Historical Probabilities of Alternations

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Introduction

- **Phonological typology** — contentious
- Two approaches: (Moreton 2008)
  - Analytic bias
  - Channel bias

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- Two approaches: (Moreton 2008)
  - Analytic bias
  - Channel bias
- Empirical evidence in favor of both hypotheses exists
  - Processes that are typologically rare have been shown to be underlearned/require more input data to be learnt
  - Processes that are the result of phonologized phonetically motivated sound changes are also typologically frequent
- Many acknowledge both AB and CB (Moreton 2008)

Questions

- Problems with typology within CB
- Unattestedness of unnatural alternations has been an argument in favor of the ANALYTIC BIAS approach to typology (Kiparsky 2006)
- Kiparsky (2006, 2008) lists several diachronic scenarios — combinations of sound changes — that would yield final voicing, yet FV is never attested
- Against CHANNEL BIAS: CB wrongly predicts the typology
- Numerous diachronic scenarios can yield unnatural alternations; yet they are not attested

Previous research

- Typology under CB not satisfactory: Rare alternations are infrequent because they are produced by rare sound changes (Blevins 2004)
- Moreton (2008) attempts to quantify phonetic precursors, but phonetic precursors and sound change do not always align
- The most elaborate attempt thus far in Cathcart (2015) lacks MSCR, fails to discriminate alternations from static phonotactic restrictions, and is computationally too demanding and the model
- Fails to yield directly implementable results

Aims

- Propose a quantitative model of typology within Channel Bias

Historical Probabilities

- A new typology within CB

Historical Probabilities of Alternations ($P_\chi(A)$)

The probability that an alternation arises based on the number of sound changes required (MSCR) and their respective probabilities/rates.

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Outline

1 Introduction

2 Number of sound changes

3 Probabilities

4 Examples

5 Discussion and conclusion

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On naturalness

- **Natural**: universal phonetic tendencies
- **Unmotivated**: lack phonetic motivations, but not against UPT
- **Unnatural**: operating in the opposite direction from UPT

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

Naturalness

- **Unnatural**: operating against universal phonetic tendency (UPT)
- Examples: post-nasal devoicing (attested), intervocalic devoicing, final voicing (unnatested, cf. Yu 2004)

natural	**unnatural**
T > D / N__	D > T / N__
T > D / V__V	D > T / V__V
D > T / __#	T > D / __#

Models

- A > B / X = UPT
- How do we get B > A / X?

Post-Nasal Devoicing

- Unnatural alternations and phonotactic restrictions

Post-Nasal Devoicing

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  - Yaghnobi (Xromov 1972)
  - Tswana and Shekgalagari (Solé *et al.* 2010)
  - Makhuwa and Bube (Janson 1991/1992, Janssens 1993)
  - Konyagi (Merrill 2015)
  - Sicilian and Calabrian (south Italian dial.) (Rohlfs 1949)
  - Murik, Buginese, and Land Dayak (Austronesian) (Blust 2009)

  - Intervocalic devoicing: Berawan and Kiput (Blust 2005, 2013)
  - Voicing after voiceless obstruents in Tarma Quechua (Adelaar 1977, Beguš and Nazarov 2017)
- Hypercorrection

Blurring Process

- Blurring Process
- A historical model for explaining unnatural phenomena
  (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

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Blurring Cycle

$$\frac{\begin{array}{l} B > C \ / \ -X \\ B > A \\ C > B \end{array}}{B > A \ / \ X}$$

Blurring Process

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Blurring Cycle

B > C / −X
B > A
C > B

B > A / X

Blurring Chain

B > C / X
C > D
D > A

B > A / X

Blurring Process

- Post-nasal devoicing (Dickens 1984), Hyman (2001)
- In all twelve cases in which PND is reported as a sound change or synchronic alternation, it arises though a combination of 3 sound changes
-

Blurring Cycle		**Example**		
		Avestan	**band**	**dasa**
D > Z / [−nas]	d > ð/[−nas]__	Sogdian	βand	ðasa
D > T	d > t	Yaghnobi	vant	*ðasa
Z > D	ð > d	Yaghnobi	vant	das

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Post-Nasal Devoicing

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Minimal number of sound changes

- "Telescoping", concatenation of sound changes explains unmotivated processes (Wang 1968, Hyman 2001)
- For UNNATURAL processes, we need a special scenario ("Blurring Process")
- The primary diachronic device for explaining unnaturalness
  HYPERCORRECTION (Ohala 1981)
- BLURRING PROCESS a new diachronic device for explaining unnatural alternations

Minimal number of sound changes

- BLURRING PROCESS also allows us to establish the minimal number of sound changes required fro unnatural processes to arise
- Unnatural alternations always require three operating sound changes

Minimal number of sound changes

- Sound change: change in a single feature value (Picard 1994)
- B > A / X

Minimal number of sound changes

- Sound change: change in a single feature value (Picard 1994)
- B > A / X
- B > A / X by definition impossible

Minimal number of sound changes

- B > C / X
  C > A

Minimal number of sound changes

- B > C / X
  C > A
- C ∼ A:

Minimal number of sound changes

- B > C / X
  C > A
- C ∼ A: ϕ_1 (A ∼ B)

Minimal number of sound changes

- B $>$ C / X
  C $>$ A
- C $\sim$ A: ϕ_1 (A $\sim$ B) and ϕ_2 (B $\sim$ C)

Minimal number of sound changes

- B > C / X
  C > A
- C ∼ A: ϕ_1 (A ∼ B) and ϕ_2 (B ∼ C), $\phi_1 \neq \phi_2$

Minimal number of sound changes

- B > C / X
  C > A
- C ∼ A: ϕ_1 (A ∼ B) and ϕ_2 (B ∼ C), $\phi_1 \neq \phi_2$
- Two sound change? Let B change to C, where B and C differ in one feature, but, to be sure, a different feature from the one that separates A and B. From this point, it is impossible for an unnatural sound change to arise without a third sound change: C cannot develop directly to A, since the two segments differ in two features: feature F_1, which distinguishes A and B, and feature F_2, which distinguishes B and C.
- By definition, two sound changes are required in order to change two features

Minimal number of sound changes

- At least three sound changes for unnatural alternations

Minimal Sound Change Requirement (MSCR)

Natural processes arise through a single sound change. Minimally two sound changes have to operate in combination for an unmotivated process to arise. Minimally three sound changes have to operate in combination for an unnatural process to arise.

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

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Model

- The model can be quantified
- Bootstrapping Sound Changes

Poisson Stochastic Process

- Poisson Stochastic Process (cf. Fussell 1976 and Eid 2011):

(1)

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

where

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

Probability of a sound change

- We can disregard temporal dimension and model sound change probabilities from a given sample as a binary outcome model if we stay within the sample

$$P_\chi(S_1) = \frac{\text{number of languages with sound change } \mathrm{S}_1}{\text{number of languages surveyed}}$$

Probability of a sound change

- **Historical probabilities**: Bootstrapping Sound Changes (BSC)
- Estimates of P_χ not a trivial task: we propose to estimate sound change probabilities using bootstrapping (Efron 1979): a sample of successes (languages in the sample with a sound change S_1) and failures (languages in the sample without S_1)
- Probability of a sound change S_1

$$P_\chi(S_1) = \frac{\text{number of languages with sound change } S_1}{\text{number of languages surveyed}}$$

Historical Probabilities

- If an alternation A_x requires $n > 1$ sound changes to arise ($n \geq 2$ for unmotivated, $n \geq 3$ for unnatural)
- Joint probabilities of n number of sound changes

$$P(A_x) = \frac{P(S_1)P(S_2) * \ldots * P(S_n)}{n!}$$

- Binomial sample: P_χ is bootstrapped from a product of probabilities based on the number of successes and failures (divided by $n!$ to account for the ordering of sound changes)

Assumptions

- Assumptions: sample is representative and well-balanced
- Occurrence of sound change properly counted: occurrence in the proto-language vs. daughter languages
- Independence of sound change
  - S_1 and S_2 independent
  - $P(S_1|\text{phonemic inventory})$, **but** some of (in)dependence captured by context
  - In the current state of the field, we lack sufficiently accurate estimates of sound change probabilities to be able to estimate their conditional probabilities
  - For practical purposes, we can disregard the phonemic inventory and generalize $P(S_1/\_\_X)$
  - If two sound changes occur in two related languages, they are considered independent

Applications

- What can we do with historical probabilities?
  1. Compare two alternations and perform inferential statistics: is historical probability of alternation X significantly more frequent than Y?
  2. Predict attestedness/unattestedness in a given sample
  3. Go below "zero probabilities"
  4. Identify historically equiprobable processes
  5. Use P_χ to encode historical or Channel Bias in a typological model

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PND vs. FV

- Post-nasal devoicing (PND) and final voicing (FV)
- Kümmel (2007) surveys approximately 200 languages
- Blurring cycle for PND:
  - 56 lang. fricativization of voiced stops
  - 11 languages unconditioned devoicing
  - 37 languages unconditioned occlusion
- Final voicing (FV) (from Kiparsky 2006):
- The only scenario in Kiparsky (2006) that results in *alternation* and involves less than four sound changes
  - 10 languages degemination
  - 45 languages post-vocalic voicing
  - 3 languages final degemination

Historical Probabilities

- Estimates of P_χ were bootstrapped using the boot package (Canty and Ripley 2016, Davison and Hinkley 1997) in R (R Core Team). The following 95% adjusted bootstrap percentile (BC_a) intervals were calculated for $P_\chi(PND)$ and $P_\chi(FV)$.
- *Bootstrapped historical probabilities*
  $P_\chi(PND) = [0.02\%, 0.11\%]$
  $P_\chi(FV) = [0.00\%, 0.02\%]$

Comparison of P_χ

- We can test whether FV is significantly different from PND
- $P_\chi(\text{PND}) - P_\chi(\text{FV}) = [0.02\%, 0.11\%]$

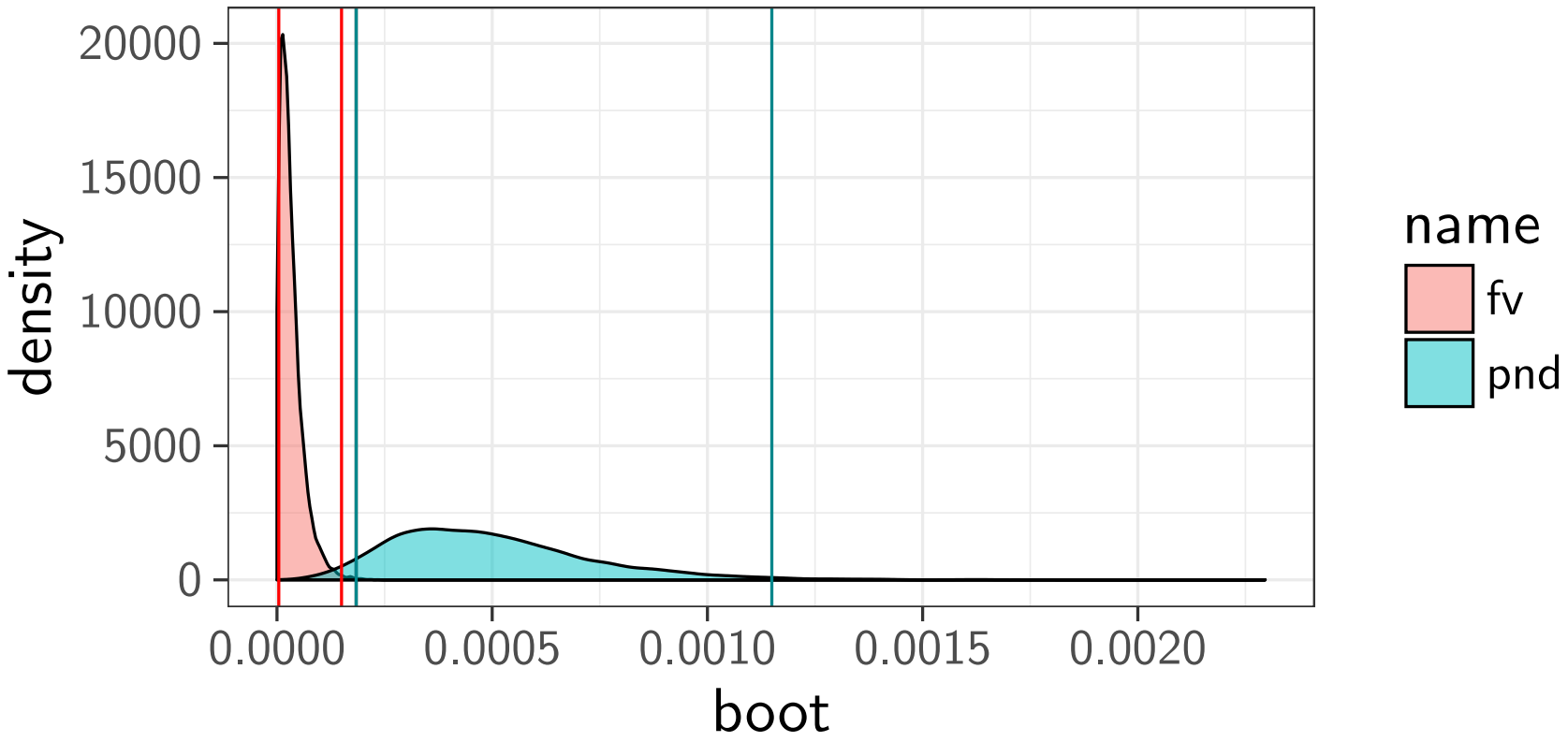
Comparison of P_χ

- We can test whether FV is significantly different from PND
- $P_\chi(\text{PND}) - P_\chi(\text{FV}) = [0.02\%, 0.11\%]$

$\rightarrow$Yes, $P_\chi(\text{PND})$ is significantly higher than $P_\chi(\text{FV})$.

- PND attested (Hyman 2001, Coetzee and Pretorius 2010), FV not (Kiparsky 2006, cf. Yu 2004)

Comparison of P_χ



Prediction of attestedness

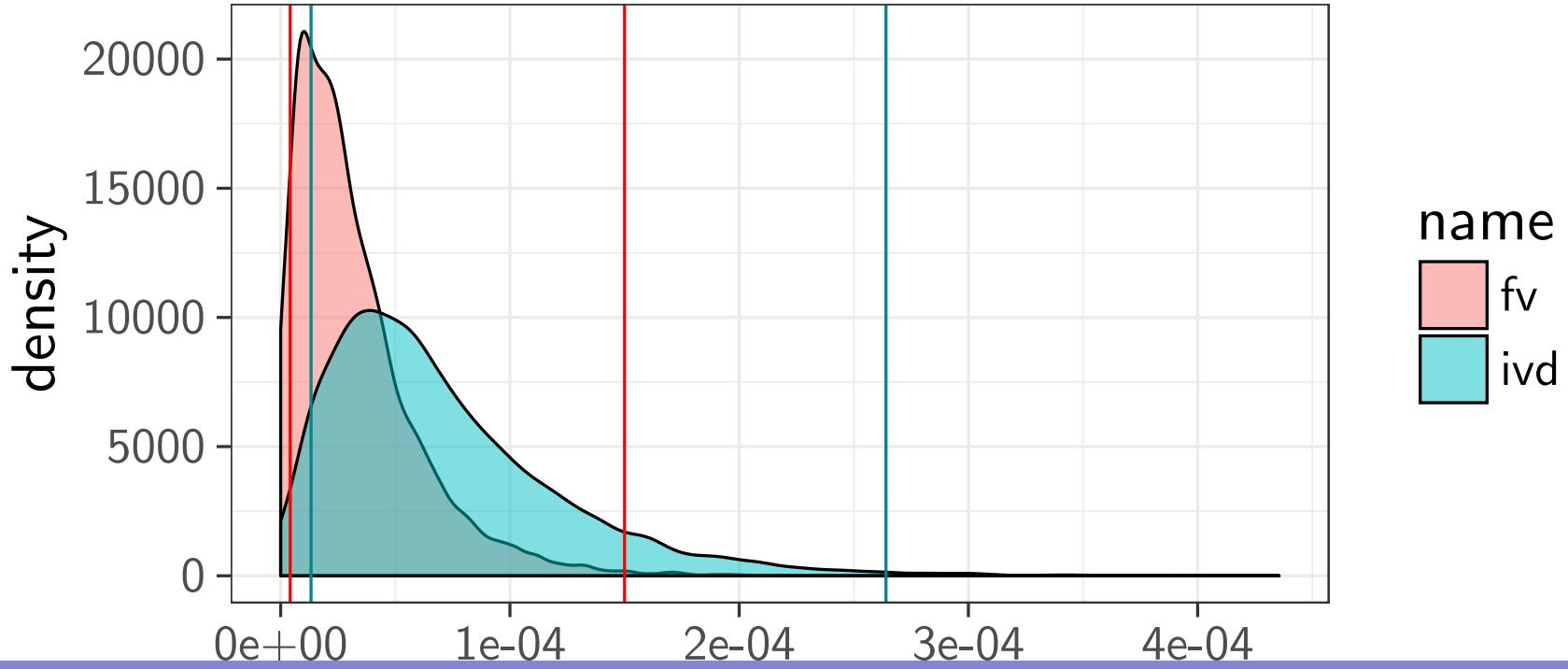
- Do we predict PND to be attested?
- Yes, difference between P_χ(PND) and P(1/200) is [-0.05%, 2.47%]
- But: P_χ(FV) and P(1/200) is [-0.003%, 2.86%]
- P_χ(FV) is not significantly smaller than probability of being attested once in the sample, but the BC_a CI is [-0.003%, 2.86%] and it is significantly different from PND

Going "below zero"

- BSC "reaches below zero"
- Can differentiate unattested processes

Going "below zero"

- FV and intervocalic devoicing both unattested (cf. Yu 2004, recently Sula in Bloyd 2017)
- According to BSC, FV is predicted to be significantly less probable than IVD, but the difference is very small [0.001%, 0.016%]



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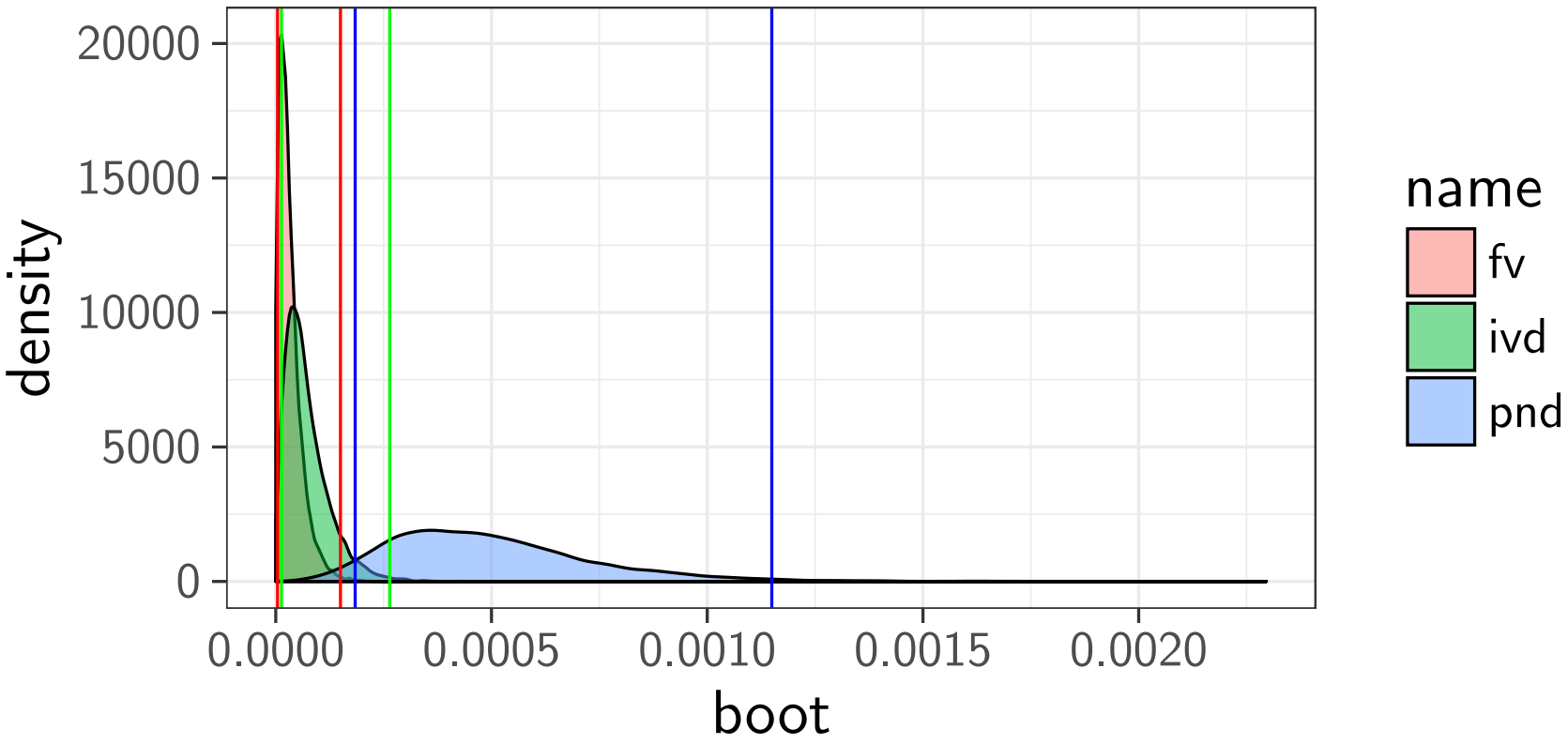

Equiprobable processes

- Equiprobable processes
- ANALYTIC BIAS approach (AB):biases in learning affect the typology
  CHANNEL BIAS approach (CB) assumes phonetic precursors and transmission of language affect the typology
  - Empirical evidence in favor of both
  - Processes that are more difficult to learn are also typologically more rare
  - Processes that are the result of phonologized phonetically motivated sound changes are also typologically frequent
- **Identify equiprobable alternations** for experimental testing

Equiprobable processes

- Test learnability of processes that are equiprobable historically.
- If an alternation A_1 is typologically more common than A_2, but $P_\chi(A_1)$ and $P_\chi(A_2)$ are not significantly different, we can test the learnability of A_1 and A_2. If biases in learnability are confirmed, we would get a direct confirmation of AB without the "duplication" problem outlined above

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Discussion

- A new quantitative model of typology within CB
  - Historical probability of FV is small enough for the process not to be attested in a given sample, historical probability PND is significantly higher
  - Based on BSC, Channel Bias would thus correctly predict the observed typology, even in the case that has traditionally been used against CB.
- Comparison of historical probabilities of alternations with inference
- Prediction of attestedness
- Quantification "below zero"
- Identification of historically equiprobable alternations

A formal model of typology

- Many acknowledge both AB and CB (Moreton 2008)
- *But*: very few attempts have been made to model AB and CB together or try to disambiguate the two
- A typological model that models both AB and CB with MaxEnt

A formal model of typology

- σ^2 in the prior (Wilson 2006) in MaxEnt models encodes some processes are underlearned
- Unnatural processes often equally learnable (Seidl et al. 2007, Do et al. 2016)
- Substantive bias?
- w_χ (CB) and σ^2 (AB)

$$\Delta w_\chi = -\log\left(\frac{P_\chi}{1-P_\chi}\right)$$

- Crucially, when modeling acquisition, speakers have no access to historical weights or probabilities
- When modeling typology, both AB and CB contribute to the typology

A formal model of typology

- A model with historical weights performs better: it generates all attested patterns, but encodes that some are rare (due to historical probabilities and learnability)
- Example: No difference in learnability experiments between PND and PNV (Do et al. 2016)
- σ^2 of PND and PNV should be equal

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A formal model of typology

- A model with historical weights performs better: it generates all attested patterns, but encodes that some are rare (due to historical probabilities and learnability)
- Example: No difference in learnability experiments between PND and PNV (Do et al. 2016)
- σ^2 of PND and PNV should be equal (also under symmetric P-map approach)
- $\Delta w_\chi(\text{PND}) = 7.66$; $\Delta w_\chi(\text{PNV}) = 1.36$
- Typologically, clear difference
  - 15 languages of 197 surveyed feature PNV as alternation (Locke 1983)
  - Only one case of PND (Coetzee and Pretorius 2010) in all surveys available to me

A formal model of typology

/NT/	IDENT-IO $w_\chi = 10$	*NT $w_\chi = 8.64$	H_χ	P_χ	Typol.
a. [NT]		-1	-10	.795	.924
b. [ND]	-1		-8.64	.205	.076

/ND/	IDENT-IO $w_\chi = 10$	*ND $w_\chi = 2.34$	H_χ	P_χ	Typol.
a. [ND]	-1		-10	.99953	$\approx$ .9975
b. [NT]		-1	-2.34	.00047	$\approx$ .0025

Disambiguation

- The model provides grounds for disambiguation
- We now *can* and *should* calculate the CB contribution (based on BSC) and AB contribution (based on learnability experiments)
- Overlap: typologically rare processes more difficult to learn *and* not the result of common sound change
- AB might influence CB and historical probabilities if it is assumed that sound change is primarily influenced by learning
- This "duplication" problem is avoided in the case of unnatural processes: we argue that a **combination of at least three sound changes** is required for any unnatural alternation (MSCR)
- The fact that sound changes need to operate in combination means that CB (transmission) has to independently influence historical probabilities of unnatural processes

Future directions

- Phonotactics — MSCR limited to alternations, but unnatural phonotactics result from "blurring process" as well

  (Beguš and Nazarov 2017)
- Further predictions: unmotivated alternations involving multiple features predicted to be less frequent compared to those requiring less features
- Larger, balanced samples
- Artificial grammar learning experiments

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Thank you!

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