Post-Nasal Devoicing and a Probabilistic Model of Phonological Typology

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Abstract

This paper addresses one of the most contested issues in phonology: the derivation of phonological typology. I present a new model for deriving phonological typology within the channel bias approach. First, a new subdivision of natural processes is proposed: non-natural processes are divided into unmotivated and unnatural. The central topic of the paper is an unnatural alternation: post-nasal devoicing (PND). I argue that in all reported cases, PND does not derive from a single unnatural sound change (as claimed in some individual accounts of the data), but rather from a combination of three sound changes, each of which is natural and motivated. By showing that one of the rare cases of unnatural sound change reported actually arises through a combination of natural sound changes, we can maintain the long-held position that any single instance of sound change has to be natural. Based on several discussed cases, I propose a new historical model for explaining unnatural phenomena: the "blurring process". Additionally, I provide a proof establishing the minimal sound changes required (MSCR) for an unmotivated/unnatural process to arise. The blurring process and MSCR result in a model that probabilistically predicts typology within the channel bias approach. This paper also presents groundwork for calculating historical probabilities of synchronic alternations with the ultimate goal of quantifying influences of CB on phonological typology.

Keywords: phonological typology, probabilistic models, sound change, naturalness, channel bias, voice

1 Introduction

Deriving typology has long been a central topic in the phonological literature. Two major lines of thought emerge in the discussion on phonological typology: the *analytic bias* (AB) and *channel bias* (CB) approaches (Moreton 2008). The AB approach assumes that typological patterns emerge because of cognitive biases against certain phonological processes. In other words, some processes are more difficult to learn and these learnability biases result in surface typology (for an overview of the AB literature, see Moreton and Pater 2012). The CB approach, on the other hand, assumes that systematic phonetic tendencies or phonetic precursors in the transmission from speaker to hearer result in surface typology. In other words, constraints on sound change are responsible for typological patterns: an inherent directionality of sound changes results in a predictable pattern of phonetic processes and phonologizations that ultimately determine surface typology (cf. Hyman and Schuh 1974, Ohala 1993, Bybee 2001, Blevins 2004, 2006, Yu 2012, see also Hansson 2008 for a survey).

Numerous experimental studies have provided evidence in favor of the AB approach: typologically common processes are significantly more difficult to learn than typologically rare processes (Moreton and Pater 2012). Studies confirming AB involve both artificial grammar learning experiments on adults as well as studies testing phonotactic learning in infants. The generalization

that typologically rare processes are more difficult to learn is especially robust when structurally complex alternations are tested against more simple alternations. The results are less uniform for alternations that control for structural complexity, but there, too, learning biases have been confirmed in at least a subset of studies (Wilson 2006).

The main evidence in favor of the CB approach is that typologically common processes align with universal articulatory and perceptual phonetic tendencies and natural sound changes. In fact, in many cases we can directly observe origins of synchronic processes through historical developments (e.g. sound change that leads to phonologization, cf. Hyman 1976, Yu 2013).

Both approaches also face challenges in modeling typology. The main objection against AB is that speech is an "overlearned skill" (Lofqvist 2006) and most studies show that more or less any alternation can be learned given enough exposure (Moreton and Pater 2012, White 2013). It is not trivial to show how learning biases result in typology. Conversely, a major objection against the CB approach is that it fails to explain why some processes are never attested in world languages (Kiparsky 2006, 2008). In other words, combinations of sound changes (or a single sound change, if we allow it to be unnatural, as proposed in Blust 2005) could in principle produce a number of unnatural alternations — yet, it seems that some hypothetically available processes are never attested. In fact, Kiparsky (2006, 2008) goes a step further and assumes some processes are impossible in synchronic grammar. This position is also encoded in the classical Optimality Theory (OT) model, where unnatural constraints are excluded from the universal constraint inventory (CON). On this approach, some output candidates are harmonically bounded and consequently some processes are impossible in synchronic grammars. For example, Kiparsky (2006, 2008) identifies several combinations of sound changes that would lead to final voicing, but the process is never attested (or at least is morphologically limited; see Yu 2004, Blevins 2004). CB faces difficulties explaining this gap and AB is invoked to explain it.

As Moreton (2008:84) points out, the two approaches have in the past often been treated as mutually exclusive, either explicitly or implicitly. A mounting body of research, however, argues that both AB and CB shape typology (Hyman 2001, Myers 2002, Moreton 2008, Moreton and Pater 2012). This position is held in this paper as well: I maintain that both AB and CB influence typology. However, the goal of phonological theory should be to disambiguate the two influences: what aspects and what proportions of phonological typology are caused by speakers' synchronic grammar (AB) and how much of phonological typology is due to directionality of sound change (CB)? To disambiguate the two influences, we first need a good understanding of how exactly each of them results in typology. This paper presents the first step in this direction. I propose a new model of typology within the channel bias approach. The new model provides groundwork for quantifying influences of CB which I label "historical probabilities" (P_χ) of processes. Historical probabilities enable quantified estimation of the influences of CB on phonology that can ultimately be compared to AB influences based on data from learnability experiments.

2   On naturalness

Directly related to the question of phonological typology is the question of naturalness and how to encode it in the grammar design. The term "naturalness" itself has received several interpretations and opposing stances in the literature; scholars have argued that unnatural processes are variously possible, disprefered, or impossible in synchronic grammar. The question of naturalness is relevant to the theory of sound change as well. It has long been believed that sound changes are always phonetically motivated, and therefore natural. This position goes back to the Neogrammarian school of thought and posits that "typologies of sound change and possible phonetic precursors

correspond perfectly" (Garrett 2014).

Before we turn to a more detailed discussion of unnatural alternations and sound changes, a clarification of the term "sound change" and a new definition of "naturalness" are necessary.

Let us first clarify the distinction between a single sound change and a combination of sound changes. A (single instance of a) sound change constitutes a change from A to B in an environment X, as a result of which A differs from B in one feature. In other words:

(1)   *A single sound change vs. a combination of sound changes*
       Sound change is a change of one feature in a given environment; a combination of sound changes is a set of such individual sound changes.

This stipulation might seem very obvious, but it is important to make this distinction explicit. Use of the term "sound change" in the literature is often confusing and fluctuates between denoting a single instance of sound change and a combination of sound changes. I will strictly distinguish between these two notions in the remainder of this paper. Unless I specify otherwise, a "sound change" denotes a single instance of sound change.

Let us now turn to a new definition of naturalness. Most studies so far have distinguished natural from unnatural processes by specifying that the former are phonetically motivated and typologically common while the latter are unmotivated and typologically rare. However, this division is insufficient, as it fails to capture crucial distinctions within the unnatural group. In the new division I propose, natural processes are phonetically motivated (as in previous proposals): they operate in the direction of universal phonetic tendencies.

(2)   *Definition of Universal phonetic tendency (UPT)*
       UPTs are phonetic processes motivated by articulatory (or perceptual) mechanisms that passively and universally operate in speech production and are typologically common.

Passive and universal operation of a tendency means that the tendency that targets some phonetic feature operates cross-linguistically, even in languages with full phonological contrast of the equivalent feature in a given position. For example, the observation that voiceless stops have universally more phonetic voicing into closure in post-nasal position compared to the elsewhere position (Hayes and Stivers 2000), even for languages with full contrast of voice post-nasally, fulfills the criterion that PND operates passively in world languages.

I argue that within the traditionally labeled "unnatural" group, we find two types of processes. I label *unmotivated* those processes that lack phonetic motivation, but do not operate against any UPT. In other words, while unmotivated processes do not correspond to a particular universal articulatory/perceptual force, they are also not operating specifically against such a force. *Unnatural* processes,[1] on the other hand, are those that operate precisely *against* some UPT and are not UPT themselves.[2]

(3)   *A new division of naturalness*

       a.   *natural processes*: defined as UPT
       b.   *unmotivated processes*: lack motivation, but do not operate against UPT
       c.   *unnatural processes*: operate against UPT, are not UPT

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1. Similar, but also crucially different, distinctions have been proposed before. Morley (2014) assumes "antinatural" processes are those that operated against implicational universals and are unattested: "unattested patterns that do not conform with posited language universals."

2. Some processes can be motivated in both directions by different mechanisms, e.g. fricativization of stops or occlusion of fricatives are two diametrically opposed processes, both motivated by different mechanisms (cf. Ladefoged and Maddieson 1996: 137, Kaplan 2010).

An example of an unmotivated process would be /i/ → [u] / d__ (Buckley 2000). This process lacks phonetic motivation, but its reverse process /u/ → [i] / d__ is not a UPT. Examples of unnatural processes include final voicing, intervocalic devoicing, or post-nasal devoicing. All of these processes operate directly against clear and well-motivated articulatory phonetic tendencies. Most of the discussions on "unnatural phenomena" in phonology in fact discusses unmotivated processes, according to the definition in (2) (Buckley 2000, Blevins 2004, 2008, Blust 2005). This paper focuses on an unnatural process, PND, and points to several implications that the treatment of this process bears for both theoretical and historical phonology.

How to model unmotivated and unnatural processes synchronically and diachronically has long been a central topic in phonology (Stampe 1973, Hellberg 1978, Anderson 1981, Archangeli and Pulleyblank 1994, Hayes 1999). Some major questions that emerge are (i) whether unnatural processes are possible productive synchronic alternations, (ii) how to encode dispreference of unnatural processes in theoretical models, and (iii) how unnatural processes arise. A study of post-nasal devoicing (PND) in Tswana and Shekgalagari by Coetzee and Pretorius (2010) can offer an answer to the first question above. The authors show that PND is a productive synchronic alternation by testing its application to nonce words. PND applies to nonce-words with equal rates as in the real world, offering strong evidence that unnatural processes (definition in (3)) do exist as productive synchronic alternations. Although unnatural alternations are rare, our models of grammar need to be able to generate such processes. A question that should be of interest to phonological theory is also why these unnatural processes are rare: does their infrequency arise due to a restriction on sound change or due to a cognitive restriction against learning unnatural phenomena? In this paper, I offer an answer to the question of how exactly restriction on sound change results in the rarity of unnatural processes. The answer to the second part of this question — how learnability causes rarity of unnatural processes — is equally important and can be answered primarily by experimental data. This, however, is beyond the scope of the present work.

As already mentioned, naturalness has been subject to debate in the theory of sound change as well. The well-accepted Neogrammarian position that sound change is always natural has recently been challenged. Blust (2005) identifies several unnatural sound changes and argues they had to operate as single instances of sound changes. The survey of consonantal sound changes in Kümmel (2007) also lists a number of unnatural sound changes, although they are not labeled as such. A subset of Blust's unnatural sound changes have been explained as a result of a sequence of multiple natural sound changes (Goddard 2007, Blevins 2007, Garrett 2014). However, the most robust cases of unnatural sound change reported in Blust (2005), including post-nasal devoicing, have yet to receive a sufficient explanation.

In this paper, I collect all known cases of PND. The collection derives from several sources: a survey of sound changes in Kümmel (2007) that examines approximately 200 languages; a UniDia database of 10,349 sound changes from 302 languages (Hamed and Flavier 2009); a survey of unnatural sound changes in Blust (2005), Blevins (2008), and Goddard (2007); a survey of *NT constraint in Hyman (2001).[3] Isolated unpublished cases have been reported to me in personal communication (Merrill 2016). So far, all cases of PND have been treated in isolation, which lead to several opposing explanations of the phenomenon. Explanations of PND rely variously on appeals to hypercorrection (Xromov 1972), combinations of sound changes (Dickens 1984, Hyman 2001), claims that unnatural sound changes *do exist* (Blust 2005), or claims that PND is phonetically or perceptually motivated (Solé 2012, Gouskova et al. 2011, Stanton 2016). I shine light on this murky

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3. It is difficult to estimate how many languages are surveyed in these collections, as authors do not report this information. A reasonable guess would be that Blust (2005) surveys most Austronesian languages and Hyman (2001) surveys most Bantu languages.

discussion by showing that, in all twelve cases[4] of PND I have compiled, there exists either direct or strong indirect evidence that PND emerges as the combined result of three separate instances of single, natural sound changes. I focus primarily on evidence from Yaghnobi and Sogdian, showing that the two languages present direct historical evidence that PND results from a combination of sound changes. I argue that the results have broader implications for the theory of sound change. Examining all cases of PND together also allows me to generalize common properties and develop a historical model for explaining unnatural phenomena. Furthermore, if we can show that one of the rare reported unnatural sound changes is in fact a product of a combination of natural sound changes, this will lend support to the position that sound change has to be natural and cannot operate against UPT (*pace* Blust 2005).

That combinations of sound changes produce unmotivated results is a long-standing and well-known claim. "Telescoping," for example, describes a phenomenon in which a sound change A > B in the environment X is followed by B > C, resulting in a sound change A > C that may not be phonetically motivated in environment X (Wang 1968, Kenstowicz and Kisseberth 1977: 64, cf. also Stausland Johnsen 2012). This paper, however, takes the concept of telescoping one step further, by focusing on alternations that are not only unmotivated, but that operate in exactly the opposite direction from UPT. Crucially, I present a proof that minimally three sound changes are needed for an unnatural alternation to arise. I also propose a new historical model, "the blurring process", that, unlike telescoping, models unnatural phenomena and yields a more precise prediction of typology. The blurring process also represents an additional strategy for explaining unnatural phenomena, alongside hypercorrection, which has so far been most common historical strategy employed for this purpose.

3   Post-nasal devoicing

The claim that PND is an unnatural process according to the definition in (2) is supported by strong articulatory phonetic evidence. Post-nasal voicing (T > D / N__), the exact inverse process to PND, is a UPT: it is phonetically well motivated, operates passively in world languages, and is typologically common.

The phonetics of PNV is thoroughly investigated in Hayes and Stivers (2000) (cf. Hayes 1999, Pater 1999). Supported by previous work by Rothenberg (1968), Kent and Moll (1969), Ohala and Ohala (1991), Ohala (1983), and others, the authors identify two phonetic factors that render stops in post-nasal position prone to voicing: nasal airflow leak during velic rising, and "compression/rarefaction" or expansion of oral cavity volume. Both of these factors promote voicing (Hayes and Stivers 2000). It has long been known that coarticulation occurs in the transition from nasal to oral stops: the velum must rise from a low position to a high position, at which point it closes the nasal cavity. During this process, nasal leakage is present "and voicing is facilitated" (Hayes and Stivers 2000). Moreover, when the velum rises from a high position to complete closure, it increases the volume of the oral cavity, which again favors voicing (Hayes and Stivers 2000).

Not only is post-nasal voicing phonetically motivated, it is also universally present as a passive phonetic tendency: that is to say, phonetic voicing is found even in languages without phonological PNV, such as English. Hayes and Stivers (2000) show that speakers produce more passive phonetic voicing on voiceless stops in post-nasal position than elsewhere. Speakers produce "significantly more closure voicing" in words like [tampa] than in words like [tarpa]. PNV thus meets all the

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4. A more conservative count gives nine cases of PND; some scholars count Sicilian and Calabrian and Tswana, Shekgalagari, and Makhuwa as two cases rather than four, due to the close genetic relationships between these language pairs.

criteria for being a UPT.

PNV is commonly attested not only as a phonological and phonetic process, but also as a sound change. Locke (1983) identifies 15 languages, out of a sample of 197, that exhibit PNV as a synchronic process (reported in Hayes and Stivers 2000). Kümmel (2007, 53f.) lists at least 32 languages in a survey of 200 in which PNV operated as a sound change. By comparison, PND in the same survey is attested only twice: once it targets stops and once affricates.

While voiceless stops tend to be universally voiced in post-nasal position — a phonetically well-motivated and natural process — the opposite process, devoicing of voiced stops in post-nasal position, is unnatural: it operates against a UPT. For reasons discussed above (nasal leakage and increased volume of oral cavity), the post-nasal environment is in all aspects antagonistic to devoicing, in the sense that it blocks the anti-voicing effects of the closure. In other words, in the transition from nasal to oral stop, the velum does not close instantaneously; as a result, air leakage occurs into a portion of the following stop closure, prohibiting the "air pressure buildup" necessary to articulate a voiceless stop. Expansion of oral cavity due to velic rising also has an effect of promoting voicing during the closure: greater volume allows longer period of time before the air pressure buildup (for a discussion on phonetics, see also Hayes and Stivers 2000, Coetzee and Pretorius 2010 and literature therein). Moreover, to my knowledge, PND has not been reported as a passive tendency in any language.

While articulatory phonetic facts clearly point to the unnaturalness of PND, some authors argue that PND might be motivated perceptually. This analysis is offered in Stanton (2016), who argues that PND is motivated as enhancement of perceptual cues in, for example, ND ∼ N contrast. The first problem with such an approach is that there exist no experimental studies that would confirm NT to be perceptually more salient than N or ND in intervocalic position. Kaplan (2008) is the only study known to me that tests this contrast perceptually and does not limit it to final position (Katzir Cozier 2008). While NT is more salient than N and ND word-finally,[5] no such significant effect has been found word-medially: all three stimuli, N, NT, and ND, were perceived with equal rates (Kaplan 2008). Moreover, PND is not attested as a repair strategy even in cases where we should expect it. For example, many languages disallow NC_1VNC_2 sequences. A recent study in Stanton (2015) suggests that avoidance of these sequences constitutes a strategy to repair the contrast in NC_1VNC_2. The vowel in NC_1VNC_2 is universally phonetically nasalized, a process which reduces cues for the contrast between NC and N. One way to repair this contrast would be to devoice the consonant. However, the survey in Stanton (p.c.) shows that NDVNC > NTVNC is not attested. The final challenge for the perception approach is that, as I will argue, strong evidence exists that in all twelve languages I have examined, PND actually arises through a combination of three natural sound changes rather than a contrast enhancement. It is possible that perceptual factors play a role in the phonologization of PND and preservation of the alternation once it arises, but the data nevertheless point to PND arising through a combination of sound changes in which contrast enhancement does not play a role. In other words, I claim that there are no instances in which PND functions as a repair strategy: all attested cases of PND are the result of a set of sound changes. It seems suspicious to suggest that a contrast will only be enhanced when a set of three

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5. Kaplan (2008) indeed argues that post-nasal voiced stops in word-final position are perceptually most confusable, and thus perceptually motivates the *ND# constraint. First, note that the "motivated" *ND is limited to word-final position. Second, in English, the repair for *ND# is not devoicing, but deletion. Finally, a survey in Stanton (2016:1106) identifies a number of other languages that devoice sequences of ND# to NT#: Neverver, Kobon, Naman, Avava, Páez, and Tape. It is crucial to note that, in these languages, voiceless stops contrast with prenasalized voiced stops. In other words, the inventories lack plain voiced stops completely. Final D > T / N__# can thus simply be analyzed as devoicing of voiced stops in word-final position. The exact treatment of this phenomena is beyond the scope of this work.

sound changes happen to operate in the pre-history of a system.

3.1   The data

Despite its unnatural status, the existence of PND as a sound change has been reported in twelve languages and dialects from seven language families.

3.1.1   Yaghnobi

PND was first proposed for Yaghnobi by Xromov (1972). Yaghnobi is an Iranian language, spoken by approximately 13,500 speakers in five different areas of Tajikistan (Paul et al. 2010:4). It is the only living descendant of Sogdian, an Eastern Iranian language that was spoken around the fourth century CE. Xromov observes that NT sequences in Yaghnobi correspond to ND sequences in ancestral Sogdian; on the basis of this observation, he posits a sound change D > T / N__ in the development from Sogdian to Yaghnobi. The following table lists cognates from Yaghnobi and Sogdian that confirm this correspondence.[6]

Yaghnobi	Sogdian	gloss
ɣantum	ɣandum	'wheat'
ʃikampa	əʃkamb	'stomach'
sank(a)	sang	'stone'
rankiːna	rang	'color'
unkuʃt	anguʃt	'finger'
ʧintir	ʧəndər	postp.
-ant	-and	3rd pl.

Table 1: PND in Yaghnobi (from Xromov 1972:128)

Note that outside of post-nasal position, Sogdian voiced stops are preserved in Yaghnobi: [dah] 'ten', [niːdoːm], [niːd] 'to sit' (data from Novák, 2010: 31, Novák, To appear).

Synchronic Yaghnobi does contrast NT and ND sequences, but this is likely secondary, introduced late in the language's development through borrowings from Tajik (cf. Xromov 1972). Some examples of borrowed ND sequences from Tajik are given in Xromov (1972: 128): [angiʃt] 'coal', [ʧang] 'dust', [baland] 'high', [lunda] 'round'. It is even possible to find instances of the inherited Yaghnobi [vant] 'tie' — with an unvoiced stop after a nasal — in contrast tothe borrowed [band] 'tie' with a voiced variant.

3.1.2   Tswana, Shekgalagari, and Makhuwa

As already mentioned, PND has been reported as a synchronic phonological process in Tswana and Shekgalagari (Hyman 2001, Solé et al. 2010), two closely related Southern Bantu languages; Tswana is spoken by approximately 4–5 million people in Botswana, Namibia, Zimbabwe, and South Africa (Coetzee and Pretorius 2010), and Shekgalagari by approximately 40,000 people in Botswana (Lewis et al. 2015). In Makhuwa, PND is reported as a sound change followed by nasal deletion (Janson 1991/1992). Makhuwa is closely related to Tswana and Shekgalagari too and is spoken by approximately 3 million speakers in Mozambique (Lewis et al. 2015).

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6. Data from older descriptions has been adjusted throughout this paper, as accurately as the descriptions allow, to fit IPA conventions.

The table below shows that voiced stops become voiceless when preceded by a nasal. Voiceless stops remain unchanged both post-nasally and elsewhere.

No *N*-prefix	*N*-prefix	gloss
χʊ-pak-a	χʊ-m-pak-a	'to praise'
χʊ-tʊt-a	χʊ-n-tʊt-a	'to respect'
χʊ-cʊ́b-á	χʊ-ɲ-cʊ́b-á	'to beat'
χʊ-kɛl-a	χʊ-ŋ-kɛl-a	'to show'
χʊ-bɔ́n-á	χʊ-m-pɔ́n-á	'to see'
χʊ-dʊʒ-a	χʊ-n-tʊʒ-a	'to annoint'
χʊ-ɟís-a	χʊ-ɲ-cís-a	'to feed'
χʊ-at-a	χʊ-ŋ-gat-a	'like'

Table 2: PND in Shekgalagari (table from Solé et al. 2010)

Several peculiarities need to be noted with respect to Tswana and Shekgalagari. First, /g/ never surfaces as a voiced stop: while it is devoiced to [k] post-nasally, it gets deleted elsewhere, e.g.[χʊ-at-a] for /χʊ-gat-a/ (cf.[χʊ-ŋ-kat-a], Solé et al. 2010). Second, voiced stops in nasal clusters of secondary origin (after syncope) do not undergo devoicing, but remain voiced in Shekgalagari and undergo assimilation in Tswana.

Sh.	/χʊ-m-bɔ́n-á/	→	[χʊmpɔ́ná]
Sh.	/χʊ-mʊ-bɔ́n-á/	→	[χʊmbɔ́ná]
Ts.	/χʊ-mʊ-bɔ́n-á/	→	[χʊmmɔ́ná]

Table 3: PND in Tswana and Shekgalagari (table from Solé et al. 2010)

Makhuwa is reported to undergo PND as a sound change, but the process did not develop into a synchronic alternation there. Table 4 illustrates PND in Makhuwa.

Proto-Batu	Emakhuwa	gloss
jega	teka	'to build'
njada	etala	'hunger'
cuma	thuma	'to buy'
mayị̈nco	maitho	'eyes'

Table 4: PND in Makhuwa (table from Janson 1991/1992)

Because the languages are very closely related and there are other instances of common innovation between Sotho-Tswana and Makhuwa, Janson (1991/1992) and Hyman (2001) imply that PND in the three languages is likely a common innovation. For the same reason, I will treat these three languages together in this study. Since the description of PND in Makhuwa is sparse and lacking in detailed phonetic descriptions, I will focus my discussion on Tswana and Shekgalagari; however in principle, the arguments for these two languages apply to Makhuwa as well.

3.1.3 Bube and Mpongwe

Unlike Makhuwa, Bube is not closely related to Tswana and Shekgalagari. Janssens (1993) reports that Bube also features PND. As will be shown below, several aspects of Bube PND are highly

reminiscent of the process reported for Tswana, Shekgalagari, and Makhuwa. Bube is a Northwest A Bantu language, spoken by approximately 51,000 speakers on Bioko island (Lewis et al. 2015). Sequences of a nasal and a voiced stop in Pre-Bube develop to voiceless stops in Bube. The following table illustrates the development.

Pre-Bube	Bube	gloss
*è-m-bódì	àpóɽî̃	'goat'
*è-m-bóà	è-pwáà	'dog'
*è-n-címbá	è-cìppà	'wild cat'
*-dámb-	-lápáà	'cook'
*-gɛ̀nd-	-ɛ̀tà-	'walk'
*-gàŋgà	-àkká	'root'
-kàŋg- ∼-bàŋg-	-àk	'attach'

Table 5: PND in Bube (table from Janssens 1993)

In the Mpongwe dialect of Myene (Bantu B language, spoken in Gabon, Lewis et al. 2015), PND is reported marginally for root initial [g] after some prefixes that historically ended in a nasal, e.g. *gàmb- > [i-kamba] (Mouguiama-Daouda 1990). However, because PND is marginal in Mpongwe — it is morphologically limited and does not apply categorically — I will for the most part leave it out of the ensuing discussion.[7]

3.1.4 Konyagi

Recently, PND as a sound change has been discovered in Konyagi (also known as Wamey, among others). Konyagi, a member of the Atlantic subfamily of the Niger-Congo group, is spoken by approximately 21,000 speakers in Senegal (Lewis et al. 2015). Note that Konyagi is not part of the Bantu family, which means that it is only very distantly related to the other Bantu languages above with PND. Merrill (2016, p.c.) reconstructs a detailed picture of Konyagi's pre-history. Notable in this reconstruction is a series of voiceless stops in post-nasal position that correspond to voiced stops in the neighboring languages Bedik and Basari of the Tenda group (data and table from Merrill 2016, based on Ferry 1991 and Santos 1996). It thus appears as if Konyagi underwent PND. The table below illustrates the development.

Konyagi	Bedik	Basari	gloss
æ̀-jamp	u-yāmb	ɔ-yămb	'millet stalk'
ì-ñə́mp	ɔ-ñʌ̀mb	a-ɟ̃ʌ̆mb	'plunge/immerse'
ì-ntæ̀w̃	gi-ndám	ɑ-ndáw̃	'animal/spirit'
ì-kônt	ɔ-hɔ̀nd	a-xɔ̀nd	'snore'
æ̀-ncæ̀nk	ga-nɟáng	a-nɟɑ̀ng	'Pterocarpus erinaceus (treesp.)'
æ̀-ncɔ́l̥	gɔ-nɟʌ̀l	ɑ-nɟʌ́n	'caterpillar'
ì-yæ̀nk	u-yáng	a-ɟ̃ɑ̀ng	'be long'
ì-nkòt	gɛ-ngɔ́t	ɛ-ngɔ̀t	'pole'

Table 6: PND in Konyagi (from Merrill 2016b)

7. The UniDia survey reports that PND targets the labial series of voiced stops in Lembaama. However, I was unable to find description of this development in the literature.

3.1.5 South Italian Dialects

Sicilian and Calabrian are dialects of Italian spoken in the corresponding regions of Italy by approximately 4.7 million speakers (Lewis et al. 2015). PND has been reported for these dialects in Rohlfs (1949, 424f.). The peculiarity about South Italian PND is that the sound change targets only the voiced affricate *ʤ, which is devoiced to [ʧ] after the nasal [n] (*ʤ > [ʧ] / N__; Rohlfs 1949, 424f.; Kümmel 2007, 376); regular voiced stops are not reported to be devoiced in the post-nasal position. The table below illustrates PND in Sicilian and Calabrian.

S.-Ital. dial.	Standard	
anʧilu	anʤelo	'angel'
pinʧiri	pinʤere	'push'
kianʧiri	planʤere	'to cry'
finʧiri	finʤere	'to feign'
tinʧiri	tinʤere	'to dye'

Table 7: PND in South Italian (from Rohlfs 1949, 424f.)

3.1.6 Buginese, Murik, and the Bengoh dialect of Land Dayak

PND has been reported in three Austronesian languages: Buginese, Murik, and the Bengoh dialect of Land Dayak. PND in the latter is simply mentioned without accompanying data (Rensch et al. 2006:69; Blust 2013); I therefore leave Land Dayak out of the discussion that follows. Buginese is spoken by approximately 5 million people in Sulawesi, an island of Indonesia; Murik is spoken in Sarawak, in Malaysia and Brunei, by approximately 1,000 speakers. These three Austronesian languages are not particularly closely related, so we cannot attribute PND to developments in a common ancestor; it is likely that PND developed independently in all three branches.

Apparent PND in Buginese is represented by the following table showing the development of Proto-Malayo-Polynesian voiced stops (data from Blust 2013). Velar stops are devoiced post-nasally. Labial stops appear devoiced after nasals, but surface as [w] initially and word-internally (with a sporadic reflex [b] in initial position). The dental stop *d is not implicated in PND; Pre-Buginese *d develops to /r/ in all positions, which does not undergo devoicing, e.g.*dindiŋ > [renriŋ]. Word-initially, however, *d is sporadically preserved as a voiced stop [d] or develops to [l]. The voiced fricative *z gets occluded to a voiced palatal stop initially, probably via rhotacism to *r intervocalically. Post-nasally, *z is devoiced to [c]. Word-finally, all stops converge as [ʔ].

	#__	V__V	N__
*b	b/w	w	p
*d	d/r/l	r	r
*g	g	g	k
*z	ɟ	r	c

Table 8: Summary of PND in Buginese

The data cited as evidence of PND as a sound change in Buginese are as follows:

Proto-SS	Buginese	
*bemba	bempa	'water jar'
*lambuk	lampuʔ	'pound rice'
*limboŋ	lempoŋ	'deep water'
*rambu	rampu	'fringe'
*rumbia	rumpia	'sago palm'
*tambiŋ	tampiŋ	'addition to a house'
*barumbun	warumpuŋ	'a color pattern'
*bumbun	wumpuŋ	'heap up'
*geŋgem	geŋkeŋ	'hold in the hand'
*tuŋgal	tuŋkeʔ	'each, single'
*aŋgəp	aŋkəʔ	'price'
*aɲɟap	ancəʔ	'offerings to spirits'
*ɟanɟi	ɟanci	'to promise'
*puɲɟuC	ma-poncoʔ	'short'

Table 9: PND in Buginese (from Blust 2005, 2013)

In Murik, both labials and alveolars undergo devoicing in post-nasal position; velars are also sporadically devoiced elsewhere. Voiced dentals appear as [l] word-initially and [r] word-internally. PMP *z develops to the voiced palatal affricate [ɟj] initially, [s] word-internally, and to the voiceless palatal affricate [cç] post-nasally. The table below illustrates the development of stops from Proto-Kayan-Murik.

	#__	V__V	N__
*b	b	b	p
*d	l	r	t
*g	g/k	g/k	k
*z	ɟj/ɟ	s	cç

Table 10: Summary of PND in Murik (as reconstructed in Blust 2005)

Similarly, PND is confirmed for Murik by the following examples:

Proto-KM	Murik	
*kelembit	kələmpit	'shield'
*bumbuŋ	umpuŋ	'ridge of a roof'
*lindem	lintəm	'dark'
*-inda	t-inta	'beneath, below'
*mandaŋ	mantaŋ	'to fly'
*tundek	tuntuk	'beak of a bird'
*lindiŋ	lintiŋ	'wall of a house'
*undik	untik	'upper course of a river'
*tandab	tantap	'catch'

*andeŋ	antəŋ	'deaf'
*pindaŋ	pintaŋ	'blossom'
*pendan	pəntan	'small fruit bat'
*nɟji	nccçi	'one'
*menɟjat	məncçat	'pull'
*unɟjuŋ	uncçuŋ	'tip, extremity'
*anɟjat	ancçat	'rattan tote bag'
*tunɟjuʔ	tuncçuʔ	'to point, indicate'
*tuŋgan	tuŋkan	'dibble stick'

Table 11: PND in Murik (from Blust 2005:259f.; Blust 2013:668)

The data presented in this subsection seem to suggest, at first glance, that PND operated as a single sound change in the development of all twelve of these languages. However, I will demonstrate below that a thorough investigation reveals a common pattern of complementary distribution in all twelve cases, strongly suggesting that a combination of natural sound changes operated in place of a single PND.

3.2 Explanations of PND

Several accounts in the literature understand PND as a single sound change; explanations for this process run the gamut from appeals to sociolinguistic factors (Xromov 1972), to hypercorrection (Blust 2005), to arguments that PND is actually a phonetically plausible or even natural process (Solé et al. 2010, Solé 2012). Three problems arise with such accounts: first, they all struggle to explain why a sound change should operate against the strong phonetic tendency to maintain voiced stops in post-nasal position; second, they each examine and account for only a single instance of PND, examined in isolation from relevant cross-linguistic data; third, most of them rely on the reconstruction of hypothetical, unattested dialects for which there is no comparative evidence.

Xromov (1972) invokes socio-linguistic factors to explain PND in Yaghnobi. He postulates the existence of two unattested dialects in Pre-Yaghnobi, the first of which (Dialect 1) voiced all post-nasal stops, and the second of which (Dialect 2) retained the contrast for voice in post-nasal position. To arrive at PND, Xromov suggests that speakers of Dialect 2 generalized voiceless stops in post-nasal position based on hypercorrection to Dialect 1. The major drawback of this explanation is its total lack of evidentiary basis; there are no data providing support for the reconstruction of Xromov's two hypothetical dialects.

Blust (2005, 2013) offers three possible explanations for the emergence of PND in Buginese, Murik, and Land Dayak. First, he notes that, much as PNV can be understood as an assimilation of stops to a voiced environment, PND can be explained as *dissimilation*. This assumption, however, lacks explanatory power: it simply restates that PND is the opposite process from PNV. Blust (2013:668) himself notes that "this does little to explain why a change of this type would occur."

Blust's second explanation for Austronesian PND postulates that the three languages in question first underwent PNV: voiceless stops became voiced in post-nasal position, thus eliminating NT sequences. According to Blust (2013), after the shift to PNV, "voice was free to vary" post-nasally, and the "voiceless variant of postnasal obstruents prevailed over time." There are two major issues with this approach. First, it is difficult to explain why a voiceless variant would prevail in an environment that strongly favors voicing. Second, it not parsimonious to assume the independent occurrence of PNV three times without any comparative evidence.

A third explanation offered in Blust (2005) invokes dissimilation by hypercorrection. Blust notes that NT sequences in Buginese and Murik develop either to T or TT. This means that, at

a certain point, NT sequences were absent from the language and only voiced stops surfaced after nasals (ND). At this point, according to Blust, speakers "may have assumed that prenasalized obstruents had acquired voicing by assimilation" and then "undid" that assumed voicing. This account faces three major difficulties. As already pointed out by Blust (2005), it is unclear what would "prompt speakers to assume that voicing assimilation had taken place in earlier clusters" of ND. Second, even if they had made this assumption, the speakers would still have to apply dissimilation in a phonetically unnatural direction. Finally, this particular approach lacks broader explanatory power, since it cannot be extended to cases of seeming PND in other languages, where the sound change NT > TT, T is not attested.

Some analyses have attempted to account for PND by motivating the process phonetically. Solé et al. (2010) and Solé (2012) specifically identify PND as a "historical process," meaning that they assume PND operated as a single instance of sound change. Moreover, these authors claim that PND is not necessarily an unnatural process and may in fact have a phonetic explanation. The main evidence for this claim comes from Shekgalagari, which is assumed to feature "early velic rising" in NT sequences. This process is supposed to follow from the fact that (i) speakers do not show any passive voicing in the NT sequences in Shekgalagari and (ii) underlying nasal–fricative sequences /nz/ yield a nasal affricate [nts]. This process of early velic rising, which is argued to account for both these observations, would also have caused a "long stop closure" in ND sequences. Because voicing is difficult to maintain, especially during longer closure, the result would be devoicing of the stop (Solé et al. 2010: 612).

This explanation has three major drawbacks. First, secondary ND sequences surface as NN in Tswana and ND in Shekgalagari. The following two examples illustrate this distribution (repeated table 3):

Sh.	/χʊ-m-bɔ́n-á/	→	[χʊmpɔ́ná]
Sh.	/χʊ-mʊ-bɔ́n-á/	→	[χʊmbɔ́ná]
Ts.	/χʊ-mʊ-bɔ́n-á/	→	[χʊmmɔ́ná]

Table 12: Secondary ND sequences in Tswana and Shekgalagari (table from Solé et al. 2010)

If early velic rising in Shekgalagari were indeed a phonetic process, we should expect to see devoicing in secondary ND sequences as well. The fact that the stops in secondary ND sequences surface as voiced speaks strongly against the proposal in Solé et al. (2010) and Solé (2012). Of course, one could assume that early velic rising operated prior to the period during which secondary ND sequences arose. However, there's a major flaw in this assumption: Solé et al. (2010) provide evidence for early velic rising from synchronic phonetic data. If we postulate that early velic rising is responsible for PND as a synchronic phonetic process, we should expect secondary sequences to undergo devoicing as well. Conversely, if we posit that early velic rising should have been completed by the time secondary ND sequences were introduced, we should not expect to find continuing evidence for this process in the current phonetic data.

Second, realization of /nz/ as [nts] is extremely common and proceeds from general phonetic tendencies cross-linguistically (cf. Steriade 1993). Because the initial part of a fricative in post-nasal position is universally almost always realized with oral closure, the fact that Shekgalagari /nz/ surfaces as [nts] hardly tells us anything about early velic rising. Third, the explanation proffered in Solé et al. (2010) neglects dialectal data from Tswana that contradict the early-velic-rising proposal. Several Tswana dialects show a pattern of unconditioned devoicing of voiced stops that is most likely connected to the PND seen in Shekgalagari. For these cases, appealing to early velic rising in NT sequences is unhelpful. Likewise, an explanation along these lines fails to account

for other, cross-linguistic cases of seeming PND where no traces of early velic rising can be found. If PND were indeed motivated by early velic rising, we should expect to find evidence that early velic rising is similarly responsible for reported cases of PND outside Tswana and Shekgalagari. The alternative argument pursued by this paper — that all cases of PND result from a combination of sound changes — has more explanatory power and captures the data better than the proposal in Solé et al. (2010).

Finally, Dickens (1984) and Hyman (2001) propose an explanation for PND in Tswana that assumes a set of three non-PND sound changes that conspire to produce apparent PND: fricativization, devoicing of stops, and occlusion of fricatives. I will argue in the remainder of this paper that this is in fact the correct explanation, and that an essentially similar historical scenario played out in all twelve cases of reported PND described above. Unfortunately, at the time of Dickens' and Hyman's work, no historical parallels existed in the literature that would support their explanation, which led other authors to propose alternative accounts of the data. Admittedly, in the absence of typological parallels, one might judge an explanation that operates with a single (albeit unnatural) sound change more parsimonious and justified than an explanation that requires three separate sound changes. By bringing numerous cases of PND from disparate language families together, the next section dispels this concern and validates the three-sound-change analysis on typological grounds. I argue that the strongest evidence in favor of the three-sound-change analysis comes from Sogdian and Yaghnobi, in which the development is historically attested.

3.3   A combination of sound changes

A closer look into the collected data from 3.1 reveals an important generalization: for all cases of PND, either direct evidence or clear indirect evidence can be found that, at some stage of development, voiced stops surfaced as voiced fricatives except in post-nasal position. In other words, in the first stage of the development of PND, a natural sound change operates that fricativizes voiced stops except post-nasally (D > Z / [−nas]__). This sound change results in a complementary distribution: voiced stops surface post-nasally, voiced fricatives elsewhere. I argue that PND is a result of this complementary distribution plus the unconditioned devoicing of voiced stops: because voiced stops surface only post-nasally, the unconditioned devoicing results in apparent PND.

3.3.1   Yaghnobi

Evidence for a stage with complementary distribution is strongest in Yaghnobi, because its prehistory is directly attested. Yaghnobi is a descendant of Sogdian, a Middle Iranian language spoken in the first millennium CE and preserved in documents from that period. In Sogdian, all voiced stops surface as voiced fricatives except post-nasally. This complementary distribution is directly attested in Sogdian and confirmed by the writing system (cf. Sims-Williams 1987:178). It is equally clear that the Sogdian pattern developed through a sound change D > Z / [−nas]__ in an earlier stage of the language. In Avestan (the ancestor of Sogdian), voiced stops correspond to Sogdian voiced fricatives except post-nasally, e.g. Avestan [dasa] vs. Sogdian [ðasa] 'ten', Avestan [gari-] vs. Sogdian [ɣarí] 'mountain' (Kümmel 2006), Avestan [asənga-] vs. Sogdian [sang] 'stone' (Bartholomæ 1961:210).

Given the complementary distribution attested in Sogdian, I propose that, on the way to Yaghnobi, an additional sound change operated: unconditioned devoicing of voiced stops (D > T). Because voiced stops surface after nasals, this combination of sound changes resulted in apparent PND. The development is summarized in the following table:

Avestan		*band
Sogdian	D > Z / [−nas]__	βand
Yaghnobi	D > T	vant

Table 13: Development of PND in from Avestan to Yaghnobi

Sogdian thus provides direct historical evidence showing that the apparent case of PND in Yaghnobi is a side effect of two natural and well-attested sound changes: (i) fricativization of voiced stops except in post-nasal position (D > Z / [−nas]__), and (ii) unconditioned devoicing of voiced stops (D > T).

To get PND, we need a third sound change: occlusion of voiced fricatives to stops (Z > D). Yaghnobi provides additional evidence for this process too: the original voiced labial and velar stops *b and *g still surface as voiced fricatives in the "elsewhere" position in the modern language (e.g. Yagh. [vant] 'tie' from Sogd. [βand]; Yagh. [ɣar] 'mountain' from Sogd. [ɣarí]). Nevertheless, the voiced alveolar fricative [ð] gets occluded in Yaghnobi and surfaces as a voiced stop [d], thus blurring the original complementary distribution (Xromov 1972:123). Apparent PND in Yaghnobi thus fully holds only for the dental series of stops, because only this series of stops underwent a sound change that turned the original voiced fricatives "back" to stops (Z > D). Table 14 illustrates the three sound changes that operated on the alveolar series of stops to produce PND.

	Avestan	band	dasa
d > ð/[−nas]__	Sogdian	βand	ðasa
d > t	Yaghnobi	vant	*ðasa
ð > d	Yaghnobi	vant	das

Table 14: Development of coronals from Avestan to Yaghnobi

Yaghnobi and Sogdian bear yet more crucial evidence in favor of the "three sound changes" approach outlined above. Consider: it would be reasonable to argue that devoicing should not be analyzed as unconditioned, precisely because it operates only in post-nasal position. This being the case, devoicing should indeed be considered unnatural according to the definition in (3). However, Sogdian and Yaghnobi provide strong evidence to suggest that devoicing of voiced stops is in fact unconditioned. I show below that devoicing targets all surface voiced stops in Yaghnobi, not just those in post-nasal position.

It is true that voiced stops surface primarily in post-nasal position in Sogdian, but they also surface in one additional, more marginal context: after voiced fricatives. This property of Sogdian, which has up to now been a lesser known fact (Novák, To appear), essentially means that voiced stops surface as fricatives in Sogdian except post-nasally and after a voiced fricative. Crucially, Sogdian sequences of a voiced fricative and a voiced stop, ZD, devoice in the development from Sogdian to Yaghnobi to ST, e.g. Sogd. [suɣd-], Yagh. [suxta]; Sogd. [əχʃɨβdí], Yagh. [xiʃift] (from Novák, To appear). The table below illustrates this development.

Sogdian	Yaghnobi
ɣd	xt
βd	ft
zd	st

Table 15: Correspondences of ZD sequences

The only plausible explanation for this development is that voiced stops undergo unconditioned devoicing in Yaghnobi (just as I proposed for post-nasal position). After the devoicing, the preceding voiced fricative undergoes voicing assimilation to the following voiceless stops. That this scenario indeed took place is strongly suggested by evidence from Western Yaghnobi, in which forms like [avd] and [avt] for Sogd. [əβdá] are attested (data from Novák, To appear). While the first form [avd] dialectally lacks devoicing, the second form [avt] shows that only voiceless stops devoice: the fricative is not assimilated to the following voiceless stop (cf. the assimilated form from Eastern Yaghnobi [aft]). The development of ZD clusters in Yaghnobi is summarized in table 16.

Sogdian		ZD	ɣd
	D > T	ZT	ɣt
Yaghnobi	assimilation	ST	xt

Table 16: Development ZD sequences from Sogdian to Yaghnobi

In the other eleven languages with PND, clusters are generally not allowed (or they became simplified before the emergence of PND), so we do not see devoicing anywhere other than post-nasal position. Devoicing in clusters in Yaghnobi thus offers a crucial piece of evidence in favor of the proposal that the devoicing of voiced stops that occurs in the development of PND is *unconditioned*; if it were not, we would not be able to unify our account of the devoicing of ND and ZD.

In summary, Yaghnobi and Sogdian provide direct historical evidence for the proposal that apparent PND in the development of Yaghnobi actually emerged from a confluence of three sound changes and never operated as a single sound change in either language.

3.3.2 Tswana, Shekgalagari, and Makhuwa

Tswana offers crucial dialectal evidence for the three-sound-change approach. There are at least three different systems of stops in the micro-dialects of Tswana. Among one set of speakers, voiced stops get devoiced in all environments: no voiced stops are allowed in the system. Speakers of this system have been labelled "devoicers" (Coetzee et al. 2007). Another set of speakers changes voiced stops into fricatives in all positions but post-nasally (these speakers are called "leniters"). A third set of speakers use the so-called PND system: for these speakers, voiced stops surface as voiceless only post-nasally. The three systems of Tswana are represented below.

	*#ba	*aba	*mba
devoicers	#pa	apa	mpa
leniters	#βa	aβa	mba
PND	#ba	aba	mpa

Table 17: Microdialects of Tswana (from Zsiga et al. 2006, Solé et al. 2010)

The PND system arises precisely through the combination of two other (devoicing and leniting) systems: leniters take on fricativization except after nasals (D > Z / [−nas]__), while devoicers undergo unconditioned devoicing (D > T). Following Dickens (1984), Hyman (2001) argues that post-nasal devoicers undergo both sound changes. Because voiced stops surfaced only after nasals, the result is apparent PND. This pattern is obscured, however, by an additional change in the dialect with PND: unconditioned occlusion of fricatives (Z > D). This change crucially blurs the initial complementary distribution of consonants, with the result that the synchronic alternation

becomes PND: voiced stops surface as voiceless only after nasals. Recall that this final sound change also occurred in Yaghnobi, but only for the alveolar series of stops.

The pattern of development of Tswana voiceless stops also speaks in favor of the proposed explanation. As Hyman (2001) points out, voiceless stops underwent fricativization along with voiced stops. The table below shows the development.

	#__	V__V	N__
*p	ɸ	ɸ	pʰ
*t	r̥	r̥	tʰ
*k	h, x	h, x	kxʰ, kʰ

Table 18: Development of voiceless stops in Tswana (table from Hyman 2001)

The synchronic alternation is exemplified below:

*p	ɸeɲa	mpʰeɲa	'conquer'
*t	rátá	ntʰátá	'love'
*k	xátá	ŋkxʰátá	'trample'

Table 19: Voiceless stop alternation in Tswana (table from Hyman 2001)

These data provide yet another strong piece of evidence that complementary distribution first occurred in Tswana and neighboring dialects, in both the voiced and voiceless series of stops. The voiceless and voiced series underwent lenition except in post-nasal position (as in the leniters dialect), and then voiced stops underwent further changes (unconditioned devoicing, as in the devoicers dialect) to produce PND, whereas voiceless stops retained the complementary distribution. Because Shekgalagari and Makhuwa are closely related to Tswana, the same analysis can be applied to these two languages as well.

3.3.3   Bube and Mpongwe

Despite the fact that Bube and Mpongwe are not closely related to Tswana, Shekgalagari, and Makhuwa, we find striking similarities between these languages that uniformly point to the conclusion that complementary distribution (with lenition of voiced stops except post-nasally) operated in Bube's and Mpongwe's prehistory, too. The data for the two languages, however, is sparse and detailed phonetic descriptions are lacking.

Several indicators in Bube data clearly point to a pre-stage with complementary distribution. Janssens (1993:37) reports that in the labial series, the voiced stop and voiced fricative [b] and [β] are in free variation in medial position. Also, exactly parallel to Tswana, the voiced velar stop is lost in Bube, pointing indirectly to an interstage with [ɣ] (also reconstructed independently in Janssens 1993:27). Finally, the alveolar series of stops undergoes lenition as expected: in the elsewhere condition, [d] develops to [l] or [r] (likely through an interstage *[ð]), depending on the vowel quality: *-dɔ́b- > [-lɔ́bâ]; *-dɔ́ɔ̀ > [-lɔ́ɔ̀] (Janssens 1993:23). In fact, Janssens independently reconstructs a proto-stage of Bube with exactly the complementary distribution we observe in other languages with PND: voiced stops surface as fricatives except post-nasally.

In Mpongwe, PND that targets only the velar series also arises through a combination of three sound changes. Mouguiama-Daouda (1990) independently reconstructs a stage in which [g] surfaced as a voiced velar fricative [ɣ] except post-nasally, citing as evidence the fact that the fricative is still

realized as [ɣ] by some older speakers (Mouguiama-Daouda 1990). PND in Bube and Mpongwe thus follows the usual trajectory: complementary distribution and unconditioned devoicing of stops that surface only post-nasally.

3.3.4   Konyagi

Konyagi and neighboring languages, too, provide very strong evidence in favor of a stage with complementary distribution, just like in Yaghnobi or Tswana. Proto-Tenda, an ancestor of Konyagi, is securely reconstructed on the basis of Konyagi and neighboring languages Basari and Bedik (Merrill 2016). The first stage of Proto-Tenda features a usual phonemic inventory with voiced and voiceless stops and fricatives. In stage II, all stops fricativized everywhere but in post-nasal position. This fricativization in Proto-Tenda was quite radical, targeting both voiced and voiceless stops, as well as nasal stops and, as I reconstruct, geminates/clusters. The fricativization is directly confirmed by the Basari dialect, which more or less preserves the Proto-Tenda II stage. The development is illustrated below.

Proto-Tenda I	p	t	c	k	f	ʃ	x	b	d	ɟ	g	w	ɣ	l	m	n	ñ	ŋ
Proto-Tenda II	f	r̥	ʃ	x	f	ʃ	x	w	ɣ	w	r	j	ɣ	l	w̃	n	ỹ	ɣ̃
Basari	f	s	ʃ	x	f	ʃ	x	w	ɣ	w	r	j	ɣ	l	w̃	n	ỹ	ɣ̃
Konyagi	f	r	s	x	f	s	x	w	l	j	/	w	/	l	w̃	n	ỹ	/

Table 20: Development of consonants from Proto-Tenda to Konyagi (table from Merrill 2016a,b, Santos 1996)

In Konyagi, too, original voiced stops surface as fricatives (further developing to voiced sonorants in some places of articulation) except after nasals. In post-nasal position, Konyagi voiced stops remain stops. The following table summarizes the development of consonants in post-nasal position in the descendants of Proto-Tenda (from Merrill 2016, p.c.).[8] Post-nasally, no fricatives occur in either Konyagi or Basari.

Proto-Tenda I	p	t	c	k	f	ʃ	x	b	d	ɟ	g	w	ɣ	l	m	n	ñ	ŋ
Proto-Tenda II	p	t	c	k	p	c	k	b	d	ɟ	g	b	g	l	m	n	ñ	ŋ
Basari	p	t	c	k	p	c	k	b	d	ɟ	g	b	g	l	m	n	ñ	ŋ
Konyagi	p	t	c	k	p	c	k	p	t	c	k	p	k	l	m	n	ñ	ŋ

Table 21: Development of post-nasal consonants from Proto-Tenda to Konyagi (table from Merrill 2016a,b, Santos 1996)

While in Bedik and Basari, post-nasal voiced stops remain voiced, they devoice in Konyagi. Here too, however — like in all other cases of PND — the voiced stops that devoiced post-nasally were in fact the only voiced stops in the language (the stage confirmed in today's Basari). Thus, again, the sound change operating in Konyagi is in fact unconditioned devoicing of voiced stops. The apparent PND is yet again the result of a combination of sound changes.

The third sound change, occlusion back to stops, is lacking in Konyagi. As a result, the synchronic alternation in question is not between voiceless and voiced stops, but between voiced fricatives and voiceless stops. Konyagi, however, does not lack voiced stops completely: original fricative geminates were later occluded to stops and simplified, resulting in voiced stops being reintroduced into the synchronic inventory.[9]

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8. Nasal is lost before voiceless stops.
9. Likewise, a Proto-Tenda sequence of a nasal and an implosive yields an ND sequence in Konyagi.

So far, I have argued that the cases of seeming PND can be accounted for through a combination of two or three well-motivated sound changes. I now turn to a case of PND from the South Italian dialects to illustrate that such sound change combinations involving complementary distribution are not limited to stops, but can apply to other segments as well.

3.3.5 South Italian

On the surface, the data in South Italian suggest that *ʤ devoices to [ʧ] only in post-nasal position. However, if we look at the development of *ʤ elsewhere, we observe that it gets de-occluded and further develops to [j] except after nasals (e.g.*faʤina > Calabrian [fajina], *leʤere > Calabrian [lejere], Sicilian [lejiri]; Rohlfs 1949:358). Again, we have evidence for a stage with complementary distribution. At this point, an unconditioned devoicing of voiced affricates occurs. This, too, is a well-attested and motivated sound change: voiced affricates are highly marked. Voice is difficult to maintain, especially in affricates, which combine two articulations that are highly antagonistic to voicing: closure and frication (Ohala 1983, 2006). One possible resolution of this markedness is to devoice the affricates.

I propose a new explanation for the emergence of apparent PND in South Italian, which postulates a two-step process: (i) de-occlusion and gliding of voiced affricates except after nasals (ʤ > j / [−nas]__), followed by (ii) unconditioned devoicing of voiced affricates (DZ > TS). The table below illustrates the development. Stage 1 shows a period of complementary distribution, with de-occlusion of voiced affricates except in post-nasal position. Stage 2 represents the development after unconditioned devoicing of voiced affricates.

	elsewhere	post-nasally
Stage 1	fajina	pinʤere
Stage 2	fajina	pinʧiri

Table 22: Devoicing of post-nasal affricates in South Italian

Note that this set of sound changes is in principle the same as in the previous cases, but here complementary distribution targets affricates instead of stops.

3.3.6 Buginese and Murik

The emergent pattern that we have seen in all three cases of seeming PND so far can be generalized as follows: (1) a set of segments enters complementary distribution; (2) a sound change occurs that operates on the unchanged subset of those segments; (3) optionally, another sound change occurs that blurs the original complementary distribution environment. Note that, according to Kiparsky (2008), the third sound change in this series is expected to be blocked by UG, since the combination would result in an unnatural process. However, this blocking clearly does not happen: sound change that blurs the original complementary distribution and thus produces the unnatural process is limited to dentals in Yaghnobi, but operates on all stops in Tswana and Shekgalagari, resulting in an unnatural synchronic alternation.

Let us now turn to the three Austronesian languages. On the surface, the data from Buginese and Murik seem to point to PND operating as a single sound change. Moreover, there is no direct historical or dialectal evidence to suggest otherwise, as is the case for Yaghnobi, Tswana, and Konyagi. If the only attested instances of PND were those found in Austronesian languages, we would likely be forced to assume the operation of a single sound change — PND. However, these

languages do, at least, show clear traces of a stage with complementary distribution. Below, I will argue that the set-of-three-sound-changes explanation again better captures the data.

The major evidence against PND as a single sound change in Austronesian comes from the voiced labial stop in Buginese. Already in Proto-South-Sulawesi (from which Buginese developed), *b had developed to [w] except word-initially and in post-nasal position (Mills 1975, 547). Later, the change *b > [w] also targeted the word-initial position, as is clear from initial stop in cases like *bumbun > [wumpun]. Thus, at one stage in the language's development, voiced stops surfaced only post-nasally: again, we have clear evidence for complementary distribution. From there, the development followed the trajectory described above: unconditioned devoicing of voiced stops occurred, but produced apparent PND because voiced stops surfaced only post-nasally. The development is illustrated by the following example from Buginese:

PSS		*bumbun
Pre-Buginese	b > w / [-nas]__	*wumbun
Buginese	D > T	wumpun

Table 23: Development of PND in Buginese

In Buginese, /w/ continues to surface as a non-obstruent (since only two changes operated in the labial series), but the voiced velar fricative *ɣ undergoes occlusion to [g] (three sound changes operated in the velar series), thus obscuring evidence for an inter-stage with complementary distribution. Note that this is precisely the same scenario described for Yaghnobi, with the only difference being that, in Yaghnobi, it was the alveolar series of fricatives that underwent occlusion, whereas in Buginese, it was the velar series. The development leading to apparent PND is illustrated in the table below.

PSS		*aŋgəp	*giliŋ
Pre-Buginese	D > Z / [-nas]__	*aŋgəp	*ɣiliŋ
Pre-Buginese	D > T	*aŋkəp	*ɣiliŋ
Buginese	Z > D	aŋkəp	giliŋ

Table 24: Development of PND in dorsals in Buginese

The dental series of stops in Buginese escapes PND because *d developed to [r] in all positions and, as such, became ineligible for devoicing of voiced stops. The development of *z also conforms to the proposal above: intervocalically, it undergoes rhotacism to [r]; post-nasally, it occludes and devoices to [c] (according to the unconditioned devoicing of voiced stops which predictably targets the palatals); initially, it remains a fricative *ʝ and later occludes together with [ɣ] to [ɟ]. The initial stage with complementary distribution in Buginese is additionally confirmed by a recent description of Buginese by Valls (2014) which reports that voiced stops [b, d, g] have voiced fricatives [β, ð/ɾ, ɣ] as allophones in apparent free variation in non-post-nasal position. For a summary of developments, see table 8 above.

In Murik, complementary distribution is likewise still attested today and can be found in the development of voiced dental stops. On the surface, Proto-Kayan-Murik *d surfaces as [l] initially, [r] intervocalically, and [t] post-nasally (see table below). I propose a historical development with the following trajectory: Proto-Kayan-Murik *d lenited to [l] or [r] (probably through an inter-stage with *ð) initially and inter-vocalically, where they still surface as such. After a nasal, however, *d remained a stop.

	#__	V__V	N__
PKM	ð	ð	d
Murik	l	r	t

Table 25: Development coronals in Murik

Again, these data point to a stage with complementary distribution (PKM in the table above). Since an unconditioned devoicing of voiced stops occurred during a period when voiced stops surfaced only after nasals, apparent PND is the result. I argue that the same development occurred with labials and velars too: original voiced stops fricativized to *β and *ɣ (except after a nasal), at which point voiced stops (surfacing only post-nasally) got devoiced (e.g. *b > [p], *g > [k]). *β and *ɣ then underwent occlusion "back" to stops, resulting in apparent PND. The table below traces the proposed trajectory from (Pre-)Proto-Kayan Murik to Murik for a labial series of stops.

	#__	V__V	N__
Pre-PKM	b	b	b
PKM	β	β	b
PKM	β	β	p
Murik	b	b	p

Table 26: Reconstructed development of labials in Murik

A peculiarity of the development in Murik is that it combines the "PND of stops" that we saw, for example, in Tswana, with the "PND of affricates" that we saw in Sicilian and Calabrian — i.e., whereas the previously discussed languages devoice either stops or affricates, Murik devoices both. The development of stops in this language is straightforward — it follows the usual trajectory of PND: complementary distribution, unconditioned devoicing, and then optional occlusion to stops (as we saw above). The development of affricates is more complicated, but nevertheless revealing. PMP *z develops to *s intervocalically already in Proto-Kayan-Murik (Blust 2005); this development cannot be considered part of PND, because it happens at an earlier stage. Elsewhere, *z is preserved as voiced and gets occluded to an affricate *ɟj. Word-initially, de-occlusion to *j takes place, just as in South Italian, whereas /ɟj/ surfaces as an affricate in post-nasal position. The affricate then gets devoiced, exactly as in Sicilian and Calabrian, together with devoicing of other voiced stops. The initial fricative *j then gets occluded to a voiced stop, together with other voiced affricates in Murik.[10]

In sum, the devoicing process that operated on voiced stops operated also on voiced affricates in Murik. Thus, even though Buginese and Murik offer neither dialectal nor historical evidence for complementary distribution, there is enough language-internal evidence to posit that, at one stage, voiced stops (and affricates) surfaced only after nasals: the original voiced labial stops surface as fricatives even today in Buginese, whereas in Murik voiced dental stops surface as lenited [r] or [l], in accordance with the reconstructed complementary distribution.

3.4 Naturalness of the three sound changes

All sound changes assumed under my new proposal are natural: phonetically well-motivated and well-attested, with clear phonetic precursors. A survey of sound changes in Kümmel (2007) lists

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10. The affricate articulation in initial position (Blust 1974) is likely secondary: there exists variation between affricate and stop articulation. It is well known that palatal stops often develop into affricates.

at least four cases in which voiced stops undergo fricativization except after nasals, plus an additional two cases in which voiced fricatives occlude to stops post-nasally. Moreover, only 2 of the 17 surveyed languages with NC sequences permit sequences of nasal + continuant phonotactically (Maddieson 1984, reported in Steriade 1993). In fact, post-nasal occlusion is a universal phonetic tendency, as the exact phonetic realization of NZ sequences almost always passively proceeds through a stage with oral closure (Steriade 1993:410). The articulatory reasons for occlusion of post-nasal fricatives are clear: in the transition from nasal stop to oral fricative, the velum rises early, causing "denasalization of the final portion of the nasal consonant" (Busà 2007:157) and resulting ultimately in a period of oral (denasalized) occlusion.

Unconditioned devoicing of voiced stops is a well-motivated process too. Closure is in all respects antagonistic to voicing for clear aerodynamic reasons: the closure causes air pressure buildup in the oral cavity, which results in an equalization of subglottal and oral pressure. When this happens, the vocal folds are unable to vibrate and voicing ceases (Ohala 1983). The antagonism of closure to voicing is also confirmed by typology: of 706 languages surveyed, 166 have only voiceless stops (Ruhlen 1975, reported in Ohala 1983). As a comparison, only four languages are reported to feature only voiced stops (Ohala 1983), and even in those languages, it appears that stops are voiceless initially.[11] Unconditioned devoicing is also attested as a sound change. In Tocharian, in addition to other examples listed in Kümmel (2007), all voiced stops devoice in all positions, including the post-nasal position.

One might question the naturalness of unconditioned devoicing when voiced stops surface exclusively in post-nasal position. We saw that, post-nasally, voicing of stops is a UPT. However, as was defined in (2), naturalness must always be evaluated with respect to a given context. Post-nasally, voicing of voiceless stops is indeed a UPT: voicing passively continues into closure in post-nasal position. However, voiced stops absent a specific context are articulatorily nevertheless disprefered when compared to voiceless stops: closure is always antagonistic to voicing for clear aerodynamic reasons. In fact, the reason for PNV's status as a UPT is that post-nasal position counters some anti-voicing effects of the closure. Closure causes airflow to stop because of pressure build up. The openness of the nasal cavity in the transition from a nasal to an oral stop, however, enables some additional airflow through nasal leakage. Moreover, expansion of volume in the oral cavity due to velic rising helps maintain some airflow despite the closure of the following stop. In other words, the global articulatory dispreference for voicing in stops is due to closure that holds in all contexts: unconditionally. Some contexts can diminish the negative effects of closure on voicing by promoting additional airflow, but the effect when evaluated globally is still present. This is the reason why unconditioned devoicing of voiced stops is articulatorily motivated.

Two pieces of evidence from the data independently support this position. First, Yaghnobi shows that unconditioned PND operated in its prehistory, not only post-nasally, but also in other positions where voiced stops surface (after voiced fricatives). Devoicing in Yaghnobi was not limited to N__ and Z__ positions, but rather was unconditioned; however, because stops surface only in post-nasal and post-fricative positions, it appears as if devoicing operated only there. The second piece of evidence in support of the articulatory motivation of unconditional devoicing comes from Tswana. As already mentioned, there are at least three microdialects within Tswana: a devoicing dialect, a leniting dialect, and a PND dialect.[12] Phonetic studies of the devoicing system show

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11. Initial stops in Yidiny have been reported to surface as voiceless, or at least partially voiced (Dixon 1977). My preliminary analysis of recordings made by Dixon and obtained from AIATSIS confirm these claims: stops tend to be voiceless utterance-initially.

12. Some other systems of stops within Tswana microdialects are also reported: e.g. positional devoicers that feature voiceless stops in all positions but initial position, where voiced stops remain voiced (Gouskova et al. 2011). Such systems are likely the result of fricativization except post-nasally, devoicing of stops, occlusion of initial fricatives and

that devoicing is complete and unconditioned: devoiced stops that go back to voiced stops are voiceless in all positions, including the post-nasal position (for instance, the devoiced post-nasal labial and alveolar stop have only 11% of closure voiced, compared to 7% and 12% intervocalically[13]; Gouskova et al. 2011). In other words, unconditioned devoicing is an attested and well-motivated sound change and where it happens, it targets stops in post-nasal position as well.

Finally, occlusion of non-sibilant fricatives to stops is also well attested and motivated, although unlike the other two sound changes, it is not as unidirectional. Non-sibilant fricatives are typologically and articulatorily dispreferred (Maddieson 1984:46). Also, there are many languages without fricatives in their inventories, but none without stops (21 or 6.6% of languages surveyed in Maddieson 1984 lack any fricative, even a strident fricative). Moreover, fricatives require a greater level of articulatory precision than other manners of articulation: compared to stops, the articulatory targets and shape of the vocal tract require greater precision for fricatives (Ladefoged and Maddieson 1996:137). Deviation from precise articulatory targets can thus lead to occlusion of fricatives to stops. Kümmel (2007) identifies at least six languages in which a sound change turned voiced fricatives to voiced stops for all places of articulation, as well as several more in which occlusion is limited to a single place of articulation.

3.5   PND as a synchronic alternation

Buginese, Konyagi, and especially Tswana and Shekgalagari, confirm that a combination of sound changes can and do result in productive unnatural synchronic processes.

PND is reported not only as a sound change, but also as a synchronic alternation in the Buginese derivational morphology. Sirk (1983:35-37) shows that sequences of N + D yield NT (except for dentals), while the sequence N + [w] yields [mp]. He also argues that the only permissible non-geminate clusters in Buginese are NT (to the exclusion of ND) (Sirk 1983:35-37).

Isolation	gloss	Compound	gloss
wərrə	'heavy'	sim-pərrə	'just as heavy'
bone	prince	arum-pone	prince Bone
gora	'shouts'	samən-kora	'loud shouts'
jaiʔ	'root'	maɲ-caiʔ	'to sew'

Table 27: Buginese PND (from Sirk 1983:35-37)

Noorduyn (2012/1955) describes PND in Buginese as part of a sandhi phenomenon. A word-final nasal before a word-initial labial approximant [w] in sandhi results in the sequence [mp], e.g. /rilaleŋ wanua/ becomes [rilalempanua]. Noorduyn (2012/1955) also reports that PND in sandhi occasionally targets voiced labial stops as well, but the process is no longer psroductive: /telluŋ bocco/ → [tellumpoco]. Data on this phenomenon are sparse, however, and detailed phonetic descriptions are lacking.

PND is also reported in Konyagi as part of a synchronic consonant mutation process in adjectives, depending on the prefix and its grade of mutation. Sonorant-initial adjectives occur after vowel-final prefixes, while voiced-stop-initial adjectives occur after consonant-final prefixes. Finally, after a nasal-final prefix, we get voiceless stops.

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devoicing of fricatives. Such systems are thus a combination of developments that we see in PND and intervocalic devoicing that we see in Berawan dialects (Author 1). The treatment of this development is, however, beyond the scope of this work.

13. For one speaker alveolars have 7% of closure voiced post-nasally and 5% intervocalically (Gouskova et al. 2011).

-V	-C	-N	gloss
-wə́nkáák	-bə́nkáák	-mpə́nkáák	'beside'
-yə̀læ̀xə́	-gə̀læ̀xə́	-nkə̀læ̀xə́	'rotten'
-wúnkǽx	-gúnkǽx	-nkúnkǽx	'bitter'
-lə̀mæ̀xə́	-də̀mæ̀xə́	-ntə̀mæ̀xə́	'sweet'

Table 28: Konyagi PND (table from Merrill 2016b, Santos 1996)

Both Buginese and Konyagi point to a productive synchronic process of PND. However, detailed phonetic descriptions of the processes are lacking, and in both languages, PND is limited in scope or involves an alternation Z ∼ NT instead of D ∼ NT. In Tswana and Shekgalagari, on the other hand, PND is not only reported as a productive synchronic alternation, but we also have detailed phonetic studies of the phenomenon and experimental data on PND in nonce words.

The major contribution to the question of productivity of PND is offered in Coetzee et al. (2007) and Coetzee and Pretorius (2010). These two papers offer three major contributions. First, the authors show that, for seven speakers of Tswana (out of 12 total), voiced stops devoice and completely merge with the voiceless series post-nasally (Coetzee and Pretorius 2010): /m-bV/ clearly "patterns" like /m-pV/ and /re-pV/,[14] the only difference being the closure duration (longer after vowels). In terms of voicing percentage, the two do not differ; indeed, /m-bV/ has an even shorter VOT. Moreover, "the contrast between /m+bV/ and /re+bV/ is significant in percentage voicing and VOT" (Coetzee et al. 2007).

Second, PND is extended to nonce-words at the same rate as it applies in the native vocabulary in Tswana (Coetzee and Pretorius 2010:411). This means that PND is not lexicalized, but rather it is a productive phonological process in the synchronic grammar of Tswana. Thus, we can see that unnatural alternations produced by combinations of sound changes can become part of productive synchronic grammars.

Finally, Coetzee and Pretorius show that the natural process of PNV operates passively even in cases in which PND is a phonological process: "all of our post-nasal stops, whether underlyingly voiced or voiceless, were realized with voicing during the initial part of the stop closure" (Coetzee and Pretorius 2010:417). The system containing the unnatural synchronic phonological process PND is attested for seven of the twelve speakers. For the other five speakers, however, Coetzee and Pretorius (2010:417) observe that they often voice the whole closure. These results suggest that these speakers have introduced a new rule into their system: the natural, phonetically motivated, and exact inverse process to PND — post-nasal voicing.[15]

4 The Blurring Process

In section 3 above, I argued that one of the rare reported cases of unnatural sound changes, PND, did not operate as a single sound change, but as a combination of natural sound changes in all twelve languages. This section presents a historical model for explaining unnatural phenomena: the blurring process. In addition, I provide a proof that at least three sound changes are required for an unnatural process to arise.

We saw above that all cases of PND proceed along a common trajectory of development. For all cases, we reconstruct a stage with complementary distribution, which is followed by an unconditioned sound change. To get a synchronic unnatural alternation, another sound change has to

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14. Note that nasals in both Tswana and Shekgalagari are always realized as syllabic.
15. If we do not interpret the data in Coetzee and Pretorius (2010) as dialect mixing.

operate that blurs the original complementary distribution. I label this historical development a "blurring process".

(4)   *Blurring process*
    a.   A set of segments enters complementary distribution
    b.   A sound change occurs that operates on the changed/unchanged subset of those segments
    c.   Another sound change occurs that blurs the original complementary distribution

Based on (4), we can identify several trajectories that result in unnatural processes: subtypes of the blurring process. Let us assume that A → B / X is a natural process: a UPT. Let us assume that its inverse process, B → A / X, is an unnatural process. How does B → A / X arise? There are a number of possible trajectories, but I will focus on two main trajectories that crucially differ in the second sound change and are both attested as historical developments. I will refer to the first development in (5) as the "blurring cycle" and the second development in (5) as the "blurring chain".[16] The crucial difference between the two is in the second sound change: in the blurring cycle, the unconditioned sound change targets the unchanged segments in complementary distribution; in the blurring chain, on the other hand, the unconditioned change targets the changed subset. The motivation for the term "cycle" is clear: one of the three sound changes in blurring cycle targets the outcome of another sound change and results in the target of that first sound change. The term "chain" is likewise motivated: the outcomes of a sound change in blurring chain become targets for following sound changes. Both developments "blur" the original complementary distribution, resulting in an alternation that operates against universal phonetic tendency.

	Blurring Cycle	*Blurring Chain*
(5)	B > C / −X	B > C / X
	B > A	C > D
	C > B	D > A

PND in all twelve cases is a result of the blurring cycle.

	Blurring Cycle	*PND*
(6)	B > C / −X	D > Z / [−nas]
	B > A	D > T
	C > B	Z > D
	B > A / X	D > T / [+nas]

The blurring process approach explains further unnatural data beyond PND. I argue that the blurring *chain* explains the unnatural voicing of voiceless stops in Tarma Quechua (Adelaar 1977, Puente Baldoceda 1977, Nazarov 2008) and unnatural intervocalic devoicing in Berawan dialects (Blust 2005, Blust 2013, Burkhardt 2014). The blurring chain in these languages, however, requires a separate treatment which goes beyond the scope of the present paper.

The blurring process thus serves as a historical model for explaining seemingly unnatural sound

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16. Other potential trajectories could also cause the emergence of an unnatural process on the basis of three individual sound changes. For example, the first scenario in Kiparsky (2006) could be schematized as: (I) B > A / −X; (ii) C > B / −X; (ii) and (iii) C > B/ X. The result here, too, is a system in which B is contrastive in both environments X and =X, but A is limited to its unnatural environment X. Such a trajectory could be termed a "blurring repetition," as C > B occurs twice in different environments. Note that the second sound change targets the changed subset in complementary distribution. However, it remains an open question whether such a trajectory could develop into a synchronic alternation. To my knowledge, no cases have been attested yet, which is why I omit this possibility from the main discussion.

changes and synchronic processes and should be considered as an alternative to other strategies. The most common strategy for explaining unnatural sound changes thus far is Ohala's (1981) hypercorrection approach. Indeed, most studies that have tried to explain PND in isolation have invoked hypercorrection: speakers analyze sequences of ND as voiced from NT and mentally "undo" that voicing. However, in the absence of any restriction, hypercorrection as an explanation for unnatural phenomena leads to overgeneration. Unrestricted hypercorrection leads to the conclusion that every unnatural sound change should be possible — since, by definition, unnatural sound changes operate against UPTs. Speakers can analyze the surface data as having undergone a UPT and "undo" the UPT to get the unnatural process. This is the reason why Ohala (1981) himself restricts the operation of hypercorrection: he notes that the voice feature is unlikely to undergo dissimilation based on hypercorrection (see also Blust 2005). Given these challenges to the hypercorrection approach, the blurring process approach I present in this paper offers an alternative strategy for explaining unnatural processes historically. However, while I have argued here that the blurring process approach is superior to hypercorrection in the case of PND, this is not to say that hypercorrection does not exist or that its validity as an explanatory strategy should be in any way diminished.

The blurring process bears another advantage: it provides groundwork for establishing the minimal number of sound changes required for natural, unmotivated, and unnatural processes to arise. Specifically, I argue that we can prove formally that the emergence of an unnatural process requires at least three sound changes to operate in combination. Let us first assume that a single instance of sound change means a change of one feature in a given context (as per the definition in (1)). For a natural sound change (A > B / X), A and B differ in exactly one feature (for example [±voice] in the case of PNV or final voicing). How do we get the unnatural B > A / X? With one single natural sound change, it is impossible, because B > A / X is by definition unnatural. Moreover, a combination of two natural sound changes also cannot yield B > A / X. Why? We know that A and B differ in one feature only. For a B > A / X sound change to arise, therefore, we first need B to change into something other than A (it cannot change to A directly because such a sound change is unnatural). So, let B change to C, where B and C differ in one feature, but, to be sure, a different feature from the one that separates A and B. From this point, it is impossible for an unnatural sound change to arise without a third sound change: C cannot develop directly to A, since the two segments differ in two features: feature F_1, which distinguishes A and B, and feature F_2, which distinguishes B and C. Since, by definition, two sound changes are required in order to change two features, it follows that at least three sound changes must take place in order for an unnatural process to arise. This proof can be formalized as the Minimal Sound Change Requirement:

(7)   *Minimal Sound Change Requirement (MSCR)*
        Natural processes arise through a single sound change. Minimally two sound changes have to operate in combination for an unmotivated process to arise. Minimally three sound changes have to operate in combination for an unnatural process to arise.

As already mentioned, rule telescoping has long been known to produce unmotivated results. However, to my knowledge this paper presents the first proof establishing the minimal number of sound changes required for different degrees of naturalness. The MSCR is a crucial concept when deriving typology within the CB approach.

It is important to note that fewer than three sound changes are required to produce unnatural static phonotactic restrictions. However, for active synchronic alternations (B → A / X), minimally three sound changes are required, as outlined above. Thus, for instance, while Kiparsky (2006)

provides several trajectories leading to the unnatural process of final voicing, all the scenarios he outlines that would result in an alternation in fact require three sound changes or more to operate,[17] thus pointing to the validity of the proposed MSCR.

We saw that, while a single sound change is constrained to follow phonetic naturalness, a combination of sound changes appears unconstrained: any number of single instances of sound change can operate on each other, and even if such a combination results in unnatural alternation, the synchronic grammar can still incorporate it; the final sound change will not be blocked (*pace* Kiparsky 2006, 2008). However, if we assume that the combination of sound changes is unconstrained, we still need to explain why unnatural processes (B > A / X) are rare — as in the case of PND — or even unattested — as in the case of final voicing. The following paragraph presents a new model for deriving typology within the CB approach that is based on the blurring process and MSCR.

5   Typology within the Channel Bias

5.1   Historical Probabilities

The aim of this section is to propose a probabilistic model of typology within the CB approach. The standard explanation offered for typology within CB is that "common sound patterns often reflect common instances of sound change" (Blevins 2013:485, also Greenberg 1978:75–6). In other words, the more common a sound change is, the more common the synchronic alternation it will produce. However, by assuming only this factor, we face the crucial problem: if sound change has to be natural, why do we nevertheless see unnatural alternations? In addition, we face problems motivating the wide spectrum of pattern frequencies — in particular, the fact that some patterns are very common, whereas others are unattested (i.e., the fact that unnatural processes are rarer than natural and unmotivated ones).

Below, I propose a model that crucially relies on the distinction between a single instance of sound change and a combination of sound changes, the blurring process, and MSCR, and adds a probabilistic dimension to the derivation of typology. I argue that this approach captures surface typology better that the proposals entertained so far: I explain why natural alternations are the most common, unmotivated alternations less common, and unnatural alternations rarest or even unattested.

The blurring process model allows us to maintain the long-held position that a single sound change is always phonetically motivated (natural) and that a single sound change cannot operate against a UPT. The blurring process, however, also allows derivation of unnatural alternations through a combination of natural sound changes. In other words, natural alternations are phonologized single instances of sound changes. Unmotivated changes are phonologized combinations of at least two sound changes. Unnatural processes are phonologized combinations of minimally three sound changes. Crucially, the number of sound changes required for a process to arise determines that process's relative frequency: all else being equal, the probability of a single sound change occurring will be greater than the probability of two and three particular sound changes occurring in sequence, which translates into a scale of probability in which natural sound changes are the most likely to occur, followed by unmotivated changes, and then unnatural sound changes.[18]

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17. One scenario requires analogy, others require typologically unusual stages (resulting in a low probability, since the needed scenario will apply to only a subset of languages), and still others do not result in synchronic alternation but in phonotactic restrictions.

18. If we do not assume that a sound change is necessarily a change in a single feature, but can involve changes of more than one feature simultaneously, typology still follows from such an assumption: even if we admit simultaneous sound changes of multiple features in the set of possible sound changes, they are still less frequent than sound changes

(8)   *A scale of decreased probabilities*
        $P_\chi(\text{natural}) < P_\chi(\text{unmotivated}) < P_\chi(\text{unnatural})$

The idea that unusual rules are rare because they require complex history is not new. The low probability of combinations of changes has been previously relied on to account for the rarity of certain morphological processes, and some attempts have been made to use this reasoning in phonology as well (Greenberg 1978:75–6, Cathcart 2015). Blevins (2004:310) briefly mentions that the rarity of certain morphological processes (such as tense marking on pronouns in Gurnu) might be explained by the low probability of co-occurrence of the factors that led to this system. This approach is employed more thoroughly in Harris (2003, 2008), who notes: "the more changes are involved, the less likely all will happen to co-occur" and "it is an idea that is necessary to discuss, because the role of probability has not been included in previous discussions of rare phenomena." However, the proposals often do not go much further than stating this generalization. The most elaborate model of calculating probabilities of combination of sound changes is offered in Cathcart (2015), who calculates combinations of sound changes that lead to a certain process (in this case, final voicing) and compares that to combinations of all sound changes in a given survey to get an estimate of the probability of certain processes. The model there, however, does not take into consideration the crucial distinctions made in this paper: the subdivision of unusual rules into unnatural versus unmotivated rules, paired with the proof that the latter require at least three sound changes to arise. In addition, Cathcart's (2015) model fails to discriminate alternations from static phonotactic restrictions. I show that MSCR and the new division of naturalness facilitate the development of the quantifiable model of typology within CB proposed in this paper and point to the novel predictions that this model brings.

Their low probability is not the only reason why unnatural processes are rare. Crucially, as soon as an unnatural process operating against universal phonetic tendency does arise and become fully and productively incorporated into the synchronic phonological grammar (B → A / X), the inverse universal phonetic tendency (A > B / X) will begin operating against it. As a result, the probability that an unnatural alternation will survive is even further reduced by the fact that a common sound change (and universal passive phonetic tendency) operates progressively against its existence.

This erosion is precisely what we see happening in Tswana: in a system with unnatural alternation (PND), a single instance of natural and opposite sound change (PNV) is in the process of imposing its will against the unnatural alternation (see section 3.5 above). One could argue that, even though combinations of sound changes are less frequent than any single instance of sound change, over the course of an almost unlimited timespan, sound changes ought to "stack up," yielding multiple unnatural alternations in any given language; given that every language has a several-thousand-year history during which sound changes have occurred continuously, we should perhaps expect many more unnatural alternations than are actually attested. Consider, however, that any given sound change has a time of operation t. In other words, a sound change becomes active at one point in time and ceases to operate at another point in time. This is primarily evident from the fact that, at some point in any language, certain sound changes cease to apply to novel vocabulary, loanwords, and morphological alternations. For an unnatural phonological alternation to arise, all the sound changes that play a part in this alternation must be active simultaneously. Thus, the timespan available to produce such unnatural alternations is not unlimited, but rather limited by the time t in which all single sound change that combine to yield the alternation in question are active. In probabilistic terms, we would say that language history is not a pure-birth

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that target only one feature. The overall probability of an unnatural alternation will thus nevertheless be smaller than the probability of an unmotivated alternation.

process, but rather a birth-death process.

The new model of typology within the CB proposed here is quantifiable. We can calculate historical probabilities (P_χ) of synchronic processes. The probability that an alternation arises depends on the number of sound changes required for that alternation and their respective probabilities or rates.

(9)   *Historical Probabilities of Alternations* (P_χ(Alt))
        The probability that an alternation arises based on the number of sound changes required (MSCR) and their respective probabilities/rates.

To calculate P_χ(Alt), we must first identify historical trajectories T that cause an alternation to arise: a combination of individual sound changes that lead to a given alternation. Several trajectories may be identified for one alternation. The historical probability of an alternation equals the sum of probabilities of all trajectories that lead to this alternation.

(10)
$$P_\chi(Alt) = P(T_1 \cup T_2 \cup T_3 \cup ... \cup T_n)$$

The statistical device appropriate for calculating combinations of sound changes in a given timespan t is the Poisson Stochastic Process. The historical probability P_χ of each trajectory T can be calculated according to (11). Let λ_i be a rate of a sound change (in a time frame t_i). Let t be the time frame of occurrence of a given trajectory T_1 composed of three sound changes that result in an alternation. The probability that a trajectory T_1 will arise from n number of sound changes in a given time frame from 0 to t equals (cf. Fussell 1976 and Eid 2011):

(11)
$$P(T_1) = \int_0^t f_1 t_1 dt_1 \times \int_{t_1}^t f_2 t_2 dt_2 \times \int_{t_2}^t f_3 t_3 dt_3 \times ... \times \int_{t_{n-1}}^t f_n t_n dt_n$$

where
$$f_i = \lambda_i e^{-\lambda_i t}$$

At the present time, we still have a poor understanding of sound change rates. While it is theoretically possible to calculate sound change rates based on the number of occurrences per time frame we have attested in a given language, such detailed calculations have not yet been defined. Until better surveys of sound changes are made (including the temporal component) and more precise rates of sound changes calculated, I propose a simplified formula for calculating historical probabilities of trajectories. The probability $P_\chi(T_1)$ under this simplified approach disregards the temporal dimension; it is a joint probability of n number of sound changes in the trajectory T_1. This approach will be employed in estimating historical probabilities by "bootstrapping" sound change (5.2 below).

(12)
$$P_\chi(T_1) = P(A_1 \cap A_2 \cap A_3 \cap ... \cap A_n)$$

The probability of a single sound change $P_\chi(A_n)$ can be calculated from the number of observed languages with a sound change A_1 and the number of surveyed languages.[19]

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19. There is another advantage of this approach: it has been noted that once the sound change [k] > [kʲ] / [+front] occurs, the likelihood of further development to [cç] and [tʃ] is very high (X, p.c.). If we assume that these sound changes proceed in series, a generalization can be easily derived: the initial sound change [k] > [kʲ] / [+front] has a certain probability, which is smaller than the probability of further development to [cç] and [tʃ]. Because [kʲ] > [cç]

(13)

$$P_\chi(A_1) = \frac{\text{number of languages with sound change A}_1}{\text{number of languages surveyed}}$$

Ideally, historical probabilities of sound changes should be evaluated with respect to the phonemic inventory of a given language. For example, it is possible that some sound changes will have different probabilities, depending on the phonological inventory at the time when the sound change operates. In a system with no low vowels, for instance, the probability of a sound change that lowers mid vowels is probably greater than it is for a system that already has low vowels. In other words, the probability of sound change should be calculated as a conditional probability $P(A_1|\text{phonemic}$ inventory). This approach allows us to treat sound changes as independent events. Occurrence of a sound change A_1 is independent of the probability of occurrence of the next sound change A_2, except in the case where A_1 alters the phonemic inventory — but this dependency is already accounted for by conditional probability $P(A_2|\text{phonemic inventory})$. In the current state of the field, we lack sufficiently accurate estimates of sound change probabilities to be able to estimate their conditional probabilities. For practical purposes, we can disregard the phonemic inventory and generalize $P(A_1)$, except in cases with obvious gaps in phonemic inventory.

5.2 Estimation

I propose a new method of estimating historical probabilities of sound changes that I label "bootstrapping sound changes" (BSC).[20] BSC involves calculating the joint probabilities of n number of sound changes. Probabilities of sound changes are bootstrapped from a sample of successes (languages in the sample with a sound change A_1) and failures (languages in the sample without a sound change A_1) (see (13) above).

Let us take a look at estimation of P_χ for the two processes discussed in this paper: post-nasal devoicing (PND) and final voicing (FV). The basis for calculating $P_\chi(\text{PND})$ is a database of consonantal sound changes in Kümmel (2007) that surveys approximately 200 languages. Recall that we have already identified the three sound changes required for PND to arise in (6), according to the blurring process. In approximately 55 languages, fricativization of voiced stops occurs for at least two places of articulation and is limited to post-vocalic position. In 11 languages, unconditioned devoicing of at least two places of articulation has been reported.[21] Finally, in approximately 45 languages, unconditioned occlusion of voiced fricatives to stops is reported in Kümmel (2007). This last sound change is counted even if only one place of articulation is targeted, since we count as PND all cases in which a full alternation of voiced~voiceless stops only holds for one place of articulation too (e.g. Yaghnobi).

The only scenario in Kiparsky (2006) that results in final voicing (FV) as a synchronic alternation and involves less than four sound changes is scenario 1, in which geminates first simplify intervocalically, stops then voice post-vocalically, and lastly, geminates simplify word-finally. First, it would be highly unlikely for intervocalic stop geminates to simplify to the exclusion of final geminates. However, degemination that is limited to some prosodic environments, such as after unstressed vowels, does exist (Kümmel 2007). For the purposes of modeling, I consider any instances of degemination of stops in the survey as potential situations that might enter the trajectory that leads to FV. In Kümmel (2007), degemination that is limited to some prosodic environment is

and [cç] > [ʧ] have comparatively very high probabilities, the development to [ʧ] is high once [k] > [kʲ] / [+front] occurs.

20. For bootstrapping, see Efron (1979).

21. I include in the count changes from lenis to fortis and devoicing caused by chain shifts.

reported for approximately 10 languages; post-vocalic voicing that targets more than one series of stops is reported for approximately 77 languages; final degemination is reported for three languages.

Estimates of P_χ were bootstrapped using the boot package (Canty and Ripley 2016, Davison and Hinkley 1997) in R (R Core Team). The probability of each sound change was calculated from the number of successes and number of failures (based on a sample of 200 languages, see above). Joint probabilities for the three sound changes in PND and FV were calculated and bootstrapped with 10,000 bootstrap replicates. The following 95% adjusted bootstrap percentile (BC_a) intervals were calculated for P_χ(PND) and P_χ(FV).

(14)   *Bootstrapped historical probabilities*
P_χ(PND) = [0.0013, 0.0081]
P_χ(FV) = [0.0000, 0.0015]

Figure 1 shows bootstrapped probabilities of the combinations of three sound changes required for PND and FV and their BC_a confidence intervals.
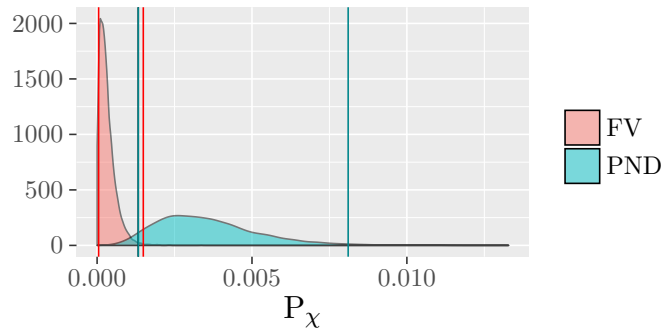

Figure 1: Bootstrapped P_χ(PND) and P_χ(FV)

We predict PND to be significantly more frequent than FV. The significance is tested using bootstrap method on the difference between P_χ(PND) and P_χ(FV). The BC_a confidence interval for the difference P_χ(PND) - P_χ(FV) equals [0.0013, 0.0075]. Because 95% BC_a CIs falls above zero, we conclude that P_χ(PND) is significantly more frequent than P_χ(FV).

We also predict that PND will be attested in the sample, while FV will not. BC_a for FV [0.0000, 0.0015] falls below the 1/200 (0.0050) probability. However, P_χ(FV) is not significantly smaller than P(1/200): BC_a for the difference in probabilities between P_χ(FV) and P(1/200) is [-0.0003, 0.0243]. In other words, the fact that FV is unattested in Kümmel (2007) may be due to chance or influences of other factors, such as analytic bias. But note that our model does make a provision: the historical trajectory for FV includes degemination that is limited to intervocalic position; such a sound change is considerably rarer than degemination limited to any prosodic environment that we model (if it exists at all).[22] If we were to incorporate this fact into our calculation, P_χ(FV) would likely get considerably smaller. Also, note that the BC_a for P(1/200) – P_χ(FV) reaches only marginally below 0.

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22. Note that a provision is also made for calculating P_χ(PND): we do not require fricativization to include initial position.
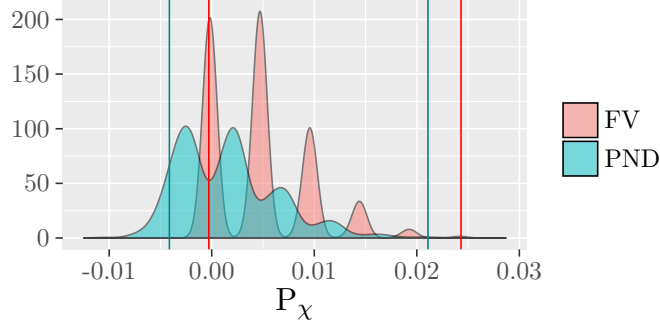
Figure 2: Bootstrapped $P(1/200) - P_\chi(PND)$ and $P(1/200) - P_\chi(FV)$

On the other hand, PND is correctly predicted to be attested, as its BC_a confidence interval [0.0013, 0.0081] falls within the $1/200$ (0.0050) probability. The BC_a for bootstrapped differences in probabilities between $P_\chi(PND)$ and $P(1/200)$ is [-0.0041, 0.0211], which means that there is not statistically significant difference between the two probabilities: according to our model, we should expect one case of PND in the original survey. PND that targets stops is indeed attested once in Kümmel (2007).

This method of "bootstrapping sound changes" or calculating historical probabilities introduces a number of further predictions and offers a device for quantifying influences of CB on typology. In the interest of space, I only illustrated one such application: I show that BSC predicts PND to be significantly less frequent than FV.

6 Conclusion

This paper examined one of the most prominent cases of unnatural alternations and sound changes, PND. By collecting all known cases of this phenomenon, I showed that common patterns emerge, yielding the conclusion that PND in all twelve cases is the result of three natural sound changes. This conclusion allows us to maintain the long-held position that sound change cannot operate against a universal phonetic tendency. I provided new crucial evidence from Sogdian and Yaghnobi that historically confirms the reconstructed development. On this basis, I then presented a new historical model, the blurring process, which can serve as a strategy for explaining unnatural phenomena historically. I argued that, at least for PND, the blurring process approach is superior to the hypercorrection approach and pointed to further cases in which the blurring process outperforms other approaches. The blurring process provided grounds to define a Minimal Sound Change Requirement (MSCR) and consequently a new model of typology within the CB approach. Based on the MSCR and sound change rates/probabilities, I demonstrated that we can calculate historical probabilities (P_χ) of synchronic alternations. Finally, I proposed a method for estimating historical probabilities that I label "bootstrapping sound changes".

The position taken in this paper is that both AB and CB influence typology: the task of phonological theory is to disambiguate and model the two. The new model presented here provides groundwork for understanding the CB part of the typology: the probability that a speaker will encounter a certain process or alternation crucially depends on the number of sound changes required for that alternation to arise and the rates/probabilities of respective sound changes. The quantified CB model of typology provides a crucial step in tackling one of the biggest tasks in phonology: to disambiguate CB and AB influences on typology. Future steps in this direction require a quantified model of AB as well as a template that will allow us to model AB and CB together.

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