Problems in Attic-Ionic Phonology
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1. Introduction
The purpose of the present paper is to analyze a set of changes in the Attic-Ionic Greek vowel system that hold interest for both historical linguists and phonological theorists. I hope to shed some light on some of the prehistoric and historical developments within the Attic-Ionic dialect group throughout the first millennium BCE by securing a relative—and, to the extent that it is possible, absolute—chronology of changes to the vocalic system of these dialects, focusing particularly on the Attic-Ionic vocalic chain shift and the Attic reversion (‘Rückverwandlung’), and by examining the phonetic motivations that led to such dramatic phonological restructuring. Finally, I discuss the import of this series of changes as it pertains to the controversy surrounding the empirical and theoretical motivations for the “push chain” mechanism.

2. Historical background
The Proto-Greek vowel system had five short vowels—two high, two mid, and one low, each with a long counterpart. This system essentially continued the Proto-Indo-European system; Greek short vowels represent PIE short vowels, while Greek long vowels represent PIE long vowels or short vowel + laryngeal sequences (Sihler, 1995: 35). I schematize the Proto-Greek vowel situation, which is also attested in Mycenaean inscriptions from the second millennium BCE, in (1) below.

(1) The Proto-Greek vowel system ca. 1800BC (Bartoněk, 1966)

\[
\begin{array}{cccc}
\text{i} & \text{u} & \text{i}: & \text{u}:\\
\text{e} & \text{o} & \text{e}: & \text{o}:\\
\text{a} & \text{a}: & \\
\end{array}
\]

We will be focusing on the Attic-Ionic dialect group. Proto-Attic-Ionic was probably spoken near Attica in the early first millennium BCE. Attic can be seen as distinct from at least some varieties of Ionic by the early eighth century BCE, simply by virtue of Ionian
colonization of the west coast of Asia Minor during this time period, which isolated what would become the East Ionic dialects. Specialists identify three dialect groups within Ionic, all of which were distinct by 500 BCE: West Ionic spoken in Euboea and north of Attica, Central Ionic spoken in the Cyclades, and East Ionic spoken in Asia Minor, south of Smyrna (Buck, 1965).

Unlike most of the other dialect groups, Attic-Ionic did not merge the results of compensatory lengthening and contractions with the inherited long mid vowels. They instead created another set of long mid vowels, higher than and distinct from the original two. These are known as the ‘spurious diphthongs,’ orthographically represented by <ει> and <ου> in the standardized Attic system. The inherited [ej] and [ow] diphthongs merged with these vowels by the fourth century BCE in Attic-Ionic.¹ The result of the new mid vowels was a system like the one in (2).

(2)  The (early) Proto-Attic-Ionic vowel system, ca. 1000 BCE

\[
\begin{array}{cccc}
i & \text{u} & \text{i:} & \text{u:} \\
\text{e} & \text{o} & \text{ɛ:} & \text{ɔ:} \\
\text{a} & \text{ɛ:} & \text{ɔ:} & \text{a:} \\
\end{array}
\]

The Northwest Greek dialects, Megarian, Corinthian, and East Argolic also followed the Attic-Ionic pattern, though they differed slightly in the details of exactly what went into the “secondary” mid vowel category. Pamphylian, East Aegean Doric, West Argolic, and Cretan had four height distinctions as well, but they derived this system in other fashions (Bartoněk, 1966. In particular see p. 61 for a chart summarizing the dialectal differences). Though symmetric, from a Structuralist perspective the four distinctions of height among

¹ The Boeotian adoption of the Ionic alphabet (probably via Attic) provides a terminus ante quem: the first half of the fourth century BCE. At that time, the Boeotians adopted <ου> for writing monophthongal [u] (Bartoněk, 1966: 80). The Boeotian borrowing will be important for dating the [u] > [ʊ] and [ɔ:] > [u:] shifts, and we will return to this fact shortly.
the long vowels was an inherent source of instability for the group of dialects with this type of vowel system (Martinet, 1952, 1955; Ruipérez, 1956; Bartoněk, 1966; Szemerényi, 1987 [1968]). Over the first millennium BCE, the system of Attic-Ionic underwent numerous changes, some common to the whole Attic-Ionic group and others unique to a subset of the dialects.

Even prior to the first Attic inscriptions, Proto-Greek /a:/ raised and fronted, ultimately merging with /ɛ:/ in Attic and Ionic. Many linguists explain this as the first of many changes which began to alleviate pressure in the crowded back series of the long vowel system (Ruipérez, 1956; Bartoněk, 1963, 1966; Szemerényi, 1987 [1968]). Orthographic evidence supports the view that [a:] raised to [ɛ:] through the intermediate value [æ:]. Cycladic Ionic inscriptions directly attest a three-way distinction between [a:], [æ:], and [ɛ:]. Most notably, the well-known Nikandre inscription from the island of Naxos (late 6th century BCE) has etymological /*e:/ represented by <Ε>, etymological /*a:/ represented by <H>, and new /a:/ from compensatory lengthening represented by <A> (inscription and analysis available in Buck, 1965: 190; cf. also Gates, 1976: 190). From this one can conclude that [æ:] did not merge with [ɛ:] in Cycladic until sometime after the sixth century BCE. This interpretation is quite uncontroversial and appears in virtually the same form in the standard reference works on Greek, such as Allen (1974), Buck (1965), Sihler (1995), and Smyth (1956).

Of course, the Cycladic situation does not reflect on the date of the merger in the other Attic-Ionic dialects. Any history of Attic-Ionic must also explain why [a:] fronted in the first place. Let us set this issue aside for the time being, because in many respects [a:]-fronting parallels [u:]-fronting, which we will see shortly. The reader should note that the [a:] to [æ:] shift is a case of the “inception problem” (Lass, 1976): it seems easy enough to explain the collapse of [æ:] and [ɛ:], but in order to get to the stage at which merger becomes possible, the [æ:] must first develop for independent, as yet unidentified reasons.
Later, the loss of /n/ in –Vns- clusters resulted in lengthening of the vowels in these environments (Smyth and Messing, 1956: 14). This change is commonly known as the second compensatory lengthening.\(^2\) The result of \(<\alpha>\) undergoing the second compensatory lengthening yielded a new [a:] phoneme, not [æ:], and can thus be conclusively dated after the [a:] > [æ:] shift. The second compensatory lengthening yielded uniform results in all Attic-Ionic dialects, so it must have occurred before the dialects split; this implies that the [a:] > [æ:] shift happened during the Proto-Attic-Ionic period. At this stage, according to conventional wisdom, it was the long front vowels that suffered from overcrowding.\(^3\)

After Attic had split off from Ionic, the remaining /æ:/ merged with /e:/ in both Attic and Ionic independently, returning the system to its former, four-height-distinction, symmetric state. Evidence for dating the merger after the Attic-Ionic split comes from the Cycladic inscriptions mentioned above, which show a three-way distinction and therefore preclude the possibility of a Proto-Attic-Ionic merger. Other evidence comes from the “Attic reversion,” which resulted in differing treatments of /æ:/ after {e, i, r} in Attic and Ionic. This reversion is the subject of §3.

\(^2\) The first compensatory lengthening, also a Proto-Attic-Ionic change, involved loss of [h] (derived from Proto-Greek *s and *) in certain sequences. The [a:] created by the first compensatory lengthening did feed into the [a:] > [æ:] change, so it must have occurred prior to any of the other changes we are discussing.

\(^3\) An alternative interpretation, suggested to me by Jeremy Rau, holds that the introduction of new /a:/ from compensatory lengthening actually preceded and caused the fronting of old /a:/: Since the new /a:/ was the result of denasalization, there was most likely an intermediate step in which the nasal consonant was lost but nasality remained on the vowel. This is supported by the eventual result of compensatory lengthening—nasalized vowels tend to be longer than corresponding oral vowels (Whalen and Beddor, 1989). This nasalization could have originally supported the old /a:/ ~ new /a:/ ([ã:]) distinction, but the distinction could have later been transferred to the front/back axis prior to or concurrent with loss of nasality. Thus, polarization of the two /a:/ phonemes would have resulted, with original [ã:] becoming [æ:] and previous [ã:] remaining further back. Note that such polarization can easily be explained as motion by both vowels towards perceptual equidistance, as would be predicted by the same mechanism in Blevins’ (2004) framework that accounts for (pull) chain shifting.
The next phase of vocalic changes takes us from this merger of [æ:] and [ɛ:] and into the period of back-vowel chain shifting discussed in §4. After motivating and dating the developments that led to the [æ:] ~ [ɛ:] merger, it will be possible to trace the developments of the [originally] back long vowels. These developments include the fronting of [u:] to [ū:] and the raising of [ʊ:] to [u:], a sequence which numerous introductions to historical linguistics cite as the flagship example of a push chain.

3. The Attic reversion

3.1 Data & motivation

Historians of the Greek dialects have long recognized that the Attic-Ionic dialect group differed from the other dialect groups in its treatment of the [a:] inherited from Proto-Indo-European. While dialects typically maintain this sound as [a:] (〈ᾱ〉 in Greek orthography), in Attic-Ionic the inherited [a:] merged with inherited [e:], written in the standard Ionian alphabet as 〈η〉. In Attic, however, this development proceeded somewhat idiosyncratically. In many cases after {e, i, r} (i.e., {ε, ι, ρ}), Attic exhibits α rather than the expected η. A summary of the correspondences among the dialect groups is provided in (3) below.

(3) Correspondences between Attic, Ionic, and common Greek */a:/ forms

<table>
<thead>
<tr>
<th>gloss</th>
<th>Attic</th>
<th>Ionic</th>
<th>other dialects</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘honor’</td>
<td>τιμή</td>
<td>τιμή</td>
<td>τιμά</td>
</tr>
<tr>
<td>‘country’</td>
<td>χώρα</td>
<td>χώρη</td>
<td>χώρα</td>
</tr>
<tr>
<td>‘house’</td>
<td>οἰκία</td>
<td>οἰκίη</td>
<td>οἰκία</td>
</tr>
<tr>
<td>‘new’</td>
<td>νεά</td>
<td>νεή</td>
<td>νεά</td>
</tr>
</tbody>
</table>

As we have already seen, [a:] raised to [e:] through the intermediate value [æ:], as attested in Cycladic Ionic inscriptions with a three-way distinction between [a:], [æ:], and [e:]. These inscriptions represent etymological */e:/ with 〈Ε〉, etymological */a:/ with 〈Η〉, and new /a:/ from compensatory lengthening with 〈Α〉. Differences of opinion begin to arise when we consider the question of how the Attic system came to have the pattern of
exceptions we noted in (3). Two logical options have been explored in the literature. Some authors have opined that [a:] never raised to [æ:] in Attic after {i, e, r}, while others have proposed that the change did proceed in all contexts in Attic as well as Ionic, but that later a reversion of [æ:] to [a:] occurred in certain environments in Attic alone. Coming from a phonological perspective, we might ask ourselves how this alleged reversion occurred. The three phonemes in question, /a/, /i/, and /r/, do not prima facie seem to have anything in common that might trigger a lowering and/or backing effect on [æ:].

The “traditional” or “linguistic” view (Brandenstein, 1954; Gates, 1976; Lejeune, 1972; and many others) of Greek historical phonology holds that the development of [a:] to [æ:] was a Proto-Attic-Ionic sound change. Under this analysis, Attic once exhibited the change to its fullest degree, and only later underwent a change taking [æ:] back to [a:] in certain environments. Other Greek scholars, most notably Schwyzer (1939), have proposed models in which the change from [a:] to [æ:] was never fully completed after {e, i, r}. Because all these changes are prehistoric in Attic-Ionic, there is no written record to help us distinguish between these two proposals and their numerous variants—a fact which the authors admit. In Appendix A, I give a representative sample of the wide range of analyses that have been proposed. It would require extensive commentary on orthographic practices, analogical comparanda, and etymological speculation to compare the relative merits of each analysis in the literature, and even then, a thorough refutation of any possibility would be impossible due to the inherent uncertainty of statements regarding linguistic prehistory. For that reason, here I focus only on what I believe is one very plausible relative chronology from a phonological perspective, and touches only lightly on defending it against alternatives.

Put simply, in the absence of an extraordinarily fortuitous archaeological find, we will never be able to know whether the [a:] to [æ:] change proceeded to completion in Attic. Recent exemplar-based models of sound change, however, can help lead a linguistic investigator to a likely scenario. I propose that the [a:] > [æ:] shift in Attic can be viewed in much the same way as /ow/-fronting in American English, as discussed by Labov (1994 et seq.) in recent work. For example, while /ow/ is generally fronted in many
dialects of American English, this fronting seems to be blocked by an /l/ following the vowel. Phonetically, the backing and rounding seems to be an effect of the vocalization of /l/ in these dialects. A group of “laggards” with exemplars clustering on the margin of a phonemic category thanks to phonetically-conditioned effects—/owl/ words, in this case—can split off from the original phoneme and stand alone as a separate category.

It is easy to see how such a scenario might translate to Greek. Perhaps the shift of [a:] to [æ:] did occur in all positions in Attic, but phonetic factors caused the pronunciation of the new [æ:] to remain a bit more open after some segments, namely {r, i, e}. The lowering effect of rhotics on a following vowel is very well documented (see Walsh Dickey, 1997:134 for an extensive list). Also, under an analysis of [a] as pharyngeal, following Delattre (1971), McCarthy (1994), and numerous others, the lowering to a more [a:]-like vowel after the rhotic can be explained as the spreading of [pharyngeal]. Dell & Tangi (1993) and Walsh Dickey (1997) have posited such occurrences for other languages. The lowering effect of [i] and [e] on [æ:] can be explained as dissimilation (Szemerényi, 1987 [1968]), especially since independent evidence shows us that Greek used many strategies to avoid having similar vowels immediately adjacent to one another. In other cases in the language where two front vowels came into hiatus, contractions or other repair strategies occurred. The one obvious counterexample is the verb ἴημι, which is a reduplicated form (< *h̥(i)h̥-i-<h̥i-h̥h̥i-h̥h̥h̥i-h̥1-h̥i-h̥i>) and could easily have been analyzed as hi-he:-mi by the desire for reduplicant-base identity even after the early loss of intervocalic [h].

At some early stage, then, I believe Attic had an [æ:] phonemic category with allophonic variation producing a lower version of the vowel after /r/ and {i, e,} for independent reasons. Later, the loss of /n/ in –Vns- clusters and resonants (with the exception of /r/) in –VsR- clusters resulted in lengthening of the vowels in these environments (Smyth and Messing, 1956: 14). This change is commonly known as the second compensatory lengthening. The result of ⟨α⟩ undergoing the second compensatory lengthening yielded a new [a:] phoneme, not [æ:], and can thus be conclusively dated after the [a:] > [æ:] shift. Since the second compensatory lengthening was uniform across Attic-Ionic dialects, this implies that the earlier [a:] > [æ:] shift also happened during the Proto-Attic-Ionic and precludes any analysis of Attic that does not assume [a:] > [æ:] in all environments. After
the re-introduction of [a:], in the new Attic dialect the low /æ:/ allophone would have severed its ties to /æ:/ and fallen together with /a://. Still later, the remaining /æ:/ merged with /æ:/ in both Attic and Ionic independently, relieving pressure in the crowded front sector of the long-vowel system.

Following Peters (1980), I believe the ‘reversion’ (i.e., the category switch from /æ:/ to /a:/) happened in two parts. Others (e.g. Schwyzer et al., 1939) have proposed such an analysis, but their proposals were criticized for being unnecessarily complicated. While it is true that a two-reversion account lacks the “simplicity and economy, one might even add ‘elegance’” of positing a single reversion (Szemerényi, 1987 [1968]: 1340), from a phonetic standpoint the former seems quite reasonable given the fact that the front vowels and /r/ do not form a natural class. Dividing the reversion into two parts allows us to explain both independently, and it accounts for more forms without appeal to analogy.

Further support for separate treatments of the /r/-reversion and the {i, e}-reversion comes from elsewhere in Greek. Other dialects exhibit either rhotic-induced lowering or front vowel dissimilation, while only Attic seems to have had both. Examples of /r/’s lowering effect on neighboring vowels include occasional instances of ⟨ε⟩ substituting for expected ⟨ι⟩ after /r/ in Aeolic and a few scattered examples in Sicilian Doric and Elean (Buck, 1965: 25-26); ⟨ε⟩ also lowered to ⟨α⟩ before /r/ in Northwest Greek (Buck, 1965: 22). Lesbian, Thessalian, and Boeotian all show raising of ⟨ε⟩ to ⟨ι⟩ before ⟨α⟩ or ⟨ο⟩ (Buck, 1965: 21-22), which is in some sense the same dissimilation as in Attic, but with the opposite repair.

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4 The lower /æ:/ allophone could also have been created in two parts, with either the rhotic effect or dissimilation happening first. The collapse of the low post-rhotic allophone with [a:] could have happened relatively early, eliminating the low allophone of /æ:/ entirely, with dissimilation later causing the re-introduction of a low /æ:/ allophone and a second merger with /a:/ . As we will see later, this chain of events seems to mesh best with Peters’ relative chronology.
3.2 Relative chronology

Keeping in mind the sketch I have just drawn of the reversion itself, we can now begin to fit the [a:] to [æ:] and [æ:] to [e:]/[a:] changes into the chronology of Attic-Ionic phonological developments. A number of other vocalic changes in Attic, some of which also occurred in Ionic, interact with the raising of [a:] to [æ:]. We can disregard compensatory lengthening (following resonant loss in –Vns- and –VsR- contexts) because it does not directly interact with the Attic reversion, but we can determine that it happened after the initial [a:] > [æ:] shift since the [a:] resulting from the compensatory lengthening did not merge with inherited /*a:/.

One rather unusual set of Attic changes, also attested in some Ionic forms, had the combined effect of exchanging vowel length in sequences of two consecutive vowels of which [ɛ:] was the first member. These changes collectively are known as quantitative metathesis. One change shortened [ɛ:] to [e] before {æ:, a:, ǫ:}, and a second change affected [ɛ:] before {o, a}, again creating [e] as the first member but also lengthening the second member to 〈ω〉 (i.e., [ɔ:]) in the case of [o] or 〈ᾱ〉 in the case of [a] (Buck, 1965: 41).

We must also account for one of many sets of hiatus-avoidance maneuvers in the history of Greek, this time a couple of contractions involving /eV/ sequences. The string [ɛ:] contracted to [æ:], and [ea] from *eha contracted to [æ:] as well. Finally, the loss of digamma (⟨φ⟩, [w]) must fit somewhere into the picture. Though all Greek dialects lost digamma sometime after the Mycenaean period, different consequences resulted in different dialects, and the change is best viewed as having spread through diffusion. In Attic, loss of digamma did not produce any effects on neighboring vowels, but in East Ionic it caused compensatory lengthening. Also, digamma is attested in a few West and Central Ionic inscriptions, but not in any Attic or East Ionic ones (Buck, 1965: 46). For this reason, I believe the disappearance of [w] in Attic-Ionic occurred after the group had already dissolved.

Of all the sound changes discussed above, only one—the change of [a:] to [æ: ]—seems to have taken place before Attic diverged from Ionic. We can confidently place this change
first in our relative chronology. To help fix the rest of the ordering, we have several unusual Attic ⟨α⟩ and ⟨η⟩ forms at our disposal. A list of these forms appears in (4) below.

(4) Unexpected and/or informative Proto-Attic-Ionic forms
a) /ea:/ contraction – *argurea: ‘silver’ (f.nom.sg) \(\rightarrow\) Attic ἀργυρά
b) /ea/ (from /eha/) contraction – *orea ‘mountains’ (n.nom/acc.pl) \(\rightarrow\) Attic ὀρη
c) Intervocalic digamma – *newa: ‘new’ (f.nom.sg) \(\rightarrow\) Attic νέα
d) Half-contraction – *kʰreea ‘debts; matters’ (n.nom/acc.pl) \(\rightarrow\) Attic χρέα
e) Intervocalic digamma & QM – *para:wa: ‘cheek’ (f.nom.sg) \(\rightarrow\) Attic παρέα
f) Intervocalic digamma, no contraction – *ennewa ‘nine’ (indecl.) \(\rightarrow\) Attic ἐννέα
   But cf. *astewa \(\rightarrow\) ἀστή
g) Postconsonantal digamma – *korwa: ‘maiden’ (f.nom.sg) \(\rightarrow\) Attic κόρη

Because all of these changes predate the written record in Attic, orthographic evidence will not be helpful in establishing the relative chronology. Instead, we are forced to rely on our intuitions about which of the forms in (4) can be trusted to show phonological developments, and which could have been formed by analogy. All else being equal, I believe analogy should be a last resort.

In item (4f) there is a direct contradiction with identical phonetic environments getting different treatments, so analogy must be at play in either ἐννέα or ἀστή. Since ἐννέα is an indeclinable numeral and completely isolated in the language, there is no reason why it should not have developed regularly. (The opposite view, taken by Gates 1976: 47, holds ἐννέα to be “marked lexically as exempt from contraction.” This seems counterintuitive.) On the other hand, ἀστή (by hypothesis from *ἀστεα) could have been formed analogically on the basis of other neuter s-stem nouns, such as ὀρη and γένη. With this assumption made, we can conclude that the [ea] > [æ:] contraction occurred prior to digamma loss.

Separating the /r/-reversion and the {i, e}-reversion allows for the placing of the [ea]-contraction between the two reversions, which helps to avoid an uncomfortable conclusion reached by Thumb & Scherer (1959) and Cauer (1909). They were forced to say that “the contraction product of εα, normally η, is diverted to α by a preceding e, i, or r, except where analogy is stronger (ἡρ, τρήρη, ἐγρηγόρη),” to quote Szemerényi’s
Summary. This explanation is quite unconstrained and not at all explanatory: there is no reason why analogy should be “stronger” for ὀρη and the like than for χρέα, ὑγιά, and ἐνδεά, given that all of those forms once ended with *-eha.

The proposal I therefore adopt is a modification of the “traditional” view, attacked by Schwyzer but modified and resurrected by Peters (1980). It incorporates all of the arguments I have made in this section and the previous one. In (5) I summarize the relative chronology of this account. It has the dual advantages of being phonetically plausible while still generating all the attested forms directly, with the exception of the ἄστη group discussed earlier. In Appendix B, I provide full derivations of the forms in (4) using this chronology.

(5) Peters’ (1980: 297ff) proposal (slightly emended):

a) Unconditioned shift \([a:] \rightarrow [æ:]\) (Proto-Attic-Ionic)
b) Contraction \([æ:] \rightarrow [æ:]\)
c) Dissimilation \([æ:]\ldots[æ:] \rightarrow [ɛ:]\ldots[æ:]\)
d) Reversion: rhotic lowering \([æ:] \rightarrow [a:] / r_\)
e) Contraction \([eа] \rightarrow [æ:]\)
f) Loss of digamma \([w] \rightarrow ø\)
g) Quantitative metathesis \([ɛ:] \rightarrow [e] / _ {æ:, α:, ɤ:}\)
h) Reversion: dissimilation \([æ:] \rightarrow [a:] / \{i, e\}_\)
i) Merger \([æ:] \rightarrow [ɛ:]\)

Not all of these rules are rigidly ordered. For instance, (b) and (c) do not have overlapping domains of application and could easily switch places. Also, digamma loss could have happened in two separate phases, intervocally at one time and post-consonantally at another time. This is not crucial to the analysis, as long as post-consonantal \([w]\) remains through (d) to correctly generate κόρη from *korwa:.

In addition to the rules I mentioned at the beginning of this section, the Peters analysis posits a dissimilation rule (c) to account for παρέα (< *para:wa:). As originally formulated by Peters, the rule would have targeted only \([æ:wa:]\) sequences, but there is some evidence to support a more general dissimilation of two \([æ:]\) vowels in the same word. Szemerényi (1987 [1968]: 1352), building on observations by Vendryès and Tucker, notes that κρήνη (not otherwise expected *κράνη) can be explained this way, as
can a couple of forms in Bacchylides.\textsuperscript{5} I therefore expand (5d) to encompass this range of cases. Finally, we must also modify the quantitative metathesis process to account for the fact that [æː] seemed to have been a trigger as well as [ɛː] and [aː]. Notably, positing a round of quantitative metathesis this late means that this was almost certainly its second application. The set of changes are unusual enough that this is uncomfortable, unless we assume that enough alternations remained in the synchronic grammar to keep the rules active throughout the time period in question.

3.3 Absolute chronology

While, as always, a relative chronology is easier to give than an absolute one, we can date a number of the changes to the front vowels with some degree of certainty. The Nikandre inscription, which maintained the distinctions between [a], [æ], and [ɛː], provides incontrovertible evidence that [æː] remained separate from [ɛː] until the sixth century, at least in Naxos. For Amorgos and Keos, the same argument holds; there the three vowels remained distinct even into the fifth century BCE (Buck, 1965). This fact about the insular dialects says nothing about the situation elsewhere in Attic-Ionic territory, however.

Bartoněk (1963; 1966), Allen (1974) and Ruipérez (1956) insist that the [æː] \(\sim [ɛː]\) merger transpired by 700 BCE, except in the dialects just mentioned, for which they assume that the merger had not yet occurred at the time of the /uː/-fronting we will discuss in the next section. Szemerényi (1987 [1968]: 1346), in direct opposition to the other scholars, retorts that “this is quite impossible, and merely postulated on account of the ‘system’.” He further notes that long α-stem and η-stem nouns remained distinct until the end of the fifth century BCE, and that choral lyric and choruses of tragedies perfectly repair instances of [æː] by lowering them to [aː], without any confusion regarding what belonged to the [æː] class and what had original long /e/. Therefore, Szemerényi follows

\footnote{Forms such as κρήνη and εἰρήνη also show that [aː] developed to [æː] in all environments in Attic, only later undergoing reversion. If this sequence of events had not happened, our dissimilation rule would not have been able to apply to these forms, and they would have yielded the unattested *κρᾱνη, *εἰρᾱνη.}

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the conclusion reached earlier by R.W. Tucker (1962) and Edgar Sturtevant (1940), that the merger took place in Central and West Ionic as well as Attic at various times throughout the fifth century BCE, while only in East Ionic did it happen earlier, possibly as early as 700.

Early inscriptions from Attica and Ionian territory settle this debate. In even the most archaic texts from everywhere but the Cyclades, we see variants of epsilon (<E>) representing etymological /aː/. Specifically, instances of <E> corresponding to what we know to be older /aː/ appear in personal names in Attic graffiti from the late seventh century BCE, and in Euboean inscriptions from c.550 BCE (Jeffery, 1961). If there were still a distinct, phonemic [æː] in the non-Cycladic dialects, one would not expect them to tolerate such orthographic conflation of [æː] and [ɛː]. Moreover, in the choruses that Szemerényi mentions, incorrect “repair” of [æː] > [aː] sometimes occurred, which suggests that the writers no longer maintained this class themselves (Björck, 1950). All this evidence indicates that the merger of Proto-Greek /aː/ (i.e., Attic-Ionic [æː]) and /ɛː/ occurred prehistorically in all these dialects.

4. The Attic-Ionic vocalic chain shift

We now turn to a discussion of changes to the Attic-Ionic back vowels during the first millennium BCE. This chain shift is commonly cited as an example of a “push chain,” that is, a chain initiated by one phoneme encroaching upon another. While the pull or drag type of chain shift is widely attested in vowel, consonant, and tone systems, the push chain has only been seen with vowels and is so rare as to cause alarm; much ink has been spilled on the debate over whether it actually exists. Some linguists have difficulty finding reasons why push chains should be theoretically expected yet defer to empirical evidence that seemingly supports push chains (Campbell and Ringen, 1981), others find the explanations for push chains too reliant on teleology and categorically deny the existence of push chains as a result (King, 1967; King, 1969a; King, 1969b), and still others have no problem with the theoretical underpinnings of the concept but lament the lack of attested examples (Hock, 1986; Trask, 1996). Recently, Labov (1994 et seq.) has also attempted to explain push chains without appealing to teleology. In the discussion to
follow, I will evaluate the purported Greek case with an eye towards determining whether it should actually be categorized as a push chain. This is part of a larger work (Samuels, 2006, 2007) in which I argue that none of the attested examples of push chains—Attic-Ionic, São Miguel Greek, Old Scandinavian, and the American Northern Cities—should actually be classified as such, and that given the difficulty of motivating push chains in modern theory, perhaps it should come as no surprise that they in fact do not exist.

4.1 Evidence & chronology

4.1.1 υ > [ü]

In 403 BCE, the Athenians officially began using the Ionic alphabet, and other groups soon followed suit, abandoning their dialectal variants of the script in favor of the standard version. The Ionic alphabet was primarily characterized by the use of <η>, indicating a long [ɛ:] sound instead of its former phonetic value of [h] (though Ionic shared this feature with some other scripts), and <ω>, innovated for symmetry, indicating a long [o7:] sound (Buck, 1965: 19). Among the groups to begin using the Ionic alphabet in the early fourth century BCE were the Boeotians. When the Boeotians adopted the Ionic system, probably through an Attic intermediary, they used the spelling <ου> for their [u] sound. This indicates that the phonetic value of <ου> in Attic-Ionic by the early fourth century was more similar to [u] than the value of <υ> was (Bartoněk, 1966: 111). Attic-Ionic /u/ must have fronted to [ü] by this time, though the question of whether fronting occurred in Euboean (either it did not, or a reversion took place) remains open (see Bartoněk, 1966 for one point of view; del Barrio Vega, 1990 and; Méndez Dosuna, 1993 for the other). Whatever the case, Euboean did not participate in any of the other chain shift steps.

Another piece of orthographic evidence that originally led linguists to recognize /u:/-fronting in Attic was once seen as compelling, but can now be rejected. The letter <Ϙ>, known as koppa or qoppa, was a letter with the phonetic value [k] that appeared in early Greek inscriptions instead of kappa when preceding the sounds /a/, /o/, or /u/. Linguists
noticed that the sequence $<\varphi \upsilon>$ is poorly attested in Attic-Ionic,\(^6\) while $<\varphi \omicron>$ spellings were once relatively common. This led some to believe that /u/ had fronted in these dialects by the time of the earliest inscriptions. Furthermore, there is the odd case of an Athenian amphora from circa 570 BCE with $\mathbfit{K\varphi\nu\lambda\omicron\acute{o}}\varsigma$ written on it, as if the scribe could not decide whether kappa or qoppa would be more appropriate before upsilon (Threatte, 1980: 22-23). This, too, has been taken as evidence for fronting of /u/ around that date. The value of this data becomes less clear when one realizes that the first attestation of $<\kappa\upsilon>$ is from about 550 BCE, by which time $<\kappa\omicron>$ was gaining ground against $<\varphi\omicron>$ and there was a “prevailing tendency to liquidate completely the sign φ” in favor of simply using kappa across the board (Bartoněk, 1963: 32). Thus, fronting might not have taken place this early. On the other hand, Bartoněk (1963: 33) notes that even a fronted [ü] was “no doubt sufficiently rounded to admit phonetically of its eventual graphic combination with the foregoing φ.” Being no ancient Athenian myself, I am far less confident on this point, but it certainly merits consideration. Méndez Dosuna (1993) goes even further, saying the distribution of kappa and koppa must be considered completely arbitrary, a mere vestige of the Phoenician system from which it was borrowed. This seems overly pessimistic, though at any rate, it is most prudent to conclude that the data pertaining to qoppa is not as definitive as it was once made out to be; it would be best to look elsewhere for corroborating evidence.

With the help of other orthographic evidence, we can ascertain the date of /u:/-fronting with greater precision. When the conventional spelling of the diphthongs was established around 700 BCE, /u/ must still have been a back vowel, or $<\text{EY}>$ and $<\text{OY}>$ would have failed to make sense as spellings for [ɛw] and [ɔw], for which all indications point to a back offglide (Bartoněk, 1966: 114). By the sixth century BCE, some Ionic texts show $<\text{EO}>$ and $<\text{AO}>$ rather than the conventional spellings for the diphthongs (Bartoněk, 1966: 113). This evidence is somewhat ambiguous, but it may suggest that /u:/-fronting had taken place by that time, leading to confusion about the identity of the diphthongs’

\(^6\) Bartoněk (1963; 1966) in fact claims that this sequence is never attested in Attic, but Threatte (1980) provides evidence to the contrary, including two cases of $<\varphi\upsilon>$ in graffiti dated to 600-575 BCE.
offglide. One also finds confusions of /u:/ and /i:/ by the sixth century, which can only be explained by /u:/ being realized as a front vowel at that date (Teodorsson, 1974: 289). Allen (1974) makes clear, however, that this does not necessarily mean that the pronunciations of <υ> and <ι> had already merged, as they eventually did, producing modern Greek [i]. What we can deduce from the combination of all this evidence is that the fronting of [u:] to [ü:] occurred between 700 and 600 BCE.

4.1.2 ου > [u:]

Any analysis of the Greek situation crucially depends on the timing of the /u:/-fronting step relative to the /ọ:/-raising step. If [ọ:] raised at least partway to [u:] prior to or concurrently with /u:/-fronting, that would be evidence for a push chain in the truest sense: an encroachment (the raising of /ọ:/) causing displacement of another phoneme (original /u:/). This would have important theoretical ramifications: there would be no choice but to allow teleology as an explanation and also accept the gradualness of sound change. As it turns out, there is good reason to believe that /u:/-fronting preceded /ọ:/-raising by several generations, and therefore this step was certainly a pull, not a push.

From the fourth century BCE onward, no confusions of <ω> and <ου> exist in Attic texts (Teodorsson, 1974: 213). Examples of <ο> substituted for <ου> also become rare after about 360 BCE in Ionic (Lasso de la Vega, 1956: 280) and 325 BCE in Attic (Threatte, 1980: 258), setting aside cases in which <ο> was most likely an abbreviation for the genitive ending <ου>, which is a well-documented practice. This suggests that the vowels were increasingly differentiated by the raising of the formerly close mid long vowel around this time. There is also a parallel change in the front vowels that would fit nicely in this chronology: a change which most likely originated in Boeotian, /ɛ:/ raising to and merging with [i:], occurred sometime in the third or fourth century BCE in Attic and also happened during the latter part of that time frame in Ionic (Bubeník, 1983). The raising of the two close mid vowels would then have operated almost concurrently, a situation leading to mutual reinforcement.
It appears that the Attic-Ionic raising of /ʊː/, then, transpired during the fourth century BCE. However unlikely it seems that “the opportunity would long have been resisted of increasing the acoustic distance” between the two mid back long vowels after /u:/ fronted (Allen, 1974: 77-78), one cannot escape the conclusion that the two changes were separated by centuries. For this reason, I agree with Szemerényi (1987 [1968]: 1349) that “it seems safest… not to force the notion of a push-chain on these changes. We should rather view the (later) change ο > ʊ as being the exploitation of an existing possibility, namely of the empty square.”

I have already mentioned that, if this series of changes can be viewed as a push chain at all, the “push” would have to be overcrowding, not encroachment. Virtually all analyses accept the relative chronology I have given with /u:/-fronting preceding /ʊː/-raising, even if they do not agree with the absolute dates I propose. During my research into this matter I found only one serious consideration of a chronology in which raising pre-dated fronting, and even that source (Bubeník, 1983) did not fully espouse it.

4.2 Analysis

Since the Attic-Ionic shift appears to have started with /u/-fronting, as did two of the other three ‘push chains’ in the literature (São Miguel Portuguese and Old Scandinavian; see Samuels 2006, 2007) it is critical to explain that step in order to claim understanding of the changes that took place in these dialects. The difficulty in explaining /u/-fronting lies in the fact that, in both cases, there were other dialects of the same language that had the same four-height-distinction vowel system, yet did not undergo the same changes. Szemerényi comments on this problem:

“Although the development we are discussing has been stated almost in terms of a natural law in the case of vowel-systems with four degrees of aperture in the back row, there have also been many dissentient voices. Thus, e.g., in Gallo-Romance Lat. ʊ developed into ʊ, while in Tuscan we find no such change. Similarly, there were a number of Greek vowel-systems with four degrees of aperture—but only in Ionic-Attic did ʊ develop into ʊ.” (1987 [1968]: 1348)
For this reason, some call upon extra-linguistic factors to explain /u:/-fronting in both Greek and Portuguese. Of Attic-Ionic, Bartoněk says that /u:/-fronting “required the coincidence of two factors, first of the substratum impulse from Asia Minor, and secondly a favourable systemic condition implying the overloading of the back long-vowel axis,” and that “this coincidence appears to have asserted itself at the time when the substratum influence of Asia Minor was still strong enough only in the Attic-Ionic dialects” (1963: 38-39). In the same vein, early observers of insular Portuguese attributed the fronting of /u/ to “Keltic” substrate influence—as scholars trying to explain French /u/-fronting have also done (cf. Ahn, 2004; Haudricourt and Juillard, 1949; Malmberg, 1964)—because of circumstantial evidence pointing to a small Breton community on São Miguel. Rogers (1940) dismisses this idea, saying such a small group was extremely unlikely to prove so influential. I believe it is unwise to appeal an implausible historical scenario before exploring all other avenues; as Malmberg (1964: 19) argues, “the substratum explanation has been seized on far too frequently as a convenient solution and often on very slender grounds.” One should at least try to find other factors. In this case, these are very possible to find.

In his recent book, Calabrese (2005) reiterates a point most explicitly stated in Optimality Theory but which is an implicit undercurrent in the earlier literature describing these particular shifts: the fronting of [u] to [ü] is an instance of “emergence of the marked.” All else being equal, linguistic change typically eliminates markedness rather than creating it. There must be some overriding factor causing these chain shifts, something powerful enough to overcome the disparity in markedness between [u] and [ü].

The fact that necessary and sufficient causes for /u/-fronting are not isolable means that, whatever our theory of why this change occurs, it will not have perfect predictive value. Like researchers studying a disease with both genetic and environmental components, the best we can do is identify “risk factors” that predispose a language towards developing in this particular fashion. At this point, we can begin to identify some of these risk factors.
Clearly, having four distinctions of height among the back vowels predisposes a language towards /u/-fronting. Labov states that “the full chain shift we call Pattern 3… takes place only when there are four degrees of height in back. The two examples of vowel shifts in Martinet (1955) and the further cases explored by Haudricourt & Juillard [French, São Miguel, Greek, and Scandinavian] are confined to this pattern” (Labov et al., 1972: 105). Twenty-five years after that original statement, Labov himself came up with a counterexample: the American West, which exhibits both a three-height distinction in the back of the mouth owing to the merger of the vowels in caught and cot. Despite this, like virtually all other American English dialects, this dialect fronts /u/ (Labov et al., 1997). Also, the seven-vowel system with three height distinctions among the front vowels (i, e, ε) and four among the back vowels (u, o, ɔ, a) happens to be one of the two most common seven-vowel systems across languages (Crothers, 1978). This seemingly rules out any proposal that argues for the inevitability of /u/-fronting simply based on the fact of a four-height distinction of back vowels, though of course frequency is not a guarantee of stability.

Another factor that has been discussed is the lack of high central vowels in /u/-fronting languages. For Attic, Teodorsson (1974: 291) posited a “latent attraction” of /u:/ to /i:/ owing to the lack of any central vowel between them. Since the Attic situation was not resolved by /u:/ merely centralizing, and because there is no reason to believe that languages prefer having a high central vowel to having a high back vowel, one can conclude that any “attraction” would be concerned with more than just filling the gap between the high vowels. At this juncture one could invoke the Pierrehumbert (2001) and Blevins (2004) approach, in which vowels move towards empty spaces to minimize perceptual confusion. However, this principle alone certainly cannot explain why /u/ would move all the way to the front. It also fails to explain why /u/-fronting would occur in languages which have competing central vowels. One could make the argument that the perceptual distance between the high central and high back vowel before fronting is

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7 A ‘Pattern 3’ shift (Labov et al., 1972; Labov, 1994: 129), such as the Attic-Ionic one treated here, consists of /u/-fronting and raising of the other back vowels.
still greater in these cases than the distance between the high back vowel and any other neighbor; this ought to be experimentally verifiable.

Calabrese (2000; 2005) instead proposes that the force overcoming the markedness of [ū]/[y] is in fact another markedness constraint. He builds on the work of Lindau (1975) and Archangeli & Pulleyblank (1994) to establish an account of why [u] and [o] are articulatorily complex in a way that [y] and [ø] are not: the vowels [u] and [o] are both pronounced with the tongue root in an advanced position. As Lindau first noticed, advancing the tongue root pushes the body of the tongue up and forward, which means that “in pronouncing [+ATR] back vowels, speakers need to suppress the natural tendency to front them” (Calabrese, 2005: 49). Thus, the changes of [u] > [y] and [o] > [ø] simplify articulation by preserving the [+ATR] feature at the cost of losing the [+back] feature. In Calabrese’s framework, this is manifested by a constraint disallowing [+ATR, +back] vowels with an associated repair deleting [+back] when [+ATR] is also present. Of course, one certainly need not subscribe to this particular theoretical idiom in order to make the best of the observation. It would suffice to say that the articulatory complexity of [u] and [o] make them susceptible to fronting.

Two other details about ATR are worth mentioning. Firstly, the low [+ATR] vowel transcribed as /A/ in Somali is realized as [æ] in a process that also produces [y] from underlying /u/ and [ø] from underlying /o/ (Calabrese, 2005: 50). This is a synchronic process of phonetic realization, but it is certainly tempting to draw a parallel between the Somali case and the Greek diachronic processes of [a:] becoming [æ:] and [u:] fronting as well. One could then view /a/-fronting and /u/-fronting as (partially) stemming from the same cause. Secondly, Calabrese (2000; 2005) reports that, in the Altamura dialect of Italian, [+ATR] rounded vowels front only when they appear in stressed syllables. This is reminiscent of São Miguel Portuguese Pattern 3 shift, in which fronting of /u/ primarily occurs under stress. This does not necessarily imply a connection between stress and ATR in particular, but it provides another instance of stress interacting with vocalic fronting.
4.3 Theoretical concerns

Pattern 3 shifts such as the Attic-Ionic one are very common. In addition to the examples we have already mentioned from São Miguel Portuguese, Old Scandinavian, and French, (Haudricourt and Juilland, 1949), we also find similar shifts in Armenian (Vaux, 1992), Somali (Antell et al., 1973), Swiss French, Yiddish, Lithuanian, Albanian, West Syriac, Akha (Lolo-Burmese) (Labov et al., 1972), “almost all dialects of American English” (Labov et al., 1997) and Norwich (U.K.) English (Labov, 1994), as well as Scots, South African, New Zealand, and southern British dialects (Lass, 1988). Dressler (1974) identifies numerous other instances of context-free /u/-fronting, both with and without associated /o/-fronting. Among the languages he mentions are Oscan, Umbrian, Gallo-Romance, some Iranian dialects, Irish Gaelic dialects, Brithonic, Mingrelian (Caucasian), Xopic (Caucasian), Holoholo (Bantu), Albanian, Frisian, and Paraći (Indo-Iranian). Hock (1986) supplies the additional example of Slavic [u:] centralizing and losing its rounding.

The high frequency of /u/-fronting of all these types supports the intuition that “there is certainly no general requirement that any particular high vowel slots in a system be filled…. The most that can reasonably be said is that maybe at least one high vowel slot per system ought to be filled, and back isn’t necessarily the one” (Lass, 1988: 399). In contrast to the abundance of [u] > [y] (> [i]) changes, examples of [y] > [u] are vanishingly rare, and Dressler (1974: 96) attributes each of them to the identifiable “influence of a neighboring language or a substratum or superstratum.” Labov was quite right to attribute special significance to /u/-fronting and /o/-raising, in contradistinction to their opposites.

One serious question remains: what does one make of these changes? Should phonologists call them push chains, pull chains, mixed chains, or something else entirely? There is hardly consensus on this issue. The chain shift of [u] > [y], [o] > [u] –in that order—receives different interpretations by different authors. Bynon (1983), Bubeník

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8 This includes changes of [u] (> [y]) > [i].
(1983), and Ahn (2004) say that this sequence constitutes a pull chain initiated by /u/-fronting, while Hock (1986: 157) invokes both pull and push mechanisms, saying that “the overcrowding which gives rise to u-fronting and to the ensuing drag-chain developments commonly results from the ‘push’ of a new segment into the back vowel system.” Though Eliasson (1992) disagrees with such an analysis for Scandinavian, he implicitly agrees with Hock’s categorization for a hypothetical case. Both these positions seemingly contradict Martinet’s (1952: 133) intent; he states that “the suggested distinction between drag and push would often be blurred” in practice because “we have to deal with pressure everywhere” in cases like the São Miguel shift.

I believe in taking Martinet’s warning seriously. Rather than forcing these shifts into push, pull, or mixed categories, which are radical oversimplifications in /u/-fronting cases, I suggest using Labov’s terminology instead. ‘Pattern 3’ is a useful designation for the shifts discussed here because it provides descriptive information about the nature and direction of the chains from a holistic perspective, whereas ‘push,’ ‘pull,’ and ‘mixed’ only indicate the possible causation of individual steps. As a corollary of being causation-based, the traditional method of classification introduce subjectivity, which should also be dispreferred; as we seen several times already, linguists often fail to agree about the causes of a particular sound change. Simply designating /u/-fronting shifts as ‘Pattern 3’ has the benefit of neutrality with respect to this issue.

As a point of historical interest, I believe one reason why the issue of push chains has been so controversial over the past fifty years stems from inconsistency in Martinet’s (1952) paper introducing the push/pull dichotomy. Martinet first gives an abstract example of a push chain that clearly involves direct encroachment: “a phoneme A drifting in the direction of a phoneme C… C, instead of awaiting the impending merger, recedes before the invader” (1952: 132). When he presents a concrete example, though, he cites the São Miguel case, which does not involve encroachment but instead, “pressure exerted upon /u/ by the other three back phonemes of a series where margins of security are, by nature, narrower than in the corresponding front series” (1952: 133). No one contests Pattern 3 cases like the São Miguel example; the controversy centers around the
hypothetical example. Those who take the abstract definition literally seem to think that Martinet thought all push chains involved encroachment, in spite of the example a few paragraphs later. This leads to the mistaken impression that “in order to be a chain shift, on the push reading there has to be a (near) collision. Push chains require that phonemes bump like balloons, billiard-balls in a rack, on a model resembling the Brownian motion of particles” (Stockwell and Minkova, 1997: 286), or that “push chains would give a relative chronology with considerable overlapping between the steps” (Anttila, 1989: 112). Looking at the spirit rather than the letter of Martinet’s introduction to push chains, we see that what he considered push chains are quite common indeed, but that push chains in the strict sense employed by other linguists do not actually exist. This inconsistency makes it all the more appealing to get rid of this nomenclature altogether.

5. General discussion & conclusions
This case study in Attic-Ionic shows how, when we are concerned with problems in historical phonology, helpful evidence can come from anywhere. Comparisons within the language as well as outside of it, orthographic evidence, phonetics, and structural phonology all played crucial roles in shaping our analysis of the Greek vowel system’s developments. Understanding of analogical change also proved useful by guiding us away from theories that could describe but not adequately explain unusual forms, and by helping us determine which words’ histories to believe when the developments of regular sound change could not have yielded two sets of conflicting forms stemming from the exact same phonological environment. None of these strategies alone can provide an answer, but the more they are synthesized into a holistic view of the language, the more we find that all the scattered evidence converges on a single, believable analysis.

If the discussion of the Attic reversions in §3 had the effect of showing that phonetics and phonological theory can inform our understanding of diachronic changes, then the analysis of the chain shift in §4 demonstrated the converse. Only by examining empirical evidence can we understand the mechanism behind chain shifting and therefore begin to tease apart the many theories that have been developed in order to account for the phenomenon. In Samuels (2006, 2007) I undertook a study of all four major examples of
push chains that have been presented in the literature of the past half-century. None of the cases presented there showed evidence of phonemic encroachment of the sort that is supposed to characterize push chains. Instead, we repeatedly saw one phoneme moving away from a crowded space and its neighbors then spreading out more evenly in the now-less-crowded space. This is precisely the type of action that typically characterizes pull chains, which leads me to the conclusion that push chains, as traditionally defined, do not exist. If all chain shifting conforms this pattern, as we have every reason to believe, then it must be the case that many previous theories are far too liberal in their predictions. This insight opens the door to new theorization in the domain of sound change, and particularly suggests that a new understanding of the mechanisms underlying chain shifting and phonemic merger may be necessary.
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Appendix A\textsuperscript{9}: some proposed relative chronologies of the Attic reversions

“Traditional / linguistic” view, adapted from Szemerényi (1987 [1968]: 1339)

1. [a:] > [æ:]  
2. [ea:] > [æ:]  
3. [ræ:] > [ra:]  
4. [w] > ø; [ea] > [æ:]  
5. [æ:] > [a:] / {i, e} _  
6. [æ:] > [ɛ:]  

Explicitly by analogy: all forms with intervocalic digamma showing reversion (e.g. υ锨α)

“Modified traditional” view – Schwyzer (1939) [Szemerényi p. 1340]

1. [a:] > [æ:] except after {e, i, r}  
2. [w] > ø; [ea] > [æ:]  
3. [æ:] > [a:] / {e, i}  
4. [æ:] > [ɛ:]  

“Thorough-going reversion” – Thumb & Scherer (1959) [Szemerényi p. 1341]

1. [a:] > [æ:]  
2. [w] > ø / V_V  
3. [æ:] > [a:] / {e, i, r}  
4. [w] > ø / C_  
5. [æ:] > [ɛ:]  

No position regarding [ea] contraction. If it occurred after (2), /rea/ cases would have to be by analogy.

“Moderate reversion” – Thumb & Scherer (1959) [Szemerényi p. 1341]

1. [a:] > [æ:] except after {e, i, r}  
2. [w] > ø / V_V  
3. [æ:] > [a:] / {i, e} _  
4. [w] > ø / C_  
5. [ea] > [a:] / {e, i, r} _  
6. [ea] > [ɛ:]  
7. [æ:] > [ɛ:]  

Explicitly by analogy: all forms with [rea] ultimately contracted to [ɛ:] (e.g. ὄρη)

\textsuperscript{9} Where I note a page number from Szemerényi (1987 [1968]), the rules shown in this appendix are adapted from the summaries of the various treatments presented there. In several cases I have added obviously implied steps, such as [æ:] > [ɛ:].
Szemerényi (1987 [1968])

1. \[ a:] > [æ:]
2. \[w] > ø / V_V; [æ:æ:] > [æ:]
3. [æ:] > [a:] / {e, i, r}_
4. [w] > ø / C_
5. [ea] > [a:] / {e, i}_
6. [ea] > [æ:]
7. [æ:] > [ę]

“Hypothesis A” – Gates (1976)

1. \[ a:] > [æ:]
2. [æ:] > [a:] / r_
3. \[w] > ø
4. [æ:] > [a:] / {i, e}_
5. [æ:] > [ę]

“Hypothesis B” – Gates (1976)

1. \[ a:] > [æ:]
2. \[w] > ø / V_V
3. [æ:] > [a:] / {e, i, r}
4. \[w] > ø / r_ [NB: unknown why only [r] was included in this rule – BDS]
5. [æ:] > [ę]

In both hypotheses, explicitly by analogy: *-ewes proper names; “[analogical] pressures… operated freely after r, but were interfered with by a variety of special circumstances after e and i.” Also in both hypotheses, [ea] and [eo] contracted prior to intervocalic digamma loss, and quantitative metathesis took place before [r]-reversion.

Sihler (1995)

1. \[ a:] > [æ:]
2. \[w] > ø / V_V
3. “Shortening of long vowels in various environments”
4. ans# > a:s#
5. [æ:] > [a:] / {e, i, r}
6. [æ:] > [ę]
7. \[w] > ø / C_

Tucker (1969)

1. \[ a:] > [æ:]
2. Vns > V:s
3. \[w] > ø
4. Vowel contractions
5. Quantitative metathesis
6. \([æ:\] > [ç:\]\)

“First and second reopenings” – Lejeune (1972)

1. \([\text{a:}:] > [æ:\]\
2. \([æ:\] > [\text{a:}:] / r_\
3. \([w] > ø / V_V\)
4. \([\text{ea}] > [æ:\]\
5. \([w] > ø / r_\
6. \([æ:\] > [\text{a:}:] / \{e, i\}\)
7. \([æ:\] > [ç:\]\

Bubeník (1983)

1. \([\text{a:}:] > [æ:\] – Attic only
2. \(V\text{rw} > V:r – Attic only
3. \([\text{a:}:] > [æ:\] – Ionic
4. \([w] > ø / r_ - Ionic (no compensatory lengthening)
5. \([æ:\] > [ç:\]\

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Appendix B: derivations of forms in (4)

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**Greek:**

κόρη  ἀργυρᾶ  ὄρη  νέα  χρέα  παρέα  ἐννέα