models listed in the introduction.

The general phonological pattern is that /s/ undergoes a process of lenition in syllable coda position, either resulting in aspiration (change to [h]) or deletion[2]. In this paper I will refer to the general process as */s/ deletion*, whether the final result is aspiration or deletion. /s/ deletion can occur either when the underlying /s/ is contained within the root or an inflectional affix. For example, /mismo/ *mismo* 'same' can surface as [mismo], [mihmo], or [mimo], and /kasa+s/ *casas* 'houses' can surface as [kasas], [kasah], or [kasa]. Table 1 describes the OT constraints that are necessary to produce these three surface variants.

constraint	description of constraint	violated by
$*s]_\sigma$	no syllable-final /s/[3]	[kasas]
MAX	every input segment has a corresponding output segment	[kasa]
ID-PLACE	the place of articulation of an output segment is identical to the place of articulation of the corresponding input segment	[kasah]
ID-MANNER	the manner of articulation of an output segment is identical to the manner of articulation of the corresponding input segment	[kasan] (non-occurring)

Table 1. Constraints necessary for a grammar of /s/ deletion in Spanish.[4]

The markedness constraint $*s]_\sigma$ militates against having [s] in the coda position of a syllable, while the three faithfulness constraints prevent changes from being made to the underlying form. In a strictly deterministic OT grammar, the constraints in Table 1 would have a fixed ranking, so there could only ever be a single output form for the input /kasas/. In order to produce the three occurring output forms—[kasas], [kasah], and [kasa]—three separate grammars would be needed. In the next section I describe how a stochastic OT grammar can account for this type of variation within a single grammar.

2 VARIATION IN A STOCHASTIC OT MODEL.

Stochastic OT models are one way to reconcile the need for a deterministic constraint ranking during speech production with the variation inherent to natural language (see Boersma & Hayes (2001:47-50) and Anttila (2002:231-233) for overviews of the formalism). In these models, each constraint has a numerical ranking whose value does not change after the grammar has been acquired, i.e., around the critical age[5]. This is called the constraint's *ranking value*. The moment when the linguistic form is processed immediately before being uttered is the *evaluation time*. At the evaluation time for every form, a stochastic element is introduced and combined with every constraint's ranking value to produce the actual value used to rank the constraint for that utterance. This value is called the *selection point*.

For any given ranking value, the process of calculating the selection point at evaluation time simply involves adding the random noise to the ranking value. This equation is provided in (1):

(1) $selectionPoint_i = rankingValue_i + noise$

The noise value is defined to have a Gaussian distribution, whose standard deviation is conventionally stipulated to be 2. This value is arbitrary, and the choice does not affect evaluation, as long as the standard deviation is the same for all constraints. This is because the ranking values themselves are arbitrary (Boersma & Hayes 2001:49). Variation in the output forms arises when the ranges for two constraints overlap, and the two different rankings cause two different forms to be optimal.

Figure 1 provides a graphical representation of this process. Two constraints are shown, with the ranking values given in bold, **A** and **B**. Most of the time, the selection point for constraint **A** will be higher than for constraint **B**; however, variation can occur, as shown by the selection points A_2 and B_2.

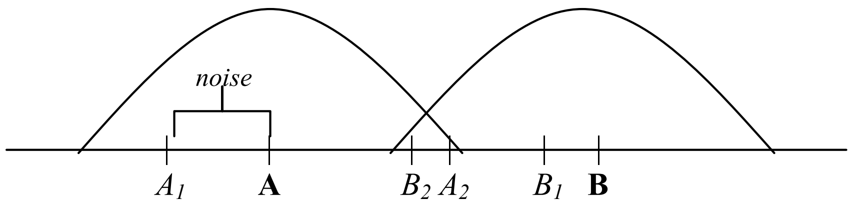

Figure 1. Illustration of two constraints in a stochastic OT grammar.

For example, a simplified analysis of Spanish /s/ deletion with only the two output forms [kasas] and [kasa] corresponding to the input /kasas/ would have the two constraints $*s]_\sigma$ and MAX. A hypothetical example of a Spanish dialect in which deletion occurs more often than retention would assign the constraints ranking values that are relatively close to each other, e.g., 100 for $*s]_\sigma$ and 99 for MAX. Table 2 shows a Praat (Boersma & Weenick 2006) implementation of ten evaluation times for these ranking values along with the resulting selection points for each constraint.

eval. time	1	2	3	4	5	6	7	8	9	10
MAX	100.4	98.3	99.6	96.5	101.8	98.6	98.2	98.8	97.3	101.0
$*s]_\sigma$	100.3	99.5	100.9	101.4	100.8	99.1	104.0	100.1	99.1	98.5
output	kasas	kasa	kasa	kasa	kasas	kasa	kasa	kasa	kasa	kasas

Table 2. 10 sample stochastic evaluations for simplified /s/ deletion.

The optimal output forms for each evaluation time are shown in the bottom row of Table 2. In these 10 evaluation times, this simulated speaker would have produced [kasas] three times (trials 1, 5, and 10) and [kasa] seven times.

The variation modeled in Table 2 is due to the fact that the ranking values of the constraints are within one standard deviation of each other. On the other hand, in order to model a speaker who does not exhibit variation, the ranking values for the two constraints would have to be several standard deviations apart. Then, variation would be extremely unlikely, and the ranking of the two constraints would be effectively categorical.

3 A STOCHASTIC OT GRAMMAR OF /S/ DELETION.

3.1 STOCHASTIC GRAMMAR FOR TOTAL OUTPUT FREQUENCIES ONLY.

Cedergren (1973) reports the results of a sociolinguistic survey of Spanish in Panama City. Her corpus contains 22,167 tokens of syllable final /s/, and Table 3 shows the distribution of the three variants: [s], [h], and [Ø].

variant	%
[s]	11
[h]	41
[Ø]	48

Table 3. Syllable final /s/ in Panamanian Spanish.

The GLA (Gradual Learning Algorithm) is an algorithm for learning the ranking values of constraints in a stochastic OT grammar (see Boersma 1997, Boersma & Hayes 2001:51-54 for details). It simulates the process of grammar acquisition for a language learner exposed to variable surface data. Table 4 presents the results of a GLA simulation with 22,167 input-output pairs with the frequencies from Cedergren's study (all constraints were given an initial ranking of 100).

22,167 IO pairs; 0.1 plasticity; [kasas] 11%, [kasah 41]%, [kasa] 48%	
constraint	ranking value
ID–MANNER	105.14
$*s]_\sigma$	99.71
ID–PLACE	98.03
MAX	97.12

Table 4. Constraint ranking values for total output frequencies, no stylistic information.

These ranking values illustrate how the GLA acquires rankings to produce both categorical and non-categorical data. First of all, ID–MANNER is ranked nearly three standard deviations higher than the next highest constraint. This means that a speaker with this grammar would produce [kasan] rarely enough to make this form indistinuishible from a speech error (Boersma 1997:45). Thus, this is effectively a categorical ranking.

On the other hand, the the constraints $*s]_\sigma$ and MAX are both within one standard deviation of ID–PLACE. This means that the output forms [kasas], [kasah], and [kasa] will all be optimal at different evaluation times with a relatively high frequency. Table 5 illustrates a sample evaluation time with [kasa] as the optimal output.

/kasas/	ID–MANNER	$*s]_\sigma$	ID–PLACE	MAX
selection point	101.49	100.42	96.36	95.28
kasas		*!		
kasah			*!	
☞ kasa				*
kasan	*!			

Table 5. Sample evaluation time of the stochastic grammar in Table 4.

The grammar described in Table 4 is an adequate formal model of a speaker's competence for the total variable output of /kasas/.[6] A speaker with that grammar will produce [kasas] 11%, [kasah] 41%, and [kasa] 48% of the time. However, this only takes into account the raw output frequencies, and ignores of the other factors that condition the variable output.

3.2 A STOCHASTIC GRAMMAR WITH STYLISTIC CONSTRAINTS INCLUDED.

The stochastic grammar for /s/ deletion in Spanish as presented in Table 4 is inadequate, since it cannot account for all of the factors that variationist studies have shown to have a significant effect on the choice of surface forms. For example, more formal styles have been shown to inhibit deletion of /s/, whereas more casual styles promote deletion. Table 6 presents style-shifting data for /s/ deletion from a study of Columbain Spanish (Lafford 1982, cited in Morris 1998:7).

style	[s]	[h]	[Ø]
casual	20	35	45
careful	28	39	33
reading	66	17	16
word list	87	5	8

Table 6. Stylistic constraints on /s/ deletion in Columbian Spanish.

In order to model these stylistic constraints using the current stochastic OT formalism, it would be necessary to posit separate ranking values for each style. These ranking values, produced using the GLA and the process described in Section 3.1 are included Tables 9-12 in the Appendix. However, this model forces us to posit that the speaker actually has four distinct grammars, each of which is evaluated stochastically. This situation combines a stochastic model with a model similar to the Multiple Grammars Theory (e.g., as described in Anttila *In press*:3-7).

In order to preserve a model in which all surface variants are processed as part of the same grammar, Boersma & Hayes suggest a modification to the equation used at the evaluation time that unifies the stochastic procedure for determining ranking values with style shifting information. This solution is shown in equation (2):

(2) $selectionPoint_i = rankingValue_i + \boldsymbol{styleSensitivity_i * Style} + noise$

(Boersma & Hayes 2001:83)

This equation adds the terms $styleSensitivity_i$ and *Style* to equation (1). *Style* is a variable whose value is determined by the style of the utterance; its values range from 0 (maximally casual speech) to 1 (maximally formal speech). Each constraint then has a specific *styleSensitivity* value, based on the effect of style on the constraint. For example, *styleSensitivity* has a positive value for $*s]_\sigma$ (producing a higher ranking in formal speech), a negative value for MAX (producing a higher ranking in casual speech), and a value of zero for ID–MANNER (since this constraint is not sensitive to style shifting). These two new terms in the equation used at evaluation time thus alter the selection point for each constraint appropriately for any given style.

With this extension to the stochastic OT grammar formalism, it is now possible to provide a model for a grammar that produces variable output that is also sensitive to stylistic constraints. However, this model is still cannot account for all of the factors that condition the appearance of the surface variants.

3.3 STOCHASTIC GRAMMAR INCLUDING ALL CONDITIONING FACTORS.

Apart from the external stylistic factors that condition the variation of /s/ deletion, variationist studies have also shown that many internal grammatical factors have significant effects on the choice of which surface variant to use. The three factor groups that Cedergren (1973) found to be significant for /s/ deletion in Spanish are part of speech (hereafter POS) of the word containing the /s/, grammatical status of the /s/, and following segment. Their effects are listed in Table 7.

Factor Group	strongly promotes /s/ deletion	mildly promotes /s/ deletion	inhibits /s/ deletion
POS	adjective	noun	determiner
grammatical status of /s/	monomorphemic	plural -/s/ suffix	2^{nd} Sg. -/s/ suffix
following segment	consonant	vowel	pause

Table 7. Internal grammatical factor groups affecting /s/ deletion.

Cedergren (1973:15) formalized her model of a speaker's competence that includes all of the conditioning factors discussed so far using a variable rule, and this has continued to be the preferred model among variationists. In order for a stochastic OT model to do the same, the formalism presented in Section 3.2 for stylistic conditioning would have to be extended to also include the internal conditioning factors in Table 7. This would involve introducing a constraint-specific weight for each of the relevant factors and modifying the equation for a constraint's selection point at the evaluation time as was done in equation (2) to account for stylistic conditioning.[7] Equation (3) presents these modifications (new terms are in bold):

(3) $selectionPoint_i = rankingValue_i + styleSensitivity_i * Style + \mathbf{posSensitivity_i * POS + gramSensitivity_i * Gram + follsegSensitivity_i * FollSeg} + \text{noise}$

Analogous to the variable *Style*, the variables *POS*, *Gram*, and *FollSeg* would have values that range from 0 to 1, depending on the effect of each factor in the given utterance. For example, in the phrase *las casas bonitas*, the variable POS would have a value close to 0 for the evaluation time of the word *las* (since determiners inhibit /s/ deletion), a moderate value for the noun *casas*, and a value close to 1 for the adjective *bonitas*. The values *posSensitivity*, *gramSensitivity*, and *follsegSensitivity* would be distinct for each constraint, and would indicate how sensitive each constraint is to the effects of the various factor groups. The selection point for each constraint at the evaluation time would then simply be the combination of the (fixed) ranking value with all of the additional values determined by the grammatical and stylistic context. Of course, the stochastic noise value would also be added as usual, so the *POS*, *Gram*, and *FollSeg* effects would end up being non-categorical, which is the desired result.

A complete stochastic OT grammar would then consist of ranking values for all of the constraints along with sensitivity values for all of the significant factor groups. This grammar would be an improvement over all previous stochastic OT grammar models, since it would actually account for all of the causes of variable data.

4 COMPARISON TO VARIABLE RULE MODELS.

The extensions to the stochastic OT formalism introduced in Section 3.3 now enable it to account for the internal and external conditioning factors that variationists have usually modeled with variable rules. However, the resulting equation in (3) looks strikingly similar to a variable rule. Equation (4) presents the standard logit-additive model of a variable rule (Sankoff 1988):

(4) $\log (p / 1 - p) = p_0 + \beta_a + \ldots + \beta_n$

In this equation, p_0 represents the input probability for the rule's application. It is an invariant likelihood, and is analogous to constraint's fixed ranking value in Stochastic OT. $\beta_a + \ldots + \beta_n$

represent the effects of the conditioning factors and are identical to the effects produced by adding the constraint-specific sensitivity weights in equation (3). Finally, log (p / 1 – p) is the probability that the rule will apply for a given utterance, and is similar to a constraint's selection point for a given evaluation time. Table 8 summarizes these commonalities between the stochastic OT model in (3) and the variable rule model in (4).

Stochastic OT	Variable Rules	Common Characteristic
ranking value	input probability (p_0)	the invariant likelihood that a rule will apply / (markedness) constraint will rank higher than the faithfulness constraints
selection point	log (p / 1 – p)	the probability for any given utterance that a rule will apply / (markedness) constraint will rank higher
constraint sensitivity weights	factor effects ($\beta_a + \ldots + \beta_n$)	the added effect of all of the factors conditioning variation

Table 8. Commonalities between Variable Rules and Stochastic OT Models.

While the two models are similar, they are not exactly the same. First of all, the stochastic OT model in equation (3) deals with *constraints*, whereas the variable rule model in (4) deals with rules. However, this is simply a difference in the form of the model, not the function. In effect, saying "rule X applies" and "markedness constraint X outranks faithfulness constraint Y" are identical in that they cause the surface form to deviate in the same way from the underlying form. When equation (3) is used to calculate the selection points for all relevant constraints at evaluation time, the result will be the same as applying a variable rule.

Secondly, the two models differ in how they introduce a stochastic element to account for variation among the surface forms. The stochastic OT model assumes a Gaussian distribution for the noise value that is added to the ranking value and factor effects to produce the selection point, whereas the variable rule model assumes a logistic distribution of error. Again, however, this is not a substantial difference. The differences between models using a Gaussian distribution and ones using a logistic distribution of error are usually insignificant. In fact, Paolillo

(2002:187) asserts that 'for many data sets the two models are equally applicable, and represent an approximate linear scaling of one another.'

Thus, when the current stochastic OT model as proposed by Boersma & Hayes (2001) is extended as in (3) to account for all factors that condition variation, the model it provides of a speaker's linguistic competence does not differ substantively from the variable rule model used by many sociolinguists.

5 CONCLUSION.

The finding that stochastic OT and variable rule models are equivalent ways of representing a speaker's knowledge of surface variants and the factors that condition their variation should help bridge the gap between formal phonologists and sociolinguistics. On the one hand, phonologists now have a way to model the internal and external factors that sociolinguistic studies have shown to be significant, and no longer need to dismiss them as free variants. On the other hand, variationists now have a way of relating their empirical findings to the framework of formal phonology. It can be hoped that further research along these lines will lead two more future collaboration between the two groups.

---

[1]I would like to thank Eugene Buckley and an anonymous reviewer for comments on earlier drafts of this paper.

[2]In some dialects (mostly Andalusian), deletion is accompanied by gemination of the following consonant, as in [mimmo]. This variant will not be considered in this study.

[3]A more general constraint against syllable-final consonants, $*C]_{\sigma}$, would not adequately describe the data, since it cannot differentiate between [kasas] and [kasah]. Also, other syllable-final consonants in Spanish do not exhibit the same kind of deletion, so it is clear that a more specific constraint is required. Morris' solution (1998:224) to use the constraint $*C_{[+strident]}]_{\sigma}$ is equivalent, since /s/ is the only [+strident] consonant that can occur in syllable-final position.

[4]Note that additional constraints are also needed to prevent other sub-optimal strategies for avoiding a violation of $*s]_{\sigma}$. For example, DEP is needed to exclude an output form with epenthesis, such as [kasasa].

[5]In order to accommodate linguistic changes that occur across a speaker's lifespan it is possible to supply a non-zero *plasticity* value to a constraint for an adult speaker (Boersma & Hayes 2001:52).

[6]The *formal* nature of this model should be stressed here. The stochastic OT formalism in itself does not make any claims about processing speed or the psycholinguistic plausibility of the model. Indeed, many aspects of the model have been criticized by psycholinguists, such as the infinite generating power of GEN.

[7]An alternative solution would be to "explode" the constraints, and have a separate constraint for each environment in each factor group. Thus, in order to account for the POS effects, $*s]_{\sigma}$ would become three constraints ranked as follows: $*s]_{\sigma\,(ADJ)} \gg *s]_{\sigma\,(NOUN)} \gg *s]_{\sigma\,(DET)}$. This solution, however, is undesirable, because not all constraints would adhere to accepted markedness theories, and it would require the addition of many language-specific constraints.

References

Anttila, Arto. 1997. Deriving variation from grammar. In *Variation, Change, and Phonological Theory*, ed. by Frans Hinskens, Roeland van Hout, & W. Leo Wetzels, 35-68. John Benjamins: Amsterdam.

---. 2002. Variation and Phonological Theory. In *The Handbook of Language Variation and Change*, ed. by J.K. Chambers, Peter Trudgill, & Natalie Schilling-Estes, 206-243. Oxford: Blackwell.

---. *In press*. Variation and optionality. In *The Cambridge Handbook of Phonology*, ed. by Paul de Lacy, Ch. 22. Cambridge: Cambridge University Press.

Bickerton, Derek. 1971. Inherent variability and variable rules. *Foundations of Language* 7:457-492.

Boersma, Paul. 1997. How we learn variation, optionality, and probability. *Institute of Phonetic Sciences, University of Amsterdam, Proceedings* 21:43-58.

Boersma, Paul & Bruce Hayes. 2001. Empirical tests of the gradual learning algorithm. *Linguistic Inquiry* 32:45-86.

Boersma, Paul & David Weenink. 2006. Praat: Doing phonetics by computer (Version 4.4.03). Downloaded from *http://www.praat.org/*.

Bybee, Joan. 2005. Grammar is usage and usage is grammar. Presidential address, The Linguistic Society of America Annual Meeting, Oakland, CA, January 8, 2005.

Cedergren, Henrietta J. 1973. On the nature of variable constraints. In *New Ways of Analyzing Variation in English*, ed. by C.-J. Bailey & Roger Shuy, 13-22. Georgetown University Press.

Cedergren, Henrietta J. & David Sankoff. 1974. Variable rules: performance as a statistical reflection of competence. *Language* 50:333-355.

Chomsky, Noam & Morris Halle. *The Sound Pattern of English*. Cambridge, MA: The MIT Press.

Cid-Hazard, Susanna Margarita. 2003. Style variation in relation to the phonological variable /s/ in the Spanish of Santiago, Chile. Southwest Journal of Linguistics 22(2):13-43.

Labov, William. 1969. Contraction, Deletion, and Inherent Variability of the English Copula. *Language* 45(4):714-762.

---. 2001. *Principles of Linguistic Change, Volume 2: Social Factors*. Oxford: Blackwell.

Lafford, Barbara. 1982. *Dynamic Synchrony in the Spanish of Cartagena, Columbia*. Doctoral Dissertation, Cornell University.

Ma, Roxana & Eleanor Herasimchuck. 1971. The linguistic dimensions of a bilingual neighborhood. In *Bilingualism in the Barrio*, ed. by Joshua Fishman & Roxana Ma, 449-464. Bloomington: Indiana University Press.

Morris, Richard E. 1998. *Stylistic Variation in Spanish Phonology*. Doctoral Dissertation, Ohio State University.

Nagy, Naomi & Bill Reynolds. 1997. Optimality Theory and word-final deletion in Faeter. *Language Variation and Change* 9:37-55.

Newmeyer, Frederick. 2003. Grammar is grammar and usage is usage. *Language* 79:682-707.

Paolillo, John C. 2002. *Analyzing Linguistic Variation: Statistical Models and Methods*. Stanford: CSLI Publications.

Poplack, Shana. 1980. The notion of the plural in Puerto Rican Spanish: competing constraints on s deletion. In *Locating Language in Time and Space*, ed. by William Labov. 55-67. New York: Academic Press.

Reynolds, William T. 1994. *Variation and Phonological Theory*. Doctoral Dissertation, University of Pennsylvania.

Sankoff, David. 1988. Variable Rules. In *Sociolinguistics: An international handbook of the science of language and society*, ed. by U. Ammon, N. Dittmar, & K.J. Matteier, 984-997. Berlin.

Zubritskaya, Katya. 1997. Mechanism of sound change in Optimality Theory. *Language Variation and Change* 9:121-148.

Appendix

Tables 9-12 represent the ranking values generated by the Gradual Learning Algorithm for the four constraints involved in the process of /s/ deletion using the stylistic data provided by Lafford (1982). Thus, these represent the four separate grammars that would be needed to produce the surface forms using the Stochastic OT model of Boersma & Hayes (2001). In Section 3.2 I propose an extension to their model that captures these effects within a single grammar.

22,167 IO pairs; 0.1 plasticity; [kasas] 20%, [kasah] 35%, [kasa] 45%	
constraint	ranking value
ID–MANNER	105.23
*s $]_\sigma$	99.18
ID– PLACE	98.19
MAX	97.40

Table 9. Constraint rankings for casual style.

22,167 IO pairs; 0.1 plasticity; [kasas] 28%, [kasah] 39%, [kasa] 33%	
constraint	ranking value
ID–MANNER	104.89
ID–PLACE	98.395
*s $]_\sigma$	98.359
MAX	98.355

Table 10. Constraint rankings for careful style.

22,167 IO pairs; 0.1 plasticity; [kasas] 66%, [kasah] 17%, [kasa] 16%	
constraint	ranking value
ID–MANNER	105.08
MAX	99.38
ID–PLACE	98.73
*s $]_\sigma$	96.81

Table 11. Constraint rankings for reading style.

22,167 IO pairs; 0.1 plasticity; [kasas] 87%, [kasah] 5%, [kasa] 8%	
constraint	ranking value
ID–MANNER	104.71
ID–PLACE	100.23
MAX	99.09
*s $]_\sigma$	95.98

Table 12. Constraint rankings for word list style.