Gradient trends against phonetic naturalness: The case of Tarma Quechua*

Gašper Beguš & Aleksei Nazarov

University of Washington, University of Toronto

1. Introduction

In Optimality Theory (OT; Prince & Smolensky 1993/2004) and related theories (Harmonic Grammar: Legendre et al. 2006, Pater 2008, 2009; Maximum Entropy Grammar: Goldwater & Johnson 2003), two questions have recently received increased attention in the literature: (i) how to represent gradient phonotactic restrictions in the grammar (Frisch et al. 2004, Anttila 2008, Coetzee & Pater 2008, Wilson & Obdeyn 2016, i.a.), and (ii) whether and how to represent unnatural processes in the grammar (Hayes 1999, Hyman 2001, Blevins 2004, Wilson 2006, Hale & Reiss 2004, Samuels 2009, Coetzee & Pretorius 2010, Hayes & White 2013, i.a.). To our knowledge, however, there exists no systematic treatment of the intersection of these two topics: unnatural gradient phonotactics, i.e. phonotactic restrictions that, given a particular environment, target a single (segmental) feature and gradiently favor the value of this feature that is unnatural in that environment.

This paper presents an initial investigation of such unnatural gradient phonotactic restrictions: we present the case of a lexically gradient phonotactic restriction that operates against what would be phonetically natural: Tarma Quechua stop voicing. The paper shows that the unnatural trend in the lexicon is statistically significant, phonetically real, and shows clear signs of productivity, with evidence from loanword phonology and from morphophonological alternations. To our knowledge, this is the first report of a (truly) unnatural gradient phonotactic restriction on segmental structure. The unnatural gradient phonotactics in Tarma Quechua bears theoretical implications: we demonstrate that Harmonic Grammar with CON restricted to natural constraints only allows phonotactic restrictions that are natural (i.e., those that favor the natural feature value in a given environment), contrary to what is attested in our data.

---

*We would like to thank Joe Pater, Kevin Ryan, Gaja Jarosz, Adam Albright, and Jay Jasanoff, as well as audiences at the mfm 23, OCP 13, BLS 42, AFLA 22, PhoNE 2016, AMP 2017, NELS 48, the Phonology Circle at the Massachusetts Institute of Technology, and the Sound Workshop at the University of Massachusetts, Amherst, for their useful comments. We are especially grateful to Willem Adelaar for his permission to analyze his Tarma Quechua recordings. All mistakes are, of course, our own.

2. Unnatural trend in the lexicon

2.1 Stop voicing

Tarma Quechua is a dialect of Quechua (Quechua I) spoken in Tarma district in the Junín province of Peru. The Quechua dialect continuum almost uniformly has only voiceless stops in native vocabulary (Adelaar & Muysken 2004). However, Adelaar (1977) and Puente Baldoceda (1977) report that some of these voiceless stops have become voiced in Tarma Quechua (henceforth: TQ). Voiceless non-coronal stops are reported as undergoing voicing in intervocalic and post-consonantal positions, but not after a nasal consonant. Adelaar (1977) and Puente Baldoceda (1977) note that voicing does not apply categorically (and that it does not apply post-nasally), but no further analyses on the lexicon are performed. Below we present results of a statistical analysis of the TQ lexicon that reveals a highly unnatural trend. We adopt the definition of unnatural processes from Beguš (2017): unnatural processes are those that not only lack phonetic motivation, but operate against some universal phonetic tendency. We show that, in addition to limitations on voicing after nasals, the relative rates of voicing in various environments, including intervocalic and post-consonantal positions, contradict several universal phonetic tendencies. This paper, to our knowledge, is the first report of this unnatural distribution in TQ.

For the purpose of the analysis, we collected all tokens of stops from the vocabulary list in Adelaar (1977). Because alveolars never undergo voicing, they were omitted from the analysis – only labials and velars were kept. In addition, word-final stops and the first members of consonant clusters always surface as voiceless, so they were also excluded from the analysis. A total of 1199 tokens were collected: 910 tokens were from the native TQ vocabulary, and 289 are labeled as loans from Spanish in Adelaar (1977). The stops in each data point were annotated for Voicing (present or not), Place of articulation (labial or velar), and Position (phonological context). The latter variable had five values: word-initial, post-nasal, intervocalic, post-sonorant, post-obstruent. The initial raw data analysis reveals a surprising trend: voicing surfaces almost never post-nasally (9.5%), in almost half of the lexicon intervocalically (42.5%), and almost always post-consonantally, including in positions after a voiceless obstruent (86.1%).[1]

(1) *Voiced vs. voiceless labial and velar stops in Tarma Quechua native vocabulary across contexts*

	#__	N__	V__V	R__	T__
voiced	7	7	99	72	68
voiceless	276	67	134	13	11
% voiced	2.5	9.5	42.5	84.7	86.1

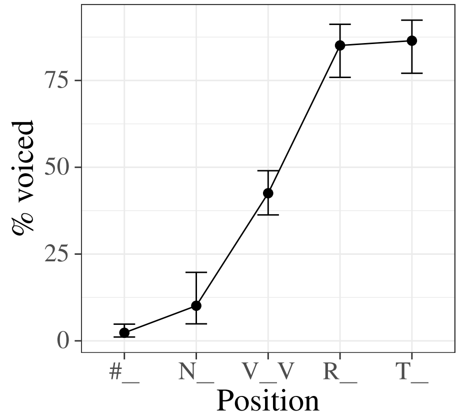
To test the statistical significance of this trend, we fit a logistic regression model to the data with the R statistical software (R Core Team 2017) using the *glm()* function. The first

---

[1] Unless noted otherwise, we will henceforth designate classes of consonants with the following abbreviations: T – voiceless obstruent, D – voiced obstruent, N – nasal, R – non-nasal sonorant, V – vowel.

model includes only native vocabulary. The dependent variable was binary: presence or absence of voicing; the independent variables were Place of articulation (treatment-coded with two levels, labial and velar, with labial as the reference level), and Position (treatment-coded with five levels: initial, post-nasal, intervocalic, post-sonorant, and post-obstruent, with intervocalic as the reference level) with no interactions. The best fitting model was chosen with the step-wise backwards model selection technique: higher order interactions were removed step-wise from a full model. If the likelihood ratio tests (LRTs) determined an interaction or predictor does not improve fit significantly, they were removed until all predictors in the model significantly improved the fit.

(2) *Percent voiced stops*



(3) *Logistic regression model*

	β	z	Pr(>|z|)
(Intercept)	-0.0	-0.3	0.7952
V__V vs. R__	2.0	6.2	0.0000
V__V vs. T__	2.2	6.1	0.0000
V__V vs. N__	-1.9	-4.5	0.0000
V__V vs. #__	-3.4	-8.4	0.0000
velar vs. labial	-0.5	-2.3	0.0191

As shown in this analysis, [+voice] in non-coronal stops is significantly less frequent word initially and post-nasally compared to intervocalic position. [+voice] is significantly more frequent in post-sonorant and post-obstruent position compared to intervocalic position in TQ native vocabulary.

Post-nasal and intervocalic position universally prefer voicing, while voiced stops after voiceless obstruents are universally dispreferred (see Beguš 2018b and literature therein). It is thus highly unnatural that TQ exhibits less voicing post-nasally and intervocalically than after voiceless obstruents (the first members of a consonant cluster never underwent voicing).[2] TQ voicing thus operates in a direction opposite to two universal phonetic tendencies: it operates more frequently where it is dispreferred (post-consonantally) and less frequently where it is preferred (post-nasally and intervocalically). These findings are summarized in (4), where “context X is dispreferred to context Y” is written as X ≺ Y.

(4) *Unnatural distribution of [+voice]*

Universal tendencies for [+voice]	Observed significant trends in TQ
T__ ≺ V__V	V__V ≺ T__
T__ ≺ N__	N__ ≺ V__V ≺ T__

---

[2] The analysis shows post-nasal ≺ intervocalic and intervocalic ≺ post-obstruent, from which post-nasal ≺ post-obstruent can be derived by transitivity.

These trends are significant even if we include loanwords in the analysis. Data with loanwords was fit to a model that initially had two independent variables: Position (treat-ment-coded with same levels as above) and Place of articulation (sum-coded with velar as the reference level). The significance of all main effects remains the same as in the native vocabulary, but now the Position × Place interaction becomes significant. Loanword status was not added to the model as a predictor.

If we isolate loanwords from the native vocabulary, we do not observe the unnatural pattern at the same magnitude as in the native vocabulary. As will be shown below, however, the unnatural voicing pattern does apply to some loanwords.

Another locus of gradient unnaturalness emerges in TQ if we look into the within-context distribution of voicing in the post-obstruent position: clusters that agree in voicing are gradiently dispreferred in TQ — clusters that disagree in voicing are significantly more frequent.

We saw that labial and velar stops surface as voiced in non-nasal post-consonantal position (1). The following consonants are attested as triggering voicing: [t, ʧ, ʈ͡ʂ, k, s, ʃ, x, l, lʲ, r, j, w]. Note that the list includes voiceless fricatives, affricates and even voiceless stops. Interestingly, in stop-stop clusters, the second member is almost never voiceless if it is non-coronal. The table in (5) below presents examples of obstruent-initial clusters that disagree in voicing, organized by first consonant (data from Adelaar 1977).

(5) *Obstruent clusters in TQ (from Adelaar 1977*

1st member	2nd member	
	Labial	Velar
t	lutbi	mutɡi
ʧ	/	aʧɡa
ʈ͡ʂ	aʈ͡ʂba	maʈ͡ʂɡa
k	takba	/
s	ʧasbu	ʈ͡ʂasɡi
ʃ	kaʃbi	iʃɡi
x	saxbi	manexax-ɡunas

Obstruent clusters that disagree in voicing are much more frequent than clusters that agree in voicing if the second consonant is either a labial or a velar. The table in (6) shows the number of occurrences of obstruent clusters in which the second element is a labial or a velar. To test the statistical significance of this distribution, the data was fit to a logistic regression model with only voicing as the dependent variable (empty model). The main effect of Place of articulation was not significant. Second-element stops (labial and velar) are significantly more frequently voiced (as opposed to voiceless) in clusters with a voiceless first element in TQ native vocabulary ($\beta = 1.8$, $z = 5.6$, $p < 0.0001$). This significance remains if we add loanwords into the counts: the best fitting model includes the intercept and a main effect of loanword status (if it is justified cognitively). Voiced stops are more frequent in obstruent clusters compared to voiceless stops ($\beta = 1.4$ z $= 5.2$, $p < 0.0001$).[3]

(6) *Voice feature in obstruent clusters*

	TT	**TD**	**DT**	**DD**
Count	11	68	0	0
Percent	13.9%	86.1%	0%	0%

TQ thus exhibits a statistically significant trend such that clusters that disagree in voicing are preferred to clusters that agree in voicing. This trend is both gradient and unnatural.

The trend against agreeing obstruent clusters in TQ is unnatural in one additional respect. The table in (6) shows a preference for TD clusters, compared to DT clusters — which goes against yet another phonetic tendency. Voicing is articulatorily easier to maintain in initial parts of closure than it is to onset voicing after a period of voiceless closure (Ohala & Riordan 1979, Ohala 1997). The reason for this articulatory dispreference is straightforward and has been identified as the Aerodynamic Voicing Constraint: airflow and a subglottal-supraglottal pressure difference, necessary for voicing, are sufficient during vowel articulation, but decrease into closure. The reason why voicing is articulatorily difficult to initialize after a period of voiceless closure is that it is difficult to reinstantiate sufficient airflow and transglottal pressure difference — once the closure has caused them to decrease — without releasing the stop closure completely. In addition, there is a typological tendency towards respecting the Syllable Contact Law (Vennemann 1988), which also prefers DT over TD clusters. Finally, decreasing phonation into closure is observed as a passive tendency in several languages (see, for instance, Möbius 2004, Davidson 2016). In other words, vocal fold vibration has language-independent grounds to decrease rather than to increase during a period of closure. The restriction in TQ against DT (decreasing in voicing) clusters in favor of TD clusters (increasing in voicing) thus also contradicts a universal phonetic tendency against voicing into closure.

2.2 Phonetics

The phonological facts described above clearly indicate unnatural tendencies in the lexicon. However, it is not *a priori* obvious that the phonological transcription used for these facts was faithful to the acoustics. In the following, we present the results of a phonetic analysis of Tarma Quechua. No previous detailed phonetic analyses of the system of voicing in TQ exist: Adelaar (1977) and Puente Baldoceda (1977) are based on qualitative descriptions of recordings and are not supported by phonetic analyses. Our analysis confirms the phonetic reality of the TQ voice system as described above, making the case for true unnaturalness in the TQ data.

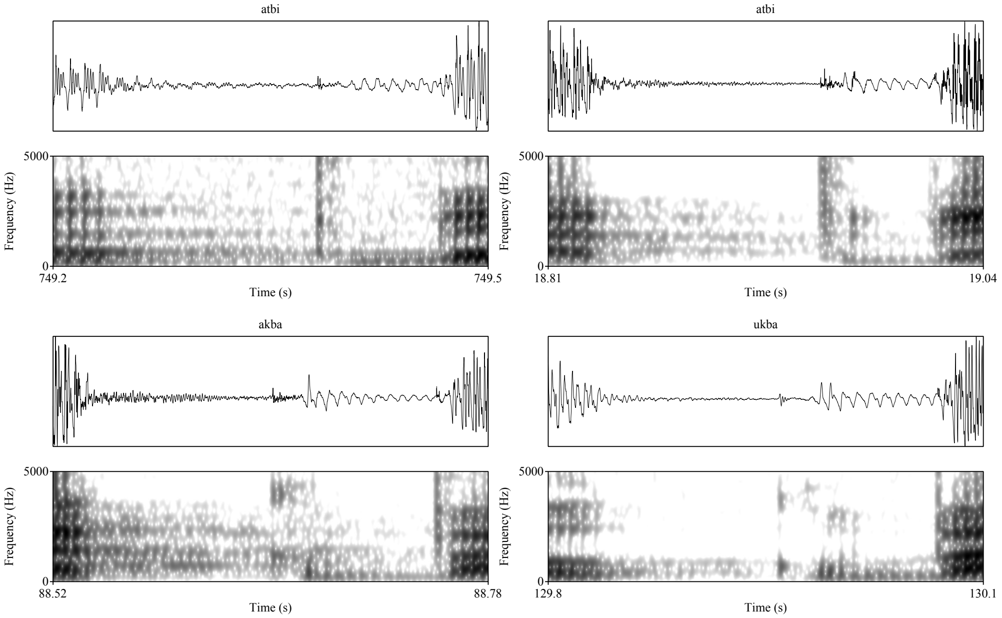
---

[3] This difference ceases to be significant if we add loanword status as predictor (sum-coded), but that might be due to the very small number of loanwords with clusters.

The analyzed recordings were obtained online[4] in .wav format, sampled at 90 kHz[5] with 16-bit quantization and analyzed with Willem Adelaar's permission in the Praat software (Boersma & Weenink 2016). The recordings were made by Willem Adelaar in 1970 in Tarma, in the Junín province of Peru. The informant was a 35 year old male speaker of TQ. The recordings are noisy with considerable echo, but the analysis nevertheless reveals important aspects of the unnatural gradient phonotactics and of the phonetic system of TQ in general.

The figure in (7) shows four waveforms and spectrograms of two TD clusters: [tb] and [kb]. All four spectrograms clearly show that the initial stop of the cluster is voiceless with almost no phonation into closure and that phonation does not start until the onset of the second stop's closure. First-element stops in the clusters show some echo noise during closure, because the recordings were made in a non-isolated room, but the voicing bar of the second stop is clearly distinguishable from noise vibrations of the first stop in all four cases.

(7) *Waveforms and spectrograms of four TD clusters: [atbi], [atbi], [akba], and [ukba]*



The exact realization of voiced stops in clusters is not completely uniform and may vary. The exact distribution is difficult to establish with limited data, but a short transitional vocalic element is occasionally found between the voiceless and voiced obstruent, indicating a smaller degree of gestural overlap (Figure in (8)). Occasionally, the voiced element surfaces as a fricative.[6]

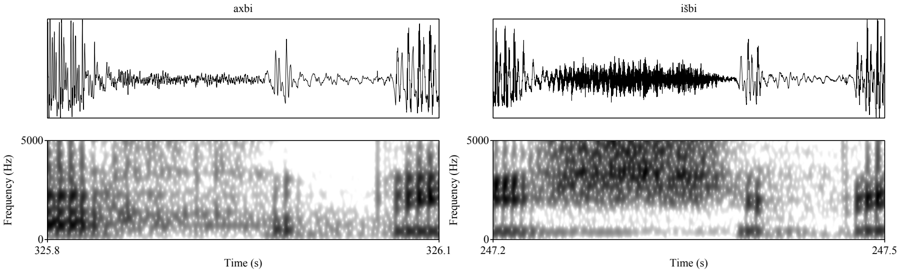
---

[4] Accesible online at: https://corpus1.mpi.nl/ds/asv/?0&0%5C&openpath=node:1483874

[5] The original sampling frequency is not known.

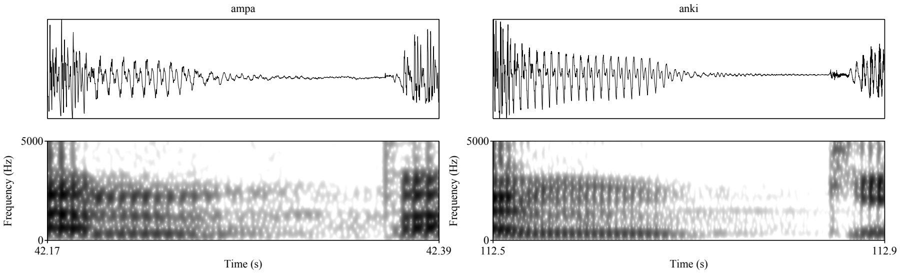
[6] In some cases, deleted or devoiced variants are observed instead.

(8) *Waveforms and spectrograms of voiced labial stops in post-consonantal position with a short vocalic element between the voiceless and voiced element: [xb] (left) and [ʃb] (right)*



After nasals, on the other hand, voiceless stops are the preferred variant, as detailed in (3). The figure in (9) shows spectrograms with voiceless [p] and [k] after nasals. Also note that voiceless stops in TQ are unaspirated, which means that the phonotactic restriction in fact targets the feature [±voice] rather than the feature [±spread glottis].

(9) *Waveforms and spectrograms of voiceless stops in post-nasal position: [mp] and [ŋk] (right)*



2.3 Productivity

The unnaturalness of the gradient phonotactic restriction is phonetically confirmed by the recordings. Corroborating its status as a phonotactic restriction, there exists evidence that it is synchronically active in some morphophonological alternations. Creider (1968) and Adelaar (1977) identify four suffixes with an initial voiced labial stop that feature morphophonemic alternation: [-ba/-pa] 'genitive'; [-bax/-pax] 'purposive'; [-bita/-pita] 'procedentive'; [-bis/-pis] 'even, too'.

The allomorph with voiced initial stops is selected after vowels and non-nasal consonants, including voiceless obstruents; the allomorph with voiceless initial stop is selected after nasals (Creider 1968). The distribution is illustrated in (10).

(10) a. *Intervocalic*
wawxi-gi-**ba** wayi-n[7]
'the house of your brother'

---

[7] These examples are in Quechua orthography, but the bolded consonants have identical IPA transcriptions.

b. *Post-nasal*
wayi-n-**pa** pasa-un
‘we’re going to walk by way of his house’

c. *Post-obstruent*
tamya-ya-n nuqa-ntik-**baq**
‘it is raining now for us’ (Creider 1968, 12–13)

This process is productive for a subset of suffixes. Other suffixes do not enter the alternation. For example, the highly frequent plural suffix /-guna/ and other suffixes /-bura/, /-gama/, and /-gasga/ have no voiceless allomorphs in post-nasal position (Adelaar 1977, 59). The productivity of this morphophonemic alternation also differs across local dialects. Adelaar (1977) reports that voiceless allomorphs are required in Vicora Congas, whereas in Huanuquillo the rate of application varies, i.e. is gradient. Even if this alternation is morphologically governed, the constraints that motivate the alternation (no voiced stops after a nasal, cf. Coetzee & Pretorius 2010, or no voiceless stop after a voiceless obstruent) are a part of the unnatural phonotactic restriction on the lexicon.

In addition, the behavior of loanwords provides further evidence for the productivity of unnatural gradient phonotactics. Most Spanish loanwords retain their original voicing. Sporadically, however, voicing or devoicing does occur (data from Adelaar 1977).

(11) a. Sp. *cuculi* > [kuguliː] ‘white-winged dove’
b. Sp. *cotpe* > [kutbi] ‘an animal from the mountains’
c. Sp. *sauco* > [sawgu] ‘magic tree’
d. Sp. *vaca* > [waːga] ‘cow’

In two loanwords, a Spanish voiced intervocalic stop devoices to a TQ voiceless stop (data from Adelaar 1977): Spanish *taruga* > [taruka] ‘deer’ and Spanish *dios se lo pague* > [jusulpaːki] ‘thank you’.

The two loanwords with devoicing of intervocalic stop are especially relevant for the discussion on the productivity of TQ unnatural gradient phonotactic restriction. The voiceless [k] in TQ [taruka] from Sp. *taruga* cannot be a result of early borrowing, supposedly before TQ voicing emerged. The historical development of TQ involves only voicing of voiceless stops, not devoicing of voiced stops. Regardless of when Spanish *taruga* was borrowed, sound change could not have produced TQ [taruka]. This means that the gradient phonotactic restriction was likely productive and resulted from the law of frequency effect: because voiced stops surfaced in approximately half of the lexicon, nativization that matches native vocabulary frequencies is predicted to occasionally voice voiceless stops of the donor language and devoice voiced ones.[8]

The unnatural phonotactic restriction presented in this paragraph is reported not only for TQ, but also for one other Quechuan dialect. A very similar voicing process whereby Proto-Quechua *p and *k voice in the same positions as in TQ is reported in the dialect

---

[8] Assuming of course that these loanwords were not borrowed to TQ via some other Quechuan dialect without the peculiar voicing process after the voicing was completed in TQ.

of Paccho (Adelaar & Muysken 2004, Adelaar, p.c.). The two dialects, Tarma and Paccho Quechua, are spoken in regions quite distant from each other and are potentially unrelated. Adelaar (p.c.) mentions that the two dialects might have been in contact historically, but the details are unclear. Because there are no descriptions or recordings of Paccho Quechua available, we leave this dialect out of our discussion.

3. Implications for theories of synchronic phonology

Deriving non-categorical processes poses a challenge for OT with categorically ranked constraints (although see Anttila 1997, 2002, 2007, Nagy & Reynolds 1997, Coetzee 2004, 2006 for models of variation with categorically (un)ranked constraints). On the other hand, the Harmonic Grammar (HG) family of grammar frameworks (Legendre et al. 2006, Coetzee & Pater 2008, 2011, Pater 2008, 2009, Albright 2009, Potts et al. 2010) has numerically weighted constraints and numerically defined well-formedness, which makes it well-suited for gradient processes (Pater 2009).[9] For our purposes, Maximum Entropy models (Goldwater & Johnson 2003, Hayes & Wilson 2008) are also a part of the HG family, since they also have weighted constraints and numerical well-formedness. We will focus here on this latter variant, since it defines a probability distribution over output candidates directly from the weights and violations of constraints, but the results presented here can be extended to other forms of HG.

The HG family has an advantage over categorical OT in that it can derive gradient processes (Pater 2009), which brings it closer to being able to account for unnatural gradient phonotactics. One problem, however, remains even under the HG approach: the derivation of unnatural processes. We will show that HG with restricted CON requires that, in any given context where CON defines a natural and an unnatural feature value, the natural value will have a probability that is at least as high as that of the unnatural value.

The classic version of OT (Prince & Smolensky 1993/2004) restricts its universal constraint inventory CON with the assumption that only a subset of possible constraints is universal and thus encodes typological asymmetries in the grammar. In HG, typological asymmetries that have to do with categorical patterns have also been tackled by restricting CON (see, e.g., Jesney 2016). There is, however, an additional aspect of the predictive power of HG under the restricted CON hypothesis that has gone largely unnoticed in the literature. If we restrict CON to only natural constraints, HG will predict that natural elements in a given environment will always be more frequent than unnatural ones (Beguš 2016).

We will illustrate this latter effect, which we call the "Natural Gradience Bias", on the basis of final (de)voicing (see Blevins 2004, Kiparsky 2006). In our illustration, we will work with phonotactic probabilities of surface forms (see Hayes & Wilson 2008). However, since we want to incorporate the effect of Faithfulness, and Hayes & Wilson (2008)

---

[9] Stochastic OT Boersma (2016) and Jarosz's 2015 framework also have numerically defined constraint rankings and define probability distributions over outputs for an input. The implications of our work for these frameworks should be similar. However, because these frameworks depend on variable categorical constraint ranking, the degree to which the results presented in this section carry over to these frameworks needs to be verified in future work.

do not allow for Faithfulness constraints, we will use Jarosz's 2006 method of marginalizing over inputs to arrive at phonotactic probabilities. Goldwater & Johnson (2003) define probabilities of input-output mappings — P(output|input) —, which, given a prior probability over inputs and Bayes' Rule, can be transformed into joint probabilities of outputs and inputs — P(output, input). We will assume that all inputs have a uniform prior probability, as Jarosz (2006) does for phonotactic learning.[10] Further following Jarosz's (2006) approach, we can derive the phonotactic probability P(output) for every possible surface form by marginalizing over inputs.

In a categorical OT grammar with a restricted version of CON, the faithfulness constraints IDENT-IO(voi) and the natural, final devoicing-promoting markedness constraint *D# are admitted in the inventory, but crucially, unnatural *T# is excluded (cf. Kiparsky 2006). Under these assumptions, there cannot be a phonotactic restriction against voiceless obstruents word-finally: IDENT-IO(voi) $\gg$ *D# implies faithful retention of word-final voiced obstruents, and *D# $\gg$ IDENT-IO(voi) implies that all word-final obstruents are made voiceless. When we switch to HG, we have an infinite number of weightings for these two constraints, but Jarosz's (2006) approach allows us to demonstrate that a gradient phonotactic restriction against voiceless obstruents word-finally is impossible with just these two constraints.

Given the assumption of uniform input probabilities, limiting our universe to [±voice] at the end of a word means that the inputs /T#/ and /D#/ have 0.5 probability: P(/T#/) = P(/D#/) = 0.5. A restricted CON and weighted constraints combined yield the following implications: if the faithfulness constraint ($\mathscr{F}$) IDENT-IO(voi) has a positive infinite weight and the markedness constraint ($\mathscr{M}$) *D# has a finite weight, the phonotactic probabilities of [T#] and [D#] (P([T#] and P([D#]) are both 0.5. If, however, the markedness constraint is weighted finitely lower than, or even higher than the faithfulness constraint, the phonotactic probability of [T#] will be greater than that of [D#] (Beguš 2016). Thus, a system that gradiently (or categorically) prefers [T#] over [D#] is impossible.

(12) a. $w(\text{IDENT-IO(voi)}) - w(\text{*T\#}) = \infty$: P([T#]) = P([D#]) = 0.5
     b. $w(\text{IDENT-IO(voi)}) - w(\text{*T\#}) < \infty$: P([T#]) > P([D#])

The same reasoning can be used for any other natural-unnatural constraint pair, which illustrates the more general point that, if we allow only natural constraints into CON, we can only derive systems with gradient phonotactic distributions in which the natural element in a given context is more frequent than the unnatural element. In other words, with restricted CON, no weighting exists that would yield a system in which the unnatural feature value has a greater posterior probability than the natural one in a given context.

(13) a. $w(\mathscr{F}) - w(\mathscr{M}) = \infty$: P(nat) = P(unnat) = 0.5
     b. $w(\mathscr{F}) - w(\mathscr{M}) < \infty$: P(nat) > P(unnat)

---

[10] This assumption can also be seen as a Bayesian interpretation of Richness of the Base (Smolensky 1996): we do not want to encode phonotactic information in the lexicon, so we should have an equal belief in the possibility of each underlying form. Note that the various inputs' probability of occurrence in a language might not be uniform, but we abstract away from frequentist probabilities in this discussion.

From (13), it follows that restricted CON allows either no phonotactic preference, or a phonotactic restriction against unnatural elements in favor of natural elements in a given environment: a Natural Gradience Bias.

(14) *Natural Gradience Bias (NGB)*
HG with restricted CON predicts that the probability of the natural feature value in a given environment is always equal or greater than the probability of the unnatural value in a given environment.

This generalization correctly predicts the major typological trend with regard to gradient phonotactic restrictions: all previously reported cases (both as trends in the lexicon, e.g., Berkley 2000, Pater 2008, Anttila 2008, and as tacit phonotactic knowledge obtained from experiments, e.g. Albright 2009) indeed operate in the natural direction, where the natural element is preferred and more frequent than the unnatural one in a given environment. Moreover, our NGB assumption receives support from the modeling literature: Hayes (2017) has recently argued that in MaxEnt with restricted CON "[a] harmonically bounded candidate can never receive a higher probability than the candidate that bounds it".[11]

However, the Tarma Quechua system of stop voicing presented in this paper suggest that HG with restricted CON undergenerates, since it requires precisely the situation excluded by the Natural Gradience Bias: a higher frequency for the unnatural feature value in a certain context. Even with the flexibility of weighting allowed by HG, no weighting of natural Markedness constraints can generate cases like Tarma Quechua. This, in turn, suggests that CON must contain some unnatural Markedness constraints.

To simply relax CON and allow all possible Markedness constraints, however, is not a desirable solution either. Hayes and Wilson's (2008) phonotactic learner is able to derive unnatural phonotactics because they do not limit CON to natural constraints — the learner is only provided with feature values and constraint templates. Their model, however, does not encode the typological rarity of unnatural processes (although, see Pater & Moreton 2012, Staubs 2014, and Beguš 2017, 2018b on how typological rarity might be derived with unrestricted CON). Ideally, the grammar would be able to derive unnatural patterns and encode their rarity at the same time (for proposals, see Beguš (2018a)).

Before firm conclusions are drawn, the unnatural gradient phonotactic restrictions in the two languages would need to be confirmed with behavioral experiments.

Unnatural categorical *alternations* have already been confirmed as being productive elsewhere: Coetzee & Pretorius (2010) show that post-nasal devoicing in Tswana extends to nonce-words. Experimental nonce-word tests in Tarma Quechua would reveal the degree of productivity and grammatical status of the two processes and therefore the ability of unnatural gradient phonotactic restrictions to be productive in general.

---

[11] Hayes (2016) calls this generalization "stochastic harmonic bounding".

References

Adelaar, Willem F. H. 1977. *Tarma Quechua: Grammar, texts, dictionary*. Lisse: The Peter de Ridder Press.

Adelaar, Willem F. H., & Pieter C. Muysken. 2004. *The languages of the Andes*. Cambridge: Cambridge University Press.

Albright, Adam. 2009. Feature-based generalization as a source of gradient acceptability. *Phonology* 26:9–41.

Anttila, Arto. 1997. Deriving variation from grammar. In *Variation, change and phonological theory*, ed. Frans L. Hinskens, Roeland van Hout, & W. Leo Wetzels, 35–68. Amsterdam: Benjamins.

Anttila, Arto. 2002. Morphologically conditioned phonological alternations. *Natural Language and Linguistic Theory* 20:1–42.

Anttila, Arto. 2007. Variation and optionality. In *The Cambridge handbook of phonology*, ed. Paul de Lacy, 519–536. Cambridge: Cambridge University Press.

Anttila, Arto. 2008. Gradient phonotactics and the complexity hypothesis. *Natural Language and Linguistic Theory* 26:179–228.

Beguš, Gašper. 2016. A natural origin for unnatural gradient phonotactics. Talk at the 13th Old World Conference in Phonology, Workshop on variation in phonology. Budapest, Hungary. January 13–16, 2016.

Beguš, Gašper. 2017. Post-nasal devoicing and a probabilistic model of phonological typology. Ms., Harvard University.

Beguš, Gašper. 2018a. A formal model of phonological typology. In *Proceedings of the 35th West Coast conference on formal linguistics*, ed. Wm. G. Bennett, 104–113. Somerville, MA: Cascadilla Proceedings Project.

Beguš, Gašper. 2018b. Unnatural phonology: A synchrony-diachrony interface approach. Doctoral dissertation, Harvard University.

Berkley, Deborah. 2000. Gradient obligatory contour principle effects. Doctoral dissertation, Northwestern University.

Blevins, Juliette. 2004. *Evolutionary phonology: The emergence of sound patterns*. Cambridge: Cambridge University Press.

Boersma, Paul. 2016. How we learn variation, optionality, and probability. In *Proceedings of the institute of phonetic sciences 21*, 43–58. Amsterdam: University of Amsterdam.

Boersma, Paul, & David Weenink. 2016. Praat: doing phonetics by computer [computer program]. Version 5.4.6, retrieved 21 Februray 2015 from www.praat.org.

Coetzee, Andries. 2004. What it means to be a loser: Non-optimal candidates in optimality theory. Doctoral dissertation, University of Massachusetts, Amherst. ROA 687-0904.

Coetzee, Andries. 2006. Variation as accessing “non-optimal” candidates. *Phonology* 23:337–385.

Coetzee, Andries, & Joe Pater. 2011. The place of variation in phonological theory. In *The handbook of phonological theory*, ed. John Goldsmith, Jason Riggle, & Alan C. L. Yu, 401–434. Oxford: Blackwell, 2nd edition.

Coetzee, Andries W., & Joe Pater. 2008. Weighted constraints and gradient restrictions on place co-occurrence in Muna and Arabic. *Natural Language and Linguistic Theory* 26:289–337.

Coetzee, Andries W., & Rigardt Pretorius. 2010. Phonetically grounded phonology and sound change: The case of Tswana labial plosives. *Journal of Phonetics* 38:404–421.

Creider, Chet A. 1968. A morphological sketch of Tarma Quechua. Master's thesis, University of Minnesota.

Davidson, Lisa. 2016. Variability in the implementation of voicing in American English obstruents. *Journal of Phonetics* 54:35–50.

Frisch, Stefan, Janet Pierrehumbert, & Michael Broe. 2004. Similarity avoidance and the OCP. *Natural Language and Linguistic Theory* 22:179–228.

Goldwater, Sharon, & Mark Johnson. 2003. Learning OT constraint rankings using a maximum entropy model. In *Proceedings of the Workshop on Variation within Optimality Theory*, ed. Jennifer Spenader, Anders Eriksson, & Östen Dahl, 111–20. Stockholm: Stockholm University.

Hale, Mark, & Charles Reiss. 2004. *Phonological enterprise*. Oxford: Oxford University Press.

Hayes, Bruce. 1999. Phonetically-driven phonology: The role of Optimality Theory and inductive grounding. In *Functionalism and formalism in linguistics*, ed. Michael Darnell, Edith Moravscik, Michael Noonan, Frederick Newmeyer, & Kathleen Wheatly, volume 1, 243–85. Amsterdam: John Benjamins.

Hayes, Bruce. 2016. Varieties of Noisy Harmonic Grammar. Handout at the 2016 Annual Meeting on Phonology, University of Southern California. October 21 - 23, 2016.

Hayes, Bruce. 2017. Varieties of Noisy Harmonic Grammar. *Proceedings of the 2016 Annual Meeting on Phonology* 27:1–17.

Hayes, Bruce, & James White. 2013. Phonological naturalness and phonotactic learning. *Linguistic Inquiry* 44:45–75.

Hayes, Bruce, & Colin Wilson. 2008. A Maximum Entropy model of phonotactics and phonotactic learning. *Linguistic Inquiry* 39:379–440.

Hyman, Larry. 2001. The limits of phonetic determinism in phonology: *NC revisited. In *The role of speech perception in phonology*, ed. Elizabeth Hume & Keith Johnson, 141–186. San Diego, CA: Academic Press.

Jarosz, Gaja. 2006. Rich lexicons and restrictive grammars — maximum likelihood learning in optimality theory. Doctoral dissertation, Johns Hopkins University. ROA 884.

Jarosz, Gaja. 2015. Expectation driven learning of phonology. Ms., University of Massachusetts, Amherst.

Jesney, Karen. 2016. Positional constraints in Optimality Theory and Harmonic Grammar. In *Harmonic grammar and harmonic serialism*, ed. John McCarthy & Joe Pater, 176–220. Sheffield: Equinox.

Kiparsky, Paul. 2006. Amphichronic program vs. Evolutionary Phonology. *Theoretical Linguistics* 32:217–36.

Legendre, Géraldine, Antonella Sorace, & Paul Smolensky. 2006. The Optimality Theory—Harmonic Grammar connection. In *The harmonic mind: From neural com-*

putation to optimality-theoretic grammar, ed. Paul Smolensky & Géraldine Legendre, 339–402. Cambridge, MA: MIT Press.

Möbius, Bernd. 2004. Corpus-based investigations on the phonetics of consonant voicing. *Folia Linguistica* 38:5–26.

Nagy, Naomi, & William Reynolds. 1997. Optimality theory and variable word-final deletion in Faetar. *Language Variation and Change* 9:37–55.

Ohala, John J. 1997. Aerodynamics of phonology. In *Proceedings of 4th Seoul International Conference on Linguistics*, 92–97. (11–15 Aug 1997).

Ohala, John J., & Carol J. Riordan. 1979. Passive vocal tract enlargement during voiced stops. In *Speech communication papers*, ed. J. J. Wolf & D. H. Klatt, 89–92. New York: Acoustical Society of America.

Pater, Joe. 2008. Gradient phonotactics in Harmonic Grammar and Optimality Theory. Ms., University of Massachusetts, Amherst.

Pater, Joe. 2009. Weighted constraints in generative linguistics. *Cognitive Science* 33:999–1035.

Pater, Joe, & Elliott Moreton. 2012. Structurally biased phonology: Complexity in learning and typology. *The EFL Journal* 3:1–44.

Potts, Christopher, Joe Pater, Karen Jesney, Rajesh Bhatt, & Michael Becker. 2010. Harmonic grammar with linear programming: From linear systems to linguistic typology. *Phonology* 27:77–117.

Prince, Alan, & Paul Smolensky. 1993/2004. *Optimality Theory: Constraint interaction in generative grammar*. Malden, MA: Blackwell. First published in 1993, Tech. Rep. 2, Rutgers University Center for Cognitive Science.

Puente Baldoceda, Blas. 1977. *Fonología del quechua tarmeño*. Lima: Universidad Nacional Mayor de San Marcos, Centro de Investigación de Lingüística Aplicada.

R Core Team. 2017. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. URL `www.R-project.org/`.

Samuels, Bridget. 2009. The structure of phonological theory. Doctoral dissertation, Harvard University.

Smolensky, Paul. 1996. The initial state and 'richness of the base' in optimality theory. ROA 293.

Staubs, Robert D. 2014. Computational modeling of learning biases in stress typology. Doctoral dissertation, University of Massachusetts, Amherst.

Vennemann, Theo. 1988. *Preference laws for syllable structure*. Berlin: Mouton de Gruyter.

Wilson, Colin. 2006. Learning phonology with substantive bias: An experimental and computational study of velar palatalization. *Cognitive Science* 30:945–82.

Wilson, Colin, & Marieke Obdeyn. 2016. Simplifying subsidiary theory: statistical evidence from Arabic, Muna, Shona, and Wargamay. Ms., Johns Hopkins University.

Gašper Beguš, Aleksei Nazarov
begus.gasper@gmail.com, glossarios@gmail.com