Chapter 5

Phonologically conditioned divergence and convergence

In this chapter, I will further support the argument that neogrammarian phonetic change targets *phonological* categories through more detailed analyses of /ay/, and /ey/ raising, /aw/, /ow/ and /uw/ fronting, and /æː/ and /ɔː/ lowering. First, I will show differential participation in phonetic change for variants within vowel categories which is best explained in terms of phonological allophony, rather than phonetic predisposition. Second, I will show convergent participation in phonetic change across multiple categories, which can be best explained as phonetic change targeting a phonological feature which defines a phonological natural class.

5.1 Phonologically divergent behavior within categories

5.1.1 /ay/ Raising and Opacity.

I didn't include pre-voiceless /ay/ raising in the rate of change analysis because even if I found that pre-voiceless /ay/ had a divergent rate of change from other /ay/ (which it undoubtedly would), it would still be ambiguous between error accumulation, or increasing coarticulation, and phonological differentiation. Unlike /ow/ and /uw/, where most contexts were undergoing the change with some contextually restricted variants exemted, for /ay/ raising, the change takes place only for contextually restricted variants. If this contextual effect were due to phonological selection, it would be indistinguishable from a gradually increasing coarticulation.

Fortunately, though, voicing neutralization of /t, d/ by flapping occurs in Philadelphia, and

provides the ideal environment for distinguishing between phonetic and phonological condition-ing of /ay/ raising. In contemporary Philadelphian English, /ay/ raising applies opaquely with respect to flapping, producing the same dilemma identified by Joos (1942) in Canada.

Table 5.1 provides an ordered rules analysis[1] of /ay/ raising in contemporary Philadelphian English.

	writer	*rider*
Input	ɹaitɚ	ɹaitɚ
RAISING	ɹʌitɚ	–
FLAPPING	ɹʌiɾɚ	ɹaiɾɚ
Output	ɹʌiɾɚ	ɹaiɾɚ

Table 5.1: Opaque interaction between /ay/ raising and flapping.

This opacity represents an important end point for the process of /ay/ raising. If we were to assume that /ay/ raising began as a coarticulatory process, then there *must* be a point in its history when it became reanalyzed as a phonological process conditioned on the underlying voicing of the following segment. And, as the rate of change analysis in the previous chapter indicated, this point of reanalysis must happen within the time period covered by the PNC, since the the onset of the change in the first place appears to be contained within the PNC.

Foundational Facts

There are some more foundational facts about /ay/ raising that should be established before delv-ing into its interaction with flapping. Specifically, I should establish how pre-voiceless /ay/ raising is conditioned in Philadelphia in contrast with previous descriptions in other dialects. Dailey-O'Cain (1997), for instance, describes /ay/ raising as applying before /r/ as well as pre-voiceless, and Idsardi (2007) reports his intuition that it can apply across word boundaries.

Figure 5.1 plots /ay/ height over date of birth as conditioned by manner and voicing of the following segment. It is clear from this figure that it is only voicing which conditions raising. While there is some considerable contextual variation in height in the following voiced contexts, it appears to be less extreme within the following voiceless context.

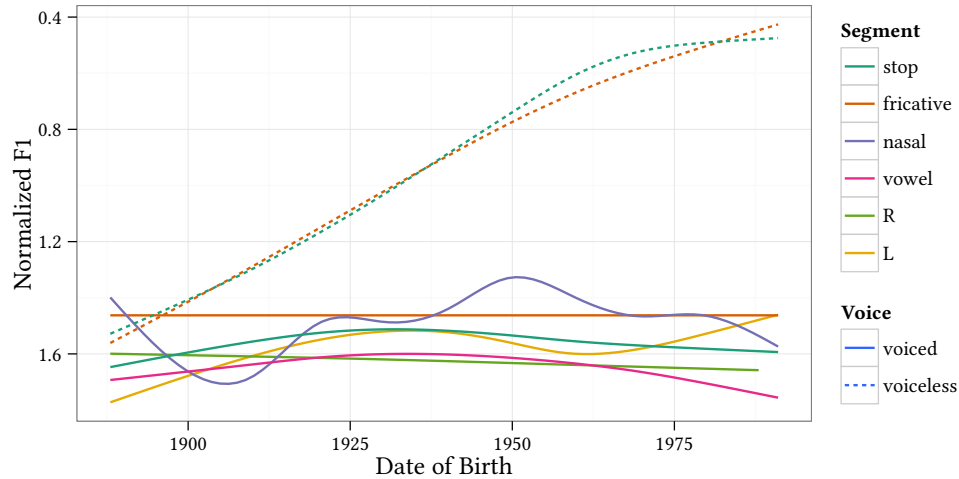[1]Intended merely for expository purposes.

Figure 5.1: The effect of following voice and manner on /ay/ height.

Most importantly, there is no tendency for /ay/ to raise when followed by /r/, distinguishing the phonological system of Philadelphia from the Northern dialects which do raise /ay/ before /r/, as reported by Dailey-O'Cain (1997). This difference is suggestive of the fact that pre-voiceless /ay/ raising is an endogenous change to Philadelphia, not a dialectal borrowing. The process of dialectal diffusion can lead to structural simplifications, but in this case there is no independent historical reason to assume that /ay/ raising diffused from Northern dialects to Philadelphia, as there was for the diffusion of the New York City short-a system to Cincinnati and New Orleans (Labov, 2007).

Next, looking at word final /ay/, there does not appear to be any conditioning of /ay/ raising by the onset of the following word. The trajectories of word final /ay/ when followed by voiced and voiceless onsets are virtually identical. Even if we take a targeted subset of word final /ay/ followed by *to* and *the*[2] there is still no evidence of /ay/ raising being conditioned across word boundaries. In contrast to the Canadian dialect from which the intuitions reported by Idsardi (2007) were drawn from, there is no evidence that pre-voiceless /ay/ raising was ever a phrase level phenomenon in Philadelphia. This in itself is already evidence for phonological conditioning of

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[2]The motivation here is to focus on prosodically weak words which are more likely to "lean" on the preceding /ay/.

/ay/ raising, since raising is sensitive to word boundaries, and word boundaries are a phonological property.
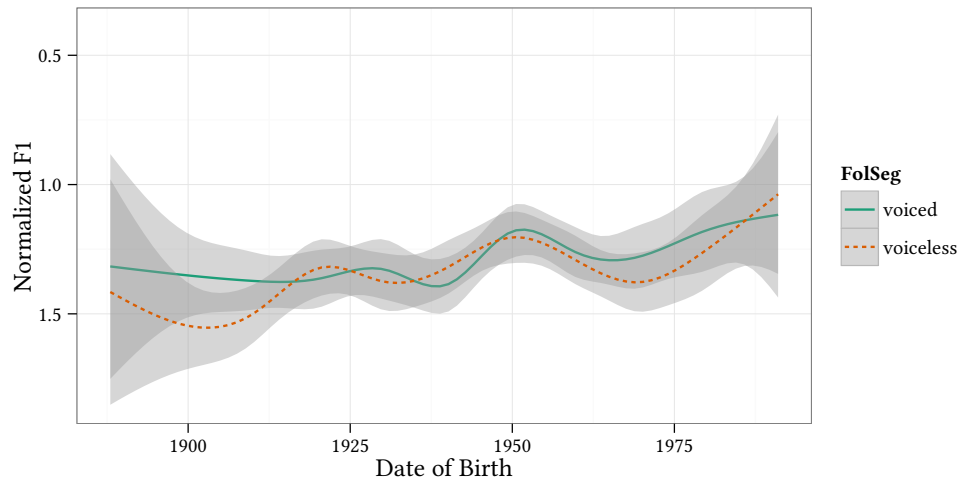

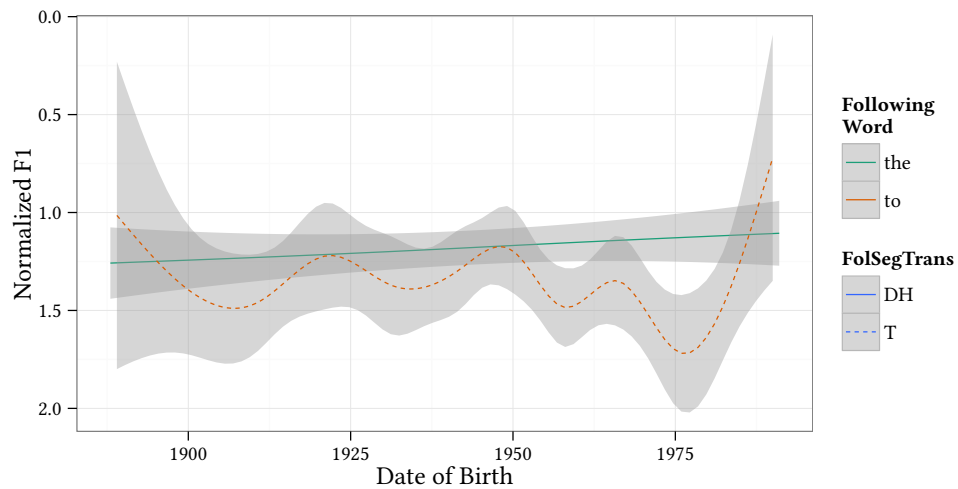Figure 5.2: Effect of following word onset on word-final /ay/.

Figure 5.3: Effect of following *to* and *the* on word-final /ay/.

Interaction with flapping

It is necessary to construct two careful subsets of the /ay/ data in order to investigate the history the interaction between /ay/ raising and /t, d/ flapping. One is a subset where /ay/ appears before

/t, d/ which are almost certainly not flapped. I will be referring to this subset as "surface" /t, d/, meaning that the underlying voicing contrast is realized on the surface. The second is a subset which appears before almost exclusively flapped /t, d/. I'll be referring to this subset as "flapped" /t, d/. I defined these subsets as follows.

(5.1) SURFACE: /ay/ followed by /t, d/ which are then followed by a pause, labeled sp in the forced alignment transcriptions.

(5.2) FLAPPED: /ay/ followed by /t, d/ which are then followed by an unstressed vowel within the same word.

I decided to restrict the surface subset to require that the following /t, d/ be followed by a pause to avoid any ambiguities introduced by phrase level flapping, or any other phrase level processes. Occassionally, the aligner will mistake an exceptionally long /t, d/ closure as a pause, but this kind of error is still acceptable for my purposes here, since a /t, d/ closure long enough to be labeled a pause will certainly not be resulting from flapped variants of /t, d/. For the flapping subset, the onset of an unstressed syllable meets the structural description for flapping to occur. I haven't inspected these tokens to make sure they are actually flaps, but as I'll show in the duration domain, the difference between /t/ and /d/ appears to be mostly neutralized. Of course, word final /t, d/ can also flap when followed by a word with a vowel onset, but I decided that including /t, d/ in this context would include a mix of flapped and surface /t, d/, and an auditory inspection of all these tokens would be necessary.

I also defined the following exclusions from the flapping subset as defined above.

(5.3) Potential glottalizing contexts. e.g. /t/ followed by syllabic /n/, as in *frighten* [fɹʌiʔn̩]

(5.4) Exceptional raising words, as identified in Fruehwald (2008). e.g. *spider, Snyder*

A justified criticism to the second of these exclusions is that I'll have excluded exactly those cases which run counter to my hypothesis. However, examining these cases separately, it appears as if the exceptional raising in these words is a later development. In the entire PNC, there are 60 tokens of *Snyder*, 12 of *spider* and 1 of *cider*. Figure 5.4 plots the mean F1 for these words for each

speaker, and contrasts them with the height of /ay/ before flapped /t, d/ for those same speakers who contributed exceptional raising words. On average, these exceptional raising words did not appear raised until approximately 1940, about 20 to 30 years after pre-voiceless raising began in the dialect. Separating out these items as being reflective of a later development in the dialect is therefore principled. Table 5.2 displays the counts of observations in each context after taking these subsets and exclusions.
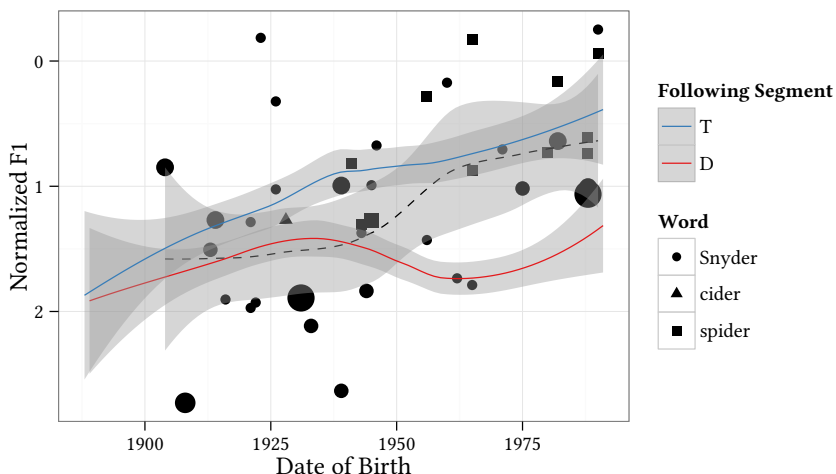

Figure 5.4: Exceptional raising words compared to /ay/ before flapped /t, d/ in all other words.

	/t/	/d/
Surface	2155	647
Flap	240	328

Table 5.2: Number of /ay/ observations in each context

Since my goal is to be able to disambiguate between phonetic and phonological conditioning of /ay/ raising, I'll first assess the phonetic pressures for /ay/ raising. Pre-voiceless vowel shortening is the most commonly appealed to phonetic precursor for pre-voiceless /ay/ raising, starting with Joos (1942) and Chambers (1973). The argument is very similar to that presented for /u/ fronting in Ohala (1981): the diphthong /ay/ involves a long gesture across articulatory space, and when the vowel is shortened before voiceless segments, this gesture must be made in a compressed amount of time. In compensation, it is argued that speakers may raise the nucleus of /ay/ to reduce the

gesture length. Moreton and Thomas (2007) make some very cogent arguments against the pre-voiceless shortening account. They point out that in dialects which monophthongize /ay/, the monophthongization is least advanced before voiceless segments, meaning that in these dialects /ay/ has the the longest articulatory gesture in the context where it is supposed to be the most difficult according to the shortening account of raising. Their alternative hypothesis is that the glide is peripheralized in pre-voiceless contexts, capturing both the coarticulatory pressure to raise the nucleus towards the glide, and the resistance to monophthongization. It's not clear that either hypothesis can account for raising /ay/ before /r/ in the Inland North, since /ay/ is both relatively long before this sonorant, and it is one of the most favorable contexts for /ay/ monophthongization. However, since /ay/ does not raise before /r/ in Philadelphia, this may be beyond the scope of relevance for the data from Philadelphia.
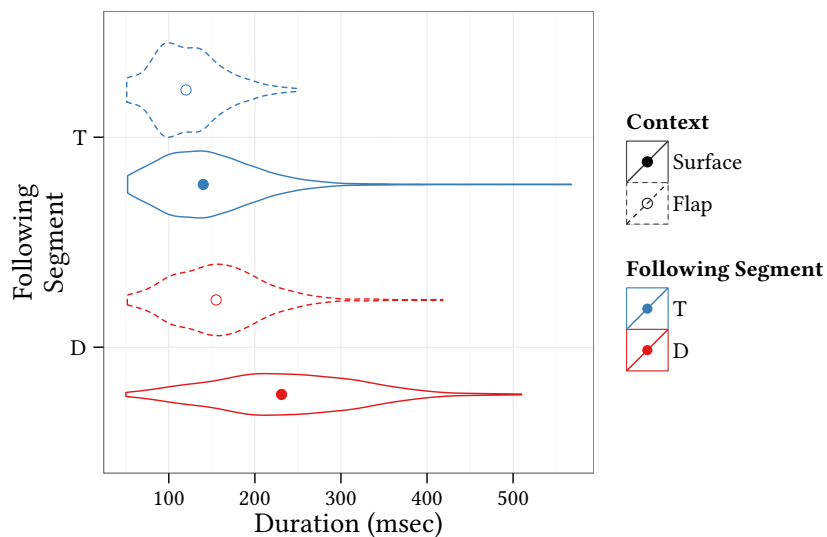

Figure 5.5: Violin plot representing the distribution of durations of /ay/ before surface and flapped /t/ and /d/.

I'll address these two hypotheses for the phonetic conditioning of /ay/ raising in turn, beginning with the pre-voiceless shortening hypothesis. Figure 5.5 is a violin plot representing the duration of /ay/ in the relevant contexts. The violin shape represents the density estimate, and the point within each violin represents the overall median. Based on the distribution in the figure, we can see that vowel duration is incompletely neutralized towards the shorter duration range before

flaps. Table 5.3 displays /ay/ contexts from shortest to longest.[3] Since the PNC data was collected for the purpose of vowel formant measurements, vowels with durations shorter than 50ms were excluded. Additionally, the force aligner only has a duration resolution of 10ms. Because the data was censored at 50ms, and because the instrument of measurement does not have fine grained enough resolution, it would be inappropriate to attempt too much statistical inference of vowel duration as a response variable. However, we can see that over all, /ay/ before flaps and /ay/ before surface /t/ form one set of distributions, and /ay/ before /d/ forms a separate distribution.

Segment	Context	Median Duration (msec)	Difference from next shortest
/t/	flapping	111	–
/t/	surface	144	34
/d/	flapping	156	11
/d/	surface	237	82

Table 5.3: Median /ay/ durations by context.

If we were to assume that /ay/ raising is phonetically conditioned, and that the relevant phonetic conditioning is duration, then we should predict that flapped /t/, surface /t/ and flapped /d/ should all participate in raising. Even though the duration difference in /ay/ before flapped /t/ and /d/ is not completely neutralized (in the PNC data by a larger margin than recently reported by Braver (2011)), the duration of /ay/ before flapped /d/ is approximately the same as before surface /t/. It is uncontroversially established that /ay/ before /t/ undergoes the raising change, and if what really matters is the phonetic properties of the pre-/t/ context, we should expect other contexts with similar properties, like before flapped /d/, to also undergo the change. The fact that /ay/ raising ultimately ends up in an opaque relationship with flapping would necessitate a later reanalysis of raising as being phonologically conditioned, which would result in a trajectory of change which would look something like Figure 5.6.

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[3]These medians were calculated in a three step process.

(i) Calculate median /ay/ duration for each word within each speaker.

(ii) From the medians in (i), calculate median /ay/ duration for each speaker in each context.

(iii) From the medians in (ii), calculate median /ay/ duration for each context.

This three step process partially mitigates the imbalanced distribution of observations across speakers and lexical items.
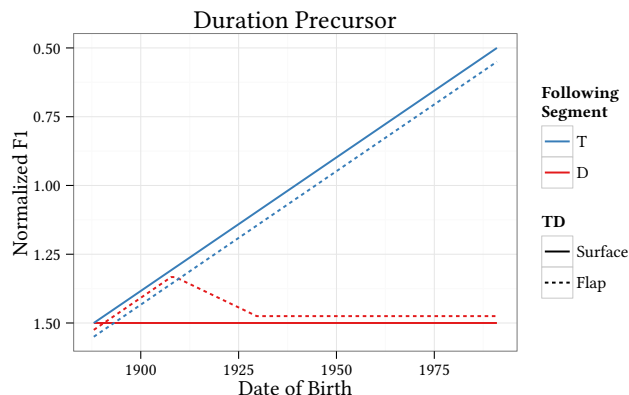
Figure 5.6: Schematic illustration of the reanalysis of /ay/ raising from being phonetically conditioned to being phonologically conditioned.

As for the glide peripheralization hypothesis, unfortunately glide measurements are not currently part of the PNC, and the results from other studies are somewhat inconclusive. Figure 5.7 plots data derived from Figures 4.1 and 4.2 of Rosenfelder (2005), a study of /ay/ and /aw/ raising in Victoria, British Columbia. The solid lines represent the average trajectories for /ay/ before all voiced and voiceless obstruents. Consistent with the glide peripheralization hypothesis, the glide targets (represented by the arrow heads) are much more peripheralized before voiceless obstruents than before voiced obstruents to a degree that is not in proportion to the the difference in height of the nucleus. The dashed lines represent trajectories of /ay/ before flapped /t/ (trajectories for /ay/ before flapped /d/ were not reported separately in Rosenfelder (2005)). The glide target for /ay/ before flapped /t/ is much more similar to the glide target of voiced obstruents than voiceless obstruents. The difference in glide targets between pre-flap /ay/ and pre-voiced /ay/ appears to be more or less in proportion to the difference in nucleus height. Kwong and Stevens (1999) did a small scale acoustic study of pre-flap /ay/, and found that there was a statistically reliable difference in glide peripherality between pre-/t/-flap and pre-/d/-flap /ay/, but they did not include nucleus measurements, so it is impossible to tell if this difference is proportional to nucleus height differences. Moreover, Kwong and Stevens (1999) do not provide any /ay/ glide measurements from surface /t, d/ contexts, so it is also not possible to tell if the glide targets

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before flaps pattern similarly across phonological categories, or if they are partially neutralized towards the pre-voiced glide targets as they appear to be in Rosenfelder (2005). Since Rosenfelder (2005) provides the relevant contrasts, the best interim assumption would be that before both /t/ and /d/ flaps, /ay/ glide targets are more similar to the targets of voiced obstruents.
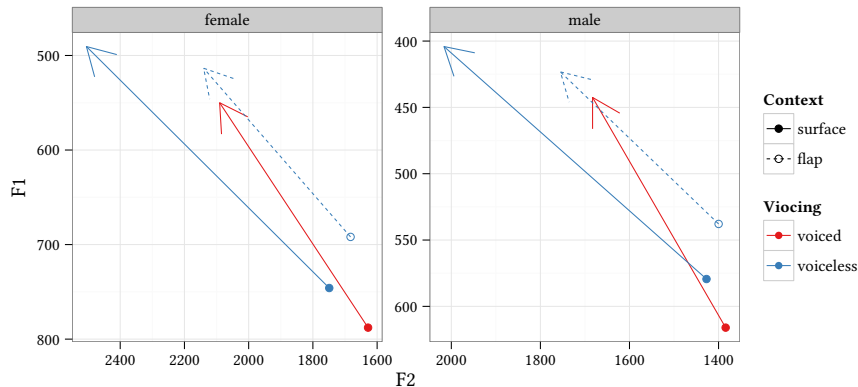

Figure 5.7: Nucleus to glide trajectories in Victoria, B.C. Derived from Rosenfelder (2005) figures 4.1 and 4.2

The glide-peripheralization hypothesis makes a very different prediction from the duration hypothesis. If voiced obstruents and both /t/ and /d/ flaps have similar glide targets, and other voiceless obstruents have peripheralized glide targets, it would predict that only surface /t/ should undergo raising. Again, the fact that /ay/ raising ultimately results in an opaque interaction with flapping means that if /ay/ raising were conditioned by glide peripheralization at first, it would eventually have to become reanalyzed as being phonologically conditioned, as illustrated in Figure 5.8.

Table 5.4 summarizes the difference between these two hypotheses in terms of which segments are predicted to undergo raising on the basis of phonetic conditioning. Under the duration precursor hypothesis, /ay/ preceding the set {surface /t/, flapped /t/, flapped /d/} should undergo raising, while /ay/ preceding {surface /d/} will not. Under the glide peripheralization precursor hypothesis, only /ay/ preceding the set {surface /t/} will undergo the change while /ay/ preceding {flapped /t/, flapped /d/, surface /d/} will not.
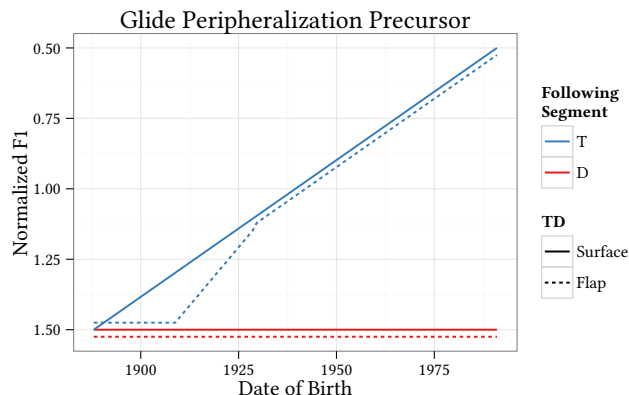
Figure 5.8: Schematic illustration of the reanalysis of /ay/ raising from being phonetically conditioned to being phonologically conditioned.

Duration Hypothesis	Raises			Low
	surface /t/	flapped /t/	flapped /d/	surface /d/
Glide Peripheralization Hypothesis	Raises		Low	

Table 5.4: Defining the undergoers and non-undergoers phonetically according to two different precursor hypotheses.

Having established the predictions of these two phonetic conditioning hypotheses, we can examine the actual data. Figure 5.9 plots cubic regression splines over speaker means for /ay/ in the contexts under discussion. The trajectories in Figure 5.9 don't match the predictions of either the duration precursor hypothesis or the glide peripheralization hypothesis. Rather, across the 20th century, the height of /ay/ appears to pattern according the underlying *phonological* voicing of the following segment, with {surface /t/, flapped /t/} patterning together, and {surface /d/, flapped /d/} patterning together.

Of course, the importance of phonological voicing to /ay/ raising is merely a qualitative impression of Figure 5.9 which will be be supported by statistical inference in the next section. The implications are that /ay/ raising has always been a phonologically conditioned process, and that this phonological process has always interacted with flapping opaquely. This would require the addition of a phonological process to the grammar at the *onset* of the phonetic change, which at
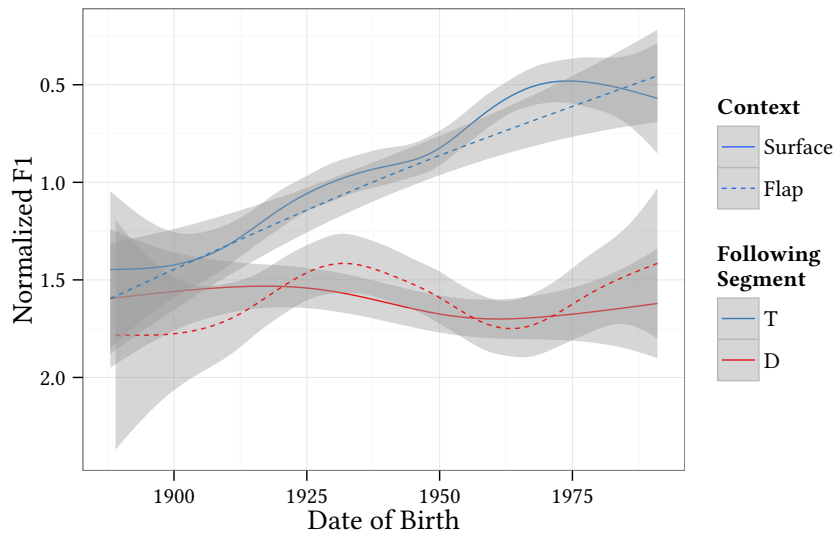
Figure 5.9: /ay/ height by date of birth and context. Cubic regression splines are fit over speaker means.

first corresponds to a small phonetic difference.

Modeling

To investigate the interaction of /ay/ raising and flapping more precisely, I constructed a hierarchical Bayesian model similar to that used in Chapter 4. The goal of this model is to determine whether there was ever a period of /ay/ raising where /ay/ allophones did not pattern according to the underlying voicing of following segment. There are at least two different ways we can try to answer this question.

(5.5)   Is there any point in time where the height of /ay/ is different between flapped and unflapped versions of the same segment?
(e.g. /ay/ could be a little bit lower before flapped /t/ than before unflapped /t/).

(5.6)   Is there any point in time when the difference in height of /ay/ between a following /t/ and /d/ is smaller when the /t/ and /d/ are flaps than when they are not flapped.

(e.g. There could be no height difference across the flaps, while there is a reliable difference between non-flapped /t/ and /d/).

As with the rate of change models from Chapter 4, I will be modeling functions over dates of birth using b-splines. See Chapter 4 §4.3.1 to review of how b-splines work. For this model, there are four variables that I want to model as a function of date of birth:

(5.7) The height along F1 of /ay/ before surface /d/.

(5.8) The difference in height for /ay/ between surface /d/ and surface /t/.

(5.9) The difference in height for /ay/ between surface /d/ and flapped /d/.

(5.10) The difference in height for /ay/ between surface /t/ and flapped /t/.

Each of these functions will be represented by γ_{le}, where l is the date of birth, and e is an index for the specific function. Each γ_{le} will be modeled using a b-spline.

$$\gamma_{le} \quad = \quad b.spline(l) \tag{5.11}$$

Now, with the exception of $\gamma_{l,1}$, none of these γ_{le} functions model the specific height of /ay/ in a given context. Instead, the community level estimate for the height of /ay/ in a specific context for a specific date of birth will be given as f_{lpk}, where l is the date of birth, p is the phoneme, and k is for the context.

$$f_{lpk} \tag{5.12}$$

$$p \quad = \quad \{D, T\} \tag{5.13}$$

$$k \quad = \quad \{surf, flap\} \tag{5.14}$$

The relationship for each height function f_{lpk} to the γ_{le} functions is given as follows.

$$f_{l,D,surf} \quad = \quad \gamma_{l,1} \tag{5.15}$$

$$f_{l,T,surf} \quad = \quad \gamma_{l,1} + \gamma_{l,2} \tag{5.16}$$

$$f_{l,D,flap} \quad = \quad \gamma_{l,1} + \gamma_{l,3} \tag{5.17}$$

$$f_{l,T,flap} \quad = \quad \gamma_{l,1} + \gamma_{l,2} + \gamma_{l,4} \tag{5.18}$$

As a consequence, each γ_{le} function can be interpreted as follows.

(5.19) $\gamma_{l,1}$

    - The height of /ay/ before surface /d/ over time.

(5.20) $\gamma_{l,2}$

    - The height difference from /ay/ before surface /d/ to /ay/ before surface /t/ over time.

(5.21) $\gamma_{l,3}$

    - The height difference from /ay/ before flapped /d/ to /ay/ before surface /d/.

(5.22) $\gamma_{l,4}$

    - The height difference from /ay/ before flapped /t/ to /ay/ before surface /t/.

For the sake of clear understanding, I won't be labeling axes in the figures which follow with the specific γ_{le} label, but rather these descriptions. Of particular interest will be whether $\gamma_{l,3}$ (the difference in /ay/ between surface and flapped /d/) and $\gamma_{l,4}$ (the difference in /ay/ between surface and flapped /t/) ever exclude 0 at any point in time. If they do, then it would mean that for that particular point in time, the effect of the following segment on the preceding /ay/ was not equivalent between surface and flapped forms.

Also of interest will be whether the difference in hight between /t/ and /d/ is always the same whether they are flapped or not. We can represent this estimate as δ_l.

$$\delta_l \quad = \quad (f_{l,D,surf} - f_{l,T,surf}) - (f_{l,D,flap} - f_{l,T,flap}) \tag{5.23}$$

If δ_l ever excludes 0, that would mean that for that period of time, the difference in /ay/ height before /t/ and /d/ is different depending on whether they are flapped.

Now, one possible criticism of the model as I've laid it out so far is that I've built in the assumption that I'm trying to test. The height of /ay/ before surface /t/ is derived from the height

of /ay/ from surface /d/ plus $\gamma_{l,T,surf}$. The height of /ay/ before flaps are then derived from the height of /ay/ before the surface realizations. However, the functions for γ_{lpe} are only very weakly biased towards 0. If there was not sufficient data to estimate, say, the function for $\gamma_{l,T,flap}$ (the difference in height for /ay/ between surface /t/ and flapped /t/), its posterior distribution would be only marginally different from its prior, which in this model was $\mathcal{N}(0, 1000)$, meaning that values ranging from -1000 to 1000 would be well within reason. Given the weak influence of the prior, the actual data should be the primary driver behind the estimate of the posterior, and if the posterior for all γ_{lpe} functions are estimated with approximately equivalent certainty, then it would be reasonable to assume that this results primarily from the posterior being supported by the data, rather than by the priors in the model.

As for the rest of the model, it follows very similarly to the one described in Chapter 4. For every speaker, indexed by j, their central tendency for /ay/ before each phoneme, p, in each context k was estimated. This by-speaker estimate is represented by μ_{jpk}^s.

$$DOB_{1,2,...n.speaker} \tag{5.24}$$

$$l = DOB_j \tag{5.25}$$

$$\mu_{jpk}^s \sim \mathcal{N}(f_{lpk}, \sigma_k) \tag{5.26}$$

In addition, to the contextual effects of the following segments, I have also modeled the effect of vowel duration on /ay/ height. This effect was treated as being the same in all contexts, but I did allow speakers to differ in the strength of this effect. The community level variable is represented by β_d, and a slope term for each speaker is represented by β_j^s.

$$\beta_d \sim \mathcal{N}(0, 1000) \tag{5.27}$$

$$\beta_j^s \sim \mathcal{N}(\beta_d, \sigma^d) \tag{5.28}$$

Finally, word level random effects were also included, and represented by μ_m^w.

$$\mu_m^w \sim \mathcal{N}(0, \sigma^w) \tag{5.29}$$

At the raw data layer of the model, normalized F1 is the outcome variable being modeled, represented by y_i. The duration variable is passed to the model as x_i, and is, in fact log(duration)-median(log(duration)). The remaining variables are indices for indexing the speaker level and word level effects. [4]

$$y_{1,2,\ldots n} \tag{5.30}$$

$$J_{1,2,\ldots n} \tag{5.31}$$

$$P_{1,2,\ldots n} \tag{5.32}$$

$$K_{1,2,\ldots n} \tag{5.33}$$

$$W_{1,2,\ldots n} \tag{5.34}$$

$$x_{1,2,\ldots n} \tag{5.35}$$

$$j = J_i \tag{5.36}$$

$$p = P_i \tag{5.37}$$

$$k = K_i \tag{5.38}$$

$$m = W_i \tag{5.39}$$

Each observation is modeled as being drawn from a normal distribution with a speaker specific variance σ_j^s. The mean of this normal distribution is the sum of the speaker level estimate for F1 for the specific following segment and context, μ_{jpk}^s, the word level effect, μ_m^w, and the speaker level duration effect, $\beta_j^s x_i$

$$y_i \quad \sim \quad \mathcal{N}(\mu_{jpk}^s + \mu_m^w + \beta_j^s x_i, \sigma_j^s) \tag{5.40}$$

This model was implemented in Stan, and was set to run with four chains with a 3,500 iteration burn in, and a 3,500 iteration sample. All location parameters which were not defined in the model

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[4] J is for speaker indices, P is for the following segment (/t/ or /d/), K is for the context (surface or flap), and W is for word indices.

above were given a prior of $\mathcal{N}(0, 1000)$, and all scale parameters were given a prior of $\mathcal{U}(0, 100)$, which for the scale of this data are relatively uninformative priors. The model converged to very stable estimates, based on the Gelman-Rubin Potential Scale Reduction Factor, $\hat{R}$. Figure 5.10 plots a histogram of $\hat{R}$ for all parameters in the model. For all parameters, $\hat{R}$ is very close to 1.
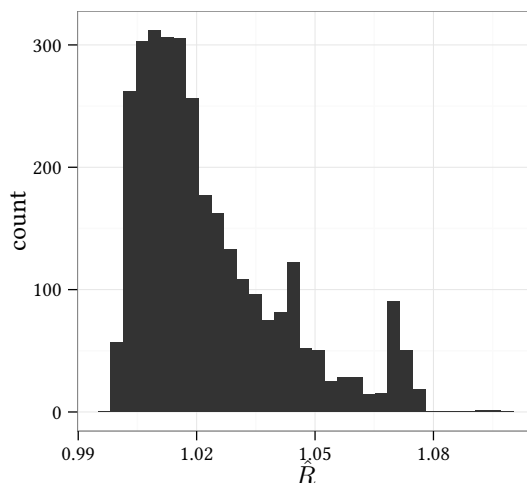

Figure 5.10: $\hat{R}$ for all parameters in the model.

Figure 5.11 plots the estimated F1 trajectories for /ay/ in each context, along with 95% highest density posterior intervals. As it was in Chapter 4, since this model is both Bayesian and fitting non-linear curves, I don't have p-values to report. Rather, there is a 95% probability that the true value lies within the colored band representing the HPD. There is a strong qualitative similarity in the trajectories in Figure 5.11 to those in Figure 5.9, which along with the $\hat{R}$ values close to 1 suggests that the model as described above is an adequate one for the data. Figure 5.12 plots the same estimated F1 trajectories from Figure 5.11, but this time faceting by the following underlying stop in order to foreground the effect of flapping. While /ay/ before /t/ looks nearly identical whether or not that /t/ is flapped, there is a much larger difference for /ay/ followed by flapped and surface /d/. The effect on flapping /t/ and /d/ are highlighted in Figure 5.13, which plots the difference in the curves in each facet of Figure 5.12.

Figure 5.13 plots the difference in height of /ay/ between flaps and surface realizations for /t/ and /d/. Values below 0 mean that flaps are lower than surface realizations, and values above 0
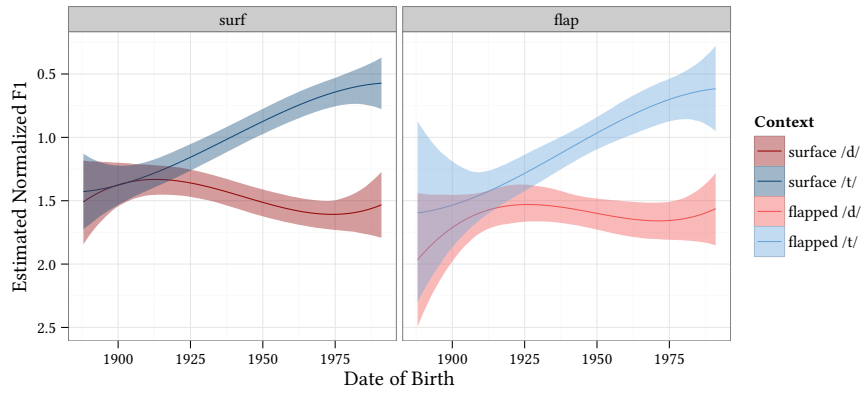
Figure 5.11: Model estimates of /ay/ F1, faceted by surface vs. flapped realizations.
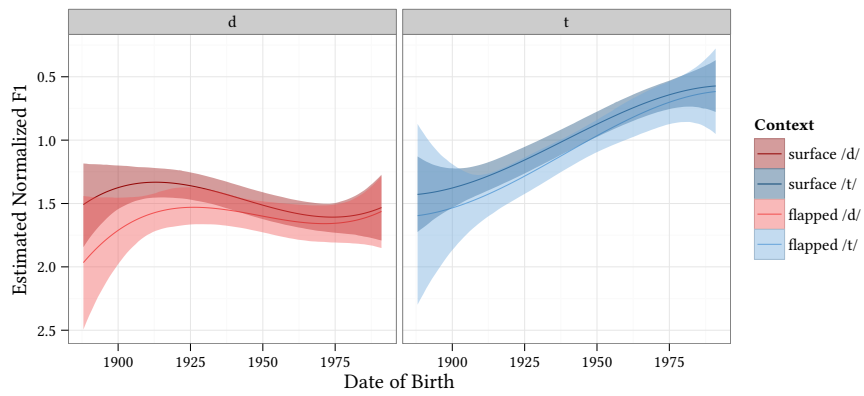

Figure 5.12: Model estimates of /ay/ F1, faceted by /t/ vs /d/.

mean that flaps are higher than surface realizations. Looking at /t/ first, the 95% HPD contains 0 throughout the entire change, meaning that the height of /ay/ is not reliably different between surface /t/ and flapped /t/. The edge of the 95% HPD comes very close to excluding 0 around 1910, but this is also true for /d/, with flapped /d/ being lower than surface /d/. If anything, there appears to be some kind of flapping main effect with /ay/ before flaps being somewhat lower, although not reliably. The lack of any difference between /ay/ before surface /t/ and flapped /t/ is anomalous under the glide peripheralization precursor hypothesis, which would predict that /ay/ before flapped /t/ should pattern more or less like /ay/ before surface /d/ at the onset of the change. The main effect of /ay/ before flaps being lower than before surface realizations is anomalous under the duration precursor hypothesis, which predicted that /ay/ before both /t/ and /d/ flaps should undergo raising. The effect of flapping on /ay/ height, therefore, is not consistent with either of the phonetic precursor hypotheses.
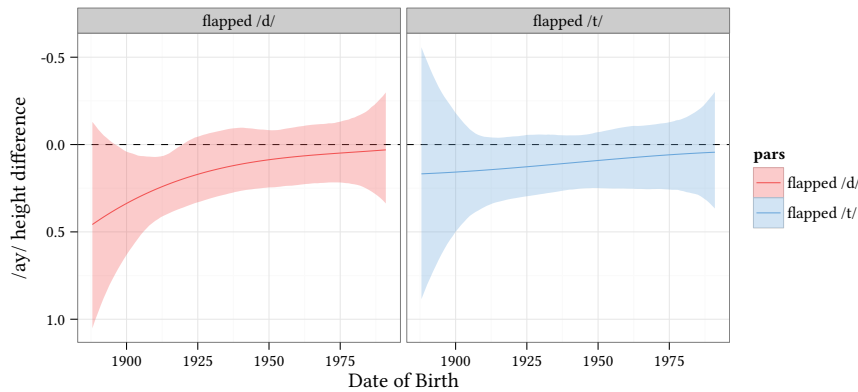

Figure 5.13: The difference in normalized F1 for /ay/ before flapped /t/ and /d/ from surface /t/ and /d/. The y-axis can be understood as (ayC$_{flap}$ - ayC$_{surf}$)

Figure 5.14 plots the second relevant comparison, the effect of /t/ within surface realizations and flaps. The way to interpret the "surface" facet of 5.14 is that it plots the height difference in /ay/ before surface /t/ and /d/. The "flap" facet plots the height difference in /ay/ before flapped /t/ and /d/. The effect of following /t/ is virtually identical for flaps and surface realizations. They both begin to exclude 0 at approximately the same time around 1920. Figure 5.15 plots the difference between the surface /t/ effect and flapped /t/ effect. This difference between /t/

effects contains 0 throughout the 20th century, meaning that the difference in /ay/ height between flapped /t/ and /d/ has always been the same as the difference between surface /t/ and /d/.
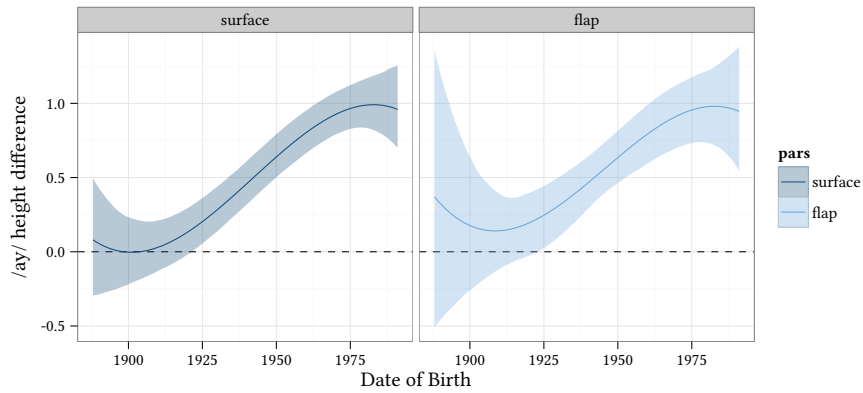

Figure 5.14: The effect of following phonological voice on /ay/ across context. The y-axis can be understood as (ayd-ayt).
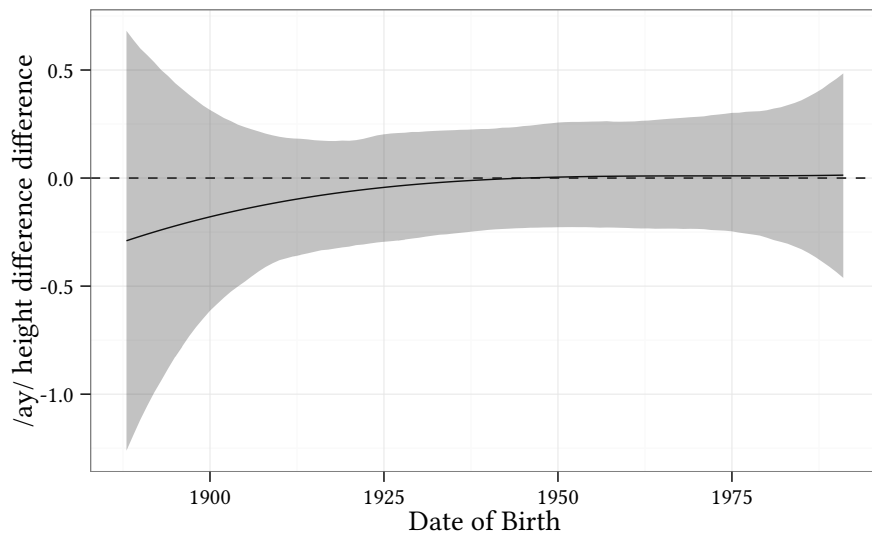

Figure 5.15: The difference in the effect of voicing between surface and flap contexts. The y-axis can be understood as $(ayd_{surf}\text{-}ayt_{surf})\text{-}(ayd_{flap}\text{-}ayt_{flap})$

/ay/ Conclusions and Discussion

The results laid out above are strikingly at odds with a model of conditioned sound change which is based on the accumulation of phonetically conditioned production and perception errors *a la*

Ohala (1981). Neither the rate of change nor the degree to which one context or the other favors the change appears to be proportional to either of the proposed phonetic precursors. Rather, it seems clear that the conditioning of /ay/ raising must make reference to *phonologically* defined categories rather than phonetically defined ones. This phonological differentiation of of raised and low /ay/ suggests that a grammatical process like (5.41) entered the phonology at the onset of the change, and was always in an opaque relationship with respect to flapping.

(5.41) ay $\rightarrow$ $-$low/___$-$voice

In many respects, this early introduction of a grammatical process is very similar to the Competing Grammars view of language change from historical syntax beginning with Kroch (1989). Kroch and students have by and large found that syntactic change does not begin in one context and then spread by analogy to others. Rather, changes begin in all contexts at the same time, although some may be more favoring than others and boost the overall rate. Given these results from pre-voiceless /ay/ raising, it is obvious that it did not begin in the most phonetically favoring environment and then analogically spread to other contexts.

One important difference between this case and most syntactic changes is that the introduction of the new phonological process to raise pre-voiceless /ay/ must have been *rapid*, in fact, too rapid to be detectable to the analysis methods I employ in this dissertation. In syntactic change, the change we observe is the rate of use of the new grammatical process, where in this case use of the new phonological process must have reached categorical use nearly immediately, and the change we observe is shifting phonetic implementation of the output of that phonological process. See Chapter 2 §2.3 for the quantitative arguments that this is the case. In Chapter 6, I'll discuss the possibility that there was a precursor phonological process for pre-voiceless /ay/ raising that may solve this rapidity problem for /ay/ raising, but this rapidity is really a problem for the phonological conditioning on sound change discussed in chapter 4 (specifically the effect of /l/ on /ow/ and /uw/), as well as for /ey/, to be discussed next.

5.1.2 /ey/ Raising

The conditioned raising of /ey/ in "checked" position was initially described as a new and vigorous change in Philadelphia in the 1970s (Labov, 2001). However, not as much work has been done on this change as has been done on /ay/, and since conditioned raising of /ey/ is not a feature shared by other dialects (or at least not reported to), a bit more exploratory description is necessary before digging into its conditioning.

To begin with, I have excluded the days of the week (*Sunday, Monday.* etc.) because of the relatively frequent lexical variation in these items between /-deɪ/ and /-diː/ which constitutes a cross-cutting factor that is not of particular relevance to the patterns discussed below. I've also excluded all cases of /ey/ followed by /g/. There has been a long lasting tendency in Philadelphian phonology to lax /iy/ and /ey/ before /g/ to /ɪ/ and /ɛ/, leading to such shibboleths as *Iggles* (*Eagles*, the local football team) and *beggle* (*bagle*). Figure 5.16 plots ellipses representing the distribution of /ey/ when followed by various stops. The distribution followed by /g/ is clearly outlying, and again, a cross-cutting factor not relevant to the problem at hand.
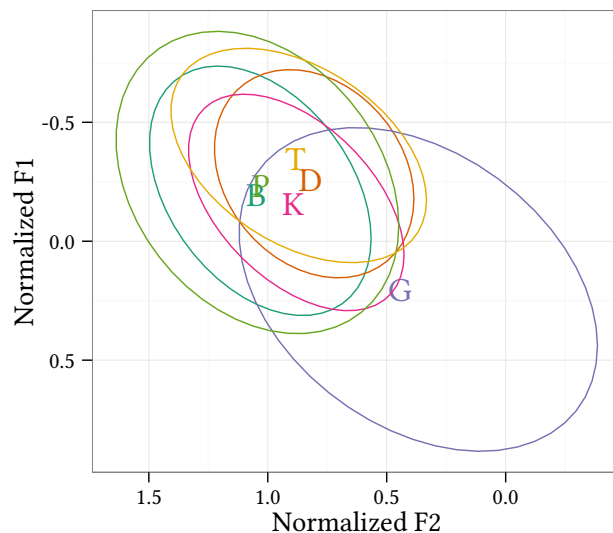

Figure 5.16: Distribution of /ey/ means by following stop.

As for the remaining possible within-word conditioning effects, Figure 5.17 plots most of them out, faceting by voicing and manner, color representing place of articulation. There are no

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standout effects, except for that of following /l/, which is more or less flat. For the rest of this section, I'll be collapsing across following consonant, separating out only /l/.
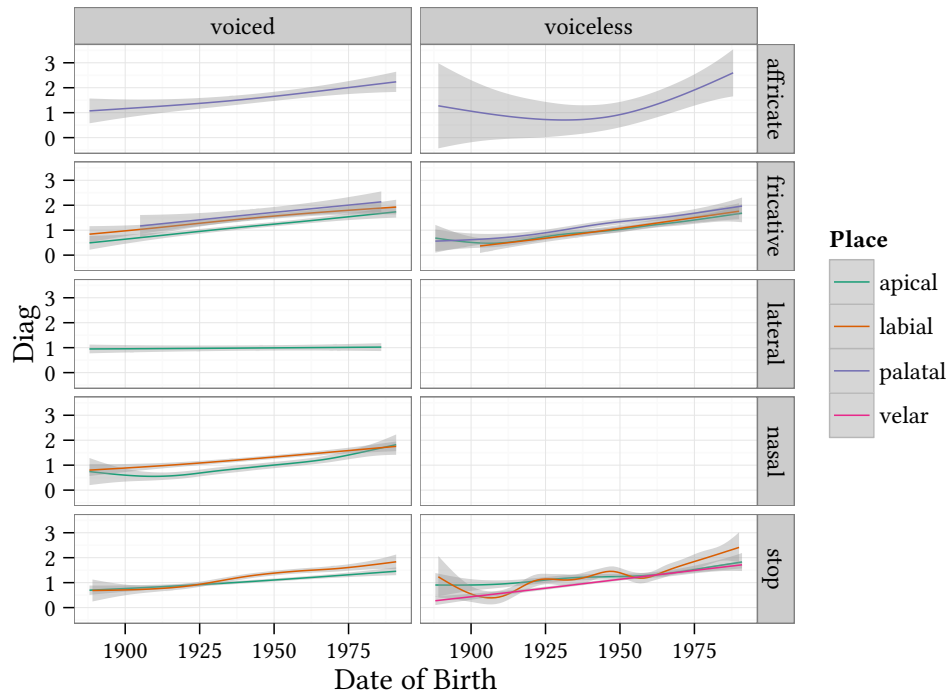

Figure 5.17: The effect of following context on word internal /ey/ raising.

One major question regarding /ey/ raising is how it interacts with syllable structure. It has been mostly defined in the previous literature as raising in "checked" position, while remaining low in "free" position. This distinction has been largely operationalized as being word final (free) versus all other contexts. However, it has not been established whether the distinction between open versus closed syllables plays any role. To determine whether or not syllabic structure plays a role in conditioning /ey/ raising, I wrote a simple syllabifier to categorize the consonants following word internal /ey/ as to whether they were in the onset of the following syllable (making /ey/ the nucleus of an open syllable) or in the coda of the syllable with /ey/ (making it closed). The syllabifier operated over the CMU dictionary style transcriptions for each word, and maximized onset (Kahn, 1976) modulo English phonotactics. There was not enough data of /ey/ followed by /l/ to further subdivide it by syllabicity. Of course, many tokens of /ey/ were pre-hiatus (e.g.

mayor, saying), and this context was also separated out. For now, I've set aside word-final /ey/.
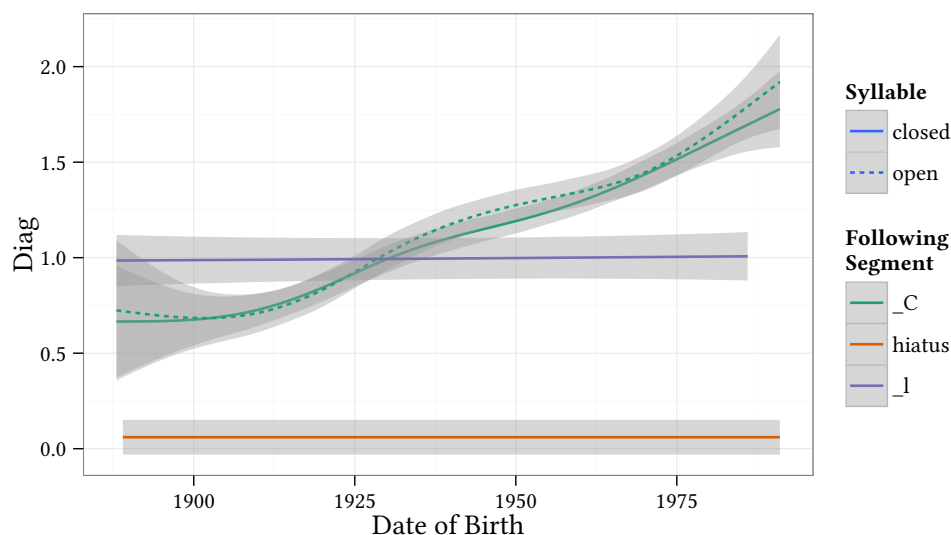

Figure 5.18: Trajectory of word internal /ey/

Figure 5.18 plots cubic regression splines over speaker means. Colors indicate the category of following segment (consonant, hiatus, /l/), and pre-consonantal /ey/ has been further subdivided according to the syllabic relationship between /ey/ and the consonant. There are a few striking results visible in this figure. First, syllabic structure appears to make no difference when the following segment is a consonant. Both *baby* and *babe* undergo the change at the same rate. Second, neither /ey/ followed by /l/ nor /ey/ followed by a vowel appear to undergo the change at all. Third, the set of contexts where /ey/ undergoes the change is not related to the degree to which those contexts appeared to favor change at the beginning. This is a change along the front diagonal of the vowel space, and in the period around 1900, the context where /ey/ was most advanced along the front diagonal was before /l/. However, the change did not take place before /l/ at all. This appears to be another clear example where the context where the change seemed to be happening first is not where it happened fastest (cf. Bailey, 1973).

The difference along the front diagonal between /ey/ followed by /l/ and /ey/ followed by other consonants is very slight in the early period of the change according to Figure 5.18, so more detailed statistics are necessary to establish its validity. To this end, I fit a mixed effects linear

model using the `lme4` package in R. I created a `Decade` predictor for the model which is equal to `(DOB-1900)/10`. This allows us to interpret the intercept effects as representing differences between the contexts in 1900, and to interpret the slope effects as representing the degree of change per decade. The fixed effects included in the model were Decade, the following segment (consonant, vowel, /l/), and their interaction. The random effects included random intercepts for speaker and word, as well as a random slope of following segment by speaker, and randoms slope of decade by word.[5] The model estimates are displayed in Table 5.5 along with t-values. For the purposes of this dissertation, t-values greater than 2 will be taken to indicate a reliable effect.[6] Since all of the t-values in Table 5.5 are greater than 2, we'll take the reported effects to be reliable.

	C Effects		Interactions		
Intercept	0.63	t=15.14	0.31	t= 2.66	/l/
			-0.55	t=-4.29	V
Decade	0.12	t=14.9	-0.1	t=-4.18	/l/
			-0.12	t=-5.22	V

Table 5.5: Regression Estimates for word internal /ey/ raising. Reference levels: Decade=1900; FolSeg=C. Model formula: `Diag ~ Decade * FolSeg + (FolSeg|Speaker) + (Decade|Word)`.

The intercept for /ey/ followed by consonants is 0.63, with a decade-over-decade rate of change of 0.12. There are approximately 9 decades between 1900 and the most recent date of birth, 1991, meaning that /ey/ rose 1.09 units along the front diagonal, from 0.63 to 1.73. The effect of a following /l/ in 1900 was 0.31, meaning it would take /eyC/ 0.31/0.12=2.55 decades to reach that level. This effect of /l/ is reliable and substantial in the direction of the change, but /ey/ does not undergo the change in this context. The slope of /ey/ followed by /l/ is estimated to be 0.1 less than /ey/ followed by other consonants, or 0.12−0.1=0.02. Given the current specification of the model, it's not possible to determine whether 0.02 is reliably different from 0, but it is unlikely to be. To be sure, I refit the model changing the reference level from a following C to following /l/. The results are displayed in Table 5.6, and, in fact, the t-value corresponding to the slope of

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[5]Due to the structure of the data, it is not possible to include random slopes for following segment by word, or decade by speaker.

[6]p-values are not included because they are non-trivial to calculate for mixed effects models (Bates, 2006) and estimation of p-values by MCMC is not yet implemented for models with random slopes.

/ey/ before /l/ is less than 2, meaning that it is not reliably different from 0. The interaction effect of following V is also not reliably different from 0 in Table 5.6, meaning /ey/ followed by /l/ and /ey/ followed by vowels are not reliably different from parallel.

	/l/ Effects		Interactions		
Intercept	0.94	t=8.12	-0.31	t=-2.66	C
			-0.87	t=-5.15	V
Decade	0.02	t=1.08	0.1	t= 4.18	C
			-0.02	t=-0.78	V

Table 5.6: Regression Estimates for word internal /ey/ raising. Reference levels: Decade=1900; FolSeg=/l/. Model formula: `Diag ~ Decade * FolSeg + (FolSeg|Speaker) + (Decade|Word)`.

The qualitative impressions from Figure 5.18 are therefore quantitatively supported. Even though /eyl/ started out higher and fronter than /eyC/, it did not undergo the raising and fronting change. In fact, around approximately 1925, /eyC/ crossed over and passed /eyl/.

Unlike /ay/ raising, there has been less work on establishing what the phonetic precursors of /ey/ raising might have been. Even without that background research, however, I believe it can still be established that the context for /ey/ raising is phonologically, not phonetically defined. Strictly phonetic effects, like those discussed in Chapter 4, specifically §4.1, can be seen to be operating early on in /ey/ just before the change begins around the turn of the century. When followed by a vowel, /ey/ is especially low, and when followed by an /l/, it is slightly higher than when followed by other consonants. Whatever phonetic precursor for raising /ey/ may be proposed, it is clear that /eyl/ has more of it, because it starts off in a more advanced position. The fact that /eyC/ comes from behind and overtakes /eyl/ means that the change must have been conditioned by something other than phonetic favorability.

The proposal that I'll put forward here about /ey/ raising is that it is conditioned by following consonants. I'll call the phonological allophone [+peripheral], following the fact that it fronts and raises along the front peripheral track (Labov, 1994). Moreover, the allophone which does not undergo raising and fronting remains with phonetics roughly similar to the realization of /ey/ in Southern English, which Labov et al. (2006, ch 3) argues is [−peripheral].

(5.42) ey → +peripheral /___C

Of course, the first issue that arises is why a following /l/ does not count as a consonant, but there is precedent for an analysis of /l/ as not being a consonant in Philadelphia. Philadelphia has fairly aggressive /l/ vocalization, taking place not only word finally and in codas, but also intervocalically and in initial clusters (Ash, 1982). /l/ also has a number of vowel-like effects on preceding vowels in Philadelphia, especially to the long back-upgliding vowels /uw, ow, aw/ as discussed in Chapter 4. Notably, it triggers glide deletion in /aw/, leading Dinkin (2011) to propose that /l/ is actually the glide in /awl/. Looking only at word internal /ey/, it is not possible to determine whether /ey/ raising is conditioned or not by other glides and liquids, but this will be addressed shortly.

Placing /ey/ raising in the grammar.

The fact that /ey/ raising excludes the most phonetically favoring context is fairly good evidence for its phonological conditioning. It is also possible to see how the proposed phonological process interacts with other phonological processes, like I did for /ay/ raising. Unfortunately, it appears that /ey/ raising applies transparently with respect to affixing, and may even apply at the phrase level.

The easiest way to demonstrate that /ey/ raising applies transparently with respect to affixing is to plot the trajectories if the relatively high frequency words *day* and *days*. Figure 5.19 plots speaker means and cubic regression splines for these two words. *Days* appears to behave like every other /eyC/ context by undergoing the change, while *day* remains low.

Figure 5.20 plots an extended comparison like the one in Figure 5.19. It compares /ey/ followed by inflectional /-z/ and /-d/ to uninflected forms of the same words where /ey/ is word final, as well as to /ey/ followed by /z/ and /d/ which are not exponents of any morpheme. /ey/ appears to pattern the same way regardless of whether the following consonant is inflectional morphology or not, and in all cases the uninflected form remains low. Again, this qualitative impression from Figure 5.20 is supported quantitatively in Tables 5.7 and 5.8, where the main effects and interactions for the comparison consonants (/z/ and /d/ which are not exponents of agreement)
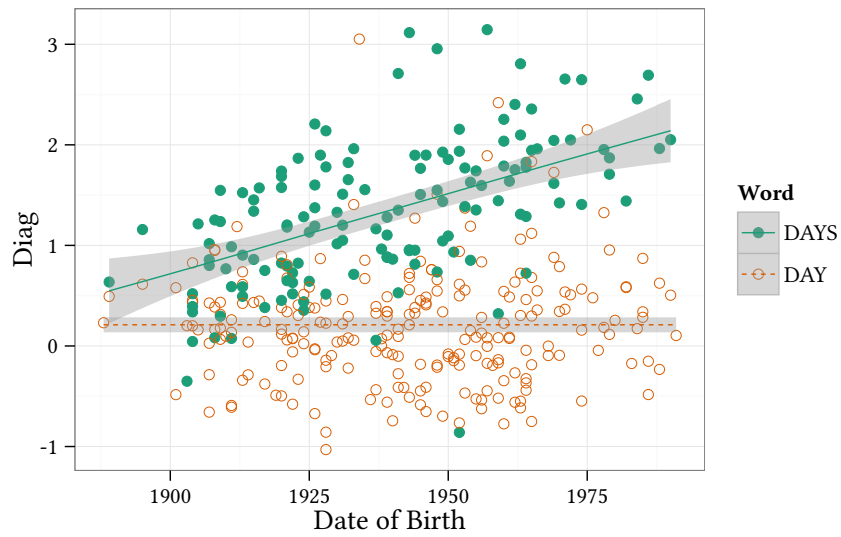
Figure 5.19: Trajectories of the words *day* and *days*.

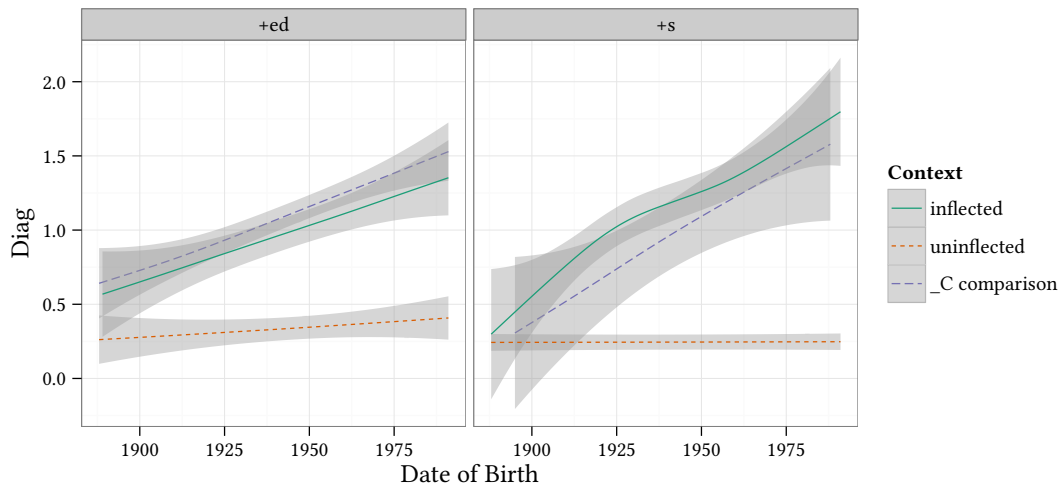are not reliably different from the inflectional morphemes.

Figure 5.20: Comparison of word final /ey/ to inflected versions of the same words, as well as /ey/ followed by non-morphological /z/ and /d/.

Additionally, there appears to be some conditioning of /ey/ raising for word final /ey/ by the onset of the following word. Figure 5.21 plots the trajectories of word final /ey/ divided up

	+ed Effects		Interactions		
Intercept	0.49	t=4.17	0.24	t= 1.67	non-inflectional C
			-0.31	t=-2.14	uninflected
Decade	0.09	t=3.3	-0.01	t=-0.25	non-inflectional C
			-0.08	t=-2.15	uninflected

Table 5.7: Regression Estimates /ey/ raising in inflected vs uninflected words. Reference levels: Decade=1900; Context=/+ed/. Model formula: `Diag ~ Decade * Context + (Context|Speaker) + (Decade|Word)`.

	+s Effects		Interactions		
Intercept	0.48	t= 4.95	-0.34	t=-1.56	non-inflectional C
			-0.26	t=-2.34	uninflected
Decade	0.14	t=6.48	0.05	t= 1.07	non-inflectional C
			-0.12	t=-5.11	uninflected

Table 5.8: Regression Estimates /ey/ raising in inflected vs uninflected words. Reference levels: Decade=1900; Context=/+s/. Model formula: `Diag ~ Decade * Context + (Context|Speaker) + (Decade|Word)`.

by the onset of the following word (the "etc." category consists of following pauses, coughs, laughs, etc.). The same conditioning effects appear to be in place, except within a substantially compressed range and a shallower slope (Figure 5.21 has the same y-axis range as Figure 5.18 for this comparison).

Both the fact that /ey/ raising interacts transparently with inflection and that it applies across word boundaries indicate that this must be a low level phonological process. In a stratal approach to phonology like Lexical Phonology or Stratal OT, this process would be taking place postlexically, or at the phrase level. I'll revise the process in (5.42) to reflect this.

(5.43) ey → +peripheral /___C]$_{phrase\ level}$

Now, there is frequently ambiguity between phrase level or postlexical rules and strictly phonetic processes, but the case for /ey/ raising being a phonological process is still evident at the phrasal level because of the exclusion of /l/ from the conditioning environments. There is more diversity in the range of contexts following /ey/ when it is word final than when word internal,
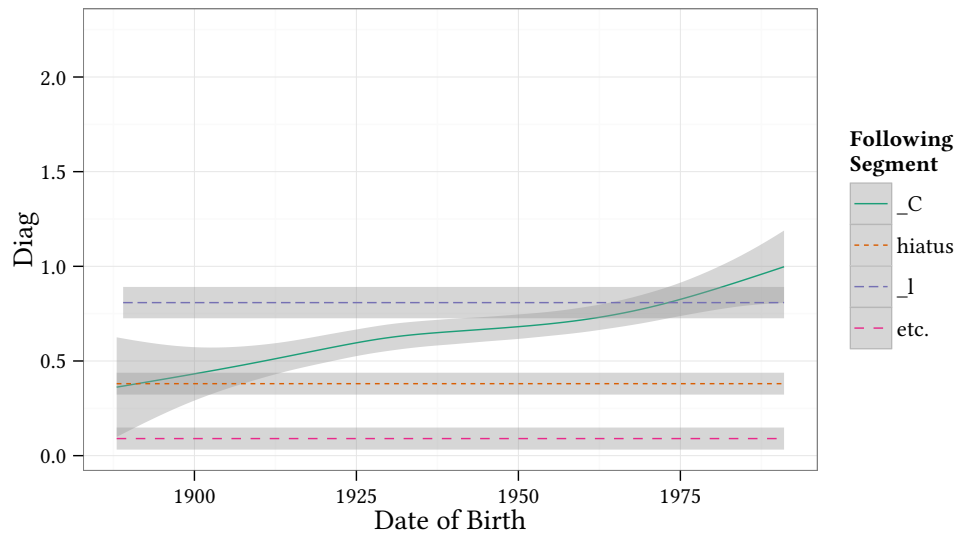
Figure 5.21: Trajectory of word final /ey/

meaning it's possible to compare /ey#C/, /ey#l/, and /ey/ followed by other liquids and glides like /r, w, y/. Figure 5.22 does exactly this, plotting cubic regression splines over speakers' means for /ey/ followed by various contexts. The erratic behavior of /ey#r/ is almost certainly due to its small volume of data, yet it does generally follow the trend of becoming higher and fronter. /ey#y/ and /ey#w/ have essentially identical trajectories as /ey#C/. The only non-participating contexts are /ey#l/, /ey#V/ and /ey#/.

The analysis that /ey/ raising is phonologically conditioned by following consonants appears to be supported again by the analysis of word final /ey/. It appears to be phonological for two reasons. First, the exclusion of /ey#l/ from the set of undergoers cannot seem to be done on a phonetic basis, as other phonetically similar segments (/r, w/) do undergo the change. Second, the following contexts appear to arrange themselves into two categorically separate classes: triggers and non-triggers.
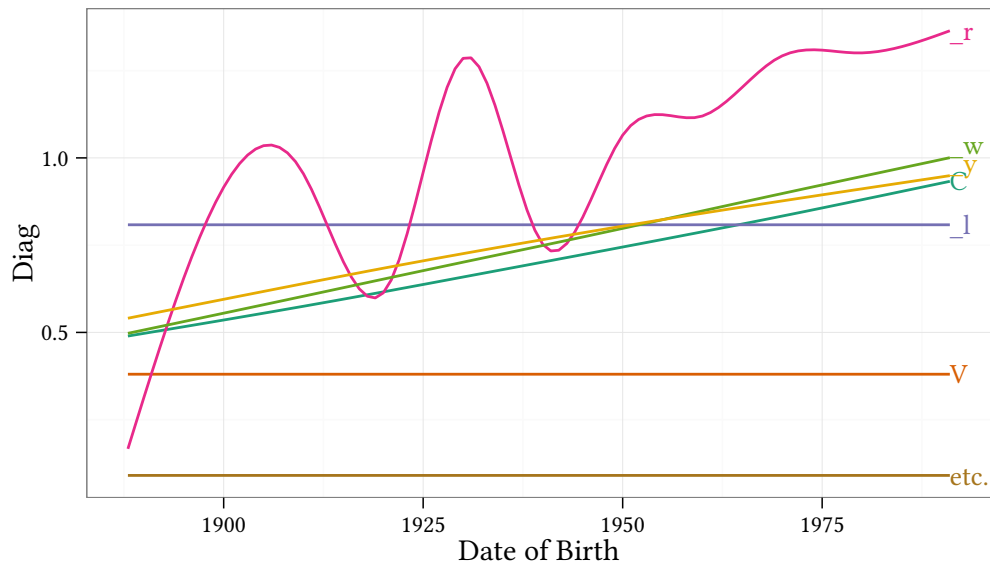
Figure 5.22: Trajectory of word final /ey/

5.1.3   /ay/ and /ey/ summary

In this section, I have examined divergent diachronic trajectories that occurred within the phonemic categories /ay/ and /ey/ and determined that they are best explained by appealing to phonological, rather than phonetic conditioning factors. In neither case did the change occur in proportion to the phonetic favorability of the contexts where it could have. In the case of /ay/ raising, we should expect /ay/ raising before flaps to have either patterned with surface /t/ or surface /d/ on phonetic grounds, depending on the precursor theory we care to adopt. However, /ay/ raising appeared to pattern strictly according to the underlying phonological voice of the following segment. One may try to argue that this result could be achieved through some kind of analogical process without resorting to phonological processes, so that [ʌi] in *write* analogizes to *writer*. Of course, whatever explanation based on analogy one comes up with must also allow for raised /ey/ in *days* not to analogize to *day*.

In the case of /ey/ raising, the exclusion of /l/ from the set of environments where the change took place is anomalous on a number of grounds. The exclusion of /eyl/ from undergoing the

change must be made on grounds other than its phonetic properties (due to the fact that phonetically similar segments /r/ and /w/ *did* undergo the change) or its phonetic favorability for the change (due to the fact that before the change began, it appeared to be the *most* favoring enviornment under consideration here). Since there is independent evidence that /l/ is not quite consonantal in Philadelphia, and since /ey/ did not raise before vowels, I'll argue that the definition of the conditioning environment for /ey/ raising is that the following segment must be a consonant phonologically.

The conditioning of these two changes support my proposal that the target of phonetic changes are surface phonological representations. For both of these changes, I have posited phonological processes that separate the phonemic categories into two phonological allophones, only one of which undergoes the change. In the next section, I'll demonstrate that phonetic changes frequently target phonological natural classes as a whole, and argue that this is the result of changing phonetic implementation of the phonological features which define these natural classes.

5.2   Natural Class Patterns

The most commonly discussed multi-vowel shifts are chain shifts, a useful typology of which is provided by Labov (1994). The observed patterns in chain shifts are frequently described in terms of maximizing the "margin of security" between vowels (Martinet, 1952), or by the maximal dispersion of vowel contrast (Liljencrants and Lindblom, 1972; Labov, 1994, 2001; Flemming, 2004*inter alia)*. For example, the low-back merger of the Lot and Thought vowels (/ɑ/ and /ɔː/, or /o/ and /oh/ in Labovian class labels) is implicated in at least two kinds of chain shifts. The first is the Canadian Shift[7] (Clarke et al., 1995; Labov et al., 2006), where the phonetic gap created by the merger of /o/ to a backer and higher position is filled by short-a, /æ/. The remaining front short vowels then lower, due to the phonetic gap created by /æ/ retraction.

The second kind of shift implicated in the low-back merger involves the lowering of /ʌ/ into the gap left behind by /o/, which has been attested in Pittsburgh (Labov et al., 2006). Figure 5.24 is a schematic diagram of this Pittsburgh Chain Shift, and Figure 5.25 plots the vowel system of a

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[7]also known as the California Shift or Third Dialect Shift

I

↓

ε   oh

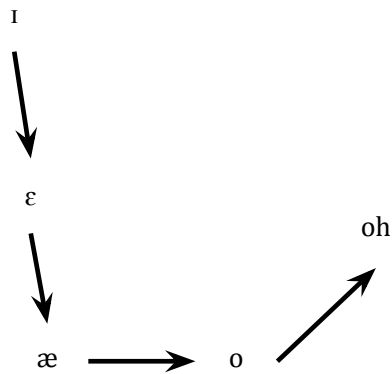↓   ↗

æ ⟶ o

Figure 5.23: The Canadian Chain Shift in reaction to the merger of /o/ and /oh/. Modified from Clarke et al. (1995).

representative speaker from the Atlas of North American English dataset.

ɪ   ʊ

ε   ʌ
                              oh
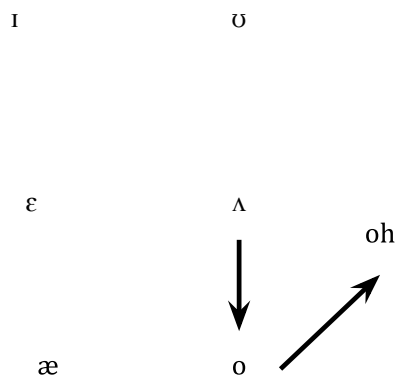   ↓   ↗
æ   o

Figure 5.24: The Pittsburgh Shift in reaction to the merger of /o/ and /oh/. Modified from Labov et al. (2006).

The retraction of /æ/ and the lowering of /ʌ/ into the gap created by the merger of /o/ and /oh/ can be motivated on largely phonetic grounds, as can the subsequent lowering of /ε/ and /ɪ/ in the Canadian Shift. Labov (2001) offers one such explanation for chain shifting whereby the creation of a phonetic gap allows for outliers to be included in the estimation of the phonetic target for that category. In the case of the low-back merger, before /o/ merges into /oh/, it has a phonetic realization of approximately [ɑ]. Outlying pronunciations of /æ/, due to production
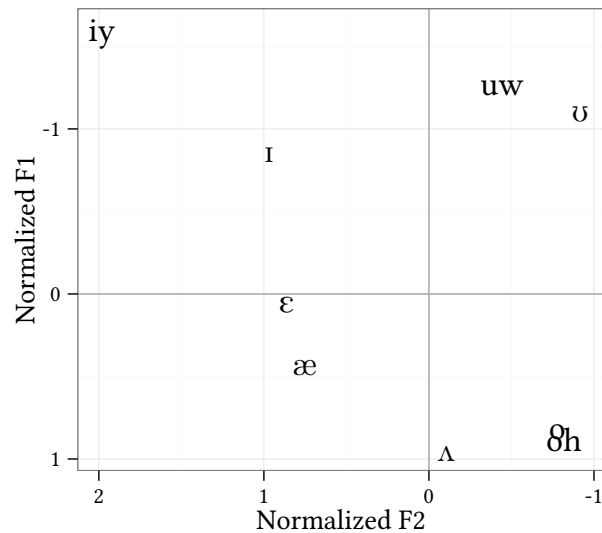
Figure 5.25: Vowel system of a 66 year old woman from Pittsburgh.

error or any other cause, which are produced sufficiently back enough may be misinterpreted as /o/. These exceptionally back realizations of /æ/ wind up not being factored into the estimate for the phonetic target of /æ/, since they were miscategorized into /o/. However, once /ɔ/ merges into /o/, moving from a phonetic realization of [ɑ] to [ɒː ∼ ɔː], there is no longer a phonemic category with a realization of [ɑ]. These exceptionally back pronunciations of /æ/ are now less likely to be miscategorized into /o/, meaning that now they will be included in the estimation of the target for /æ/, leading to /æ/ retraction. For the Canadian Chain Shift, this process repeats with /ɛ/ leading to /ɛ/ lowering. For The Pittsburgh Shift, this process played out for /ʌ/ instead of /æ/.

Other implementations of this basic model of chain shifting exist, from more teleological ones, like Martinet's (1952) margins of security or Flemming's MɪɴDɪsᴛ constraints on contrast , to more mechanistic ones, like those relying on exemplar models and agent based models (de Boer, 2000, 2001; Ettlinger, 2007, e.g.), or Boersma and Hamann's (2008) model of bi-directional cue constraints . A more vexing phenomenon for all of these models which adequately explain either /æ/-retraction or /ʌ/-lowering in reaction to the low-back merger is when *both* happen. The original description of the shift in Clarke et al. (1995) included both /æ/-retraction and /ʌ/ lowering

(shown schematically in Figure 5.26), and an ANAE speaker from Winnipeg who appears to be exhibiting both is shown in Figure 5.27.
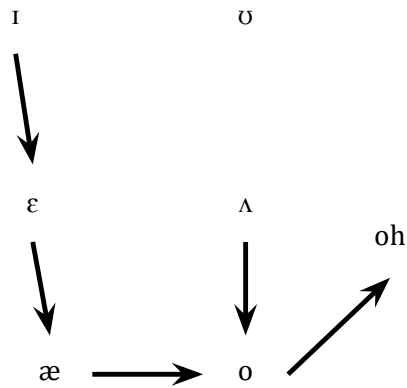

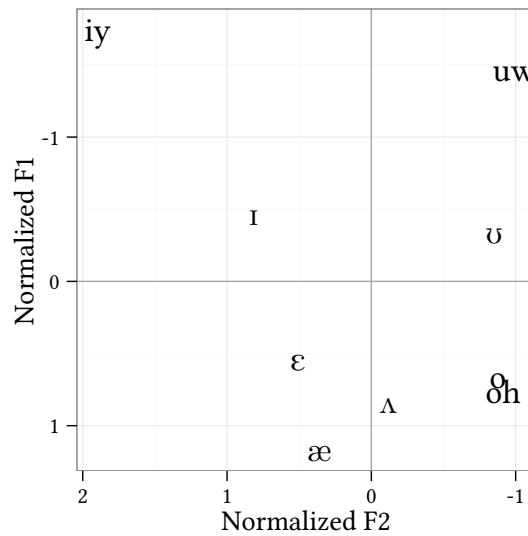Figure 5.26: The Canadian Chain Shift with /ʌ/ lowering. Modified from Clarke et al. (1995).

Figure 5.27: Vowel system of a 36 year old woman from Winnipeg.

The focus of this section, however, is a third reported pattern of the Canadian Shift which is also inexplicable in terms of gap creation and filling, the maximization of contrast, or any other operationalizations of those concepts. Boberg (2005) reports that in Montreal, the dominant pattern of movement for /ɛ/ and /ɪ/ is their parallel *retraction*, rather than a rotation in a chain shift. Figure 5.28 plots the normalized F1 and F2 values for the 3 generational groups Boberg

(2005) studied.[8] The parallel retraction of /æ/, /ɛ/, and /ɪ/ has also been reported as occurring in Columbus, OH by Durian (2012, ch 5), who found relatively strong and significant correlation in the mean F2 of /æ/ and /ɛ/ across speakers. In these cases, the only phonetic pressure explicable in terms of gap creation and filling is for the retraction of /æ/ into the space vacated by /o/. The subsequent parallel retraction of /ɛ/ and /ɪ/ cannot be similarly explained, especially since this parallel retraction compresses the distance between the short front vowels and the short back vowels in a way unexpected under a maximal dispersion kind of account. Instead, it appears that in Montreal and Columbus, the retraction of /æ/ is generalizing to the other short front vowels along phonological dimensions.
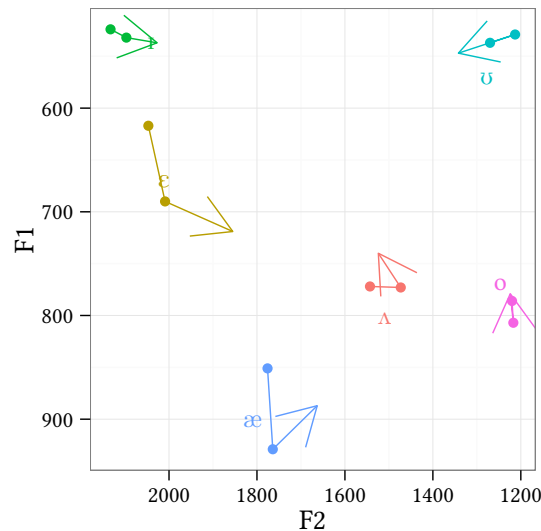

Figure 5.28: The Canadian Parallel Shift. Data from Boberg (2005) Table 4. Points represent 3 generational groups. F1 and F2 have been normalized according to the method reported in Labov et al. (2006)

5.2.1   Back vowel fronting in Philadelphia

Philadelphia has so far been resistant to the low-back merger (Labov et al., 2006), and there is no evidence in the PNC of any retraction of the short front vowels. However, the fronting of the back

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[8]Boberg (2005) employed a one-factor Nearey log-mean normalization, similar to that used in the Atlas of North American English (Labov et al., 2006). The generational groups were defined as "(1) born before 1946, (2) born 1946-1965, and (3) born after 1965."
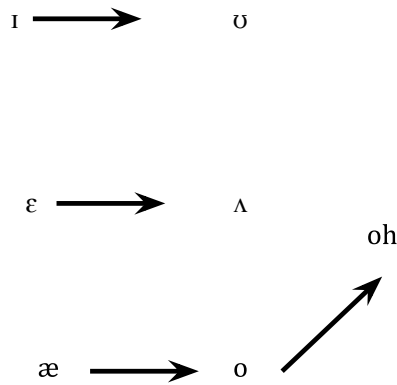
Figure 5.29: The Canadian Parallel Shift. Modified from Boberg (2005).

up-gliding vowels /aw/, /ow/, /uw/ in Philadelphia appear to progress in parallel, a noted trend in many North American Dialects (Labov et al., 2006; Fridland, 2001; Baranowski, 2008; Durian, 2012, *inter alia*). The only plausible "triggering event" for back vowel fronting is proposed by Labov (2010). He argues that the merger of post-coronal /iw/ and /uw/ (e.g. *dew* [djuː] and *do* [duː]) triggered the eventual fronting of /uw/. As discussed in Chapter 4, the rate of change data for [Tuw] is ambiguous with respect to whether [Tuw] and [uw] are phonologically distinct, but in combination with the plausible historical event of [Tiw ∼ Tuw] merger, and the results in Labov, Rosenfelder, and Fruehwald (2013) which found that [Tuw] patterns separately from [uw] along social dimensions, I believe it is reasonable to conclude that [Tuw] and [uw] are phonologically distinct. Of particular interest in this chapter, however, is the degree to which fronting occurs in parallel between all of these back upgliding vowels, so I will be excluding [Tuw] from the data in this section, as well as /aw/, /ow/ and /uw/ followed by /l/, which I found to be phonologically distinct allophones in Chapter 4. Figure 5.30 plots the trajectory for these back vowels along normalized F2. /aw/ starts out much fronter than /ow/ and /uw/, and this is probably because its nucleus has a different phonological specification for backness (in fact Dinkin (2011) argues that /aw/ has merged with /æl/). Strikingly, however, all three vowels appear to front at nearly the same rate, reach a maximum at about the same time, and then begin to reverse together.
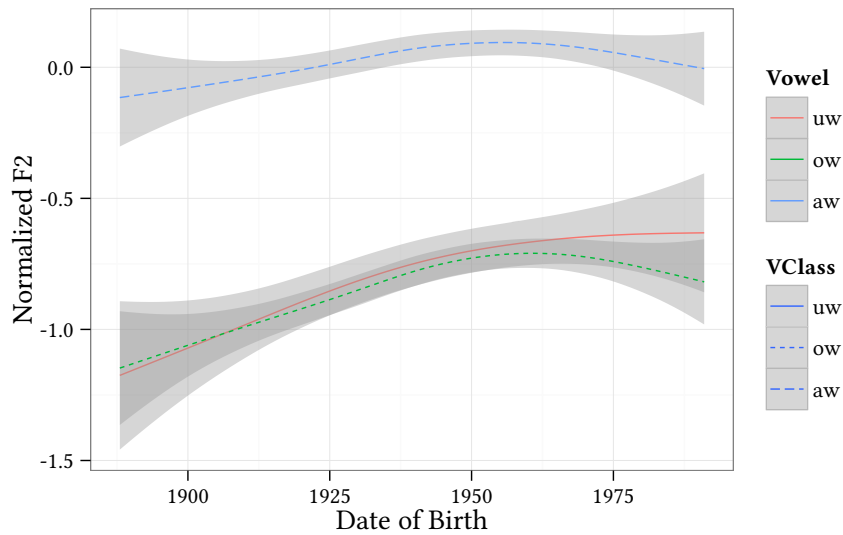
Figure 5.30: The fronting of back vowels in Philadelphia

If we plot speakers' means for /uw/, /ow/ and /aw/ against each other, as Figures 5.31, 5.32 and 5.33 do, we can see a relatively strong relationship between the frontness of one vowel and the others, meaning speakers who have very fronted /aw/ are likely to also have very fronted /ow/ and /uw/. This relationship is strongest for the vowels which are adjacent in height (/aw/ and /ow/, and /ow/ and /uw/), and weakest for the vowels which are two steps away from each other in height (/aw/ and /uw/). However, correlation tests find that the correlation between all three pairwise comparisons of /aw/, /ow/ and /uw/ are significant.

Table 5.9 displays the results of statistical tests using three different correlation statistics. The well known Pearson's r is a measure of the linear correlation of the two vowels, and Spearman's ρ is a similar statistic which measures the correlation of the two vowels given any monotonic function. Kendall's τ is a measure of the concordance of two vowels. For example, taking two speakers and their /ow/ and /aw/ measurements, if the first speakers' /ow/ and /ow/ were *both* fronter than the second speakers', this would be a "concordant" pair of speakers. On the other hand, if only the first speaker's /ow/ were fronter than the second speaker's, but their /aw/ was backer, this would be a "discordant" pair of speakers. Kendall's τ is the proportion of all pairwise
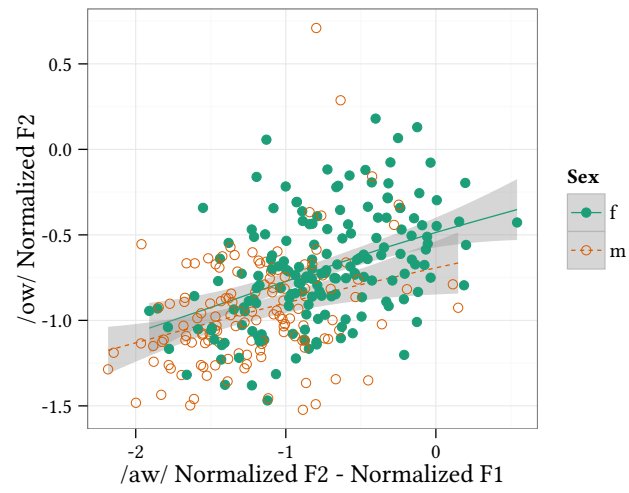
147

Figure 5.31: The relationship between /aw/ and /ow/ across speakers.
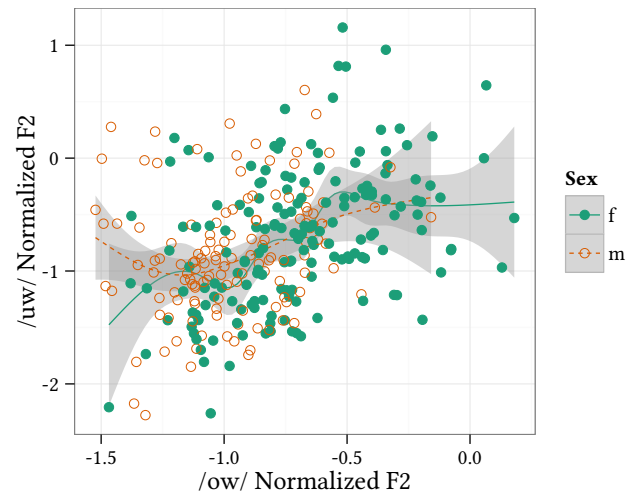

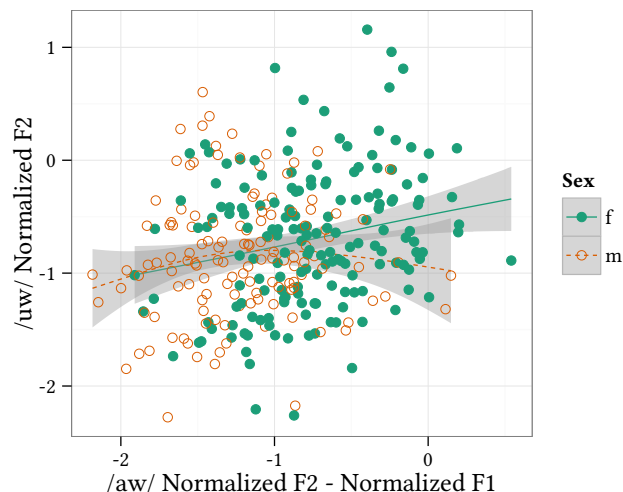Figure 5.32: The relationship between /uw/ and /ow/ across speakers.

Figure 5.33: The relationship between /uw/ and /aw/ across speakers.

comparisons of speakers which are concordant. For all three of these correlation statistics, the relationship between /aw/, /ow/ and /uw/ are significantly and positively correlated.

	Pearson's r		Spearman's ρ		Kendall's τ	
/uw/∼/ow/	0.38	(*p < 0.001*)	0.4	(*p < 0.001*)	0.28	(*p < 0.001*)
/ow/∼/aw/	0.5	(*p < 0.001*)	0.52	(*p < 0.001*)	0.36	(*p < 0.001*)
/uw/∼/aw/	0.22	(*p < 0.001*)	0.2	(*p = 0.001*)	0.14	(*p = 0.002*)

Table 5.9: Correlation of /uw/, /ow/ and /aw/ across speakers (reported p-values have been Bon-ferroni corrected within each test statistic).

My argument is that this pattern of parallel fronting and retraction of /aw/, /ow/ and /uw/ is due to their shared membership in a phonological natural class. I've already argued in Chapter 4 that these three vowels are phonologically active together with respect to a following /l/. The particular label that should be used to define the set {aw, ow, uw} is not of great importance. If Mielke (2008), is correct, the set of phonological features may in fact be "emergent," meaning language learners identify sets of phonologically active segments, and assign a label to them. Following the Labovian approach to the phonology of English vowels (Labov et al., 1972; Labov, 2006; Labov et al., 2006), I'll use the label "+Vw" for this set with the understanding that this is

the label for a feature. In Philadelphia at least, [+Vw] both defines a set of phonologically active vowels, but is also an input to phonetic implementation. At the beginning of the change, the phonetic implementation rule would have mapped the nuclei of [+Vw] vowels to a relatively back target. Then the rule changed, and began mapping the nuclei of [+Vw] vowels to slightly fronter targets, dragging all of the [+Vw] vowels forward. This change continued until approximately 1950, at which point it reached a maximum and began to reverse, dragging all of the [+Vw] vowels back.

A reasonable counter proposal to the phonological one I've put forward here is that the correlation of frontness of /aw/, /ow/ and /uw/ is not due to a shared phonological feature, thus shared phonetic implementation, but is rather due to a shared sociolinguistic evaluation. This is, in fact, the argument Watt (2000) makes for the parallel behavior of /ey/ and /ow/ in Tyneside English, which I will discuss more below. Labov, Rosenfelder, and Fruehwald (2013) argue that the reversal of /aw/, /ow/ and /uw/ fronting is due to Philadelphia's dialectal reorientation from being a Southern dialect city to a Northern one. It could be possible that these three vowels pattern together not because they are phonologically related, but because fronted pronunciations for them are all understood as being "Southern." Of course, it is possible for the reversal of fronting to be socially motivated, but it does not eliminate the need to appeal to their shared phonological features to explain their parallel behavior. As Labov (2006, [1966]) pointed out, social evaluation cannot be tied to strictly phonetic categories. In New York City, [iə] was a stigmatized realization of /æh/, and it was frequently corrected to [æ] or [a̰]. However, this negative evaluation was restricted to the phonological-phonetic mapping of /æh/ to [iə], since the mapping of /iːr/ to [iə] due to NYC r-lessness did not result in the correction of *beer* to [bæː]. In the case of [+Vw] fronting, the social evaluation of fronted /aw/, /ow/ and /uw/ as being "Southern" explains the motivation for reversing their fronting trend, but it does not explain why this reversal generalized to all three vowels immediately, nor why it did not effect any other vowel. For example, the lax, pre-vocalic allophone of /ey/ which was discussed above is similar to the realization of this vowel in the Southern Vowel Shift (Labov et al., 2006). The fact that this allophone of /ey/ remained low, and did not begin to raise at the same time that [+Vw] vowels began to retract is unaccounted

for under the strictly social evaluation analysis. The combination of a negative social evaluation of Southern speech in combination with a phonological natural class [+Vw] can explain both the reversal of [+Vw] fronting *and* the fact that it applied to all and only [+Vw] vowels.

However, it is possible to try to factor out the effect of social evaluation of [+Vw] fronting and see if the frontness of /aw/, /ow/ and /uw/ is still correlated across speakers. Figure 5.34 plots cubic regression splines which were fit using generalized additive mixed effects models. For each vowel, for each gender and educational level, I fit a gamm where the outcome variable[9] was predicted by a cubic regression spline of date of birth. Also included in the model were random intercepts by speaker and by word. I'll be using the by-speaker random intercepts as a sort of by-speaker residual, by which I mean that any by-speaker effects which are not accounted for by their date of birth, sex, and educational level should be captured by their random intercept. As Figures 5.35, 5.36, and 5.37 show, even after controlling for social factors as much as possible, there is still a fairly strong relationship in frontness across these three vowels. That is, speakers with exceptionally front /aw/ for their gender, educational level and birth cohort are also likely to have exceptionally front /ow/ and /uw/. Due to the constraints on how random intercepts are estimated, it does not seem appropriate to do significance testing for their correlation. However, I still calculated the correlation statistics, and compare them to the correlation statistics estimated just over speaker means in Table 5.10. In some cases, the correlation of the random intercepts is weaker, but over all they appear to be largely similar.

	Pearson's r		Spearman's ρ		Kendall's τ	
	means	random effects	means	random effects	means	random effects
/uw/∼/ow/	0.38	0.38	0.4	0.39	0.28	0.26
/ow/∼/aw/	0.5	0.34	0.52	0.34	0.36	0.23
/uw/∼/aw/	0.22	0.14	0.2	0.14	0.14	0.1

Table 5.10: Comparison of correlation statistics based on speaker means to those based on random effects.

Another alternative for the parallel [+Vw] fronting is proposed by Durian (2012), who suggests it can be understood as "phonetic analogy." According to Durian (2012), "phonetic analogy refers

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[9]The outcome variable was normalized F2 for /ow/ and /uw/, and normalized F2 minus normalized F1 for /aw/.
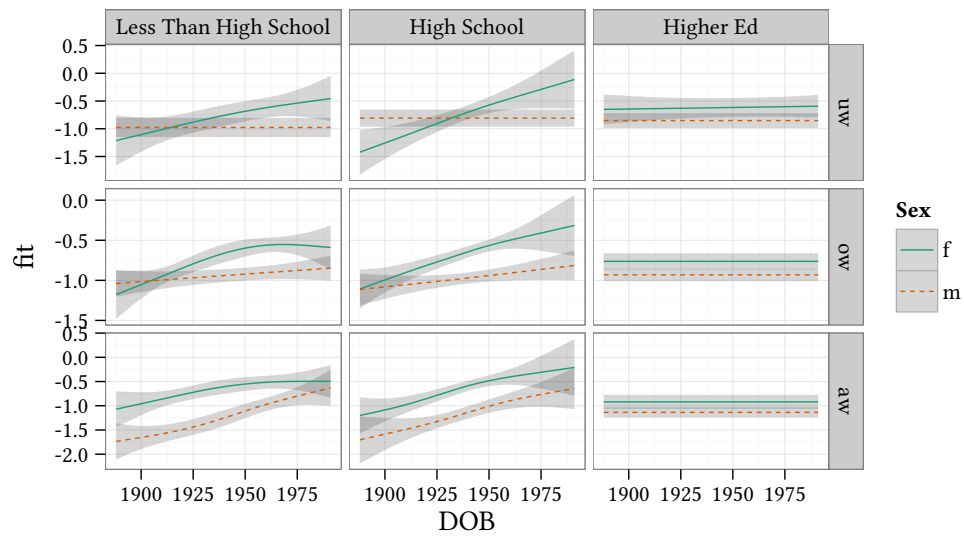
Figure 5.34: Cubic regression spline fits from the generalized additive mixed effects models.
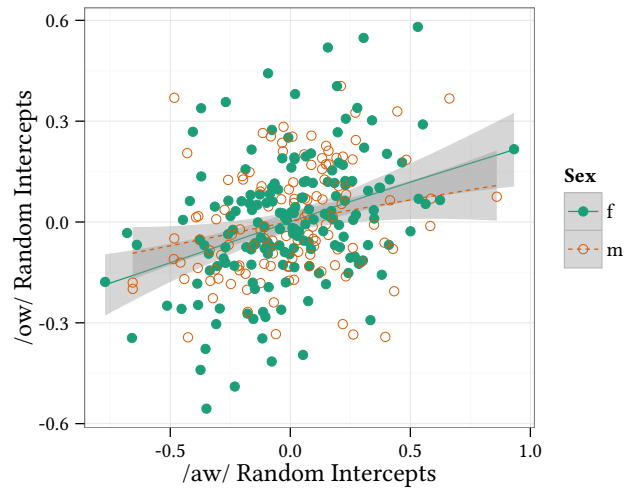

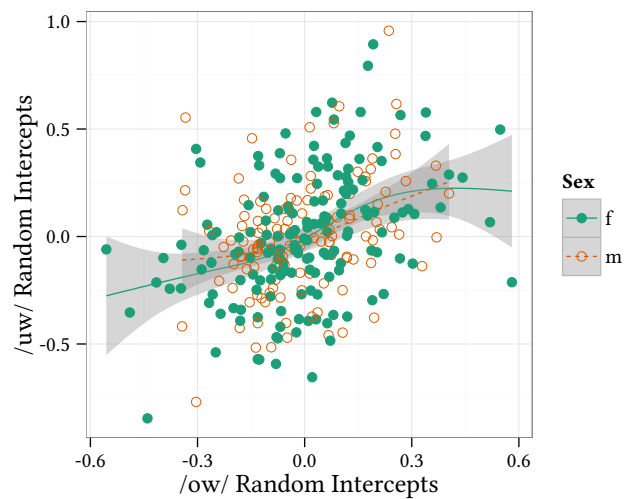Figure 5.35: The relationship between /aw/ and /ow/ across speakers.

Figure 5.36: The relationship between /uw/ and /ow/ across speakers.
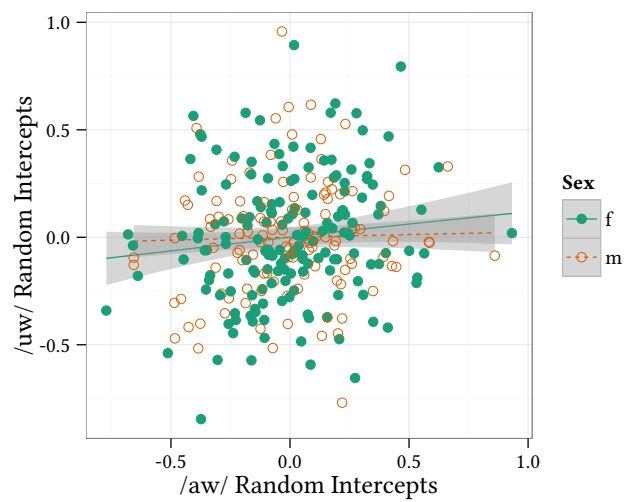

Figure 5.37: The relationship between /uw/ and /aw/ across speakers.

to a process in which a likening between two entities, along some definable dimension, in this case phonetic (and/or possibly phonological) is drawn between two entities, by a speaker." The substantive difference between Durian's proposal and the one put forward here is how we propose the fronting trend generalizes to all [+Vw] vowels. Durian cites the fact that the conditioning effects of preceding coronals are so similar between /uw/ and /ow/ as evidence that fronting is generalizing from *context to context.* The degree of fronting of /uw/ when preceded by /s/ analogizes from /suw/ to /sow/, and so on, essentially turning the parallel fronting of /uw/ and /ow/ into multiple simultaneous changes, one for each phonetic context. My proposal is that there is only one change, and it is to the phonetic implementation of [+Vw], which drags along all [+Vw] vowels with it. I attribute the fact that the conditioning is so similar across phonetic contexts to the uniform and independent set of coarticulatory processes in the language. If the effect of preceding coronals or following fricatives is strictly due to natural acoustic or coarticulatory phenomena, then they *should* be consistent across phonetic context. Ultimately, the appeal to phonetic analogy and my appeal to phonetic implementation of phonologial features will be able to account for most of the same phenomena. I believe that my approach will prove to be more fruitful, however. It is more restrictive, meaning it predicts fewer kinds of possible sound changes than phonetic analogy, and it provides a linking hypothesis between observed phonetic changes and phonological representation, meaning that it can lend support to other sorts of phonological investigation. For example, the fact that {aw, ow, uw} are a phonologically active set of vowels (losing their glides when followed by /l/) and the fact that they all front in parallel are intrinsically related, under my account, to the fact that they have a shared phonological feature which I am calling [+Vw].

5.2.2   Long-ingliding vowel lowering in Philadelphia

Another parallel vowel shift in Philadelphia is the lowering of /oh/ and /æh/. Like the broader Mid-Atlantic region, Philadelphia's realization of /oh/ is a mid tense ingliding vowel, ranging somewhere from [ɔː] to [ɥə] (Labov, 2001, 2006; Labov et al., 2006). Also, like New York City, Philadelphia has a split short-a system, with one allophone being tensed and raised under a num-

ber of complex conditions to something between [æ̞ə] and [iə]. Both of these vowels are undergoing change in both Philadelphia and New York City. Becker and Wong (2010) report that the complex conditioning of /æh/ is breaking down in favor of something more like a nasal system, and Labov, Rosenfelder, and Fruehwald (2013) found a similar pattern in younger speakers in Philadelphia. Also, Becker (2010) found that /oh/ was lowering among white New Yorkers on the Lower East Side, and Labov, Rosenfelder, and Fruehwald (2013) found a similar pattern obtaining in Philadelphia. For the sake of this discussion, the reorganization of the Philadelphia short-a system to a nasal system is an orthogonal issue. I am strictly interested in whether the tense and ingliding short-a is moving in parallel with tense and ingliding /oh/, so the tokens of short-a under consideration here are those which would be tense under either phonological system, meaning only short-a which appear before front nasals /m, n/ in closed syllables. Figure 5.38 plots the relationship between /oh/ and /æh/ height, and there is a substantial correlation, similar in magnitude to what Labov (2006, [1966], p.349, Fig 14.1) found in New York City. Using the same correlation statistics as we did for [+Vw] fronting above, we can see similarly strong and statistically significant correlations for [+Vh] height in Table 5.11.
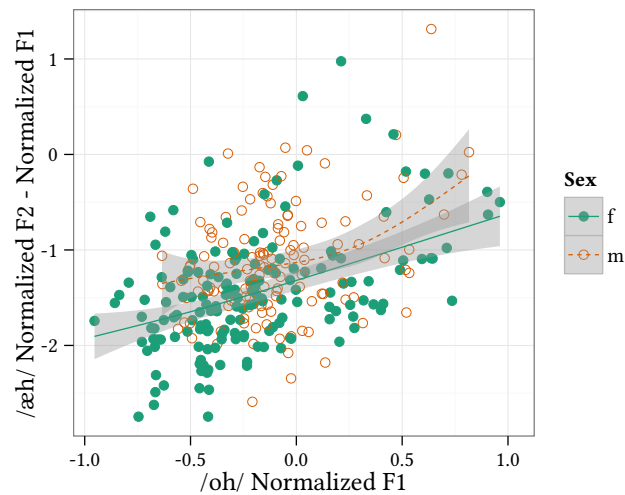

Figure 5.38: The correlation of /oh/ and /æh/ in Philadelphia

Again, the argument could be made that the correlation between /æh/ and /oh/ could be due to social rather than phonological factors. Both raised /æh/ and /oh/ are subject to negative social

	Pearson's r		Spearman's ρ		Kendall's τ	
/uw/~/ow/	0.43	($p < 0.001$)	0.39	($p < 0.001$)	0.27	($p < 0.001$)

Table 5.11: Correlation of /oh/ and /æh/ across speakers.

evaluation (Labov, 2001), and Labov, Rosenfelder, and Fruehwald (2013) found that both education and gender had an effect on the height of both of these vowels. Just like I did for [+Vw] vowels, I fit a generalized additive mixed effects model for each vowel for each gender and educational level where the outcome variable was predicted by a cubic regression spline over date of birth. Random intercepts for speaker and word were also included, and the speakers' random intercepts taken to indicate the individual level variation which was not explained by the other effects. Figure 5.39 plots the by speaker random intercepts for /oh/ and /æh/ against each other. The same basic correlation still exists after accounting for social factors, as the correlation statistics for the random intercepts show in Table 5.12.
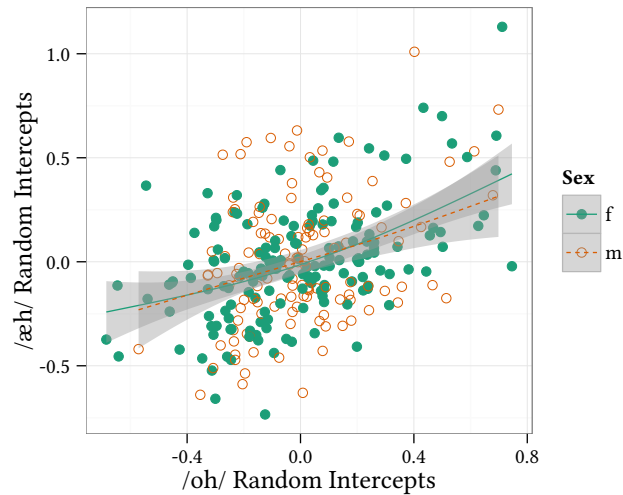

Figure 5.39: /oh/ and /æh/ Random Intercepts

	Pearson's r		Spearman's ρ		Kendall's τ	
	means	random effects	means	random effects	means	random effects
/oh/∼/æh/	0.43	0.43	0.39	0.36	0.27	0.25

Table 5.12: Comparison of correlation statistics based on speaker means to those based on random effects for /oh/ and /æh/.

5.2.3 Searching for more parallel shifts.

Parallel shifts seem to suffer from having been under-labeled. The conceptual notion of "chain shifts" is relatively salient in the field, and subsequently many sound changes are described in terms of chain shifting. Parallel shifts, on the other hand, are much less commonly described, but this may not be due to their rarity in reality. Durian (2012) points out, for example, that the relatively obvious case of parallel [+Vw] fronting, has occasionally been described as being a chain shift, even though its mechanics must be different. If the concept of parallel shifting becomes more salient in the field, my belief is that more sound changes will be described as such. Labov (2010, ch 5) addresses the question of whether all chain shifts could be recast as parallel shifts of a sort. The last two stages of the Southern Vowel Shift, for example, is the lowering of /ey/ and /iy/ to a non-peripheral position, a process which could be described in my framework as a change in the phonetic implementation rule for non-low front upgliding vowels.

$$(5.44) \quad \begin{bmatrix} \text{Vy} \\ \text{-low} \end{bmatrix} \rightsquigarrow 0.5 \text{ Diag}$$

However, Labov (2010) stresses the importance of "bends in the chain of causality," where the initial trigger for the subsequent changes cannot be subsumed into the same generalization which describes them. Keeping with then Southern Vowel Shift Example, the triggering change is argued to be the monophthongization of /ay/ (Labov et al., 2006). Whether /ay/ monophthongization is a phonological or phonetic process, it cannot be subsumed under the generalization in (5.44). The same point can be made about the low-back merger of /ɑ/ and /ɔ/ triggering the Canadian Shift. So while the notion of sequential, chained, movement is applicable to the triggering of many shifts, a large portion of the subsequent shifts can be recast as parallel. In this section, I'll briefly

discuss some examples of phonetic changes which I believe could be parallel shifts, even though they have not been described as being so.

[+Vw] glide fronting in Southern British English

In their description of koine formation in the town of Milton Keynes, Kerswill and Williams (2000) provide the following transcriptions as possible innovative variants of the [+Vw] vowels.

(5.45) /uw/ [ʉ̟ː], [yː]

/ow/ [ɐʏ], [ɐɪ]

/aw/ [æʊ], [aːə], [ɛː], [ɛʉ̯], [ɛɪ]

Of particular interest to me here is the possibility of fronting the glide in /ow/ and /aw/. Kerswill and Williams (2000) don't describe how common the fronted glide is for /aw/, nor how the frontness of the /aw/ glide might covary with the frontness of the /ow/ glide, but glide fronting is a striking possibility especially when compared to North American [+Vw] fronting. For the most part, when the nuclei of [+Vw] vowels front in North America, the glide retains its high back target.[10] It would seem that in Southern British English, the phonetic implementation of [+Vw] which is changing not only affects the nucleus, but the glide as well. The stand out exception would appear at first to be /uw/, which Kerswill and Williams (2000) describes as fronting as a long monophthong. However, Chládková and Hamann (2011) provide an acoustic analysis of Southern British English /uw/ fronting and find that, in fact, fronted /uw/ is diphthongal with a backward trajectory.

There are two important facts here. First, the same sort of phonetic change (fronting) is affecting the same sets of vowels, but result in two different kinds of phonetic outcomes highlights the non-triviality of phonetic change. Presumably, North American and Southern British English speakers have comparable articulatory and perceptual systems such that the fact that North American [+Vw] fronting retains a back glide target and SBE [+Vw] fronting includes the glide cannot be explained on grounds of such naturalness. The second important fact, however, is that

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[10]In Philadelphia, the glide may lower to [ɔ], but it certainly doesn't front.

even though North American and Southern British English differ from each other, they are internally consistent. If in North America, the glide for /ow/ fronted while the glides for /uw/ and /aw/ remained back, or vice versa for Southern Britain, that would be inexplicable under my account of changing phonetic implementation rules. The fact that the fronting is consistent within each country suggests that within each country there is not three separate fronting processes, but rather *one*. In North America there is one change occurring to the phonetic implementation rule for [+Vw] which leads to a fronter nucleus, and all [+Vw] vowels are affected. In Southern British English, there is a different change occurring to the phonetic implementation rule for [+Vw] which leads to fronted nuclei and glides, and all [+Vw] vowels are affected.

GOAT and FACE **diphthongization in the North of England.**

Haddican et al. (forthcoming) report on a change in /ow/ and /ey/ in York, UK, where they are diphthongizing from traditional [eː] and [oː] to [eɪ] and [oʊ], respectively. Figure 5.40 is from Haddican et al. (forthcoming), and plots the relationship across speakers in the diphthongality of /ey/ and /ow/, measured using the Euclidian distance between vowel onset and 90% into the vowel. The correlation in these two measures is much stronger than the ones presented already in this chapter. Haddican et al. (forthcoming) report a significant Spearman's ρ of 0.9.

Watt (2000) reports a similar kind of trend in Tyneside English which is complicated by the fact that ingliding variants of /ey/ and /ow/ ([ɪə] and [ʊə], respectively) are possible. Watt (2000) finds that use of ingliding variants tracks understood patterns of covert prestige, and is used the most by working class men. However, the overall rate of ingliding variants decreases with age, and the rate of diphthongal variants is increasing. The rate of use of each kind of variant is tightly correlated across speaker groups and stylistic contexts. Watt (2000) rejects the kind of internally motivated parallelism that I am advocating here, largely because his data does not support the historical development of these vowels that many people have argued for, namely that given in (5.46).

(5.46)
$$
\begin{matrix}
\text{eː} & & \text{ɪə} & & \text{eɪ} \\
& \rightarrow & & \rightarrow & \\
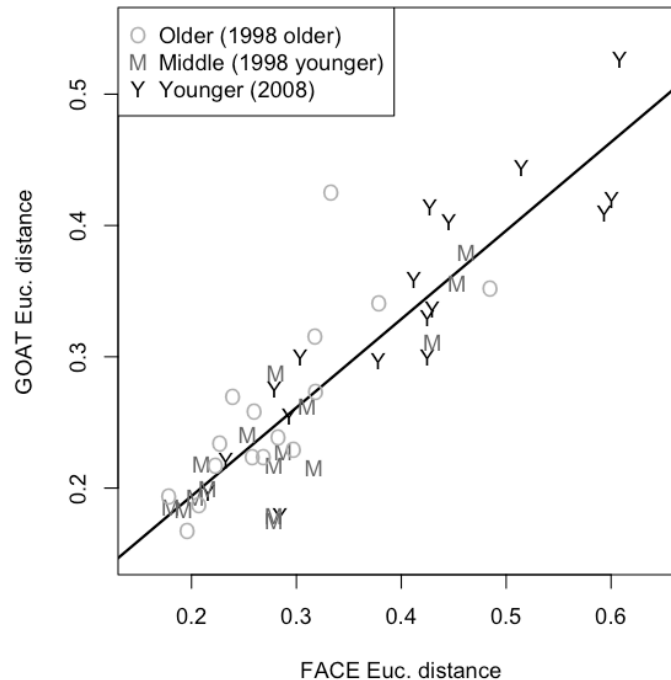\text{oː} & & \text{ʊə} & & \text{oʊ}
\end{matrix}
$$

Figure 5.40: The relationship between /ow/ and /ey/ diphthongization. Figure from Haddican et al. (forthcoming, Figure 2)

Rather, he argues that the introduction of the diphthongal [eɪ] and [oʊ] is introduced through a process of dialect leveling. As I argued for the case of [+Vw] fronting above, however, while the motivation for a particular sound change may be socially defined, we must also explain which set of sounds the change applies to, and which are excluded in some way, and in this case, as it was for [+Vw], there is an obvious phonological dimension at work. The combination of a social evaluation with a phonological dimension across which it applies has the greatest explanatory adequacy.

The parallel diphthongization of /ey/ and /ow/ in Northern British English is a nice example of a phonetic change which is not just a movement along the front/back or high/low dimension. Here, what is changing is the phonetic realization of the long mid vowels, or perhaps just the phonetic realization of their second mora, depending on how we want to represent diphthongs phonologically.

5.2.4 Parallel Shifts are Changing Phonetic Implementations of Phonological Features, but there are Complications

As I've been making the argument that parallel phonetic changes are the result of changing phonetic implementations of phonological features, I have not tried to provide a formalization of this process. There are a few reasons for this. To begin with, the data I am working with are formant measurements of vowel nuclei, but it is not clear whether the mental representations of phonetic form are the same as these formant measurements. Redoing this study with articulatory measurements would probably not resolve the issue (although it would certainly reveal other interesting properties (Mielke et al., forthcoming)), since it is not altogether clear that the mental representation of phonetic forms is strictly articulatory either. As Pierrehumbert (1990) pointed out, "[p]honetic representation is one of the most difficult problems in linguistics," and I will not be attempting to resolve that problem here. Instead, I'll refer to these changes as occurring along abstract phonetic dimensions, like "backness" or "diphthongality," which can be reinterpreted in acoustic or articulatory terms as necessary.

Aside from taking the phonetic measurements too literally, a second problem is that a number of the natural classes which are moving in parallel require multiple phonological features to define them under most feature theories. For example, the parallel retraction of the short front vowels in Montreal and Columbus does not include the front long vowels. Taking into account that for the moment we should understand the phonetic dimensions that phonology-phonetic interface rules map to as being more abstract than just literal acoustic or articulatory dimensions, the interface rule at the beginning of the phonetic change would have to look something like (5.47), where the possible values for the phonetic dimension of backness are understood as ranging from 0 to 1. The interface rule in (5.48) is a later stage, as the vowels have moved further back.

$$(5.47) \quad \begin{bmatrix} -\text{back} \\ -\text{long} \end{bmatrix} \rightsquigarrow 0.1 \text{ backness}$$

$$(5.48) \quad \begin{bmatrix} -\text{back} \\ -\text{long} \end{bmatrix} \rightsquigarrow 0.3 \text{ backness}$$

It is crucial that the long front vowels be excluded from undergoing this change. One option to avoid using two features to pick out the set of short front vowels for undergoing this change would be to define an ad hoc emergent feature (in the sense of Mielke (2008)) for this class, perhaps [+V̌]. However, if the phonetic frontness of these short front vowels were determined by this [+V̌] feature, then the phonetic frontness of /iy/ and /ey/ would be phonologically accidental, meaning /iy/ and /ey/ would not fall into a phonological natural class with /ɪ/, /ɛ/ and /æ/ with respect to frontness. While this is not necessarily undesirable *a priori*, there is some empirical evidence to suggest that /iy, ɪ/ and /ey, ɛ/ minimally differ. For example, a number of dialects neutralize these vowels before /l/ (Labov et al., 2006), leading to the *feel∼fill*[11] and *bail∼bell* merger. If the phonological representation for /iy, ey/ were [−back, +long], and the phonological representation for /ɪ, ɛ/ were [−back, −long], the process of neutralization before /l/ could be understood as (5.51) or (5.50).

(5.49) $\begin{bmatrix} -\text{back} \\ +\text{long} \end{bmatrix} \rightarrow [-\text{long}]/\text{___}l$

(5.50) *[+long]l

However, if the phonetic backness of /ɪ, ɛ/ were not defined by the same phonological feature as it is for /iy, ey/, then to map /iy/→/ɪ/, we would need to eliminate /iy, ey/'s specification for the phonological feature [±back], and replace it with with the phonological feature for /ɪ, ɛ/, a decidedly more complex process.

(5.51) $\begin{bmatrix} -\text{back} \\ +\text{long} \end{bmatrix} \rightarrow \begin{bmatrix} \cancel{\text{back}} \\ \cancel{\text{long}} \\ +\text{V̌} \end{bmatrix}/\text{___}l$

The phonological inelegance of the above proposal also has empirical problems on the basis of parallel shifts. For example, for the sake of expository clarity, I defined an *ad hoc* phonological feature [+Vw] which defines /uw, ow, aw/ as a natural class. However, in a number of regions of the Midland and South, back vowel fronting *also* affects /ʊ, ʌ/(Labov et al., 2006; Fridland, 2001;

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[11]http://val-systems.blogspot.com/2008/04/feel-bag.html

Labov, 2010). In Philadelphia, where this is not the case, the back vowel fronting change could be
formalized as in (5.52)[12]

$$(5.52) \quad \begin{bmatrix} +\text{back} \\ +\text{long} \end{bmatrix} \rightsquigarrow 0.9 \text{ backness } > 0.8 \text{ backness}$$

In the Midland and South, on the other hand, the phonological definition of the vowels undergoing
the change is more underspecified, thus pulling in more vowels.

$$(5.53) \quad [+\text{back}] \rightsquigarrow 0.9 \text{ backness } > 0.8 \text{ backness}$$

The conclusion to be drawn from this discussion of parallel shifts is that while they present
fairly clear evidence that phonological natural classes as defined by phonological features are
targets of phonetic change, the implications of this result depends a great deal on the theory of
phonological representation and of phonetic implementation one wants to adopt. Minimally, it
must be the case that the objects which are the targets of phonetic change must also be the inputs
to phonetic implementation. If the process of phonetic implementation is restricted to map just
one phonological feature to one phonetic dimension, then a more complex theory of phonological
representation and computation is necessary to account for problems like harmonizing the retrac-
tion of just the short front vowels with their phonological relationship to the long front vowels.
If the phonology phonetics interface can map bundles of features to phonetic dimensions, then
the problem becomes one of limiting the power of the interface rules. For example it would be
undesirable for $[-\text{back}, -\text{long}]$ to map to a very back target, and have $[-\text{back}, -\text{long}, +\text{low}]$ map
to a very front target, because it would eliminate the isomorphism between phonetic quality and
phonological relatedness which is both the primary cue for linguists doing phonological analysis,
and presumably also language learners.

Proposing a resolution to this problem would be an overreach at the moment, but I hope to
have at least demonstrated that studying patterns of language variation and change will prove
central to resolving them.

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[12]I set aside here the extra complication that /aw/ is probably not phonologically [+back] in Philadelphia.

5.3 Conclusions

In this chapter I have reported and analyzed results with two overarching patterns.

(5.54) Divergent patterns of change within a vowel category which are best attributed to categorical allophones created by the phonology.

(5.55) Parallel, or convergent patterns of change across vowel categories which are best attributed to phonetic change targeting phonological natural classes.

These examples highlight the key thesis of this dissertation that gradient phonetic changes must be understood in terms of their relationship to categorical phonological representations. As a consequence, a full understanding of these changes can't be obtained without also attempting to understand the system of phonological representation, organization and computation, but at the same time, these changes provide valuable evidence for trying to understand the systems of phonological representation, organization and computation.

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