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. I argue that in all reported cases, post-nasal devoicing 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 diachronic model for explaining unnatural phenomena: the Blurring Process. Additionally, I provide a proof establishing the minimal sound changes required for an unmotivated/unnatural process to arise. The Blurring Process and Minimal Sound Change Requirement result in a model that probabilistically predicts typology within the Channel Bias approach. This paper also introduces the concept of Historical Probabilities of Alternations (P_χ) and presents a groundwork for their estimation called Bootstrapping Sound Changes. The ultimate goal of the new model is to quantify the influences of Channel Bias on phonological typology.

Keywords: phonological typology, probabilistic modeling, bootstrapping, sound change, naturalness, Channel Bias, voice, post-nasal devoicing

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 (Hayes 1999, Tesar and Smolensky 2000, Kiparsky 1995, 2006, 2008, Wilson 2006, Hayes et al. 2009, Becker et al. 2011, de Lacy and Kingston 2013, Hayes and White 2013, White 2017, for an overview of the experimental AB literature, see Moreton and Pater 2012a,b). The CB approach, on the other hand, assumes that systematic phonetic tendencies or phonetic precursors in the transmission from speaker

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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. Greenberg 1978, Ohala 1981, 1983, 1993, Lindblom 1986, Barnes 2002, Blevins 2004, 2006, 2007, 2008a,b, Morley 2012, see also Hansson 2008 and Garrett and Johnson 2013 for an overview of the literature).

Empirical evidence in favor of both approaches exists. Numerous experimental studies have provided evidence in favor of the AB approach: typologically rare processes are significantly more difficult to learn than typologically common processes (Moreton and Pater 2012a,b). 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 (Moreton and Pater 2012a,b). The results are less uniform for alternations that control for structural complexity: some studies report significant differences in learnability between natural and unnatural processes (Carpenter 2006, 2010, Wilson 2006 via Moreton and Pater 2012a,b), while others do not (Pycha et al. 2003, Wilson 2003, Kuo 2009, Skoruppa and Peperkamp 2011, via Moreton and Pater 2012a,b, Seidl et al. 2007, Do et al. 2016, Glewwe 2017).

The main evidence in favor of the CB approach is that typologically common processes align with universal articulatory and perceptual tendencies and natural sound changes. In fact, in many cases we can directly observe the origins of synchronic processes through historical developments: phonetically motivated sound changes that leads to phonologization (Hyman 1976, Barnes 2002, Blevins 2004, Garrett 2014).

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 2012a,b, White 2013). In addition, Rafferty et al. (2011) suggest that learnability bias is not a sufficient factor for deriving a linguistic universal. Moreover, it is not trivial to show how learning biases result in typology (Staubs 2014, i.a.). Finally, artificial grammar learning experiments in fact often fail to yield positive results when testing structurally equally complex alternations: many studies find no significant differences in learnability between phonetically natural and unnatural processes (Seidl et al. 2007, Do et al. 2016, Glewwe 2017, Moreton and Pater 2012a,b), although there exist substantial differences in the typology between natural and unnatural processes.

Conversely, a major objection against the CB approach is that it fails to explain why some processes are never attested (Kiparsky 2006, 2008, de Lacy and Kingston 2013). 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; Prince and Smolensky 1993/2004) 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, de Lacy 2002). CB faces difficulties explaining this mismatch and AB is invoked to explain it (Kiparsky 2006, 2008, de Lacy and Kingston 2013).

It is true that current models of typology within CB are insufficient. The most common line of thought in deriving the typology within CB has been to assume that rare sound changes produce rare alternations (Blevins 2004); related to this line of reasoning is Ohala's (1989) proposal that the probability of perceptual confusion is proportional to the frequencies of sound changes. Moreton

(2008) attempts to quantify phonetic precursors with the goal of reaching a more transparent phonetic metric for disambiguating sound changes, but this approach has problems, too (Yu 2011). As will be shown in this paper, the results of sound changes operating in combination and phonetic precursors or perceptual confusability do not always align, which makes the quantification of precursors or confusability unsuitable for deriving the typology of all processes (including the unnatural ones). The low probability of combinations of changes has been previously invoked to account for the smaller likelihood of alternations that require more than a single change, especially in morphology (Harris 2003, 2008, Blevins 2004), but also in phonology (Bell 1970, 1971, Greenberg 1978:75-6, Morley 2015). Morley (2012) outlines a diachronic explanation for the typology of epenthesis which states that the more diachronic conditions a certain type of epenthesis requires, the less likely it is to arise in the typology. The non-existence of some unnatural alternations, Morley (2011, 2015) suggests, might be due to an interplay between diachronic development and the learning of grammar ("hypothesis selection") from surface forms. Morley further argues that one of the scenarios in Kiparsky (2006) that leads to an unnatural process is rare because "the probability of the combined event is the multiplicand of the two probabilities (under assumptions of independence), [and] this number might prove to be small enough to render it unlikely to occur in the given sample" (Morley 2015: e43). None of these models, however, are sufficiently quantified for a typological model, or they fail to yield implementable results. Finally, Cathcart (2015) attempts to quantify the CB influences on typology by automatically identifying the number of combinations of sound changes that produce an unnatural alternation or phonotactic restriction such as final voicing. For each combination of sound changes, that number is then compared to the number of all possible sound changes given the number of permutations and a sample of sound changes. The problem with this approach is that it is computationally too demanding to provide outputs that could be currently used for a typological model within CB. The model in Cathcart (2015) also fails to distinguish alternations from phonotactic restrictions and does not establish the minimal number of sound changes required for an unnatural process to arise (see (8)).

As Moreton (2008:84) points out, the AB and CB 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 2012a,b, de Lacy and Kingston 2013). 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 learnability/learning biases (AB) and how much of phonological typology is due to the 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 features five crucial components. First, I argue for a new subdivision of naturalness (Section 2), whereby processes traditionally labeled as *unnatural* should be subdivided into *unmotivated* and *unnatural* processes. Second, based on a reported unnatural synchronic alternation and sound change, post-nasal devoicing (PND), I contend that sound change is always phonetically motivated and cannot operate in a phonetically unnatural direction. In other words, one of the rare reported cases of an unnatural sound change can be explained through a combination of natural sound changes (Section 3), not only in Tswana and Shekgalagari (as proposed in Dickens 1984, Hyman 2001), but in all other cases collected in this paper. I present new evidence from Sogdian, Yaghnobi, and other languages that crucially contributes to this conclusion. This allows us to maintain the long-held position that sound change can only operate in a phonetically natural direction (which has recently been challenged by Blust 2005). Third, the paper establishes a diachronic model for deriving and explaining *unnatural* alternations called the Blurring Process and fourth, argues with a formal proof that a minimum of three sound changes are required for an unnatural process to arise and a minimum of two for an unmotivated process (Minimal Sound Change Requirement) (Section 4). Finally, the paper outlines a quantitative model that predicts the typology within the Channel Bias by introducing the concept of Historical Probabilities of Alternations, which is based on the two crucial concepts developed in this paper, the Blurring Process and MSCR (Section 5). Section 5 also proposes a statistical technique for estimating Historical Probabilities, Bootstrapping Sound Changes (BSC), and illustrates one implication of this method for the Channel Bias approach to phonological typology. A larger exploration of all potential applications of the new methods, Historical Probabilities and BSC, is beyond the scope of this paper and is discussed elsewhere (Author 1).

2 Background

2.1 Subdivision of naturalness

Directly related to the question of phonological typology is the question of naturalness and how to encode it in the grammar design (Bach and Harms 1972, Stampe 1973, Catford 1974, Hellberg 1978, Donegan and Stampe 1979, Anderson 1981, Westbury and Keating 1986, Archangeli and Pulleyblank 1994, Hayes 1999, Buckley 2000, Hyman 2001, Blevins 2004, 2008a,b, Yu 2004, Blust 2005, Wilson 2006, Hayes et al. 2009, Carpenter 2010, Becker et al. 2011, White 2013, Hayes and White 2013, i.a.). The term *naturalness* itself has received several interpretations and opposing stances in the literature; scholars have argued that unnatural processes are variously possible, dispreferred, or impossible in synchronic grammar. The question of naturalness is relevant to the theory of sound change as well (Catford 1974, Blust 2005). 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).

Natural and unnatural processes have traditionally been distinguished 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 (for the term, see Hyman 1972). I define a *universal phonetic tendency (UPT)* as one which exhibits three crucial properties: (i) passive operation, (ii) cross-linguistic operation, and (iii) the ability to result in common sound patterns.

(1) *Definition of Universal Phonetic Tendency (UPT)*
UPTs are phonetic pressures motivated by articulatory or perceptual mechanisms that passively operate in speech production cross-linguistically and result in typologically common phonological processes.[1]

Passive operation of a phonetic tendency means that the tendency targeting some phonetic feature operates automatically (with no active control by the speakers, Kingston and Diehl 1994), 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

1. As Moreton (2008) points out, some phonetic precursors do not cause typologically common phonological processes (see also de Lacy and Kingston 2013). This paper focuses on those unnatural processes that operate against phonetic precursors that are robust enough to yield common sound patterns.

contrast of voice post-nasally, fulfills the criterion that post-nasal voicing 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[2], on the other hand, are those that operate precisely *against* some UPT and are not a UPT themselves.[3]

(2) *A new division of naturalness*

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

An example of an unmotivated process would be Eastern Ojibwe "palatalization" of /n/ to [ʃ] before front vowels (e.g. [ki-naː**n**-aː] 'you fetch him' vs. [ki-naː**ʃ**-im-i] 'you fetch us'; Buckley 2000). This process lacks phonetic motivation, but its reverse process [ʃ] → [n] / __[+front] is not a UPT. Examples of unnatural processes include final voicing, intervocalic devoicing, and post-nasal devoicing. All of these processes operate directly against clear and well-motivated articulatory phonetic tendencies (see Section 3). It has to be noted that phonetic motivation of a process must always be evaluated with respect to the context. For example, devoicing of voiced stops is a natural process word-finally, but unnatural intervocalically.

Most of the discussions on unnatural phenomena in phonology in fact discuss unmotivated processes, according to the definition in (2) (Buckley 2000, Blevins 2004, 2008a,b, Blust 2005). This paper focuses on an unnatural process, post-nasal devoicing (PND), and its implications for both theoretical and historical phonology.

While naturalness and how to represent it in the grammar design has been primarily the focus of synchronic studies (Stampe 1973, Hellberg 1978, Anderson 1981, Archangeli and Pulleyblank 1994, Hayes 1999, Hyman 2001, Coetzee and Pretorius 2010), it has been the subject of debate within 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

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

3. As will be shown in Section 3.4 below, some processes might be motivated in both directions by different mechanisms; the voicing and devoicing of stops, or the fricativization of stops and the occlusion of fricatives are two examples of diametrically opposed processes. However, naturalness always needs to be evaluated in a given context; evaluated globally, in all positions, devoicing of stops and occlusion of fricatives are natural, i.e. phonetically motivated, but in a leniting environment, such as pre-vowel position, voicing or fricativization of stops is the natural direction (see Section 3.4 and Ladefoged and Maddieson 1996:137, Kaplan 2010). Different contexts that determine the naturalness of a process can sometimes superficially overlap, e.g. in a language that lacks target segments in those contexts that distinguish the natural from the unnatural direction (as we will see, this is precisely what happens in the case of post-nasal devoicing). It is also possible that two diametrically opposed processes could both be phonetically motivated in a given context: vocalic sound change is usually less unidirectional, but even there, clear principles can be established in which only one direction is the natural one (Labov 1994). To my knowledge, no detailed research is available on sound change that is motivated in both directions in exactly the same context; further research on this topic is a desideratum.

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 the *NT constraint in Hyman (2001); and a recent description of post-nasal devoicing in Brown (2017).[4] Isolated unpublished cases have been reported to me in personal communication (Merrill 2014. 2016a,b). So far, all cases of PND have been treated in isolation, which has led to several opposing explanations of the phenomenon. Explanations of PND rely variously on appeals to hypercorrection (Blust 2005, Xromov 1972), combinations of sound changes (Dickens 1984, Hyman 2001), claims that unnatural sound changes *do exist* (Blust 2005), or claims that PND is articulatorily or perceptually motivated (Solé 2012, Gouskova et al. 2011, Stanton 2016). I shine light on this murky discussion by showing that, in all thirteen cases[5] 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 (as has been argued for Tswana in Dickens 1984 and Hyman 2001). 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. Examining all cases of PND together also allows me to generalize common properties and develop a diachronic model for explaining unnatural phenomena. Furthermore, showing that one of the rare reported unnatural sound changes is in fact a product of a combination of natural sound changes lends support to the position that sound change has to be natural and cannot operate against UPTs (*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, 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 of UPTs. I show that for unnatural processes to arise we need a special type of combination of sound changes which I term the Blurring Process.

2.2 Sound change

Before we turn to a more detailed discussion of unnatural alternations and sound changes, a clarification of the term *sound change* is necessary (Blevins 2004, Garrett 2014). Despite more than a century of scientific research on sound change, Garrett (2014) in his recent overview of the field acknowledges that sound change has "no generally accepted definition". Many definitions involve the concept of "phonologization" (Hyman 1976, 2013, Barnes 2002) "whereby an automatic phonetic property evolves into a language-specific phonological one" (Garrett 2014) and this process constitutes a sound change. The question remains, however, at what level of abstraction should we define sound change: at a "language-specific phonetic" or "phonological (structured)" level (Hyman 2013, Fruehwald 2016)? Even more relevant for our discussion is the question of what distinguishes a single sound change from a combination of sound changes.

Every model, be it phonological or diachronic, has to operate with some level of abstraction. We could assume that sound change is a change of any articulatory target/gesture (cf. Browman and

4. It is difficult to estimate how many languages are surveyed in these collections, as authors often fail to report this information. A reasonable guess would be that Blust (2005) surveys most Austronesian languages and Hyman (2001) surveys most Bantu languages.

5. 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 five, due to the close genetic relationships between these languages.

Goldstein 1992) or, in exemplar theory's terms, a change in any label of a category (Pierrehumbert 2001, Bybee 2001), regardless of how small the difference between the two diachronic stages would be. For example, a minimally higher degree of coarticulation (fronting of [k] in [ki]-sequences) or a minimal change in the F1 target in low vowels would constitute a sound change according to this definition. In such a model, for example, a gradual sound change [a] > [æ] would involve an infinite or at least a very large number of individual sound changes. To be sure, each of these minimal sound changes would have no phonological implications: languages cannot contrast /a/ and /a̝/ with a minor difference in the F1 target or other similarly minimal phonetic differences. While such a radical and phonetically oriented model, in which sound change represents a change in any phonetic specification that is not automatic, is valid, it would fail to provide results that would be meaningful to phonological theory (for a discussion on the "notoriously fuzzy boundary" between phonetics and phonology, see Kingston and Diehl 1994, Hyman 2013, Cohn 2006, Keyser and Stevens 2006).

The focus of this paper are non-analogical regular sound changes (regardless of the mechanisms of their origin; for an overview, see Garrett and Johnson 2013, Garrett 2014)[6] that, via phonologization, result in synchronic phonological alternations (allophonic or neutralizing). We thus adopt the concept of features from phonology, together with the level of abstraction of the phonological feature system (Chomsky and Halle 1968, Hall 2007, Keyser and Stevens 2006, Hyman 2013) and define sound change as a change in one feature that is phonologized and non-automatic (Hyman 2013, Keyser and Stevens 2006) and that operates throughout the lexicon in a given environment. Synchronic alternations are alternations of at least one feature in a given environment, but can also involve alternations of multiple features simultaneously. We posit that a single instance of sound change can only involve change of a *single* feature in a given environment. That a single sound change involves a change in a *single* "phonetic property" has in fact been previously claimed by Donegan and Stampe (1979) and Picard (1994). Picard (1994) calls this assumption the "minimality" principle: "sound changes are always minimal, and so can involve no more than one basic phonetic property." The minimality principle arises from the assumption that "the substituted sound" should be "as perceptually similar to the original target as possible" (Donegan and Stampe 1979): a diachronic version of the P-map (Steriade 2001). There is also an articulatory argument for the minimality principle: variation in coarticulation which is the initial mechanism of sound change (cf. Ohala 1983, Lindblom 1990, Lindblom et al. 1995, Beddor 2009) is often continuous and gradual (cf. Garrett 2014, Pierrehumbert 2001), which means that phonologically relevant change proceeds through minimal phonetic changes, and minimal phonetic changes are usually not substantial enough to change two phonological features. We adopt this assumption of minimality (Donegan and Stampe 1979, Picard 1994) and posit that a single sound change is a change in one feature in a given environment. A combination of sound changes is a set of such individual sound changes operating in a given language.

(3) *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 operating in a given language.

To my knowledge, no detailed studies exist on the question of whether a single sound change can involve a change of more than one feature simultaneously. Direct evidence of such a sound change is hard to obtain because we have only limited access to sound changes in progress and even apparent sound changes in process might not always yield conclusive results: it is, for example, possible that what seems to be a sound change in progress that targets two features simultaneously might in fact be variation between two end-points that result from operation of two individual sound changes. Typological surveys of sound change support the minimality hypothesis, at least as a strong tendency:

6. We are interested in sound changes that operate categorically throughout the lexicon, regardless of whether they result from lexical diffusion or the Neogrammarian regular sound change.

the substantial majority of sound changes surveyed in Kümmel (2007) do involve a change of only a single feature. Likewise, in a phylogenetic modeling of sound changes in Turkic in Hruschka et al. (2015), 79% of consonantal and 70% of vocalic sound changes involved a change in a single feature. It is reasonable to assume that at least a subset of the two-feature changes involve an additional sound change that is not observed on the surface, although this assumption cannot be proven (see discussion below).

To be sure, universally redundant (automatic) features (cf. Hyman 2013, Keyser and Stevens 2006) do not contribute to sound change minimality: if stops nasalize (D > N), [±sonorant] is changed along with [±nasal], but [±sonorant] is not contrastive in either nasals or voiced stops and this change does not count as an instance of an additional sound change. More problematic for the minimality assumption are (i) cases of perceptually driven sound changes that involve change of place of articulation, (ii) cases of total assimilation, and (iii) cases of epenthesis or deletion. Some of the recurrent sound changes that appear to target more than a single feature simultaneously are changes that primarily arise due to perceptual similarity, e.g. changes between [ɣ] and [w], [k^w] and [p], or [p^j] and [t] (Ohala 1989). It is nevertheless reasonable to assume that such changes proceed through intermediate stages, e.g. [ɣ] > [β] > [w]. While Ohala (1989) argues strongly against such proposals, there is independent evidence that makes such intermediate stages plausible. Ohala (1989), for example, specifically argues against Whatmough (1937) (via Ohala 1989) who claims that Proto-Indo-European *k^w develops to Greek [pp] through an interstage with [k͡p]. Northwest Caucasian languages, however, confirm that labialized alveolar stops [t^w] or [d^w] can and do develop to doubly articulated bilabio-alveolar stops [t͡p] or [d͡b] (for example in Ubykh), even though these are typologically much rarer than bilabio-velar stops (Catford 1972, Ladefoged and Maddieson 1996, Garrett and Johnson 2013, Author 1a). Some dialects of Ubykh then merge these with plain labial stops [p] and [b] (Fenwick 2011), which means we have the full chain of developments [t^w] > [t͡p] > [p] attested. Intermediate stages can thus be motivated at least for a subset of cases that are traditionally used as examples of non-gradual changes involving more than a single feature.

While it has been stipulated that assimilation in more than one feature often (or always) arises through inter-stages or that a segment often (or always) deletes with an intermediate stage with [ʔ], [h], or a glide [j] (Hock 1991), one of the most well-studied sound changes in progress, t/d-deletion in English, points to the contrary (if t/d-deletion is not in fact variation between two endpoints of a hypothetical series of sound changes [t/d] > [ʔ] > ∅). Moreover, while epenthesis can be a gradual process (Morley 2012), it would be difficult to represent it with a change of a single feature value. Complete deletion or epenthesis of a segment/feature matrix thus has to count as a single sound change under our approach. Metathesis is another non-canonical sound change: it does not involve a change in a feature's value, but rather a change in the ordering of features/feature matrices. While usually a sporadic sound change, metathesis *can* be regular (Blevins and Garrett 1998) and it can also be gradual, involving several intermediate stages. Slavic metathesis (/VRC/ > /RVC/), for example, most likely involves an interstage with vowel epenthesis (/V_1RC/ > /V_1RV_2C/) and vowel deletion (/V_1RV_2C/ > /RV_2C/) (Blevins and Garrett 1998).

In sum, we adopt phonological features to represent sound changes that via phonologization yield synchronic alternations. By the word "change" in (3) we mean either a change of one non-automatic feature value in a given environment, a complete deletion/insertion of a feature matrix, or a change of ordering of features/feature matrices. In all cases, our assumption is that a single sound change is minimal: it involves a change of a single feature or deletion/epenthesis/reordering of a single feature matrix. Further research on sound changes in progress is needed to confirm the minimality assumption — currently, we can claim that the minimality assumption is at least a strong tendency: it holds for at least the majority of sound changes documented and it is articulatorily and perceptually well-grounded.

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__; PNV), 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 are thoroughly investigated in Hayes and Stivers (2000) (cf. Hayes 1999, Pater 1999). Supported by previous work including Rothenberg (1968), Kent and Moll (1969), Ohala and Ohala (1993), Ohala (1983), and others, the authors identify two phonetic factors that render stops in post-nasal position prone to voicing: (i) nasal airflow leak and (ii) expansion of oral cavity volume during velic rising. Both of these factors promote voicing, i.e. counter the anti-voicing effects of closure (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, airflow can leak through the nasal cavity, which means that the airflow necessary to maintain voicing that would otherwise stop during the closure can be maintained longer (Hayes and Stivers 2000). Moreover, when the velum rises from a high position to complete closure, the volume of the oral cavity increases, which again allows a longer period of sufficient airflow that would otherwise stop due to closure (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 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 approximately 32 languages in a survey of approximately 200 in which PNV operates as a sound change. By comparison, PND in the same survey is attested only twice: in one instance it targets stops and and in the other affricates.

While post-nasal voicing is a 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 (compared to other positions, e.g. word-initial and word-final), in the sense that it operates against the voicing-promoting effects of post-nasal position (that counters 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 the 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 (2016a), who argues that PND is motivated as enhancement of perceptual cues in, for example, ND $\sim$ 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,[7] 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 (2016b) 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_1 and N. One way to repair this contrast would be to devoice the first consonant C_1. 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 thirteen languages I have examined, PND actually arises through a combination of three natural sound changes rather than through 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 (see also Section 3.2). 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 sound changes happen to operate in the pre-history of a system.

3.1 The data

According to our survey, the existence of PND as a sound change has been reported in thirteen languages and dialects from eight 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.[8]

7. 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 (2016a: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.

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

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)

Outside of post-nasal position, original voiced stops surface as voiced fricatives [β, ð, ɣ] in Sogdian: this is the result of a sound change that turns voiced stops into voiced fricatives except post-nasally. In Yaghnobi, velar and labial fricatives in the elsewhere condition are preserved as fricatives [w/β] and [ɣ]. The Sogdian dental fricative [ð], on the other hand, surfaces as a stop: [dah] 'ten' for Sogdian [ðəsa] (data from Novák, 2010: 31, Novák 2014). Voiceless stops remain unchanged in Sogdian, except post-nasally, where they become voiced (Yoshida 2016) before being devoiced in Yaghnobi.

Regarding the Yaghnobi synchronic system, Novák (2010) reports voiceless stops to be aspirated except pre-consonantally and voiced stops to be phonetically voiced, although no instrumental studies are offered. Synchronic Yaghnobi phonology contrasts voiced and voiceless stops in all positions: initially, finally, intervocalically, in clusters, and post-nasally. The fact that [±voice] contrasts fully in NT and ND sequences in synchronic Yaghnobi means that PND is not an active alternation anymore, 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 to the borrowed [band] 'tie' with a voiced variant.

3.1.2 Tswana, Shekgalagari, and Makhuwa

PND has been reported as a synchronic phonological process in the languages/dialects of the Sotho-Tswana group, especially in Tswana and Shekgalagari (Hyman 2001, Solé et al. 2010), but also in Sotho (Janson 1991/1992), three closely related and mutually intelligible Southern Bantu languages (Makalela 2009). Because PND is least well-described in Sotho, I will focus on Tswana and Shekgalagari. Tswana is spoken by approximately 4–5 million people in Botswana, Namibia, Zimbabwe, and South Africa (Coetzee and Pretorius 2010), and Shekgalagari by approximately 272,000 people in Botswana (Solé et al. 2010).

In Makhuwa, PND is reported as a sound change followed by nasal deletion (Janson 1991/1992). Makhuwa is closely related to Sotho-Tswana too and is spoken by approximately 3 million speakers in Mozambique (Lewis et al. 2015).

Table 2 shows that synchronic voiced stops (that surface as a voiced stop in the elsewhere condition) in Shekgalagari 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-kat-a	'like'

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

Both Tswana and Shekgalagari feature unaspirated voiced and voiceless and aspirated voiceless stops in their inventories (for phonetic studies, see Coetzee and Pretorius 2010 and Solé et al. 2010): they surface initially, intervocalically, and post-nasally. The only permitted syllable structures are "V, CV, CGV, N" (where G = glide and N = syllabic nasal; Coetzee and Pretorius 2010). Detailed instrumental acoustic studies of the Tswana and Shekgalagari stop system in Coetzee and Pretorius (2010) and in Solé et al. (2010) confirm that post-nasal devoicing is indeed realized as change in the feature [±voice], and not as a change in [spread glottis].

Several peculiarities need to be noted with respect to Tswana. 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 alveolar stop [d] surfaces as an allophone of /l/ before the high vowels /i/ and /u/ (Coetzee and Pretorius 2010). Third, voiced stops in nasal clusters of secondary origin (after syncope) do not undergo devoicing, but undergo assimilation in Tswana (see Table 3). Finally, the nasal in NT sequences Tswana (and Shekgalagari) is retained when stressed and in the 1st person object prefix, but gets deleted elsewhere (see Dickens 1984). Hyman (2001) gives an example of preservation of N-: in the case of class 9 and 10 prefix, when roots are monosyllabic. In Shekgalagari, secondary ND clusters remain voiced (Table 3); /d/ can surface in the elsewhere condition (not only before /i/ and /u/), but it does not alternate with devoiced [nt] ← /nd/ (because /d/ corresponds to Tswana /tl/). Shekgalagari (unlike Tswana) also features the palatal series of stops that enters PND (Solé et al. 2010). For a detailed discussion of differences between Tswana and Shekgalagari, see Solé et al. (2010) and Dickens (1984).

Ts.& 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 also reported to undergo PND as a sound change. Sequences of a nasal and a voiced stop (ND) develop to voiceless unaspirated stops (T) (Janson 1991/1992), but the process did not develop into a synchronic alternation in Makhuwa. To my knowledge, no elaborate accounts of the phonetic realization of voiced and voiceless stops in the elsewhere condition exist for Makhuwa.

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 (and Sotho) 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	àpóɽîì	‘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 4: PND in Bube (table from Janssens 1993)

Table 4 illustrates that Pre-Bube sequences of a nasal and voiced stop (ND) yield a single voiceless stop (T) with the nasal being lost. In the elsewhere condition, the labial voiced stop surfaces as such, the alveolar develops to [r/l], and the voiced velar stop gets lost (similar to the situation in Tswana and Shekgalagari) (Janssens 1993). Voiceless stops can either delete, develop to [h] (in the labial series), or continue to surface as voiceless stops. NT sequences develop to a plain voiceless stop (T; Janssens 1993). The Bube synchronic system features no alternation between voiceless and voiced stops in the post-nasal vs. elsewhere condition, but the development is intriguing from a diachronic perspective: it appears as if PND operated in Pre-Bube.

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.[9]

3.1.4 *Konyagi*

Recently, PND as a sound change has been discovered in Konyagi (also known as Wamey, among others; Merrill 2014, 2016a,b). 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 (2014, 2016a,b, 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 2014, 2016a,b, based on Ferry 1991 and Santos 1996). It thus appears as if Konyagi underwent PND. Voiceless NT sequences develop to a plain voiceless stop (T) in Konyagi. Both voiceless and voiced stops fricativize in the elsewhere condition. Table 5 illustrates PND in Konyagi.

9. The UniDia survey (Hamed and Flavier 2009) reports that PND targets the labial series of voiced stops in Lembaama. However, I was unable to find a description of this development in the literature.

Konyagi	Bedik	Basari	gloss
æ̀-jamp	u-jāmb	ɔ-jămb	'millet stalk'
ì-ñə́mp	ɔ-ñʌmb	a-ɟ̃ʌ̆mb	'plunge/immerse'
ì-ntæ̀w̃	gi-ndám	ɑ-ndɑ́w̃	'animal/spirit'
ì-kônt	ɔ-hɔ̀nd	a-xɔ̀nd	'snore'
æ̀-ncæ̀nk	ga-nɟáng	a-nɟàng	'Pterocarpus erinaceus (treesp.)'
æ̀-ncə́l̰	gɔ-nɟʌ̀l	ɑ-nɟʌ́n	'caterpillar'
ì-jæ̀nk	u-jáng	a-ɟ̃àng	'be long'
ì-nkòt	gɛ-ngɔ́t	ɛ-ngɔ̀t	'pole'

Table 5: PND in Konyagi (from Merrill 2014, 2016a,b)

Synchronically, Konyagi features voiceless and voiced stops as well as voiceless and voiced fricatives. Non-nasal clusters are not permitted. Post-nasally, only voiceless stops are allowed. Elsewhere, voiceless and voiced stops can contrast with voiceless and voiced fricatives, except initially where only fricatives are allowed (Merrill 2014, 2016a,b). PND is part of a synchronic mutation process in Konyagi: devoiced stops after prefixes that historically ended in a nasal alternate with voiced fricatives after prefixes that historically ended in a vowel and voiced stops after prefixes that ended in another consonant (see Section 3.5 and Merrill 2014, 2016a,b). No instrumental phonetic data is available for Konyagi.

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__). Elsewhere, *ʤ develops to [j] in these dialects (Rohlfs 1949, 424f.; Kümmel 2007, 376). Voiced stops are not reported to be devoiced in the post-nasal position: the feature [±voice] is contrastive for stops. Voiceless affricate either remains unchanged or develops to [ʃ] (Rohlfs 1949). Table 6 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 6: PND in South Italian (from Rohlfs 1949, 424f.)

3.1.6 Buginese and Murik

PND has been reported in three Austronesian languages: Buginese, Murik, and the Bengoh dialect of Land Dayak (Blust 2005, 2013). 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 (Lewis et al. 2015). 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 (Blust 2005, 2013).

Apparent PND in Buginese is represented by the following table showing the development of Proto-Malayo-Polynesian (PMP) 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 is occluded to a voiced palatal stop initially, and develops to a sonorant [r] intervocalically. Post-nasally, *z is devoiced to [c]. Word-finally, all stops develop to [ʔ]. Voiceless NT sequences develop to a geminate voiceless stop (TT) in Buginese (Mills 1975, Blust 2005). Voiceless stops remain unchanged in the elsewhere position (Mills 1975).

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

Table 7: 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'
*anɟap	ancəʔ	'offerings to spirits'
*ɟanɟi	ɟanci	'to promise'
*punɟuC	ma-poncoʔ	'short'

Table 8: PND in Buginese (from Blust 2005, 2013)

In Murik, labials, alveolars, and velars undergo devoicing in post-nasal position. In the elsewhere condition, the developments vary according to the place of articulation. Bilabial voiced stops surface as such in the elsewhere condition. Voiced dentals appear as [l] word-initially and [r] word-internally. Velars are devoiced not only post-nasally, but sporadically also in the elsewhere condition. PMP *z develops to the voiced palatal affricate [ɟʝ] initially, to [s] word-internally, and to the voiceless palatal affricate [cç] post-nasally. Table 9 illustrates the development of voiced stops from Proto-Kayan-Murik. Voiceless NT sequences develop to a plain voiceless stop (T) in Murik, while plain voiceless stops remain unchanged (Blust 1974, Blust 2005).

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

Table 9: Summary of PND in Murik (as reconstructed in Blust 2005)

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'
*nɟʝi	ncçi	'one'
*menɟʝat	məncçat	'pull'
*unɟʝuŋ	uncçuŋ	'tip, extremity'
*anɟʝat	ancçat	'rattan tote bag'
*tunɟʝuʔ	tuncçuʔ	'to point, indicate'
*tuŋgan	tuŋkan	'dibble stick'

Table 10: PND in Murik (from Blust 2005: 259f.; Blust 2013: 668)

Synchronically, PND in Buginese is reported to be an active phonological alternation (Sirk 1983) as well as an active sandhi process (Noorduyn 2012/1955). Buginese contrasts voiceless and voiced stops (Noorduyn 2012/1955), but voiced labial, palatal, and velar stops /b, d, g/ and a glide /w/ are reported to devoice (and change to a stop in the case of /w/) post-nasally in synchronic Buginese (see also Table 25 below). In Murik, PND is reported as a synchronic alternation only for the palatal stop series which alternates between [ɟ] in the elsewhere condition and [c] post-nasally. For other places of articulation, Blust (2005) reports PND to be synchronically inactive due to "phonemic restructuring".

3.1.7 Nasioi

The most recent report of PND is that in Brown (2017) for the South Bougainville language Nasioi, spoken in Papua New Guinea by approximately 20,000 speakers (Lewis et al. 2015). Brown (2017), based on Hurd and Hurd (1970), claims that PND in Nasioi is a synchronic alternation and supports this claim by showing that while bilabial and alveolar voiced stops /b/ and /d/ contrast in voicing with unaspirated voiceless /p/ and /t/ word-initially and after a glottal stop, only voiceless variants appear in post-nasal position. Elsewhere, stops fully contrast in the feature [±voice], but are not permitted other than word-initially and after a glottal stop: intervocalically, labial and alveolar stops surface as a voiced fricative [β] and a flap [ɾ], respectively. The velar voiced stop /g/ is not permitted in the system. This distribution points to a clear case of post-nasal devoicing. PND in Nasioi is not only a phonotactic restriction, but also seems to be an active synchronic alternation, which is illustrated by the example in (4). The voiceless version of the personal pronoun -p/b- surfaces post-nasally; the voiced one surfaces elsewhere.

(4) a. *kara-**b**-ant-∅-in*
talk-him-I-SG-did
'I talked to him.'

b. *tiom-**p**-ant-∅-in*
follow-him-I-SG-did
'I followed him.'

Brown (2017) specifically argues that post-nasal devoicing is an innovation in Nasioi and that the fact that a related language, Nagovisi, shows traces of post-nasal *voicing* (with a speculation that this might be indicative of the proto-language) suggests that Nasioi PND operated as a single sound change. In other words, this suggests that PND is not "derived from the confluence of multiple independent changes" (according to Brown 2017:275).

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 thirteen of these languages. However I will demonstrate below that a thorough investigation reveals a common pattern of complementary distribution in all thirteen cases along with other pieces of evidence, strongly suggesting that a combination of natural sound changes operated in place of a single PND sound change.

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 hypercorrection (Xromov 1972, 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 devoicing would operate in post-nasal position, where nasal leakage and volume expansion (Hayes and Stivers 2000, Coetzee and Pretorius 2010) militate against the anti-voicing pressure of closure (Ohala and Riordan 1979), whereas in other contexts, where speakers have to accommodate for voicing considerably more than post-nasally, voicing is preserved (see also the discussion in 3.4). Second, they each examine and account for only a single instance of PND, examined in isolation without the relevant cross-linguistic data. Finally, most of the existing proposals fail to explain recurrent patterns that are observed in all thirteen languages (e.g. fricativization of voiced stops elsewhere, see Section 3.3) and why only a subset of places of articulation enter into post-nasal devoicing. In Section 3.3, I argue that all cases of reported PND (that have until now been studied in isolation) in fact result from a combination of sound changes. This explanation was proposed for Tswana already in Dickens (1984) and Hyman (2001).

Xromov (1972) appears to invoke hypercorrection to explain PND in Yaghnobi. He postulates that in Sogdian and Yaghnobi, all stops voice post-nasally, but that this sound change is in progress, which results in variation between [NT]∼[ND] for the underlying /NT/. He further claims that the underlying /ND/ joined this pattern (probably through hypercorrection), which means that at some stage variation between [NT]∼[ND] existed for /ND/ as well. Once the voicing process was finished, the voiceless variant became more frequent for both inputs. No motivation is given for why the voiceless variant becomes prevalent, except for an assumption that devoicing might have been influenced by morphological analogy in dentals and then spread to other places of articulation. Xromov's explanation might be more convincing if we assumed hypercorrection arose from an interaction between two hypothetical dialects, where one voices all stops, and the other preserves the contrast; speakers of the neutralizing dialect could then hypercorrect their voiced stops to voiceless ones in post-nasal position. Not only do we lack evidence for the stage with the two dialects, but this assumption also fails to explain the connection between post-nasal devoicing and the development of voiced stops to voiced fricatives in the elsewhere condition.

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 and does not specify whether such dissimilation would be driven by perceptual or other factors, why it fails to target some places of articulation, and why it fails to target other contexts, such as the intervocalic position. 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 PNV, "voice was free to vary" post-nasally, and the "voiceless variant of postnasal obstruents prevailed over time." In other words, Blust (2005) seems to suggest that the lack of contrast in [±voice] enables devoicing in this position. There are three major issues with this approach. First, it is not parsimonious to assume the independent occurrence of PNV three times without any comparative evidence. Second, it is difficult to explain why a voiceless variant would prevail in an environment in which voicing is preferred compared to other environments (e.g. word-initially), but would fully contrast in those other environments, where voicing is dispreferred. While it is true that the functional load/frequency of phonemes can influence the probability of a merger (Wedel 2012, Wedel et al. 2013, Hay et al. 2015), it is unclear why a merger would first happen to voiced stops and then to voiceless stops. On the other hand, Blust is right in that diminished functional load of post-nasal stops in the languages that do not contrast [±voice] in post-nasal position can influence the operation of devoicing in the sense that the unconditioned devoicing (proposed in Section 3.3) does not get blocked for functional reasons (Wedel et al. 2013). Finally, this line of reasoning, like many others proposed thus far, fails to explain some common patterns, such as fricativization in the elsewhere condition or the absence of devoicing for some places of articulation (Section 3.1).

Somewhat related to Blust's (2005) second proposal is the idea that the loss of contrasts could influence the operation of sound change (cf. Keyser and Stevens 2001, Hyman 2013). PND is, however, attested both in languages in which [±voice] likely does not contrast post-nasally (e.g. in Yaghnobi, Konyagi) as well as in languages in which [±voice] fully contrasts post-nasally at the time of devoicing (e.g. in Tswana, where the nasal is not lost before stops in all environments). Similarly, an analysis of devoicing as a loss of contrast in [voice] in the elsewhere condition is not appealing. Devoicing is attested in languages in which voiced stops fricativize elsewhere (which means that the contrast is that of T ~ Z, e.g. in the Austronesian languages) and there are no voiceless fricatives (S) in the systems, meaning [voice] could be redundant (and [continuant] contrastive), as well as in languages in which the contrast in the elsewhere position is between voiceless and voiced fricatives (S ~ Z, e.g. in Konyagi or Tswana) and stops surface only post-nasally (and contrast in voice), meaning [voice] cannot be redundant. Finally, the fact that complete devoicing occurs in some subdialects of Tswana without any contrast being lost beforehand and that in Yaghnobi devoicing targets all stops, not only post-nasal ones, speaks against this line of reasoning (see also Sections 3.3.1 and 3.3.2 for further discussion).

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, i.e. devoicing in a context that strongly promotes voicing compared to other positions. Finally, this particular approach with hypercorrection lacks broader explanatory power, since it cannot be extended to cases of apparent PND in other languages, where the sound change NT > TT, T is not attested (e.g. in Tswana).

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 of 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):

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

Table 11: 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 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 is a 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. The only reasoning that could explain why secondary ND sequences do not undergo devoicing under the early velic rising approach would be to assume that devoicing is blocked in order to prevent the merger of two grammatical morphemes, /m-/ and /mʊ-/. Even if this is indeed the case, it still means that early velic rising is not completely automatic in synchronic Shekgalagari, but can be overridden for functional reasons. Also, Solé et al. (2010) note that Shekgalagari features ND sequences in approximately ten items that do not arise from the /mʊ-/ morpheme. While "most" of the ten items are assumed to be borrowings, it is unclear if all items indeed are borrowings (at least one of them is a grammatical marker [ǹde-]). This reinforces the view that early velic rising is not a completely automatic phonetic tendency in Shekgalagari, but can be blocked by at least functional and loanword factors. 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, an explanation along these lines fails to account for other cross-linguistic cases of apparent 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. Finally, the explanation proffered in Solé et al. (2010) fails to explain the connection between PND and the recurrent pattern of fricativization in the elsewhere condition or the pattern of unconditioned devoicing of voiced stop found in subdialects of Tswana.

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 not only for Tswana and Shekgalagari, but that an essentially similar historical scenario played out in all thirteen 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 and arguing that diachronic developments very similar to that proposed for Tswana in Dickens (1984) and Hyman (2001) operated in all thirteen languages, the next section dispels this concern and validates the three-sound-change analysis on typological grounds.

3.3 A combination of sound changes

A closer look into the collected data from Section 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 in all thirteen cases 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. While this explanation has been proposed for Tswana in Dickens (1984) and Hyman (2001), this paper argues that the same diachronic scenario plays out in all thirteen cases by pointing out two thus far unobserved pieces of evidence in favor of the three-sound-change approach. It is also argued that Yaghnobi offers the most direct evidence in favor of the three-sound-change approach, since all three diachronic stages are historically attested in written sources. Yaghnobi also provides crucial evidence in favor of the assumption that the second sound change, devoicing of voiced stops, is unconditioned.

3.3.1 Yaghnobi

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, which is closely related to Sogdian (but more archaic) and can be used to represent the parent language 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' (Bartholomae 1961:210).[10]

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). Evidence for this sound change in Yaghnobi are attested as directly as a sound change can be attested diachronically: Stage 2 (Sogdian) features voiced stops which surface as voiceless at Stage 3 (Yaghnobi). Because voiced stops surface after nasals, this combination of sound changes results in apparent PND. The development is summarized in Table 12.

Stage	**Sound change**	**Language**	**Example**
1		Avestan	band
2	D > Z / [−nas]__	Sogdian	βand
3	D > T	Yaghnobi	vant

Table 12: Development of PND 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 13 illustrates the three sound changes that operated on the alveolar series of stops to produce PND.

Stage	**Sound change**	**Language**	**N__**	**Elsewhere**
1		Avestan	band	dasa
2	d > ð/[−nas]__	Sogdian	βand	ðasa
3	d > t	Yaghnobi	vant	*ðasa
4	ð > d	Yaghnobi	vant	das

Table 13: Development of coronals from Avestan to Yaghnobi

Yaghnobi and Sogdian contain yet more crucial evidence in favor of the three-sound-change approach outlined above. One of the most serious objections to the three-sound-change approach in Yaghnobi and elsewhere is 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 (2). However, Sogdian and Yaghnobi provide strong and

10. Yaghnobi examples are primarily taken from Xromov (1972) and Novák (2010, 2013, 2014).

unique 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. The origin of such a distribution is straightforward: voiced stops did not fricativize after another fricative in order to avoid clusters of two fricatives. This property of Sogdian and Yaghnobi, which has up to now been a less discussed fact (Novák 2013), essentially means that voiced stops surface as fricatives in Sogdian in all positions except post-nasally and occasionally 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 (in central and western dialects), e.g. Sogd. [pəzda], Yagh. [past] or [pajst] 'smoke'; potentially also Sogd. [ðəɣ^{w}da], Yagh. [duxtar], Sogd. [suɣd-], Yagh. [suxta]; Sogd. [əχʃɨβdi], Yagh. [xiʃift][11] (from Novák 2013, 2014). Conversely, Sogdian clusters of two voiced fricatives (that arise from a cluster of a voiced fricative and an approximant [dw]), [ðβ], do not devoice in Yaghnobi (although they are realized with an automatic epenthetic vowel): Sogd. [ðβəri] 'door' or [əzβaːk] 'tongue, language' vs. Yagh. [z^{i}voːk] or [d^{i}var] (Novák 2013). Table 14 illustrates this development.

Sogdian	**Yaghnobi**
zd	st
zβ	z^{i}v
ðβ	d^{i}v
ɣd	xt
βd	ft

Table 14: Correspondences of ZD sequences

Sequences of a voiced fricative and a voiced stop ZD show that voiced stops undergo unconditioned (not only post-nasal) devoicing in Yaghnobi. After the devoicing, the preceding voiced fricative undergoes voicing assimilation to the following voiceless stops. That this scenario indeed took place is suggested by evidence from Western Yaghnobi, in which forms like [avd] and [avt] for Sogd. [əβdá] are attested (data from Novák 2014). 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 15.

Stage	**Sound change**	**Language**	**Sequence**	**Example**
1		Sogdian	ZD	zd
2	D > T		ZT	*zt
3	assimilation	Yaghnobi	ST	st

Table 15: Development ZD sequences from Sogdian to Yaghnobi

In the other twelve languages with PND, non-nasal clusters are generally not allowed (or they became simplified before the emergence of PND), so we do not see devoicing anywhere other than in 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

11. While it is possible, although unlikely, that Yagh. [suxta] and [xiʃift] preserve an earlier (pre-Sogdian) stage where the cluster of a fricative and a stop was not yet voiced, this cannot be the case in Yagh. [past] < Sogd. [pəzda] (and potentially also Yagh. [duxtar]), where the cluster is voiced already in Proto-Iranian (see reconstructions in Novák 2013).

unconditioned; if it were not, we would not be able to unify our account of the devoicing of ND and ZD.

3.3.2 Tswana, Shekgalagari, and Makhuwa

If Yaghnobi provides crucial evidence for the three-sound-change approach on historical grounds, Tswana offers crucial *dialectal* evidence for this hypothesis. 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 labeled "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 (Zsiga et al. 2006, Coetzee et al. 2007, Coetzee and Pretorius 2010). The three systems of Tswana are represented below.

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

Table 16: Microdialects of Tswana (from Zsiga et al. 2006, Coetzee et al. 2007)

As Hyman (2001) argues, 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. In other words, Dickens (1984) and Hyman (2001) argue that PND in Tswana results from a combination of three sound changes, the first of which is fricativization of voiced stops except post-nasally. Unconditioned devoicing happens next, and because voiced stops surface only after nasals, the result is apparent PND. This interstage is confirmed by Kutswe, a variety of Sotho in which the alternation is between [p] post-nasally and [β] elsewhere (as mentioned in Dickens 1984). This pattern is obscured in Tswana and Shekgalagari, however, by an additional change in the dialect with PND: unconditioned occlusion of fricatives (Z > D). After this change, voiced stops surface as voiceless after nasals and, crucially, the feature [±voice] is fully contrastive in the elsewhere condition (Hyman 2001). Recall that this final sound change also occurred in Yaghnobi, but only for the alveolar series of stops.

The attestation of the subdialect of Tswana that features unconditioned devoicing of voiced stops also speaks against analyses that assume post-nasal devoicing results from the loss of contrast in the feature [voice], when voiced stops develop to voiced fricatives elsewhere (see Section 3.2). In the "devoicer" subdialect, unconditioned devoicing occurs without the development of voiced stops to fricatives (i.e. when the feature [voice] is fully contrastive).

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 (except post-nasally) along with voiced stops. Table 17 shows this development.

	#__	**V__V**	**N__**	**#__**	**N__**	**Gloss**
*p	ɸ	ɸ	p^h	ɸeɲa	m-p^heɲa	'conquer (me)'
*t	r̥	r̥	t^h	rátá	n-t^hátá	'love (me)'
*k	h, x	h, x	kx^h, k^h	xátá	ŋ-kx^hátá	'trample (me)'

Table 17: Development of voiceless stops in Tswana with examples (table from Hyman 2001)

These data provide yet another piece of evidence that complementary distribution occurred first in Tswana and neighboring dialects, in both the voiced and voiceless series of stops (Hyman 2001). 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 other Sotho-Tswana languages and Makhuwa are closely related to Tswana, the same analysis can be applied to these 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, e.g. *-dɔ́b- > [-lɔ́bâ] (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 related languages, too, provide strong evidence in favor of a stage with complementary distribution, just like in Yaghnobi or Tswana. Proto-Tenda, an ancestor of Konyagi, is reconstructed on the basis of Konyagi and its neighboring languages Basari and Bedik (Merrill 2014, 2016a,b). The first stage of Proto-Tenda features a 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[12]. The fricativization is directly confirmed by the Basari dialect, which preserves the Proto-Tenda II stage with minor deviations. Table 18 shows the development of consonants in non-post-nasal position from Proto-Tenda I and II to Basari and Konyagi.

12. I reconstruct that voiced geminate fricatives later undergo occlusion to voiced stops.

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

Table 18: Development of non-post-nasal consonants from Proto-Tenda to Konyagi (table from Merrill 2014, 2016a,b, Santos 1996)

Just like in Basari, original voiced stops surface as fricatives in Konyagi (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 2014, 2016a,b, p.c.).[13] 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	ɲ	ŋ
Proto-Tenda II	p	t	c	k	p	c	k	b	d	ɟ	g	b	g	l	m	n	ɲ	ŋ
Basari	p	t	c	k	p	c	k	b	d	ɟ	g	b	g	l	m	n	ɲ	ŋ
Konyagi	p	t	c	k	p	c	k	p	t	c	k	p	k	l	m	n	ɲ	ŋ

Table 19: Development of post-nasal consonants from Proto-Tenda to Konyagi (table from Merrill 2014, 2016a,b, Santos 1996)

While in Bedik and Basari, original post-nasal voiced stops remain voiced, they devoice in Konyagi. Here too, however — like in all other cases of PND — the voiced stops that devoice post-nasally are 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 once more the result of a combination of sound changes.

The third sound change, occlusion back to stops, is lacking in Konyagi. As a result, it is not voiceless and voiced stops that alternate at some stage of development in Konyagi, but rather 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.[14] All these changes result in a synchronic mutation that involves voiced and voiceless stops and voiced fricatives or approximants (see Section 3.5).

So far, I have argued that all cases of apparent 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). Given the cases of post-nasal devoicing discussed so far, de-occlusion of the affricate and the development to the glide provides evidence for a stage with complementary distribution. At the point when *ʤ appears post-nasally and [j] (or probably *ʒ)

13. The nasal stops are lost before voiceless stops.
14. Likewise, a Proto-Tenda sequence of a nasal and an implosive yields an ND sequence in Konyagi.

elsewhere, an unconditioned devoicing of voiced affricates occurs. This, too, is a well-attested and motivated sound change: voiced affricates are highly dispreferred, which is why devoicing is a natural tendency in these segments. Voice is difficult to maintain, especially in affricates, which combine two articulations that are highly antagonistic to voicing: closure and frication (Ohala 1983, 2006). Table 20 illustrates the reconstructed development: Stage 2 shows a period of complementary distribution, and Stage 3 represents the development after the unconditioned devoicing of voiced affricates.

Stage	**Sound change**	**Elsewhere**	**N__**
1		faʤina	pinʤere
2	ʤ > j / [−nas]__	fajina	pinʤere
3	DZ > TS	fajina	pinʧiri

Table 20: 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. Also, Stage 4 is absent from South Italian: the change that would occlude [j] to [ʤ] is absent.

3.3.6 Buginese and Murik

The emergent pattern that we have seen in all the apparent cases of 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.

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 argue that the three-sound-change explanation again better captures the data, despite the lack of direct historical or dialectal evidence.

The main 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 post-nasally (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 in Table 21.

Stage	**Sound change**	**Language**	**Example**
1		PSS	*bumbun
2	D > Z / [−nas]__	Pre-Buginese	*wumbun
3	D > T	Buginese	wumpun

Table 21: Development of PND in bilabials in Buginese

In Buginese, /w/ continues to surface as a non-obstruent (since only two changes operated in the labial series). Based on the development of the labial series, we can reconstruct that the velar series likewise undergoes complementary distribution and unconditioned devoicing. Unlike the labial series, however, the voiced velar fricative *ɣ undergoes occlusion to [ɡ] (all three sound changes operated in the velar series), thus obscuring evidence for an inter-stage with complementary distribution.[15] Note that this is precisely the same scenario attested in 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 in velars (with all three sound changes operating) is illustrated in Table 22.

Stage	**Sound change**	**Language**	**N__**	**Elsewhere**
1		PSS	*aŋɡəp	*ɡiliŋ
2	D > Z / [−nas]__	Pre-Buginese	*aŋɡəp	*ɣiliŋ
3	D > T	Pre-Buginese	*aŋkəp	*ɣiliŋ
4	Z > D	Buginese	aŋkəp	ɡiliŋ

Table 22: Development of PND in velars in Buginese

The dental series of stops in Buginese escapes PND because *d developed to [r] in all positions (*dindiŋ > [renriŋ]) and, as such, became ineligible for the devoicing of voiced stops. The development of *z also conforms to the proposal above: intervocalically, it undergoes rhotacism to [r] (possible through an interstage with *ʝ); post-nasally, it occludes to *ɟ 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] (in other words, there was likely a stage of complementary distribution: *ɟ post-nasally, *ʝ/r elsewhere). The initial stage with complementary distribution in Buginese stops 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.

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 23). These data point to a stage with complementary distribution (PKM in the Table 23). 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. After a nasal, however, *d remained a stop.

Stage	**Language**	**#__**	**V__V**	**N__**
1	Pre-PKM	d	d	d
2	PKM	ð	ð	d
3	Murik	l	r	t

Table 23: Development of coronals in Murik

Next, I argue that unconditioned devoicing of voiced stops occurred. Because devoicing operated during a period when voiced stops surfaced only after nasals, apparent PND is the result. Based on the development of the alveolar series, I reconstruct that fricativization targeted 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]). Unlike the alveolars, *β and *ɣ

15. The reconstruction of the interstage with [ɣ] thus relies on the labial series.

then underwent occlusion "back" to stops, resulting in apparent PND. Table 24 traces the proposed trajectory from (Pre-)Proto-Kayan Murik to Murik for the labial series of stops.

Stage	**Language**	**#__**	**V__V**	**N__**
1	Pre-PKM	b	b	b
2	PKM	β	β	b
3	PKM	β	β	p
4	Murik	b	b	p

Table 24: 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 palatalizes to *ʝ. Post-nasally, occlusion to an affricate *ɟʝ takes place.[16] The affricate gets devoiced, exactly as in Sicilian and Calabrian, together with devoicing of other voiced stops. The initial fricative *ʝ then gets occluded to a voiced stop, together with other voiced fricatives in Murik.[17]

In sum, 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.

3.3.7 Nasioi

That PND in Nasioi results from a combination of three natural sound changes is strongly suggested by Nasioi internal evidence and by diachronic development of its related languages. Evidence for a stage with complementary distribution comes from Nasioi itself: voiced stops /b/ and /d/ surface as a fricative [β] and a flap [ɾ] intervocalically. Lenition of voiced stops in related languages strongly suggests that a complementary distribution consisting of voiced stops developing to voiced fricatives except post-nasally, operated already in pre-Nasioi. In Buin and Nagovisi, for example, [ɾ] and [d] are in complementary distribution whereby [d] surfaces post-nasally and [ɾ] elsewhere (Brown 2017). In Motuna, the complementary distribution is not limited to alveolars, but targets labials as well. The stops [b] and [d] are in complementary distribution with [w] and [r] such that the stops surface only post-nasally and the approximants surface elsewhere, including in word-initial position (Onishi 2012).

It is reasonable to assume that Motuna represents the proto-stage of Nasioi. In the development of Nasioi, voiced stops devoice, but because they surface only post-nasally, the change looks like post-nasal devoicing. Finally, Nasioi undergoes occlusion of fricatives to stops (like Tswana and

16. Alternatively, *z gets occluded to an affricate *ɟʝ in all positions and later undergoes deocclusion to *ʝ in initial position, parallel to the South Italian development.

17. 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.

Shekgalagari, Yaghnobi, and Buginese and Murik), but this occlusion is contextually limited to the initial and post-obstruent positions. Intervocalically, voiced fricatives still surface as fricatives. Occlusion of fricatives that is limited to initial position or to clusters is a well-motivated and common sound change (see Kümmel 2007 and the discussion in Section 3.4 below).

3.4 Naturalness of the three sound changes

All sound changes assumed by the proposals above are natural, that is, both phonetically well-motivated and well-attested, with clear phonetic precursors. A survey of sound changes in Kümmel (2007) lists approximately 56 cases in which voiced stops undergo fricativization in either post-vocalic or intervocalic position (in four cases the non-nasal environment is specifically mentioned), plus an additional two cases in which voiced fricatives occlude to stops post-nasally. Moreover, only two 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 the 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 due to the lack of airflow and voicing ceases. This mechanism has long been known as the Aerodynamic Voicing Constraint (Ohala 1983, 2011). 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), among others "Cantonese, Hawaiian, Zuñi, Ainu, and Quechua" (Ohala 2011:64). 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.[18] Unconditioned devoicing is also attested as a sound change. In Tocharian and in some subdialects of Tswana (Gouskova et al. 2010), 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: what mechanisms motivate devoicing if it operates only in the post-nasal position which itself favors voicing? As 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 because nasal leakage and volume expansion counter the anti-voicing effect of closure (compared to stops in other positions). The increased amount of passive voicing, which is a phonetic precursor based on coarticulation, can result in a sound change of post-nasal voicing. However, voiced stops absent a specific context are nevertheless articulatorily dispreferred when compared to voiceless stops: closure is always antagonistic to voicing for clear aerodynamic reasons. Closure causes airflow to cease because of pressure build up (Ohala and Riordan 1979). To counter this effect, speakers must passively or actively accommodate for voicing by expanding the volume of the oral cavity; otherwise vocal folds cease to vibrate after 5–15 ms (without any accommodation) or after approximately 70 ms (with only passive accommodation) from the onset of closure (Ohala and Riordan 1979). Because of nasal leakage and volume expansion due to

18. 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.

velum rising, speakers need to accommodate for voicing the least in post-nasal condition; much less than, for example, word-initially or word-finally (Westbury and Keating 1986, Steriade 1997, Iverson and Simon 2011). This means that devoicing that only targets the post-nasal position in a language that features voiced stops in other positions would indeed be unnatural. Despite nasal leakage and volume expansion, however, speakers still need to accommodate for voicing (all else being equal), in order to counter the anti-voicing effect of closure — even in post-nasal position. Failure to accommodate for voicing will result in devoicing, which means that devoicing is motivated post-nasally when it targets other positions as well. If voiced stops happen not to surface other than post-nasally due to an earlier sound change, devoicing is still phonetically motivated precisely because closure is antagonistic to voicing and speakers have to accommodate for voicing in all positions (despite the fact that some environments counter the antagonistic effect of closure on voicing).

Two pieces of evidence from the data independently support the position that unconditioned devoicing operates in the development of PND. None of the languages with reported PND, with exception of Yaghnobi, feature non-nasal clusters or permit voiced stops to surface in any other position than post-nasally (at some stage of development). This means that the effect of unconditioned devoicing can only be observed post-nasally. Yaghnobi, however, shows that devoicing of voiced stops operated in its prehistory, not only post-nasally (N__), but also in the other position where voiced stops surfaced: after voiced fricatives (Z__). In other words, devoicing in Yaghnobi had to be unconditioned rather than limited to post-nasal position, which is clear from the fact that devoicing targeted all positions where voiced stops surfaced: both ND *and* the more marginal ZD clusters.

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 (Table 16).[19] Phonetic studies of the dialect that devoices all stops in all positions show 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[20]; Gouskova et al. 2011). These instrumental results support our assumption that unconditioned devoicing is an attested sound change, motivated by the anti-voicing effect of closure, even if it appears to operate only post-nasally. The devoicing microdialect of Tswana confirms that where unconditioned devoicing happens, it targets stops in all positions, including the post-nasal position, precisely because closure is always antagonistic to voicing. Furthermore, the fact that unconditioned devoicing, confirmed by instrumental phonetic studies, operates precisely in the subdialect of the language that features PND, additionally strengthens the assumption that the second sound change in the three-sound-change combination leading to PND was *unconditioned* devoicing.

Finally, unconditioned occlusion of non-sibilant fricatives to stops is also well attested and motivated.[21] Non-sibilant fricatives are typologically and articulatorily dispreferred (Maddieson 1984:46). 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, frica-

19. 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 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.

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

21. The occlusion of fricatives is another example of naturalness needing to be evaluated with respect to a given context. While unconditioned occlusion of fricatives is well-motivated (see the discussion in this paragraph), intervocalically its opposite process, fricativization of stops, is the natural direction (see also Ladefoged and Maddieson 1996: 137, Kaplan 2010).

tives 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 (Ladefoged and Maddieson 1996:137). Deviation from precise articulatory targets can thus lead to the 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. Kümmel (2007) also identifies cases of occlusion of fricatives that is limited to the initial position or to clusters (as is reconstructed for Pre-Nasioi).

3.5 PND as a synchronic alternation

Buginese, Konyagi, Nasioi, and especially Tswana and Shekgalagari, confirm that a combination of sound changes *can* and *do* result in productive unnatural synchronic processes. Note that, according to Kiparsky (2008), the third sound change in the series of the three sound changes that result in PND is expected to be blocked by UG, since the combination would result in an unnatural process and the surface pattern does not allow for phonological reanalysis.[22] However, this blocking clearly does not happen: sound change that blurs the original complementary distribution and thus produces a synchronically unnatural process is attested in Buginese, Konyagi, Nasioi, and Tswana and Shekgalagari in particular.

As mentioned above, the combination of three sound changes is reported to yield 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	'Bone (name)'	arum-pone	'prince Bone'
gora	'shouts'	saməŋ-kora	'loud shouts'
ɟaiʔ	'root'	maɲ-caiʔ	'to sew'

Table 25: 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, e.g. /telluŋ bocco/ → [tellumpoco], but the process is no longer productive. 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 (Merrill 2014, 2016a,b). Adjectives surface with a sonorant in initial position after vowel-final prefixes that go back to vowel-final prefixes (-V_V), while voiced stops surface in the initial position of these adjectives after vowel-final prefixes that go back

22. Kiparsky (2008) posits that either the changes that would cause unnatural alternations are blocked or "the system they appear to give rise to must be reanalyzed". It is unclear to me, however, how the system of PND as is attested, for example, in Tswana could be phonologically reanalyzed. It is impossible to assume that stops in post-nasal position are underlyingly voiceless (and get voiced elsewhere), because voiced and voiceless stops contrast in the elsewhere condition in Tswana. PND could be analyzed as morphologized, but Coetzee and Pretorius (2010) show that the rule extends to nonce words, although they admittedly test only one morphological environment (for a discussion against a morphological analysis, see Hyman 2001). If reanalysis is not available, we would (in line with Kiparsky's 2008 reasoning) expect the last sound change that would result in the unnatural alternation to be blocked.

to consonant-final prefixes (-V_C). Finally, adjectives surface with voiceless stops in initial position after a nasal-final prefix (-N) (Merrill 2014, 2016a,b).

	-V_V	**-V_C**	**-N**	**gloss**
bilabial	-wə́nkáák	-bə́nkáák	-mpə́nkáák	'beside'
alveolar	-lə̀mæ̀xə́	-də̀mæ̀xə́	-ntə̀mæ̀xə́	'sweet'
palatal	-jə̀læ̀xə́	-gə̀læ̀xə́	-nkə̀læ̀xə́	'rotten'
velar	-wúnkǽx	-gúnkǽx	-nkúnkǽx	'bitter'

Table 26: Konyagi PND (table from Merrill 2014, 2016a,b, Santos 1996)

PND is reported as a synchronic alternation in Nasioi as well. Voiceless and voiced labial and alveolar stops contrast initially and after a glottal stop. Intervocalically, voiced stops are lenited to a voiced fricative and a flap, but post-nasally they devoice and merge with voiceless stops. The alternation (PND) that might be morphologically limited is reported for two morphemes: the second person object suffix /-d/ and the third person object suffix /-b/ (e.g. [oo-**d**-a-∅-maan] 'I see you' vs. [manton-**t**-a-∅-maan] 'I feel you'; Brown 2017).[23] Further research is required to establish the synchronic status of PND in Nasioi.

Buginese, Konyagi, and Nasioi feature a synchronic process of PND, although the scope of PND in these languages is limited in that either it involves an alternation Z ∼ NT instead of D ∼ NT, or it is morphologically limited, or it targets only a subset of voiced stops. Detailed phonetic descriptions of PND in these languages are lacking. In Tswana and Shekgalagari, on the other hand, PND is not only reported as a productive synchronic alternation, but we also have detailed acoustic and experimental studies of it.

Two major contributions addressing the synchronic status and productivity of PND are Coetzee and Pretorius (2010) and Solé et al. (2010). These papers first show that the process in question in Tswana and Shekgalagari is in fact a phonetic devoicing of stops in post-nasal position. For seven speakers of Tswana (out of twelve total), voiced stops devoice and completely merge with the voiceless series post-nasally (Coetzee and Pretorius 2010); for example, /m-bV/ completely merges with /m-pV/, and the stops in post-nasal position (both the underlyingly voiceless and the devoiced) "agree nearly completely" in all relevant parameters with /re-pV/ and significantly differ from the underlying /re-bV/. The same conclusion is drawn for Shekgalagari based on acoustic and laryngographic data in Solé et al. (2010).[24]

Second, Coetzee and Pretorius (2010: 411) show that PND is fully productive, extending to nonce-words at the same rate as it applies to the native vocabulary in Tswana. The results from nonce-word experiments suggest that PND is not lexicalized, but rather a productive phonological process in the synchronic grammar of Tswana speakers. This means that unnatural alternations produced by combinations of sound changes can become part of productive synchronic grammars.

Finally, Coetzee and Pretorius (2010) show that the natural process of PNV operates passively even in cases in which PND is a phonological process. The system containing the unnatural synchronic phonological process PND is attested for seven of the thirteen speakers. For the other five speakers, however, Coetzee and Pretorius (2010: 417) observe that they often realize the whole closure "with voicing" in post-nasal position. This suggests that the five speakers have introduced a new rule into their system, which is the natural, phonetically motivated, and exact inverse process to PND: post-nasal voicing.[25]

23. Hurd and Hurd (1970) suggest that /-b/ can be optionally deleted in intervocalic position.
24. Note that nasals in both Tswana and Shekgalagari are always realized as syllabic.
25. The new rule, post-nasal voicing, might also be interpreted as dialect mixing.

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 unnatural sound change, but as a combination of natural sound changes in all thirteen languages in which PND is reported either as a synchronic alternation or as a sound change. This typological study provides a basis for establishing a new diachronic model for explaining unnatural phenomena, the Blurring Process, which I present in this section. Using the Blurring Process, I also provide a proof that at least three sound changes are required for an unnatural process to arise: the Minimal Sound Change Requirement.

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 operate that blurs the original complementary distribution. I label this historical development a *Blurring Process.*

(5) *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 (5), 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 alternation and a UPT, whereby A and B represent feature matrices that select one or more segments in a given language and X specifies the environment of the alternation. Because A → B / X is a UPT, A and B differ in exactly one feature, ϕ_1, such that the value of ϕ_1 in B is universally preferred in the environment X. This means that its inverse process, B → A / X, is an unnatural process: the value of ϕ_1 in A is universally dispreferred in X. How does B → A / X arise? There are a number of possible trajectories, but I will focus on two main trajectories, i.e. combinations of sound changes, that are attested as historical developments. I will refer to the first development in (6) as the *Blurring Cycle* and the second development in (6) as the *Blurring Chain.* The crucial difference between the two is that in the Blurring Cycle, the sound change B > A does operate, but because it is unconditioned, i.e. not limited to the unnatural environment X, it can be phonetically motivated. In the Blurring Chain, on the other hand, B > A never operates. Instead a "chain" of developments occurs: B > C (/X) > D > A. The motivation for the term "cycle" is clear: the last sound change in the Blurring Cycle reverses the first sound change (although the two differ in their contexts). In other words, the last sound change targets the outcome and results in the target of the 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 (B > A / X).[26]

(6)

Blurring Cycle	*Blurring Chain*
B > C / –X	B > C / X
B > A	C > D
C > B	D > A
B > A / X	B > A / X

26. Although some aspects of the Blurring Process resemble rule ordering in opacity (Kiparsky 1971, 1973), we avoid the opacity terminology, because the end result of the Blurring Process is a non-opaque simple alternation. Moreover, opacity concerns synchronic alternations, whereas the Blurring Process is a diachronic development. We likewise avoid the Duke-of-York terminology (Pullum 1976): the sound changes in the Blurring Process never operate in the opposite (unnatural) direction, as would be the case in the Duke-of-York derivation.

PND in all thirteen cases is a result of the Blurring Cycle.

(7)

Blurring Cycle	*PND*
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 (Author 1&).

The Blurring Process thus serves as a diachronic model for explaining seemingly unnatural sound 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" this 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 with a single sound change. This is the reason why Ohala (1981) himself restricts the operation of hypercorrection to "those consonantal features [...] which have important perceptual cues spreading onto adjacent segments". He specifically notes that the voice feature is unlikely to undergo dissimilation based on hypercorrection (see also Blust 2005). I have argued here that the Blurring Process approach is superior to hypercorrection in the case of PND; elsewhere (Author 1&), I argue that the Blurring Process better explains other unnatural processes, such as intervocalic devoicing. While this paper does not argue against the existence of hypercorrection, further research should reveal what processes are better explained by one or the other strategy.

The Blurring Process has 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 what we observe typologically: that the emergence of an unnatural process requires at least three sound changes to operate in combination. As per the definition in (3), we assume that a single instance of sound change means a change of one feature in a given environment (Section 2.2). For a natural sound change (A > B / X), A and B differ in exactly one feature ϕ_1 (for example [±voice] in the case of PNV or final voicing), so that a given value of ϕ_1 in B is universally preferred in environment X and its opposite value $-\phi_1$ in A is dispreferred in the same environment X. 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? A and B differ in one feature only (ϕ_1). 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, ϕ_2, but, to be sure, a different feature from the one that separates A and B (ϕ_1). From this point, it is impossible for an unnatural sound change to arise without a third sound change. Indeed, C cannot develop directly to A, since the two segments differ in two features: feature ϕ_1, which distinguishes A and B, and feature ϕ_2, which distinguishes B and C, with $\phi_1 \neq \phi_2$. Since, by definition, two sound changes are required in order to change two features (see the discussion in Section 2.2), 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*:

(8) *Minimal Sound Change Requirement (MSCR)*
Natural processes arise through a minimum of one sound change. A minimum of two sound changes have to operate in combination for an unmotivated process to arise. A minimum of three sound changes have to operate in combination for an unnatural process to arise.

The MSCR is derived even more clearly if we use feature notation to represent the Blurring Process. Let ϕ_1 and ϕ_2 be two features in a feature matrix. Let us assume that a change in the direction $-\phi_1 > +\phi_1$ is a universal phonetic tendency, given $+\phi_2$ (and other participating features) and given an environment X. How does the unnatural change in the direction $+\phi_1 > -\phi_1$ arise? According to the definition, sound change cannot produce $+\phi_1 > -\phi_1$ in a single step, given the constant value of ϕ_2. The change from $+\phi_1 > -\phi_1$, however, *can* be phonetically motivated with different values of ϕ_2 (e.g. in a Blurring Chain) or when $[+\phi_1, +\phi_2]$ only appears in a given environment, which means the context becomes irrelevant ($\varnothing$) for evaluating naturalness (as is the case in the Blurring Cycle). In other words, we cannot change $[+\phi_1,+\phi_2]$ to $[-\phi_1,+\phi_2]$, but it is possible that $+\phi_1 > -\phi_1$ is motivated under $-\phi_2$ or $\varnothing$ (motivated under a different context). This means that first, a sound change that targets ϕ_2 has to operate and change its value, either in a given environment X (Blurring Chain) or in the elsewhere condition $-$X (Blurring Cycle). Under the changed ϕ_2, the $+\phi_1 > -\phi_1$ can be motivated (which is the second sound change in the Blurring Process). Finally, in order for the change $+\phi_1 > -\phi_1$ to appear unnatural, the value of ϕ_2 has to change to the initial stage (the third sound change). Feature values of each stage in the Blurring Process that produce the unnatural $[+\phi_1,+\phi_2] > [-\phi_1,+\phi_2]$ are illustrated in Table 27. At least three changes are needed to get from Stage 1 to Stage 4 (MSCR).

Stage	1.	>	2.	>	3.	>	4.
$\boldsymbol{\phi_1}$	+		+		−		−
$\boldsymbol{\phi_2}$	+		−/∅		−/∅		+

Table 27: Changes in feature values in a blurring process

As already mentioned, rule telescoping has long been known to produce unmotivated results. However, to derive unnatural alternations, we need a special combination of sound changes: the Blurring Process. To my knowledge, this paper also 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 unnatural alternations (B $\rightarrow$ A / X), minimally three sound changes are required, as outlined above. 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 arise (as predicted by MSCR),[27] thus pointing to the validity of the proposed MSCR.

A combination of more than one sound change can in some rare cases also result in what would usually be analyzed as a natural alternation. This is primarily true for processes that allow multiple intermediate stages in their development. For example, the natural process /k/ $\rightarrow$ [ʧ] / __[+front] can

27. One scenario requires analogy, others require a certain phonotactic restriction that would itself require a sound change to arise, and still others do not result in synchronic alternation but in phonotactic restrictions.

arise through a combination of individual sound changes as defined in Section 2.2 (with intermediate stages such as [c] > [cç]). The resulting process, /k/ → [ʧ] / __[+front] is nevertheless natural because it operates in the direction of a universal phonetic tendency of fronting of velars before front vowels (Guion 1996).

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 (limited of course by the timeframe of active operation), and even if such a combination results in unnatural alternation, the synchronic grammar can still incorporate it (Section 3.5); 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 crucially relies on the Blurring Process and MSCR.

5 Typology within the Channel Bias

5.1 Probability of combination of sound changes

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? Of course, we can assume that unnatural alternations arise through combinations of sound changes (as is argued for in this paper). Under this hypothesis, however, we are faced with the problem that was raised by Kiparsky (2006, 2008) and de Lacy and Kingston (2013): if any combination of sound changes is possible, why are some patterns very common, others less common, and even more importantly, some non-existent.

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 derives surface typology more accurately than the proposals entertained so far: the new model not only explains why natural alternations are the most frequent, unmotivated alternations less frequent, and unnatural alternations the least frequent, but also estimates historical probabilities of individual synchronic alternations, thus quantifying the Channel Bias contribution to phonological typology.

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 instances of at least one sound change. Unmotivated alternations are phonologized combinations of at least two sound changes. Unnatural alternations 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 or three particular sound changes occurring in sequence, which translates into a scale of probability in which natural alternations are the most likely to occur, followed by unmotivated changes, and then unnatural alternations. Even if we do not assume that a sound change is strictly minimal, but can in some instances involve changes of more than one feature simultaneously (Section 2.2), typology in (9) still holds: even if we admit simultaneous sound changes of multiple features in the set of possible sound changes, they are still considerably less frequent than sound changes that target only one feature (see Section 2.2). The overall probability of an unnatural alternation will thus nevertheless be smaller than the probability of an unmotivated alternation, all else being equal.

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

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 operating 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. In other words, 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 the Blurring Process must be active as ordered: a sound change in the Blurring Process must be active and exceptionless, but can cease to operate by the time of the following sound change, provided that the substantial novel/loan vocabulary or morphological contexts are not introduced that would fail to undergo the change.[28] Thus, the timespan available to produce such unnatural alternations is not unlimited, but rather limited by the time t in which single sound changes that combine to yield the alternation in question are active/affect all lexical items and morphological alternations in a given language. In probabilistic terms, we would say that language history is not a pure-birth process, but rather a birth-death process.

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 (Bell 1970, 1971, Greenberg 1978:75–6, Cathcart 2015, Morley 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 by Harris (2005, 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 the generalization that combinations of changes produce rare patterns. To my knowledge, none of the proposals so far actually explain the mechanism for why the least frequent processes are also

28. The first sound Change in the Blurring cycle in fact has to be inactive at the time of the second sound change for the unnatural process to arise.

phonetically unnatural (and less frequent phonetically unmotivated): a generalization that follows automatically from the formal proof that unnatural alternations require at least three sound changes (MSCR).

Two models attempt to quantify probabilities of occurrence of various, primarily static phonotactic processes and explain the relative rarity of some processes. Bell (1970, 1971) and Greenberg (1978) propose a "state-process model". Their model operates with typological states (phonological, morphological, and syntactic) that can arise from other states, depending on transitional probabilities from one state to the other and rest probabilities of each state, and is as such most suitable for modeling probabilities of various phonotactic restrictions. A probability of each state is determined by the number of previous states it can arise from and transitional probabilities between states. They propose a Markov Chain Model for determining probabilities of each state. Their modeling of probabilities of transitions (processes) in the one instantiation of the model in Bell (1971), however, involves relative probabilities that only tangentially reflect frequencies of processes in samples. The most elaborate model of calculating probabilities of combination of sound changes is offered by 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 models in Greenberg (1978) and Cathcart (2015), however, do 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, Greenberg's (1978) and Cathcart's (2015) models fail to discriminate alternations from static phonotactic restrictions. Cathcart's (2015) model is also computationally too demanding to yield applicable results. The model in Bell (1971), on the other hand, is not elaborate enough to provide applicable results. Finally, the model of automated reconstruction in Bouchard-Côté et al. (2013) estimates probabilities of individual sound changes, but does not deal with combinations of sound changes. Other quantitative approaches to sound change (e.g. Kirby and Sonderegger 2013, Hruschka et al. 2015) do not directly deal with estimating probabilities of sound changes that operate in combination, but computationally model initiation and propagation of single sound changes. I show that MSCR and the new division of naturalness facilitate the development of a quantifiable model of typology within CB and point to the novel predictions that the proposed model brings.

5.2 Historical Probabilities of Alternations

We saw that the MSCR predicts natural processes will be the most frequent, unmotivated less frequent, and unnatural the least frequent (9). MSCR, however, only predicts *categorical* relations between alternations with different degrees of naturalness. Our goal is to propose a model that would quantify probabilities of natural, unmotivated, and unnatural processes further. We can combine MSCR with the assumption that frequencies of sound changes influence the frequencies of synchronic alternations. Crucially, the probability that an alternation arises depends on the number of sound changes it requires to arise and the probability of each individual sound change in the combination. We call such probabilities *Historical Probabilities of Alternations* (P_χ).

(10) *Historical Probabilities of Alternations* (P_χ)
The probability that an alternation arises based on the number of sound changes required (MSCR) and their respective probabilities that can be estimated from samples of sound changes.

The concept of Historical Probabilities of Alternations provides a tool for estimating the Channel Bias contribution to phonological typology for any given alternation. All its applications cannot be discussed in the scope of the present paper. This paper outlines the new proposed method for estimating Historical Probabilities of Alternations and one application of this method that offers insights to our initial discussion in Section 1: the objection raised against the Channel Bias approach that it fails to explain why some processes are unattested, despite the fact that they could arise through a combination of sound changes. More specifically, while an unnatural alternation, PND, is attested synchronically (Section 3.5), another unnatural alternation, final voicing (FV), is not (Kiparsky 2006, 2008, cf. Yu 2004, de Lacy 2002), despite several diachronic scenarios that could lead to it. Our model suggests that CB is capable of explaining this typological discrepancy as well.

To estimate P_χ for a given alternation A, we must first identify historical trajectories (T) that cause an alternation to arise. By a trajectory we mean a combination of individual sound changes that leads to a given alternation. Several trajectories may be identified for one alternation. The Historical Probability P_χ of an alternation equals the sum of probabilities of all trajectories that lead to this alternation.

(11)

$$P_\chi(A) = P(T_1 \cup T_2 \cup T_3 \cup \ldots \cup T_n)$$

I propose that the historical probability for each trajectory $P_\chi(T_x)$ is a joint probability of all sound changes (S) required for a trajectory to arise (e.g. one sound change in case of natural alternations, at least three in case of unnatural alternations, according to MSCR), divided by $n!$ (where n is the number of sound changes in the trajectory) if a specific ordering of sound changes in combination is required for the alternation to arise.

(12)

$$P_\chi(T_x) = \frac{P(S_1 \cap S_2 \cap S_3 \cap \ldots \cap S_n)}{n!}$$

I further propose that the probability of each individual single sound change $P_\chi(S_y)$ can be estimated from samples of sound changes (i.e. representative surveys of sound changes) based on the number of observed languages with a sound change S_y and the number of surveyed languages,[29]

(13)

$$P_\chi(S_y) = \frac{\text{number of languages with sound change } S_y}{\text{number of languages surveyed.}}$$

There are a few crucial assumptions that the new proposed model has to make. In order to estimate $P_\chi(T_x)$ by estimating joint probabilities of each individual sound change for alternations that require more than a single sound change, we have to assume that sound changes that operate in combination are independent events. Under this assumption, we estimate the Historical Probability of each trajectory by estimating the product of individual probabilities of sound changes (according to (13)), divided by $n!$,

29. One of the advantages of the new model that assumes sound change is a change in a single feature value and estimates probabilities of each individual sound changes is that it can model changes that involve multiple intermediate stages. It has been noted that once the sound change [k] > [kʲ] / __[+front] occurs, the likelihood of further development to [c], [cç] and [ʧ] 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 [c], [cç], and [ʧ]. Because [kʲ] > [c], [c] > [cç], and [cç] > [ʧ] have comparatively very high probabilities, the development to [ʧ] is high once [k] > [kʲ] / __[+front] occurs.

(14)

$$P_\chi(T_x) = \frac{P(S_1) \cdot P(S_2) \cdot P(S_3) \cdot \ldots \cdot P(S_n)}{n!}.$$

The independence of sound changes that operate in combination is not problematic:[30] since there is no reason to believe that operation of one sound change influences the operation of the second sound change as long as the first does not crucially alter the phonemic inventory of the language in question. This brings us to the more problematic assumption that sound changes are independent of the general phonemic inventory of a given language (cf. Wedel 2012). For example, we assume devoicing of stops is equally likely in a language with three vocalic phonemes than it is in a language with ten vocalic phonemes. More generally, for practical purposes we can assume that phonemic inventories do not crucially influence probabilities of sound changes, as long as a property of the phonemic inventory in question is not immediately related to the sound change itself, i.e. is not the target or the context of that sound change. Properties of phonemic inventories, can of course, influence probabilities of sound changes when they concern the target or the context of the sound change in question. At least some of this immediate dependency between a sound change and a phonemic inventory, however, is captured by the fact that when estimating Historical Probabilities we always evaluate sound change given a target, a result, and a context. For example, a Blurring Process that involves less frequent segments will be correctly predicted to be less frequent since sound changes that target or result in rare segments will be less frequently represented in our samples, provided of course that the samples are representative.

The independence of sound change from the general phonemic inventory (of course, when phonetic environment is factored in) is strongest with consonantal changes; vocalic changes can be much more dependent on vocalic inventory, due primarily to the effects described by the Theory of Adaptive Dispersion (Liljencrants and Lindblom 1972, Lindblom 1990). While our model currently assumes independence of sound change and phonemic environment for practical reasons and because we are interested in such consonantal changes that are unlikely to be influenced by phonemic environments, this assumption is not inherently necessary in our model. When more comprehensive typologies of sound change are available, we can estimate sound change probabilities with respect to properties of the phonemic inventories on which they operate, which means that the independence assumption will not be necessary anymore.

Finally, sound changes are influenced by many internal linguistic as well as external factors. Functional load, phoneme/word frequency, and sociolinguistic factors, for example, have been identified as influencing probabilities of sound changes (Wedel 2012, Wedel et al. 2013, Hay et al. 2015, Bybee 2002, Labov 1994). Moreover, language contact can influence the frequency of sound change. Note that while the concept of *Sprachbund* is well-established for syntactic, morphological, or even phonological features (Campbell 2006), it does not seem that some types of sound change are more common in some areas than in others (once of course phonemic inventories are factored in).[31] In any case, our proposal does not specifically model functional load, sociolinguistic factors, individual phoneme frequencies, or phonemic inventories. For practical purposes, we can disregard these influences and assume that they are already reflected in representative samples of sound changes based on which we estimate probabilities of each individual sound change.

The model also makes no predictions on how the sound change is initiated or propagated or what the driving forces behind sound change initiation and propagation are (for modeling of sound change initiation and propagation, see Kirby and Sonderegger 2013, Stadler et al. 2016; for an

30. The same assumption is made, for example, in Greenberg (1978) for the process-state model.

31. More research is needed on the question of whether some types of sound changes are more frequent in language areas.

attempt to quantify phonetic precursors, see Moreton 2008; for a discussion, see Yu 2011). We treat sound change as a completed event that changes the value of one feature ϕ (or a feature matrix, see Section 2.2) in a language L and, regardless of whether it proceeds through lexical diffusion or regular Neogrammarian operation, its end-result ideally operates categorically on all of its native lexicon. We estimate its probability based on the observed frequency of occurrence in a sample. If the sample is representative, the final results of various influences (mechanisms of sound change and phonetic precursors) that affect the frequency of individual sound changes are reflected in the sample itself. Historical Probabilities also disregard the temporal dimension: we do not estimate what the probability of a combination of completed sound changes is given a timeframe and a language L, but only the probability of a combination, given a language L, which is limited by the timeframe that equals the mean of timeframes of languages in the survey.

In sum, if L is a language (similar to other languages in the sample), the Historical Probabilities of Alternations, as defined in (10), (11), (12), (13), and (14) tell us the probability that L (disregarding its phonemic inventory, the functional load of each phoneme, its contact situation, and other external factors) will feature an alternation A (via trajectories T), given that T requires n number of sound changes S and that each sound change S has a certain probability of occurrence that is estimated from a sample of sound changes. To the author's knowledge, this is the most accurate estimation of Historical Probabilities currently possible, especially given available typological surveys of sound changes.

5.3 Estimation

I propose a new method of estimating Historical Probabilities of Alternations that I call *Bootstrapping Sound Changes*. BSC involves estimating the joint probabilities of n sound changes in a trajectory T_x according to the formula in (12) by a statistical technique called *bootstrapping* (that estimates the "sampling distribution of some prespecified random variable [...] on the basis of observed data" by resampling with replacement, see Efron 1979). Probabilities of individual sound changes in T_x are estimated from a sample of successes (languages in the sample with a sound change S_y) and failures (languages in the sample without a sound change S_y), according to (13) above.

The method of estimating Historical Probabilities of Alternations (P_χ) by BSC introduces a number of further predictions and offers a device for quantifying the influence of CB on typology. In the interest of space, we only illustrate one such application: we show that BSC predicts P_χ of PND to be significantly smaller than of FV, which suggests Channel Bias is able to predict that some processes, especially unnatural ones, are very rare and others unattested, thus dismissing one of the major objections against CB raised in the literature. Further implications of estimating Historical Probabilities of Alternations by BSC are beyond the scope of this work and will be developed elsewhere (see Author 1).

The sample of sound changes used for estimating P_χ(PND) by BSC is the database of consonantal sound changes in Kümmel (2007) that surveys approximately 200 languages. We have already identified the three sound changes required for PND to arise in (7), according to the Blurring Process. We disregard other trajectories involving more than three sound changes that lead to PND since their Historical Probabilities are much smaller: the higher the number of sound changes required, the smaller the Historical Probability. In approximately[32] 56 languages, fricativization of voiced stops occurs for at least two places of articulation in the post-vocalic environment.[33] In approximately 11

32. Counts are based on languages listed for every sound change in Kümmel (2007).

33. Fricativization in post-vocalic position that is not necessarily specifically limited to non-post-nasal position is counted as qualifying for the Blurring Cycle that leads to PND for two reasons. First, a system in which [±voice] would contrast intervocalically, but would neutralize to [−voice] post-nasally (and initially), would count as PND — initial devoicing would be analyzed as a separate (well-motivated) process. Second, it is not always clear from the

languages, unconditioned devoicing of at least two places of articulation has been reported.[34] Finally, in approximately 37 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 also count as PND all cases in which a full alternation of voiced∼voiceless stops only holds for one or two places of articulation.

The one scenario in Kiparsky (2006) that would result in final voicing (FV) as a synchronic alternation and involves less than four sound changes is Scenario 1 that posits a language with simple and geminate stops.[35] First, a sound change operates that simplifies geminates word-finally. Next, simple stops get voiced in the post-vocalic position. Finally, a third sound change operates that simplifies all geminates (including the inter-vocalic ones). This hypothetical development would fall under the Blurring Cycle with only one difference: the first sound change that causes complementary distribution does not operate on B in environment −X, but on C in environment X (the other two sound changes are identical to the Blurring Cycle in (6)). Schematically, Scenario 1 in Kiparsky (2006) would be represented as (i) C > B / X, (ii) B > A, (iii) C > B (a "modified" Blurring Cycle). The three hypothetical sound changes would result in a synchronic alternation: word-final voicing, i.e., a system of underlying voiced and voiceless stops, which merge to voiced stops word-finally. In Kümmel (2007), word-final geminate simplification is reported in approximately 5 languages, post-vocalic voicing is reported in approximately 45 languages, and unconditioned degemination in approximately 28 languages.

Estimates of P_χ for PND and FV were bootstrapped using the *boot* package (Canty and Ripley 2016, Davison and Hinkley 1997) in R (R Core Team 2016). The probability of each sound change is estimated from the number of successes and number of failures, according to (13) above. The counts of successes and failures (languages with the sound changes needed for PND and FV to arise, outlined in the paragraph above) were obtained from the sample of approximately 200 languages (in Kümmel 2007). Joint probabilities for the three sound changes in PND and FV were estimated (according to the formula in (14)) by bootstrapping with 10,000 bootstrap replicates. The BSC yields the following 95% adjusted bootstrap percentile (BC_a) intervals for P_χ(PND) and P_χ(FV).

(15) *Bootstrapped Historical Probabilities*

$$P_\chi(\text{PND}) = \frac{\text{P(D>Z/V)}\cdot\text{P(D>T)}\cdot\text{P(D>Z)}}{3!} = \frac{\frac{56}{200}\cdot\frac{11}{200}\cdot\frac{37}{200}}{6} = 0.05\%, [\mathbf{0.02\%}, \mathbf{0.11\%}]$$

$$P_\chi(\text{FV}) = \frac{\text{P(TT>T/\_\#)}\cdot\text{P(T>D/V\_)}\cdot\text{P(TT>T)}}{3!} = \frac{\frac{5}{200}\cdot\frac{45}{200}\cdot\frac{28}{200}}{6} = 0.01\%, [\mathbf{0.004\%}, \mathbf{0.04\%}]$$

BSC correctly predicts that both unnatural alternations, PND and final voicing will be very rare or non-existent. The bootstrapping technique further allows us to estimate and perform inferential statistics on the difference between the Historical Probabilities of the two alternations, PND and final voicing. The 95% BC_a confidence interval for the difference P_χ(PND) − P_χ(FV) is [0.01%, 0.09%]. Because 95% BC_a CIs falls above zero, we can conclude that P_χ(PND) is significantly larger than P_χ(FV) (at $\alpha = 0.05$). In other words, the Historical Probability of PND is significantly higher than the Historical Probability of FV. This agrees with the typology: PND is attested once in the sample in Kümmel (2007), reported in twelve more cases elsewhere, and develops to a productive synchronic alternation in at least Tswana and Shekgalagari (for other cases, see the discussion in Section 3.5), whereas FV is not attested in any of the known languages, with the only possible exception being Lezgian (Yu 2004, cf. Kiparsky 2006), where the alleged final voicing is limited in scope and the

survey in Kümmel (2007) whether post-vocalic position in fact implies non-post-nasal position.

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

35. Scenario 2 also includes three sound changes, but the last sound change (apocope after a single consonant) is never attested in the UniDia database (Hamed and Flavier 2009) of sound changes (Kümmel's 2007 survey does not include vocalic changes, which is why we use the UniDia database that surveys 10,349 sound changes from 302 languages). Because the last sound change is never attested in our surveys, we exclude Scenario 2 from the estimation of P_χ(FV).

neutralization is not phonetically complete.

This case study shows that CB is capable of deriving typology, even for those examples that have traditionally been used against it. While MSCR predicts the typology categorically for processes with different degrees of naturalness, the BSC estimation of Historical Probabilities probabilistically predicts that there are differences even between unnatural processes and, moreover, that some processes such as FV might not be attested precisely because their Historical Probabilities are low enough that they will never surface in attested languages.

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 is not only in Tswana and Shekgalagari (Hyman 2001), but in all thirteen cases 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 diachronic 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. I introduced the notion of Historical Probabilities of Alternations that builds on the MSCR and extends it to include probabilities of individual sound changes. I demonstrated that we can thus estimate the Channel Bias contribution to phonological typology for any given alternation. Finally, I proposed a method for estimating Historical Probabilities that I label Bootstrapping Sound Changes and outlined a subset of its applications. I argue that with the proposed model, CB is, contrary to the objections against it, capable of explaining why some processes are very rare (such as PND) and others non-existent (such as final voicing).

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 lays a groundwork for understanding the CB part of the typology: the probability that a language will feature a certain process or alternation crucially depends on the number of sound changes required for that alternation to arise (MSCR) and the probabilities of respective sound changes. The quantified CB model of typology proposed in this paper provides a crucial step in tackling one of the biggest tasks in phonology outlined in Section 1: 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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