The phonologization of redundancy

Length and quality in Welsh vowels*

Pavel Iosad

1st November 2016

Abstract

'Phonologization' is a process whereby a phonetic phenomenon enters the phonological grammar and becomes conceptualized as the result of categorical manipulation of phonological symbols. I analyse the phonologization of a predictable phonological pattern in Welsh, with particular attention to identifying criteria for whether phonologization has occurred. I argue for a model where phonologization experiences bottom-up and top-down biases. From the bottom up, there is pressure to phonologize phenomena with a categorical distribution; from the top down, there exist formal constraints on featural specification. I focus on the requirement for featural specifications to obey the Contrastivist Hypothesis, which denies that redundant features can be involved in phonological computation, in the context of a framework with emergent features. I suggest that the Contrastivist Hypothesis acts as a useful check for emergent-feature theories, whilst independent phonologization criteria provide contrastivist approaches with a more solid conceptual underpinning.

*Portions of this paper were presented at the 1st Edinburgh Symposium on Historical Phonology, the Edinburgh P-workshop, GLOW workshop *Phonological Specification and Interface Interpretation* (Brussels), the 8th North American Phonology Conference (Montreal), the 21st and 22nd Welsh Linguistics Seminars (Gregynog), the 1st Conference on Linguistic Diversity in Wales (Aberystwyth), and the 24th Manchester Phonology Meeting. Thanks to the audiences at these forums for questions and comments, particularly Gwen Awbery, Ricardo Bermúdez-Otero, Josef Fruehwald, Daniel Currie Hall, and Michaela Hejná. For help with fieldwork, thanks to Christine Jones and Mererid Hopwood (University of Wales Trinity Saint David) and Diarmuid Johnson (Menter Rhos-y-Gilwen). At *Phonology*, a huge thanks to three anonymous reviewers, an anonymous associate editor, Ellen Kaisse, and Colin Ewen for numerous questions and suggestions that have immeasurably improved the paper. All errors of fact or interpretation remain entirely mine.

1 Introduction: contrast, predictability and phonologization

This paper explores the relationship between *contrast*, interpreted as the absence of redundant information from phonological representations, and the *phonologization* of predictable properties. I argue that although phonologization via the life cycle of phonological processes introduces predictable information into phonological representation, this fact is compatible with a version of the Contrastivist Hypothesis (Hall 2007, Dresher 2009), which requires redundant features to be absent from the phonology. To demonstrate the viability of such a framework, I offer a case study involving *mutually predictable distribution*, where standard criteria fail to unequivocally identify a 'contrastive' phonological property. I address the following three questions:

- Can mutually predictable distribution of phonological specifications be reconciled with the Contrastivist Hypothesis?
- How can we establish that a distinction is accessible to the phonology as a featural specification, and hence subject to contrastivist restrictions?
- Can the Contrastivist Hypothesis be reconciled with the process of phonologization introducing redundant information into the phonology?

1.1 The Contrastivist Hypothesis and its discontents

Our starting point is the Contrastivist Hypothesis, formulated as follows by (Hall 2007: 20): 'The phonological component of a language *L* operates only on those features which are necessary to distinguish the phonemes of *L* from one another.' As charted by Dresher (2009), this principle was historically important in structuralist phonology, but downgraded by many (though not all) currents of generative phonological theory. More recently years it has again attracted the attention of phonologists, notably those working within the 'Toronto school' (e. g. Dresher, Piggott & Rice 1994, Dresher 2009, Hall 2007, Cowper & Hall 2014, Mackenzie 2013).

Under the version of the Contrastivist Hypothesis given above, contrastiveness is defined over *phonemes* as understood in generative phonology, that is segments found in underlying representations in a language. Kiparsky (2017) calls them 'm-phonemes' (for 'morphophonemes') — a usage that I adopt here. Hence, establishing whether a feature is 'contrastive' in the language can be non-trivial, since the set of m-phonemes can only be discovered through careful analysis.

Disagreements over such analysis are frequent in cases of mutually predictable distribution, where two apparently distinct phonological properties are coextensive in surface representations. Both properties are candidates for being contrastive (and thus available to the phonological grammar), but under strict contrastivist assumptions one of them *must* be redundant. The problem for contrastivist approaches is that this choice must be made, but it appears to be vacuous and forced only by theoretical considerations, since the data seem equally compatible with either solution.

I consider a case of mutually predictable distribution in Welsh, focusing on vowel quantity and quality. As in familiar languages like English and German, Welsh vowels can be divided into two classes simultaneously differing in quantity and 'tense'/'lax' quality. The analysis of these systems is controversial: some scholars view the contrast as primarily one of length (e. g. Durand 2005), others see the quality distinction as primary (e. g. Harris 1994); yet others subsume the difference under 'syllable cut' (e. g. Botma & van Oostendorp 2012).

I focus on dialectal diversity in Welsh vowel systems and concentrate in particular on south-western varieties, where, according to previous descriptions, vowel quantity and quality have diverged in ways unattested in other dialects. I report an acoustic study and argue that in these varieties quality *must* be represented in the phonology separately from the length. I argue that this is consistent with a view of phonologization where the *extraction* of phonological patterns proceeds bottom-up, on the basis of categoricity in the ambient data, but the precise characterization of the resulting phenomena in terms of distinctive *features* is driven at least partly by top-down contrastivist pressures.

1.2 Establishing the criteria

Being able to verify or falsify a theory that allows for manipulation of predictable information by the phonology requires criteria to establish whether a phenomenon falls within the purview of phonological grammar. It is common to ascribe 'gradient' phenomena to 'phonetics' and to take categoricity of distribution as a sign of phonologization (e. g. Myers 2000). However, this approach can be problematic. Even classifying phonological phenomena as 'categorical' or 'gradient' is not trivial (Strycharczuk 2012).

In this paper, I argue that the phonological status of a pattern should be determined with reference to criteria of *modularity* (e. g. Scheer 2010, Bermúdez-Otero 2012), which requires that the flow of information between grammatical modules be restricted. I focus on *representational* incommensurability between modules. Specifically, some kinds of objects are proprietary to 'their' module: for phonology, examples are featural specifications, autosegmental association lines, metrical constituency, etc. Under this approach, if a pattern makes crucial reference to such proprietary phonological information, it must also be phonological, because only computation inside the phonological module can access such phonology-internal information.

Using this criterion, we can establish if a pattern is within the scope of phonological grammar and thus, ideally, contrastivist restrictions. The Contrastivist Hypothesis can be reframed as follows:

- If $\mathcal{P}$ is the set of patterns that can be established as phonological in language $\mathcal{L}$; and
- If $\mathcal{PH}$ is the set of phonemes in $\mathcal{L}$; and
- If $\mathcal{F}$ is the set of features necessary to distinguish the phonemes of $\mathcal{PH}$; then
- No pattern in $\mathcal{P}$ makes crucial reference to features that are not in $\mathcal{F}$.

Assuming that we can establish the extent of $\mathcal{P}$ and $\mathcal{PH}$ using the modularity criteria suggested above — as I will exemplify in this paper — the content and correctness of the contrastivist hypothesis turn on the understanding of 'necessity' in the definition of the set $\mathcal{F}$. In this paper I argue that contentful predictions can indeed be made, if it is understood with reference to a contrastive hierarchy of distinctive features (Dresher 2009).

1.3 Phonologization and redundancy

Another problem, directly relevant to the issue of phonologization, is the determination of $\mathcal{PH}$, the set of relevant 'phonemes'. Kiparsky (2017) calls segments posed by the analyst for underlying representations 'm-phonemes' ('morphophonemes'), and contrastivists in the generative tradition have usually concentrated on this m-phonemic level. Kiparsky (2017), however, suggests distinguishing between m-phonemes and 'l-phonemes', for 'lexical phonemes': segments produced by phonological grammar at the lexical level (word-level phonology) in a stratal framework that builds on the insights of Lexical Phonology. Kiparsky (2017) argues that typological and theoretical generalizations such as those concerning the structure of inventories or historical change should properly refer to this l-phonemic level. Crucially, he argues, the l-phonemic level may contain predictable information such as redundant feature specifications, if it is introduced by phonological computation at the lexical level. Hence, this framework appears incompatible with the Contrastivist Hypothesis.

The presence of redundant information in the phonological computation is only to be expected if the source of phonological patterns lies in the life cycle of phonological patterns, and specifically within the process of *phonologization* (Hyman 1976, 2013, Kiparsky 2015). This term is commonly used to describe a linguistic change whereby a phenomenon previously construed as 'phonetic' enters the purview of phonological grammar. Phonetic processes give predictable (if stochastic) outcomes. Therefore, the system immediately after phonologization is likely to have the new symbols standing in predictable distributions. 'New' phonological patterns will therefore tend to be allophonic, potentially reducing the scope for positing an m-phonemic contrast that could justify the phonological involvement of the relevant feature under contrastivist assumptions.

There is a tension between the Contrastivist Hypothesis and the study of phonologization, because contrastivist approaches privilege 'top-down' information about contrast and morphophonological patterning, whilst models of phonologization recognize the important role of ‘bottom-up’ information. Under contrastivist assumptions, the evidence for the existence of a phonological segment and its representational make-up comes from categorical information, such as the structure of the inventory and the segment’s morphophonological behaviour. Theories of phonologization, on the other hand, emphasize the role of variation in the speech signal, whether inherent and uncontrolled or speaker-specific.

A third argument in this paper is that this tension can be resolved in a framework where phonological features are categorical and assigned on the basis of contrastivist reasoning, but emergent and phonetically arbitrary (‘substance-free’). This makes it possible to construct an adequate theory of phonologization that takes the speech signal as its starting point. In this framework, contrastivist assumptions serve both to capture the existence of top-down, featurally implemented biases in phonologization, and to restrict the set of possible specifications one could assign to a given inventory.

The remainder of this paper is structured as follows. In section 2 I review the available knowledge regarding vowel quantity and quality in dialects of Modern Welsh. Section 3 presents the results of an acoustic study of a south-western variety of Welsh that has been reported to show an unusual deviation from the common Welsh system; I argue that in this variety ‘tense’/‘lax’ quality and quantity are separately represented in the phonology. In section 4 I take the criteria for phonological status developed in the course of this argument and apply them to other varieties of Welsh, showing the extent of dialect variation in feature specifications. Finally, in section 5 I reconsider the status of contrastive specifications in an emergent-feature framework and their role in phonologization.

2 Vowel quantity and quality in Welsh

Here I review available descriptions of vowel quantity and quality and Welsh and argue that there is good evidence for viewing quantity as a phonological distinction, specifically one expressed via suprasegmental (metrical) structure. I also review the controversies in the literature around the phonemic interpretation of the Welsh vowel system.

Height	Front	Central	Back
High	iː ɪ	(ɨː ɨ)	uː ʊ
Mid	eː ɛ	ə	oː ɔ
Low		aː a	

Table 1: Representative vowel inventory

2.1 The received view

A representative inventory of Welsh stressed monophthongs is shown in table 1 (Ball & Williams 2001, Mayr & Davies 2011, Hannahs 2013). Some variation of this system is common throughout the Welsh-speaking region. Apart from the differences in the realization of short and long vowels, subject to discussion below, the following dialectal variations should be noted:

- The vowels [ɨː] and [ɨ] are found only in northern Wales;
- The vowel [ə] lacks a phonologically long counterpart;
- In many varieties there is an additional low vowel, variously a low front [æː] or a raising and/or centralizing diphthong, considered to be an allophone of [aː].

Here, I concentrate on the relationship between the short and long vowels.

2.1.1 Distribution

All dialects of Welsh restrict phonologically long vowels to stressed syllables. In monosyllables we find both short and long vowels.

(1) All dialects

a. [ˈtʰoːn] *tôn* 'tune'

b. [ˈtʰɔn] *ton* 'wave'

In polysyllabic words, stress overwhelmingly falls on the penult, apart from a small number of native words with final stress and a handful of borrowings with antepenultimate stress.

There is a major distinction between northern and southern varieties of Welsh in the behaviour of stressed penults (Awbery 1984). In South Welsh, short and long vowels are distinct in both penultimate and final stressed syllables. However, long vowels in penultimate syllables are phonetically shorter than long vowels in final syllables (e. g. G. E. Jones 1971), and often described as 'half-long'.

(2) South Welsh

a. [ˈtʰoˑnɛ] *tonau* 'tunes'

b. [ˈtʰɔnɛ] *tonnau* 'waves'

In North Welsh, stressed vowels are always short in penults, so the minimal pair in (2) is impossible in such varieties: both *tonau* and *tonnau* are realized as [ˈtʰɔna].

In addition to these patterns, the native lexicon of Welsh enforces restrictions on the distribution of short and long stressed vowels depending on the properties of following consonants (Wells 1979, Awbery 1984). The restrictions in final stressed syllables (including monosyllables) are as follows:

- Short before [pʰ tʰ kʰ m ŋ];
- Long before [b d g f θ χ v ð];
- Long or short before [n l r], with lexically determined distribution;
- In northern varieties, short before [s ɬ]. In the south, long before final [s ʃ ɬ];
- Before [w j], vowels are always short in the south. In the north, they may be long in final stressed syllables, but the distribution is lexical;
- In the south, vowels are always short before consonant clusters. In the north, vowels are obligatorily long before fricative-stop clusters [sp st sk ɬt ft] but obligatorily short before other clusters.

In non-final stressed syllables, vowels are always short in Northern Welsh. In the south, the distribution of length in stressed penults is very similar to that in stressed ultima, but not fully identical: vowels are obligatorily short before medial [s ʃ ɬ] but long before the same consonants word-finally.

To summarize, phonologically long vowels are restricted to stressed syllables. In northern Welsh they are further restricted to *final* stressed syllables. Vowel length in the native lexicon is largely predictable. It depends both on syllable structure (with a dispreference for long vowels in closed syllables) and on the melody of the following consonant. Most often, the length of a stressed vowel is predictable from the manner and laryngeal specification of a following consonant, with the exception of [n l r], where the distribution is lexically conditioned.

2.1.2 Phonological length and phonetic duration

The phonetic correlates of the phonological distinction identified above as 'length' include both vowel quality and duration. First, phonologically long vowels have greater duration than phonologically short vowels (e. g. G. E. Jones 1971, Grawunder, Asmus & C. Anderson 2015). As for consonant duration, descriptions of South Welsh agree that consonants after a short stressed penult are 'half-long' irrespective of whether the vowel is followed by a single consonant (['tʰɔnˑɛ] *tonnau* 'waves'), or by a consonant sequence (['amˑsɛr] *amser* 'time'); see e. g. A. R. Thomas 1961, Awbery 1986, C. H. Thomas 1993. The situation is less clear in North Welsh. Many sources (summarized in Hannahs 2013: §2.2.6) mention 'gemination' of fortis stops [pʰ tʰ kʰ] after a stressed penult, and there are scattered references to other consonants being lengthened in the same position. Subject to further research, it appears that the lengthening of consonants after a short stressed vowel in a penultimate syllable is universal across Welsh dialects.

Similar facts obtain in stressed ultima. G. E. Jones (1984: p. 54) states that consonants are long after short vowels in this context:

(3) a. ['manː] *man* 'place'
    b. ['mɑːn] *mân* 'fine, small'

(4) a. [ˈtalː] *tal* ‘tall’

b. [ˈtɑːl] *tâl* ‘payment’

A. R. Thomas (1966) gives a similar statement for the Alyn Valley dialect (North Wales). For South Wales, the length of final consonants after a short stressed vowel is mentioned by C. H. Thomas (1993: pp. 69–70). For North Welsh monosyllables, the claim is corroborated experimentally by Grawunder, Asmus & C. Anderson (2015).

Thus, phonological ‘length’ is reflected by phonetic duration, and there is also a trading relation between the duration of stressed vowels and following consonants.

2.1.3 Length and quality

Another correlate of phonological ‘length’ is vowel quality. Vowels other than [ə] (and likely [a]) come in ‘tense’ and ‘lax’ pairs: [oː] vs. [ɔ], [iː] vs. [ɪ], and so on. Such pairs pattern together, as they participate in alternations determined by the consonantal context:

(5) a. [ˈtʰeːg] *teg* ‘fair’

b. [ˈtʰɛkʰa] *tecaf* ‘fairest’

It is sometimes desirable to refer to such vowel pairs without prejudice to the exact realization; here, I adopt the useful notation from Wmffre 2003 using double slashes: //i//, //e// etc.

The precise quality of vowels depends on their phonological quantity and their position with respect to stress. The standard picture is as follows:

1. Non-low stressed long vowels are ‘tense’ [iː uː eː oː]. Sources differ as to whether there is a similar qualitative distinction between long and short //a//: for instance, Awbery (1986) does not describe a difference between [a] and [aː], but G. E. Jones (1984) describes long [aː] as somewhat retracted compared to [a]. Some descriptions (e. g. C. H. Thomas 1993, G. E. Jones 2000) use the symbol [ɑ(ː)] for the ‘long’ member. However, in an instrumental study Mayr & Davies (2011) do not find a reliable qualitative distinction between short and long //a// in monosyllables, and Wmffre (2007) states that long //a// is never phonetically [ɑ];

2. Stressed short vowels in South Wales are lax [ɛ ɪ ɔ ʊ]. This is confirmed for monosyllables by Mayr & Davies (2011). For North Wales, detailed descriptions are lacking, especially for stressed penults, but broadly the situation appears similar;

3. The length contrast is neutralized in unstressed syllables. There is agreement in the literature that quality varies between 'tense' and 'lax'. For instance Awbery (1986) describes the unstressed vowel system of Pembrokeshire Welsh thus:

   - In pretonic syllables and in closed final syllables, both 'tense' and 'lax' variants are allowed: [pʰ**ɛ**ˈdɔːli] ~ [pʰ**e**ˈdɔːli] *pedoli* 'to shoe (a horse)', [ˈwɛːd**ɪ**n] ~ [ˈwɛːd**i**n] *wedyn* 'afterwards';
   - In pretonic syllables in hiatus, only 'tense' variants are allowed: [r̥ʰ**e**ˈoːle] *rheolau* 'rules' (*[r̥ʰ**ɛ**ˈoːle]);
   - In final open syllables, high vowels can only be 'tense', but mid vowels are in 'free' variation.

   Thus, it appears that greater leeway in the qualitative properties of unstressed vowels compared to those of stressed vowels is characteristic of most varieties of Welsh.

2.2 Analysis

As discussed in section 1.1, the close relationship between vowel quantity and vowel length such as that found in Welsh, presents a potential problem if redundant information has no place in phonological representation. One such approach is the traditional taxonomic framework that aims to represent all utterances as uniquely identifiable phoneme strings, where 'phonemes' are understood as minimally redundant units standing in overlapping distribution. Kiparsky (2017) dubs these units 's-phonemes' (for 'structuralist phonemes') and argues that they have no privileged place in phonological architecture.

As the existing literature on Welsh demonstrates, an s-phonemic framework requires a choice between length and tenseness, but the data do not provide much guidance on which analysis is better. Much of the literature designates quality as primary (e. g. Pilch 1957, Watkins 1967, G. E. Jones 2000, C. H. Thomas 1993), with length marks often altogether omitted from the phonemic transcriptions. Length is more consistently written in early literature that does not use a phonemic approach (e. g. Sommerfelt 1925), but also in some later work (e. g. A. R. Thomas 1960).

The reasons for this choice are seldom explicitly discussed. A. R. Thomas (1966) justifies his choice of length by referring to 'symmetry'. Length is independently required to distinguish /a/ and /aː/: since it is used in the phonology of the language, it can be applied to express the same contrast in other pairs, making 'tongue position' redundant. On the other hand, Watkins (1967) points out the existence of long 'lax' vowels in English borrowings, quoting [ˈbrɔːn] 'brawn' and [ɪnd͡ʒɪˈnɛːr] 'engineer', and argues that this makes tenseness unpredictable and thus phonemic.

Both approaches are open to criticism. The symmetry-based argument for a quantity analysis is not empirical; it might also not go through if varieties with a quality distinction between [a] and [ɑː] do exist. The argument for a quality analysis based on borrowings might be more plausible, but it runs into the unclear status of borrowings in the broader phonology. Moreover, it is not entirely clear that the borrowed long vowels *are* qualitatively identical to the native short ones: for instance, C. H. Thomas (1993) uses different symbols for the native short //o// (she writes [ɒ]) and the borrowed long [ɔ].

Here, I adopt the analysis defended in Iosad (2012), according to which *quantity* (more specifically, moraicity) must be present in underlying representations (i. e. it is m-phonemic). This is motivated by the interaction of the abstract 'length' distinction with the consonantal context; such systems, where vowel length depends on the properties of the following consonant, even where that consonant is not part of a cluster, submit to a moraic analysis (see, for instance, Morén 2001 on Metropolitan New York English, Bye & de Lacy 2008 on Latvian, and Torres-Tamarit 2015 on Northern Romance).

The basic idea, developed in depth in Iosad (2012), to which I refer for details, and also shared by Hannahs (2013), is that lengthening is driven by a stress-to-weight requirement, which is counteracted by faithfulness to underlying moraic specifications and by restrictions on what segments can acquire a mora. Within this framework, the phonotactics of stressed syllables across Welsh dialects can be analysed as a mix of 'distinctive' and 'coerced' weight in terms of Morén (2001). Weight coercion arises when a (stressed) syllable is required to be bimoraic. This can be satisfied by the lengthening of either the consonant or the vowel (with the choice dependent on the ranking of relevant constraints), or fail to be satisfied (as in the case of North Welsh penultimate syllables in hiatus, where stressed vowels remain short). In an Optimality Theoretic (Prince & Smolensky 1993) framework such as Morén's (2001), the typology can be derived from the ranking of DepLink-μ constraints for vowels and various kinds of consonants vis-à-vis each other and the stress-to-weight constraint.

'Distinctive weight', with underlying moraic specification faithfully reproduced on the surface, arises in the case of [n l r], which can be preceded by both long and short vowels, with a lexical distribution. In cases such as the minimal pair in (2), vowel lengthening depends on whether the post-tonic consonant is underlyingly moraic: if it is, there is no need for lengthening, because the second mora is already provided; if it is not, lengthening ensues (Iosad 2012).

Thus, the behaviour of Welsh stressed vowels can be derived from moraic structure, some of it underlying. The moraicity of the vowels is definitely involved in the phonological grammar. It appears more difficult to offer a principled account of these facts if vowel quality is the sole phonologically relevant property, and so I conclude that if a choice between quantity and quality *is* to be made, then quantity is preferred.

Even if we accept this, however, the status of vowel 'tensing' (and/or 'laxing') in the grammar still remains ambiguous. One option is that it is *not* a symbolic phonological operation but part of 'phonetic implementation', with tenseness never entering the phonological computation. The other possibility is that the distribution is introduced by the grammar, via a rule along the following lines (or an equivalent OT ranking):

(6) $\mathrm{V} \rightarrow [\alpha\mathrm{tense}] \;/\; \begin{bmatrix} +\mathrm{stressed} \\ \alpha\mathrm{long} \end{bmatrix}$

This could be a problem for contrastivist approaches, since the feature [(±)tense] is not needed for 'm-phonemic' contrasts: it is entirely predictable, being only introduced by rule (6). Crucially, the same cannot be said of moraicity, because it *must* be encoded in underlying representations at least for [n l r] in Welsh.[1] In a sense, this approach subverts the entire controversy: once a moraic representation of quantity is accepted, there is no need for a segmental feature [±long], and there is no obligatory choice between [±long] and [±tense] to make. (I return to this issue briefly in section 6.)

However, this analysis does *not* rule out the distinction between 'tense' and 'lax' vowels being visible to the phonology. In the remainder of the paper, I will argue that this distinction in Welsh must *also* be part of the phonological computation, despite being redundant at the 's-phonemic' level (in some varieties). To verify this, I use the criteria for phonological status offered in section 1.2. Specifically, I discuss the distribution of length and quantity in several varieties of Welsh, and show that the 'tenseness' distinction fulfils the following two criteria:

- It is inherently (not accidentally) categorical, in that its categoricity both can be established and cannot be derived using a continuous function from some *other* categorical distinction;[2] and
- Its distribution is regulated by proprietary phonological factors.

Having established that 'tenseness' has undergone phonologization to a degree where it is now part of 'l-phonemic' representations in Welsh, I will then reconsider the criteria of contrastive status necessary for the Contrastivist Hypothesis to be falsifiable.

3 Quantity and quality in South-West Welsh

This section focuses on varieties of Welsh spoken in the south-west part of the country, specifically the counties of Carmarthenshire, Cardiganshire (Ceredigion), and the northern part of Pembrokeshire. These dialects possess a sound pattern that, unusually for Welsh, involves 'lax' long mid vowels [ɛː ɔː] in the native vocabulary. As far as I am aware, these data have not previously been examined instrumentally, or brought to bear on the question of quantity-quality interactions in Welsh, which provides the motivation for the study.

[1] It is also likely that underlying moraicity for vowels may be necessary to account for exceptional final stress, as in [maŋˈgiː] *mamgu* 'grandmother' (see Iosad 2012: §6.4.5.3.2).

[2] See Scobbie (2007) for a discussion of such 'accidental' categoricity.

3.1 Available descriptions

Several descriptions of dialects from this area are available. C. Jones & Thorne (1992) offer an overview for a general audience. Awbery (1986) provides an explicit description of the phonology of Pembrokeshire Welsh in a generative framework. Wmffre (2003) is focused on Cardiganshire placenames, but also provides numerous details of the phonology of relevant dialects. All these descriptions recognize the existence of distinct allophones for long mid vowels: [eː oː] and [ɛː ɔː]. The latter appear in penultimate syllables when the vowel in the following (unstressed) syllable is high //i// or //u//:

(7) Tense vowels before non-high vowels

a.	[ˈeːdɛ]	*edau*	‘thread’
b.	[ˈoːgɔv]	*ogof*	‘cave’

(8) Lax vowels before high vowels

a.	[ˈtʰɛːbɪg]	*tebyg*	‘similar’
b.	[ˈkʰɔːdi]	*codi*	‘rise’

Long mid vowels in monosyllables are always tense. No similar allophony is described for either low or high long vowels or any kind of phonologically short vowel. Changes in relevant types of phonological conditioning produce the expected alternations:

(9)	a.	[ˈtʰreː]	*tref*	‘town’
	b.	[ˈtʰrɛːvɪð]	*trefydd*	‘towns’

(10)	a.	[ˈkʰɔːdi]	*codi*	‘to rise’
	b.	[ˈkʰoːdɔð]	*cododd*	‘((s)he) rose’

If these descriptions are correct, then these dialects are a potentially valuable testing ground for the status of [ɛː ɔː] in native (rather than borrowed) vocabulary. However, auditory descriptions cannot give us confidence that this south-western pattern is, in fact, categorical. In this paper, I report the results of an acoustic study conducted to verify these descriptions and establish the status of the pattern.

3.2 Methods

Eight participants in Carmarthen were recruited beforehand and on the spot; the demographic data are reported in table 5 in the Appendix. The convenience sampling has created some skewing in terms of gender and age. Since the focus of the study is on phonological aspects of the patterning rather than on precise factors driving sociolinguistic variation, this skew will not be further discussed.

Also as a result of the convenience sampling, the study included two speakers who have lived in the relevant area for a considerable period of time but reported being brought up elsewhere in Wales. Sp4 was brought up in the capital, Cardiff; however, their Welsh-speaking parent is from the south-western area, and they show much the same system as the other south-western speakers. Their data was therefore pooled with other south-western speakers. Sp8, on the other hand, who was brought up in Aberystwyth, in mid-Wales, but has lived in the area for over ten years, turned out to have a different system. I report the data gathered from this speaker in section 3.3.3 by way of contrast to the south-western system, but do not offer a detailed analysis for lack of complete data. In addition, one of the demographically south-western speakers (Sp1) did not show the expected pattern, but instead demonstrated the system described for other South Welsh varieties. Since that system is relatively well understood, I do discuss those data in detail in section 3.3.1.

In contrast to Mayr & Davies (2011), the present study used actual rather than nonce words. Disyllabic words of a suitable shape were chosen, with reference to frequency counts in a corpus of written Welsh (Ellis et al. 2001). As far as possible, the wordlist aimed for balanced representation of the following variables:

- Quality of the stressed vowel. All of //ə i u e o// were included; //a// was excluded, as it is not expected to show qualitative variation in these varieties;
- Phonological length of the stressed vowel, in several consonantal contexts
- Consonant place of articulation;
- Phonological category of post-tonic vowel (high vs. non-high)

The full wordlist of 118 words is given in table 6 in the Appendix, with the expected pronunciation of the item in a south-western dialect. There were a total of 2,767 tokens analysed. Words were presented in their orthographic representation in the standard language: Welsh spelling is transparent enough for the intended vowel to be easily recoverable. Although some patterns of interest are less common in the standard language than in dialects (notably //u// in non-final syllables), meaning no suitable test items could be found for some conditions, no attempt was made to guess dialectal pronunciations and represent them in the stimuli.

Stimuli were presented to participants in a self-paced reading task, with items appearing on a screen in three independently randomized blocks. The stimuli were embedded in the carrier phrase *Glywes i'r gair _ ddoe* 'I heard the word _ yesterday'. In the briefing, speakers were instructed to produce natural rather than spelling-based forms (which they did to varying extents).

The acoustic analysis was completed using Praat (Boersma & Weenink 2015). The segments were marked up by hand, noting the duration of vocalic intervals, consonantal intervals (stop closure, frication duration etc.) and pre- and post-aspiration intervals separately. Formant measurements were taken at the midpoint of every vowel in final and penultimate syllables. The raw acoustic data, Praat TextGrid files, formant measurements, as well as an R package with the resulting data are available online (Iosad 2016).

3.3 Results

The study reveals the existence of at least three different patterns of quantity-quality interactions. We begin with speaker Sp1, who shows the neat co-occurrence of length and tenseness characteristic of most dialects of South Welsh. The largest group of speakers exemplify the south-western system as described in the literature. Finally, Sp8 shows a pattern that appears to not have been systematically described before.

3.3.1 The standard southern system

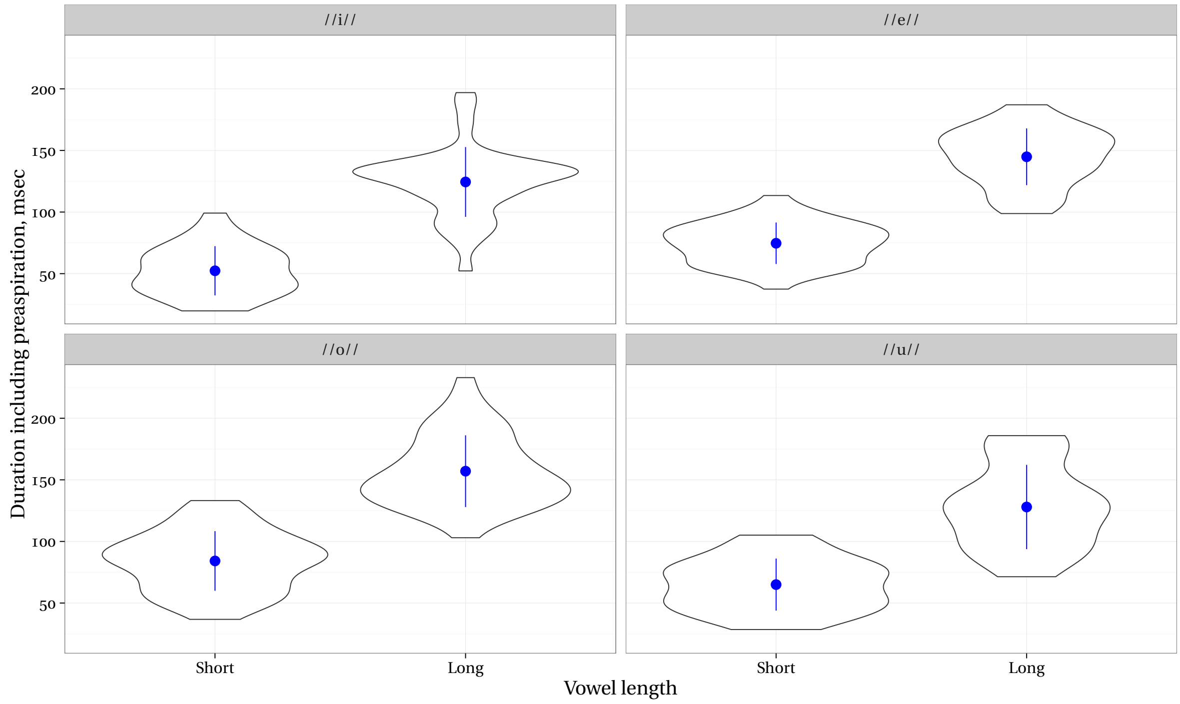


Figure 1: Vowel duration by vowel category and length, Sp1

Speaker Sp1 shows the 'standard' South Welsh system. There is a distinction in duration between phonologically short and long vowels. Figure 1 demonstrates this by plotting the density of the distribution of durations for different short and long vowels, together with means and ± 1 standard deviations. A two-way ANOVA with vowel length and vowel quality as independent variables and vowel duration including preaspiration[3] shows both factors to be significant: for vowel length, the ANOVA gives $F(1, 278) = 554.36$, $p < 0.00001$ and for vowel quality $F(3, 278) = 23.74$, $p < 0.00001$, presumably reflecting inherent length effects.

As for vowel quality, fig. 2 shows F1 and F2 values for this speaker in short and long vowels. Instead of the traditional dot plot, the plot shows a binned 2D kernel density estimate of the distribution of tokens for each category on the basis of this data. Thus, the plot shows the

[3] I do not discuss the status of preaspiration in detail here. Its existence in Welsh has until recently gone largely unnoticed, apart from a brief mention by Ball & Williams (2001); however, more recently it has been described for some varieties (e. g. Morris 2010). Iosad (2017) discusses its characteristics in the present dataset in more detail. Briefly, preaspiration is found before the fortis stops [pʰ tʰ kʰ], which are preceded by short vowels. If the duration of preaspiration is included, then the duration of such short vowels is in line with the duration of short vowels that do not precede fortis stops; I take this to indicate that vowel duration including preaspiration is a suitable measure, although further research is needed to reliably establish this.

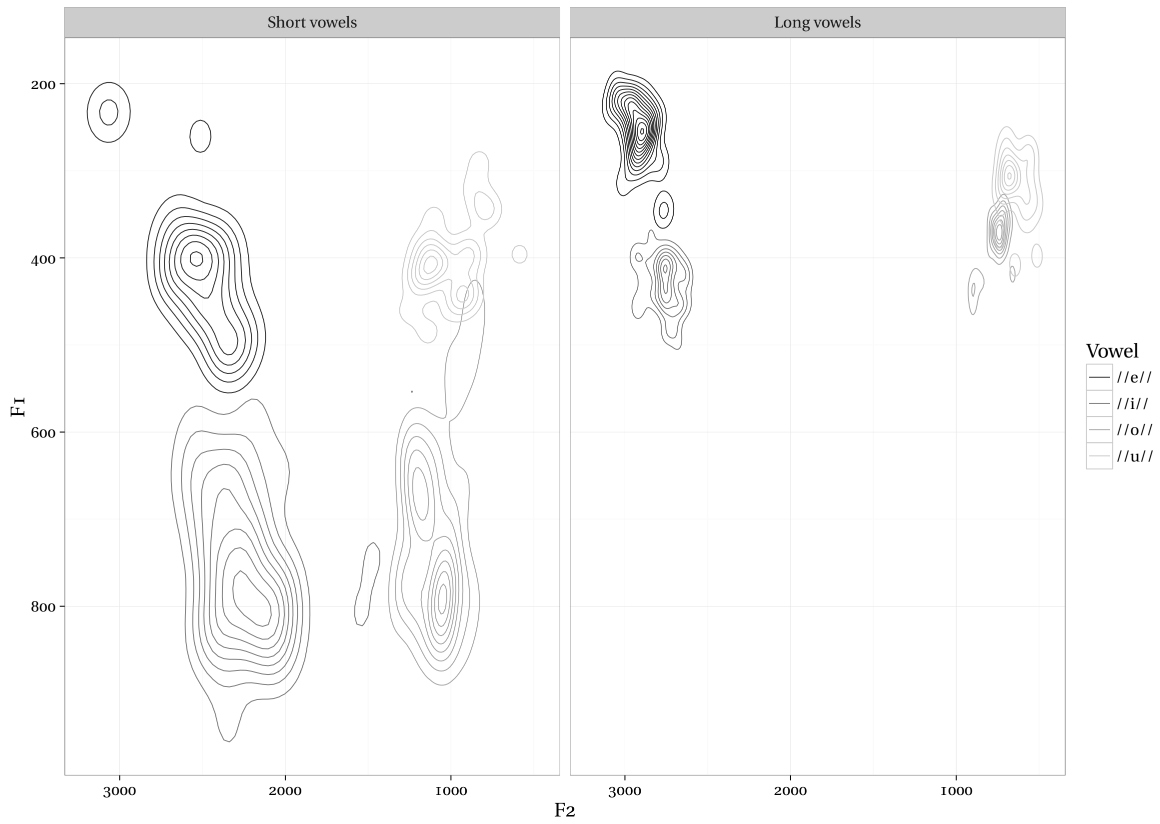


Figure 2: Formant values of vowels by length, speaker Sp1

extent of variation within each category but also the region of the vowel space where most of the tokens are concentrated.

In this case, long and short vowels form distinct clusters in the vowel space, particularly along the F1 dimension. However, in principle this qualitative difference could be an effect of under- or overshoot (Lindblom 1963) relative to a fairly high target, so that the shorter the duration of the vowel, the lower ('laxer') it is in quality. The apparently categorical difference could then derive not from the existence of two qualitative categories underlying the distribution of the tokens but simply from the distribution of duration, without a categorical quality distinction.

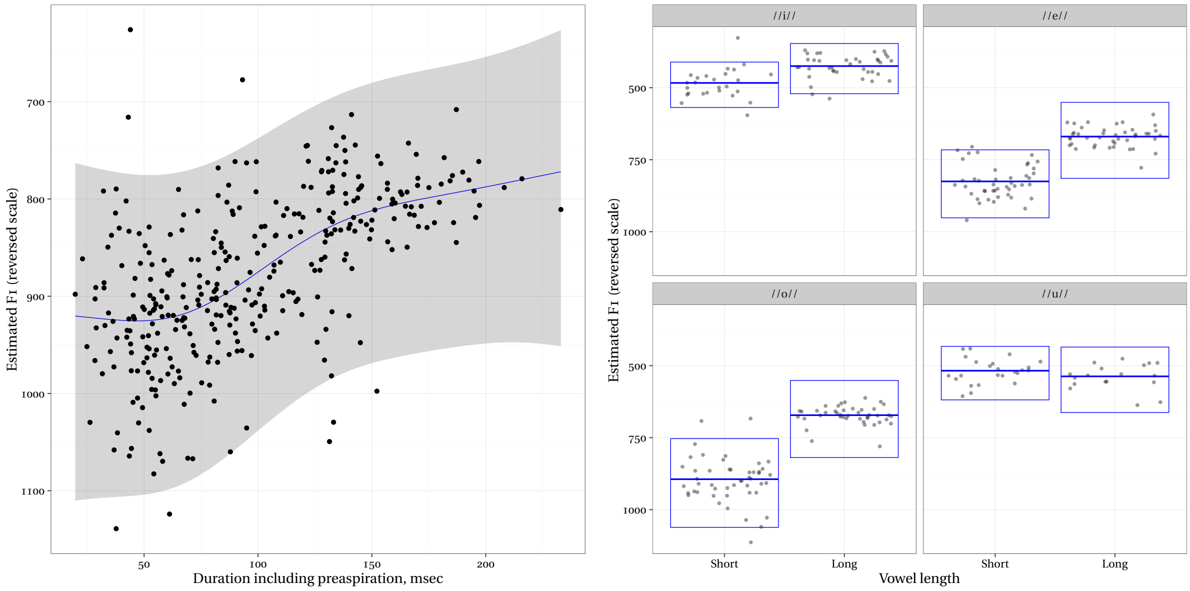
If this were the case, we expect the relationship between the duration of the vowel and its quality to be expressible as a continuous function. To verify whether the relationship of vowel duration and vowel quality is continuous or discrete, several generalized additive models were fit using the `mgcv` package (Wood 2006) in the R statistical environment (R Core Team

2016). A major motivation for the use of additive rather than linear models is their ability to model non-linear effects, which, as we shall see, are present in the data. After initial modelling, the residuals showed a non-normal distribution; this was corrected by treating $\log_2$ of F1 as the dependent variable. Independent variables included vowel quality, F2 (since the vowels are not evenly distributed in the vowel space), and the duration of the vowel including preaspiration of the following consonant.

A good fit was obtained in a model that included an interaction between vowel length and vowel quality, as well as a random intercept for lexical item. A selection of the better models is shown in table 7 in the Appendix, which includes the estimated coefficients and 95% confidence intervals. An effect is considered significant if the confidence interval excludes zero (these cases are marked with an asterisk).

To evaluate goodness of fit of the different models, we can use the Akaike Information Criterion (see Burnham & D. R. Anderson 2004 for a brief practical introduction). Briefly, the AIC produces a measure of the deviance explained by the model with a trade-off against the degrees of freedom, to avoid overfitting. Burnham & D. R. Anderson (2004) recommend using *second-order AIC* (AIC_c) in cases with relatively small samples, as is the case for all the data sets in this paper. Absolute $AIC_{(c)}$ values for different models are less informative than difference ($\Delta_{AIC_{(c)}}$) between the best model in the set (the one with the smallest value) and the model of interest. It is commonly assumed that a model with a $\Delta_{AIC} \leq 2$ is substantially supported by the data, one with a Δ_{AIC} of between 4 and 7 is substantially less supported by the data, and a model with a Δ_{AIC} of over 10 has essentially no support.

This type of modelling allows us to disentangle the influence of phonetic duration on vowel quality (e. g. undershoot effects) from the effects of a phonological 'length' category. Table 7 shows that *both* of these factors exert an influence. Specifically, a model including both is superior to models that exclude one of these terms: excluding phonological length produces a Δ_{AIC_c} of 28, and excluding duration gives a Δ_{AIC_c} of 10. The precise influence of both factors can be seen in fig. 3. The line shows the estimated effect, the shading the 95% confidence interval and the dots represent residuals. The vertical axis is reversed to ease the interpretation of the figures in terms of the vowel space.



(a) Effect of duration

(b) Effect of phonological length by vowel

Figure 3: Effects of duration and phonological length, Sp1

As fig. 3a shows, longer duration generally corresponds to a lower value for F1, although the effect is highly non-linear. I interpret this as an effect of undershoot: relatively short vowels are lower than the target. This is especially pronounced with vowels of greater duration (presumably mostly phonologically long ones), but less visible at short durations. This effect, however, cannot account for the full range of variation in F1, with the category of phonological length making a clear additional contribution (especially in the case of the mid vowels), as seen in fig. 3b.

Thus, Sp1 exemplifies the vowel system in penultimate syllables seen in existing descriptions of South Welsh. This speaker demonstrates a reliable distinction in duration between vowels in phonologically ‘short’ and ‘long’ contexts, and a categorical distinction in quality between the two classes. This applies to all the vowels that enter the length contrast, and the quality distinction cannot be accounted for solely by undershoot. This is precisely the phonologically ambiguous situation described in section 2.2.

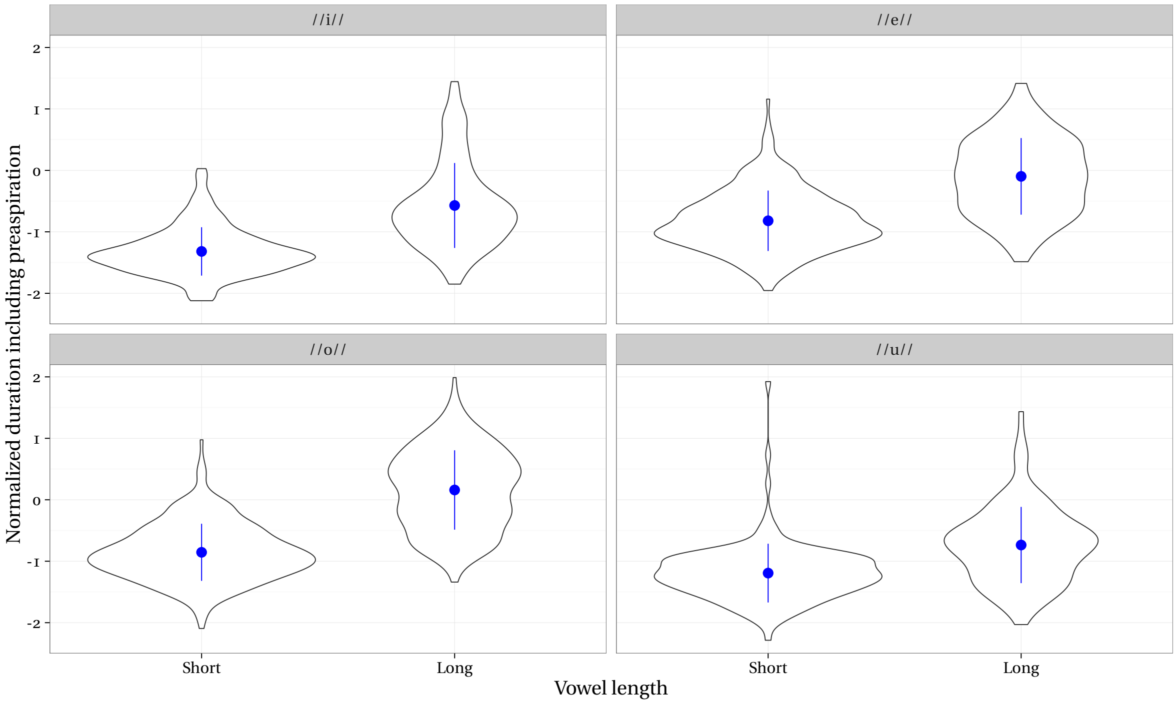


Figure 4: Vowel duration by category, south-western speakers

3.3.2 The south-western system

Six of the eight speakers exemplify the south-western system, where the quality of long mid vowels depends on the phonological category of the post-tonic vowel. Figure 4 demonstrates that all vowels show the expected difference in duration between the 'short' and 'long' contexts. (Durations have been normalized by converting to z-scores, with the mean duration of *all* vowels, including post-tonic ones, taken as 0.) A two-way ANOVA with normalized duration as dependent variable again shows that both vowel length ($F(1, 1699) = 744.85$, $p < 0.00001$) and vowel quality ($F(3, 1699) = 122.05$, $p < 0.00001$) are significant predictors of duration.

Figure 5 illustrates the distribution of vowel qualities by vowel duration, with formant values Lobanov-normalized (i. e. converted to z-scores) by speaker (Adank, Smits & van Hout 2004). The plot shows long mid vowel tokens to be concentrated in *two* regions of the vowel space: one with approximately the same quality as the corresponding short vowel and one

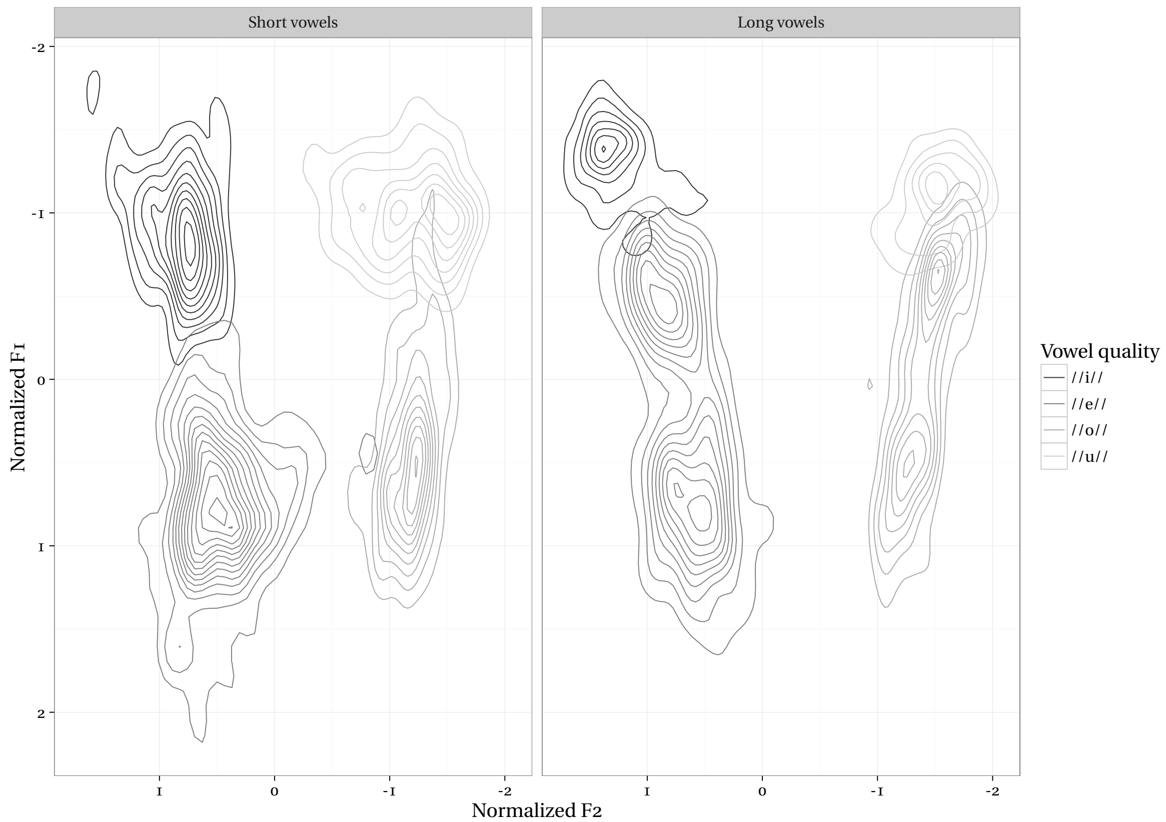


Figure 5: Densities of vowels for the south-western group, by vowel length

corresponding to a higher, more peripheral vowel in the same region of the vowel space as the long 'tense' vowels of Sp1.

The distribution of the lower ('lax') allophones of long mid vowels is consistent with the descriptions: they appear, almost without exception, before a high vowel. (Due to the restrictions of the lexicon, the high vowel in the post-tonic syllable was always //i//.) There is, however, at least one exception. The word *ffenestr* 'window' consistently has [ɛː] despite the non-high vowel in the post-tonic syllable: [ˈfɛːnɛst(r)]. Most speakers produced all three tokens of *ffenestr* in the task with a vowel with a normalized F1 of well above zero, even though most other tokens of long //e// before a non-high vowel have negative normalized F1. The exception is speaker Sp4, who always has tense [eː] here.[4]

[4]Recall that this is the speaker who was brought up in Cardiff, and otherwise shows a south-western system. Speculatively, this could be a case of incomplete dialect acquisition due to insufficient input: having successfully acquired the general rule, speaker Sp4 nevertheless may not have received enough input to acquire the lexical exception.

Given the highly consistent behaviour of *ffenestr* (but not any other lexical items) across speakers, it seems likely that it is not an artefact of experimental conditions but a true lexical exception. To take this into account, further modelling was conducted on the assumption that the stressed vowel of *ffenestr* for all speakers except Sp4 falls within the same category as other 'lax' long vowels.

To identify the nature of the following vowel's influence on the stressed vowel, we again fit several generalized additive mixed models, all with random intercepts for speaker and word (see table 8 in the Appendix). The results show that the quality of the stressed vowel is influenced by the high or non-high specification on the post-tonic vowel. A model without the height of the post-tonic vowel as a predictor fares worse than one that does. However, a model with only a single fixed effect of post-tonic vowel height (i. e. consistent across vowel quality and length specifications of the stressed vowel), does significantly worse than one with a three-way interaction between stressed vowel quality, stressed vowel length, and post-tonic vowel height ($\Delta_{AIC_c} = 20$).

As table 8 shows, most of the effect of the height of the post-tonic vowel is accounted for by the mid stressed vowels — neither short vowels nor the long high vowels are affected by a post-tonic high vowel, exactly as the descriptions claim. The effect of the post-tonic high vowel essentially cancels out the raising effect of phonological length, making the 'lax' long vowels identical to the corresponding short ones. For short //e// (i. e. [ɛ]) the estimated effect of vowel category is 1.58 standard deviations (relative to the F1 of [ɪ]), while for a long lax //e// (i. e. [ɛː]) the sum of all relevant effects is 1.55 SDs; for //o//, the corresponding numbers are 1.54 for [ɔ] and 1.72 for [ɔː].

The results of the acoustic study confirm the existence of two qualitative categories within most vowel pairs.[5] Among high vowels, the distribution is identical to that found elsewhere in Welsh: 'lax' [ɪ ʊ] are associated with phonological shortness, and 'tense' [i u] are found in contexts requiring phonological length. The distribution of mid vowels is different: 'lax' [ɛ ɔ] are associated with short contexts and with long contexts if there is a following high

[5]The exception is //u//, which does not show a significant difference in F1. However, further modelling identifies a robust difference between short and long //u// in F2; it is also probable that F3, not measured here, contributes to this distinction.

vowel; 'tense' [e o] are found elsewhere in long contexts (before a non-high vowel and — following traditional descriptions and Mayr & Davies 2011 — presumably in stressed final syllables).

Modelling also allows us to exclude the hypothesis that the dissimilation is an artefact of a continuous trade-off in duration between two neighbouring vowels. Such an explanation has been proposed to account for height dissimilation phenomena (Crosswhite 2000), and continuous trade-offs along these lines has been identified in Kera (Pearce 2007) and in dialectal Russian (Kniazev & Šaul'skij 2007). However, modelling with the duration of the post-tonic vowel or its (normalized) F1 as the explanatory variable gives results inferior to those with the phonological category of the post-tonic vowel as the chief factor: $\Delta_{AIC_c} = 27$ for normalized duration and $\Delta_{AIC_c} = 32$ for normalized F1. Thus, we are dealing with a categorical effect of the following vowel's height specification on the quality of the stressed one, rather than a continuous interaction. This justifies treating the 'mid vowel dissimilation' as a categorical process that, crucially, involves access to proprietary phonological information — the featural specification of the post-tonic vowel. Under modularist assumptions, this presents clear evidence for the *phonological* nature of the distinction between the 'tense' and 'lax' variants, at least of the mid vowels.

3.3.3 The non-enhanced system

Finally, speaker Sp8, brought up in Aberystwyth in Mid Wales, apparently shows another type of interaction between vowel quantity and quality. Like other speakers in the study, Sp8 shows some difference in vowel duration between the 'short' and 'long' contexts, with the exception of //u//. Unfortunately, the dataset for the single speaker is insufficiently large for any definite pronouncements on statistical significance. A two-way ANOVA with vowel duration as dependent variable indicates that both phonological length ($F(3, 276) = 50.38$, $p < 0.001$) and vowel quality ($F(1, 276) = 17.89$, $p < 0.001$), as well as their interaction ($F(3, 276) = 6.41$, $p < 0.001$) are significant

The existence of a quantitative distinction between short and long vowels in this variety is further confirmed by a distinction in the duration of post-tonic *consonants*, which are

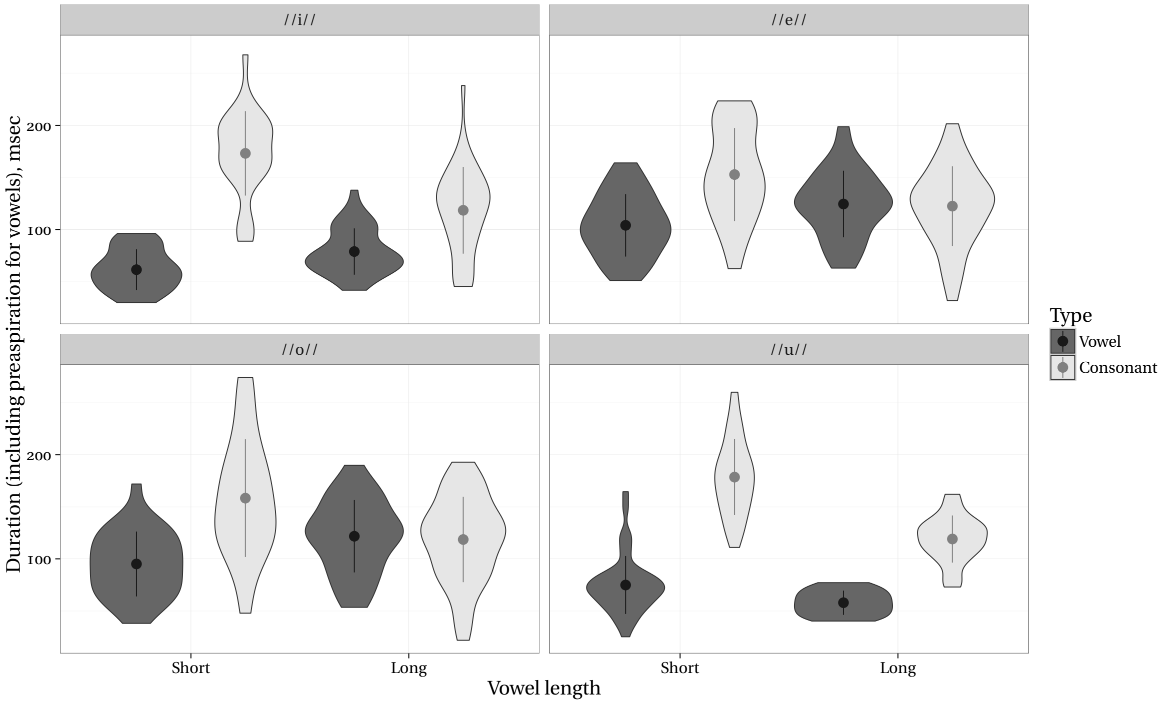


Figure 6: Vowel and consonant duration by context, Sp8

longer after short vowels and shorter after long vowels, consistent with the moraic structure postulated for South Welsh varieties in section 2.2. This is seen in fig. 6.

Vowel quality shows a different picture. Figure 7 demonstrates that 'long' and 'short' vowels occupy the same position in the vowel space (with the possible exception of //o//). It also shows that a large number of tokens coded as short //o// are located in the same region as tokens coded as //u//. This may be the result of a sound change, as the distribution of these anomalous tokens of //o// appears to be at least some extent lexically driven. Those cases where all tokens of a given word show an F1 value of under 400 Hz (unless this was the sole representative of the item in this data set) were recoded for the purposes of modelling as representing the category //u// rather than //o//. As the plot indicates, this is clearly not sufficient, as many tokens coded as //o// nevertheless clearly occupy much the same position in the vowel space as tokens of //u//, but barring further investigation of relevant varieties no other attempts to prejudge the categorization were made.

The results of modelling of the stressed vowel's F1 as predicted by vowel quality, vowel length, and their interactions are shown in table 9 in the Appendix. They confirm that there

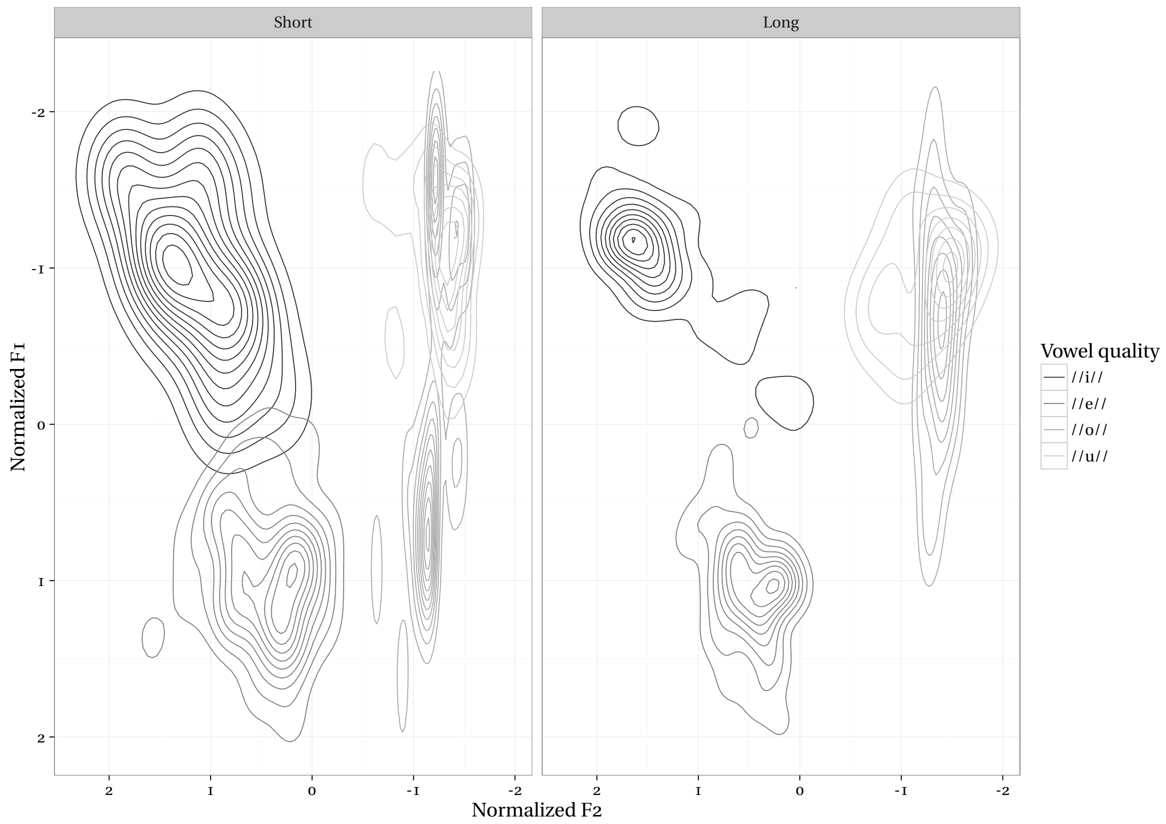


Figure 7: Density plot for vowel quality, Sp8

is no significant effect of phonological length on the quality of the stressed vowel, in contrast to the standard southern system. Adding duration as a predictor improves model fit ($\Delta_{AIC_c} = 14$). Specifically, increased vowel duration gives a *higher* F1, i. e. a *lower* vowel (fig. 8; as with fig. 3, the y axis is reversed).

The variation in the quality of stressed vowels in this system is not sensitive to phonological factors, notably length, that are so prominent in other varieties of Welsh. In fact, the raising effect of shorter duration seen in fig. 8 is consistent with undershoot of a relatively low target: the target qualities of at least the mid vowels for this speaker are in the region of other speakers' [ɛ ɔ], even when the vowels are phonologically long and have long duration. This clearly contrasts with Sp1, where undershoot produces relatively *low* vowels (fig. 3).

Subject to further investigation, I tentatively conclude that speaker Sp8 exemplifies a variety of Welsh without a robust distinction in quality between long and short stressed vowels (at least in penultimate syllables), with all mid vowels being 'lax' in quality.

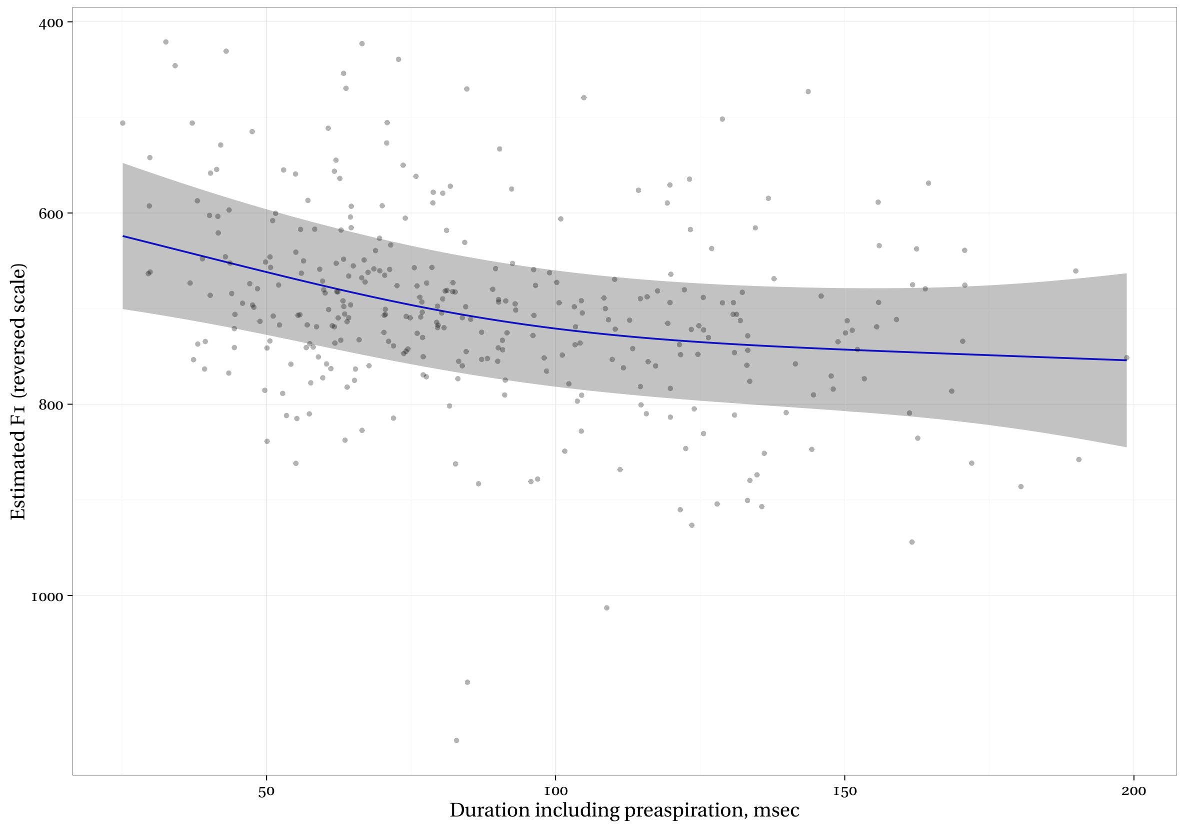


Figure 8: Effect of vowel duration on F1, Sp8

It is not clear whether such a system has been described in detail before in Welsh. Pilch 1957 presents an auditory study based on the speech of a single informant from Bow Street, a village 3.5 miles outside Aberystwyth. Although no explicit statement of the distribution of 'tense' and 'lax' vowels is given, at least for the mid vowels the distribution appears to be 'tense when long in a stressed monosyllable and pretonically, lax otherwise': [ˈmɛðɪg] *meddyg* 'doctor' vs. [m**e**ˈðəgɔn] *meddygon* 'doctors', [ˈh**e**n] *hen* 'old'. Pilch (1957) does not, however, write length unless it has 's-phonemic' function: thus, in his transcriptions the minimal pair *ton* 'wave' vs. *tôn* 'tune' is written [t$^{\mathrm{h}}$ɔn] vs. [t$^{\mathrm{h}}$on], even though the latter presumably has a long vowel. Hence, it is not clear whether his <mɛðɪg> corresponds to the [ˈmɛːðɪg] expected for Sp8.

The situation is different in the description of the dialect of (rural) north-west Ceredigion by Lewis (1960). He confirms that there is no length distinction in the penultimate syllables in this variety: [ˈt$^{\mathrm{h}}$ɔn] *ton* 'wave' and [ˈt$^{\mathrm{h}}$oːn] *tôn* 'tune' are distinct, but the plurals *tonnau* and *tonau* are not. However, according to Lewis (1960) the realization of vowels in penultimate syllables shows 'free variation' between a half-long tense vowel (followed by a short consonant) and a short lax vowel (followed by a long consonant): [ˈtʰoˑnɛ̝] ~ [ˈtʰɔnːɛ]. In final stressed syllables, the system described by Lewis (1960) is identical to the standard one for mid vowels, but, interestingly, he does not describe a quality difference between short and long *high* vowels even in stressed final syllables. Thus, although there are suggestive similarities between the system shown by Sp8 and those discussed by Pilch (1957), Lewis (1960), it appears that so far the pattern discussed here cannot be identified with another pattern described in the literature without further research.

3.3.4 Unstressed syllables

Finally, we turn to qualitative differences in post-tonic, unstressed syllables. As noted in section 2.1.3, previous descriptions lead us to expect no 's-phonemic' contrast in that position: the quality of the unstressed vowel is predictable, if sometimes variable. The distribution depends at least partly on syllable structure, with, for instance, high vowels always tense in final open syllables and always lax in final closed syllables.

If we accept the suggestion in section 2.2 that short vowels in stressed syllables precede moraic codas, then this distribution is in fact very similar to the distribution in stressed syllables: tense vowels are obligatory in open syllables, whether stressed (and thus phonologically long) or post-tonic (where the phonological quantity contrast is neutralized), while lax vowels are possible only in closed syllables (whether stressed or unstressed). The nature of the effect is open to question: given that vowels in closed syllables are commonly shorter than those in open ones, it could be due to duration rather than syllable structure.

The acoustic study allows us to conduct a preliminary examination of post-tonic vowels. A subset of the words were coded as containing a 'closed' or 'open' final syllable[6] and further models were fitted to this data set.

Figure 9 shows (normalized) vowel quality in final syllables by syllable type. It indicates that the descriptions are largely, but not entirely, correct. There is obvious separation in the

[6]Some items were disregarded, in particular those ending in [ð] or [v], which are prone to variable deletion. In all, there were 32 items coded as having a final open syllable and 68 items with a closed final syllable.

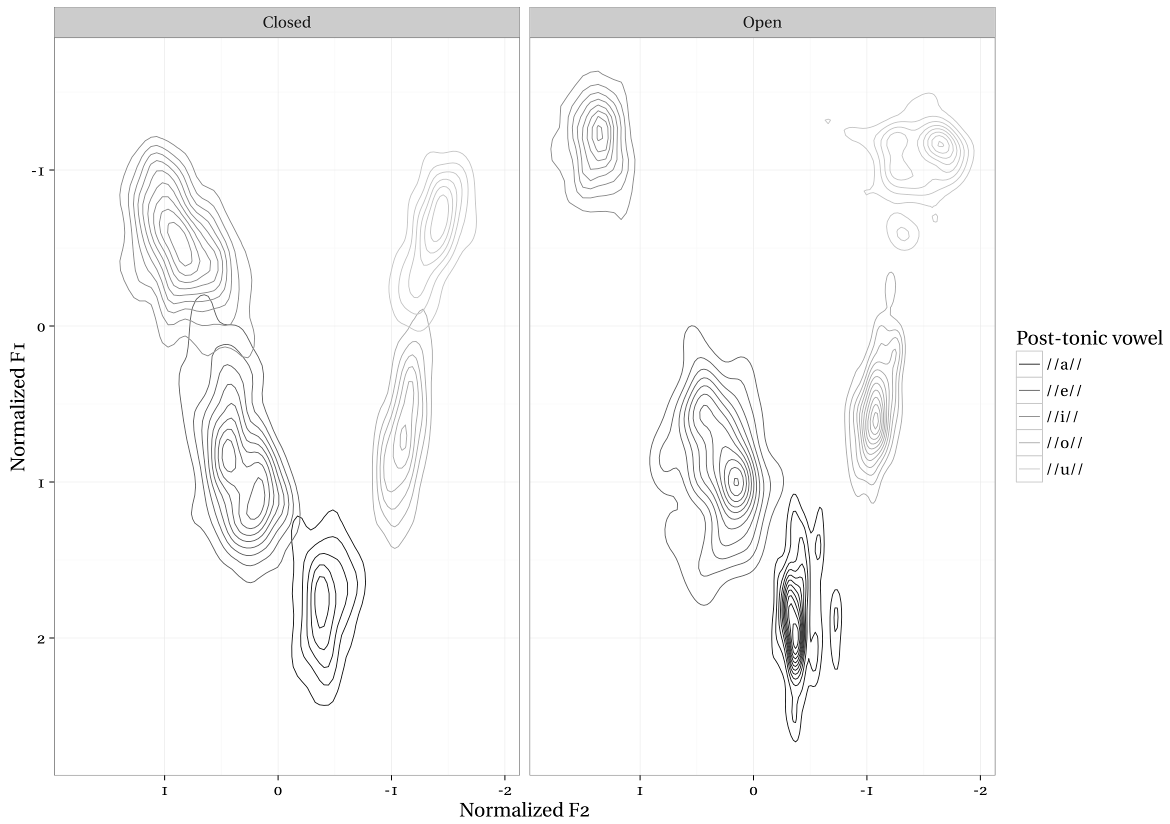


Figure 9: Normalized vowel quality, by final syllable type, all speakers

case of the high vowels //i// and //u//, with significantly centralized quality in closed syllables, but no clear distinction among the non-low vowels. This is shown in fig. 13 in the Appendix, plotting the estimated values of normalized F1 in a model that includes an interaction of vowel quality and syllable type (open or closed) in postvocalic syllables, as well as normalized duration, normalized F2, and random intercept by speaker as independent variables: as the figure shows, the 95% confidence intervals for vowels in open or closed syllables do not overlap for //i// and //u//, but do overlap for other vowels.

Thus, if the picture painted by the present data set is representative, the sources appear to be imprecise when they describe the realization of //e o// in final syllables as variable. Instead of a stochastic choice between 'lax' [ɛ ɔ] and 'tense' [e o], or a phonetic continuum with the 'tense' and 'lax' qualities as endpoints, we observe unimodal distributions in the case of the mid vowels. Moreover, the F1 values of these posttonic //e o// are very close to the F1 values for the corresponding short stressed vowels. Thus, we can tentatively conclude that post-tonic mid vowels are realized as [ɛ ɔ] in both closed and open syllables.

Since the conditions in post-tonic syllables were not controlled in this study, it is too early to give significant credence to the quantitative results reported here, even if the difference in the magnitude of the effects is highly suggestive. Further research is required to fully verify the hypotheses.

3.4 Summary

To summarize, the acoustic study has demonstrated the existence of three different types of interaction between vowel quantity and vowel quality:

- The 'standard southern' system: robust phonetic distinction between 'tense' and 'lax' vowels driven by phonological length, with an unclear phonological significance;[7]
- The 'south-western' system: robust distinction between 'tense' and 'lax' vowels driven by phonological length *and* phonological specification of neighbouring vowels, and thus available to the phonological grammar;
- Provisionally, the 'non-enhanced' system: phonological length distinction expressed via duration, but no robust qualitative distinction.

In post-tonic syllables, high vowels are obligatorily tense in open syllables and lax in closed ones; mid (and low) vowels show no influence from syllable structure, in all systems. Although in general terms the distribution of the allophones is similar, we can highlight the following differences between the systems:

- In the standard southern system, all long vowels are tense. Word-final high vowels are also tense;
- In the south-western system, tense vowels are either long or word-final, and restricted to a subset of open syllables; not all long vowels are tense;

[7]This conclusion must be slightly tentative given that only a single speaker in this data set represents this system. However, given the weight of available evidence for this type of patterning, including the quantitative study by Mayr & Davies (2011), it seems reasonable to conclude that this state of affairs is general.

- In the non-enhanced system, tenseness is found only word-finally, for a subset of vowels. Mid vowels are never tense. However, the situation in monosyllables is unclear.

In the next section I offer a phonological interpretation of these patterns of cross-dialectal diversity.

4 Analysis

This cross-dialectal variation requires a phonological analysis, with particular reference to the exact status of the 'tenseness' distinction. The acoustic study allows us to establish the *categorical* nature of the 'tenseness' distinction in the standard southern system; however, its *phonological* status can only be established with reference to a concrete analysis. To approach such an analysis, we begin with the south-western system, where the phonological status of the distinction is more secure.

4.1 The south-western system

As discussed above, I take the results of the acoustic study reported in section 3.3 to mean that the co-incidence of vowel tenseness and length in these varieties of Welsh is due to a phonological pattern, because the distinction is categorical (rather than continuously dependent on the duration of the vowel) and sensitive to phonological information. Specifically, the distribution is as follows:

- High vowels are tense in open syllables and lax in closed syllables, irrespective of stress and length;

(11) Tense high vowels

a. [.ˈkʰli̠ː.dɔ.] *cludo* 'to move'

b. [.ˈhɛð.li̠.] *heddlu* 'police'

c. [.ˈtʰi̠ː.] *tŷ* 'house'

(12) Lax high vowels

a. [.ˈhʊ̱n.nu.] *hwnnw* ‘that’

b. [.ˈmɔd.rɪ̱b.] *modryb* ‘aunt’

c. [.ˈtʰʊ̱pʰ.] *twp* ‘stupid’

- Mid vowels are lax irrespective of syllable structure, unless they are long and not followed by a high vowel:

(13) Tense mid vowels

a. [.ˈse̱ː.rɛn.] *seren* ‘star’

b. [.glo̱ː.] *glo* ‘coal’

(14) Lax mid vowels

a. [.ˈmɛ̱ː.ðʊl] *meddwl* ‘to think’

b. [.ˈɛ̱b.rɪɬ] *Ebrill* ‘April’

c. [.ˈneː.gɛ̱s] *neges* ‘message’

d. [.ˈboː.rɛ̱.] *bore* ‘morning’

e. [.ˈpʰɛ̱n.] *pen* ‘head’

- To complete the picture, we should discuss the vowel [ə]. It is not found in final syllables.[8] In penultimate stressed syllables, it is always short, and hence requires a moraic coda: [ˈkʰəvˑan] *cyfan* ‘all’. It is also impossible in hiatus. In other words, the schwa only appears in closed syllables, fully patterning in this respect with *high lax vowels* [ɪ] and [ʊ].

Hence, accounting for the distribution of tense and lax vowels in this system requires reference not just to the featural specifications of neighbouring vowels but also to syllabic structure (the presence of a coda) and moraic structure more specifically (vowel length). This is

[8]Exceptions are function words like *fy* ‘my’, *y(r)* ‘the’ (plausibly proclitics), and borrowings like *syr* ‘sir’.

clearly proprietary phonological information, and hence by the modularity criterion laid out in section 1.2 the 'tenseness' specifications of these vowels are also phonological by nature. In other words, both the acoustic data (categoricity) and the details of the distribution (reference to moraic structure) converge on an analysis where pairs such as [e] and [ɛ] are distinct in the phonological grammar. Such distinctions are normally encoded via *featural* structure.

4.1.1 The featural analysis of tenseness

To address the exact featural difference between [i] and [ɪ] or [e] and [ɪ], I draw on the major insight of contrastivist approaches to phonology, which seeks evidence for featural specifications primarily in the grammatical behaviour of the relevant segments and not (just) in their phonetic properties. As noted in section 1.3, I implement this in a substance-free framework with emergent features (e. g. Mielke 2008, Morén 2006, Blaho 2008, Odden 2013). In this approach, features do not have *intrinsic* phonetic content, highlighting the fact that they are arbitrary labels useful for designating sets of segments that show similar phonological behaviour, but without any claim to a one-to-one phonology-phonetics mapping.

In such a framework, we cannot assume that all pairs entering the 'tenseness' contrasts differ by the *same* feature. In fact, a closer analysis shows that 'tenseness' behaves differently in the high and mid vowel subinventories in south-western Welsh.

In mid vowels, the necessary condition on the presence of tenseness is bimoraicity. Bimoraicity itself is only possible in the absence of a coda, but this is an incidental generalization unrelated to vowel quality. However, this condition is not sufficient: some long mid vowels are still lax. Moreover, the 'tense' specification of mid vowels interacts with featural specifications of other vowels, specifically with their height. Crucially, the *tenseness* of the post-tonic vowels is irrelevant: both tense and lax high vowels trigger laxing of a stressed mid vowel:

(15) a. [ˈgɛːlɪ̠n] *gelyn* 'enemy'
     b. [ˈhɛːdi̠] *heddiw* 'today'

High vowels (and [ə]), on the other hand, show a symmetric patterning of tense-lax pairs driven solely by syllable structure and only coincidentally related to length thanks to open

Segment	[coronal]	[dorsal]	[lax]	[open]	[closed]
/i/	✓				✓
/ɪ/	✓		✓		✓
/u/					✓
/ʊ/			✓		✓
/ə/	✓	✓	✓		✓
/e/	✓			✓	✓
/ɛ/	✓				
/o/		✓			✓
/ɔ/		✓			
/a/				✓	

Table 2: Featural specifications for vowels: South-West Welsh

syllable lengthening: lax vowels are impossible in open syllables (some of which are bimoraic), and tense vowels are impossible in closed syllables. There is little evidence for the interaction of this distinction with any other element of the phonological grammar.

If we start from emergentist, substance-free assumptions that require phonological, ideally positive, evidence before assigning a common feature to a set of segments, it is apparent that the assumption of a single 'tenseness' feature covering all four non-low pairs in Welsh (and the unpaired [ə]) is unfounded. Moreover, and perhaps even more seriously, common universal feature systems are unable to describe the relevant phonological classes: for instance, the class of segments excluded from open syllables — [ɪ ʊ ə] — cannot be described by a conjunction of features that excludes [ɛ ɔ] in common systems such as that of Jakobson, Fant & Halle (1951) or Chomsky & Halle (1967);[9] it is even more difficult to express in featural terms the connection between mid vowel tenseness and the height of the following vowel.

Instead, I propose that the vowel patterns of South-West Welsh can be accounted for using the emergent featural specifications shown in table 2. For concreteness, I use privative features with vaguely phonetic labels reminiscent of versions of Unified Feature Theory (Clements & Hume 1995); it is important to remember, however, that since the featural theory assumed here is substance-free, the labels do not lay claim to inherent phonetic content

[9]The phonological class /ɪ ʊ ə/ appears to be rare cross-linguistically: the PBase database (Mielke 2008) contains one example (Punjabi) of a pattern exclusively involving these vowels.

(thus, for example, the co-occurrence of [open] and [closed] in [e] is not meant to represent a paradox like the co-occurrence of [+high] and [+low] in some theories). For reasons of space and focus, I do not present an explicit account of how the specifications in table 2 are manipulated by the grammar to produce the patterns; they can be quite straightforwardly implemented in a rule-based or OT formalism.

This system can be justified as follows:

- The feature [closed] covers segments implicated in the height dissimilation pattern, namely all high vowels (its triggers) and the 'tense' mid vowels [e] and [o];
- The feature [lax] covers the class [ɪ ʊ ə] banned from open syllables;

The distribution of 'tenseness' vis-à-vis length is largely accounted for by restrictions on [closed] and [lax]. The [lax] vowels [ɪ ʊ ə] cannot be long, because they are always found in closed syllables. The mid 'lax' vowels [ɛ] and [ɔ] do not fall within the scope of this generalization — correctly, as they *are* found in open syllables in this variety of Welsh (example 15). In fact, the system in table 2 implies that the markedness relationships of tense and lax vowels are reversed in high and mid subinventories: among the high vowels, lax [ɪ ʊ] are more marked (they bear the extra feature [lax]), and among the mid vowels, tense [e o] are more marked (they bear the extra feature [closed]).

In the high subinventory, this can be justified because the lax [ɪ ʊ ə] are associated with the more cross-linguistically marked context of closed syllables. We can think of the obligatory laxing of vowels in this context as a in instance of licensing: it is common in privative feature theories to assume that marked elements can only be retained in the presence of some additional material, and in this case [lax] licenses the coda.

As for the mid subinventory, in order to understand the markedness relationships between the sets [e o] and [ɛ ɔ], we need to determine the direction of the mid vowel tenseness alternation. Does the alternation in [ˈkʰɔːdi] *codi* 'rise' vs. [ˈkʰoːdɔð] *cododd* '(s)he rose' reflect an underlying /ɔ/ raised before a non-high vowel or an underlying /o/ lowered before a high one?[10]

[10] A reviewer rightly suggests a third possibility, namely that the underlying vowel is featurally identical to neither surface allophone. Particularly with binary features, one could, for instance, imagine an underspecified

I suggest that the word *ffenestr* 'window', consistently realized with [ɛː] rather than the expected [eː] before a non-high vowel, provides a clue. Rather than being arbitrarily marked as exceptional, it could indicate that the phonological grammar fails to raise an input mid lax vowel, ensuring a faithful mapping in terms of quality even if the vowel is contextually lengthened. This analysis is, of course, also consistent with the possibility of long lax [ɛː ɔː] in English borrowings, discussed in section 2.2. Thus, alternations in *codi* ~ *cododd* are examples of lowering, or deletion of [closed] in the presence of another instance of this feature within a final disyllabic domain; the domain could be, for instance, an uneven trochaic (H́L) foot.

This deletion gives the expected result when applied to /o/. Deletion of [closed] from /e/ results in the disallowed segment {[coronal], [open]}, so [open] is further deleted to produce [ɛ]. In the high vowels, which are all [closed], deletion of this feature would produce disallowed segments in the case of /i/, /ɪ/, and /ʊ/; and the empty segment (presumably also disallowed) in the case of /u/, and therefore can be straightforwardly blocked.

I take the existence of the form [ˈfɛːnɛst] (and possibly also English borrowings) as indicating that there is no obligatory raising of long lax mid vowels, at least in monosyllables. Given that long mid vowels are (apparently) obligatorily tense in forms with final stress like [ˈheːn] *hen* 'old', this requires us to posit either a tensing process somehow restricted to final stressed syllables, or to admit a lexical gap, i. e. the absence of lexical items of the shape /hɛn/ that would map to a surface [ˈhɛːn], as opposed to input /hen/, crucially with a [closed] /e/ that lengthens. The latter is not in fact entirely unattractive, because a diachronic explanation for the gap is readily available: if mid long vowels in final closed syllables are originally tense, there is no historical process by which they would become lax, and so the gap is simply due to the vagaries of history.[11]

The relatively unrestricted patterning of [ɛ] and [ɔ] contrasts with the fact that [e] and [o] *are* subject to a further requirement. They are only allowed to surface when bimoraic:

vowel and a feature-filling process. With unary features, this option is less appealing as the less marked vowel essentially *is* the underspecified correspondent. In the absence of strong *positive* evidence for setting up a third vowel category this option does not seem to have obvious advantages.

[11]See also Iosad 2017 for more evidence that historically long vowels in Welsh can enter an underlying ('m-phonemic') tenseness contrast.

	Stressed				Unstressed			
	Short		Long		Closed		Open	
Input	Output	Pattern	Output	Pattern	Output	Pattern	Output	Pattern
ɪ ʊ	ɪ ʊ		i u	OST[1]	ɪ ʊ		i u	OST
i u	ɪ ʊ	CSL[2]	i u		ɪ ʊ	CSL	i u	
e o	ɛ ɔ	SVL[3]	e o		ɛ ɔ	SVL	ɛ ɔ	SVL
			ɛ ɔ	HD[4]				
ɛ ɔ	ɛ ɔ		ɛ ɔ		ɛ ɔ		ɛ ɔ	
			(e o)	(FLT)[5]				

[1] Open syllable tensing: ɪ ʊ → i u / in any open syllable
[2] Close syllable laxing: i u → ɪ ʊ / in any closed syllable
[3] Short vowel laxing: e o → ɛ ɔ / when monomoraic
[4] Height dissimilation: e o → ɛ ɔ / before [closed] vowel
[5] Final long vowel tensing: ɛ ɔ → e o / in a final stressed syllable

Table 3: Input-output mappings in a grammar of South-West Welsh

mid vowels are obligatorily lax in unstressed syllables and in stressed syllables with moraic codas. This patterning asymmetry further supports the proposition that the 'tense' vowels [e o] are *more* marked than the 'lax' [ɛ ɔ], in a reversal of the situation observed in the high subinventory.

The phonological grammar of tenseness and laxness in South-Western Welsh is summarized in table 3. It shows various types of potential inputs in different contexts, and any rules (or, in OT parlance, unfaithful mappings) that are required to effect the necessary changes. As discussed above, it is not clear whether input [ɛ ɔ] become [e o] when long in a final syllable.

4.1.2 Other phonological processes

Apart from the grammar of tenseness and laxness, the proposed featural specifications should also be consistent with other morphophonological alternations in Welsh. These tend to involve the coarser vowel categories (i. e.//i//, //u// etc.). The most important phenomena are the following (Iosad 2012, Hannahs 2013):

- 'Vowel mutation': /ə/ is realized as //i// in a final syllable; this neutralization can be analysed as deletion of [dorsal] (and [lax] if necessary because of syllable structure) to produce //i//;[12]

- 'Vowel mutation' in some varieties also encompasses the alternation between the diphthong [ai] in a final syllable and [ei] in a non-final one: [ˈbraiχ] *braich* 'hand' ~ [ˈbreiχɛ] *breichiau* 'hands', analysed as spreading of [coronal] from the glide to the nucleus of the diphtong;

- Finally, an underlying [ɔ] in some stressed monosyllables alternates with [ə], or [ɪ] where schwa is excluded from this context: [ˈfɔn] *ffon* 'stick', pl. [ˈfən] or [ˈfɪn] *ffyn*; Iosad (2012) analyses this is as addition of a floating [coronal], and uses this evidence for the analysis of //ə// as the union of the features of //o// and //i//.

The present proposal preserves in the main the analysis in Iosad (2012); I refer to that work for detailed justification. The specifications are consistent with a substance-free approach in that they refer *only* to phonological patterning: for instance, //o// and //u// do not share features, in contrast to an approach where they would share a colour specification, because they do not act as a class in any phonological pattern of Welsh.

4.1.3 The feature analysis and the contrastive hierarchy

I will now discuss how the present analysis is relevant to the Contrastivist Hypothesis. In particular, what is the import of contrastivism if phonological representations are constructed 'from the bottom up', on the basis of the inventory of categorically distinct units and their behaviour in the grammar? One could imagine that if there is enough evidence for phonological activity of redundant distinctions, then this could defeat the Contrastivist Hypothesis (cf. Blaho 2008: §1.2.2).

Indeed, the emphasis in much contrastivist practice has been on identifying the proper assignment of a closed set of universal features, and Hall (2011) in particular presents a defence of this approach over emergent-feature theories in a contrastivist context. However,

[12] Traditionally 'vowel mutation' also encompasses the alternation between final-syllable [u] and non-final [ə], but see Iosad 2012 for arguments that this is not a phonological pattern in Modern Welsh.

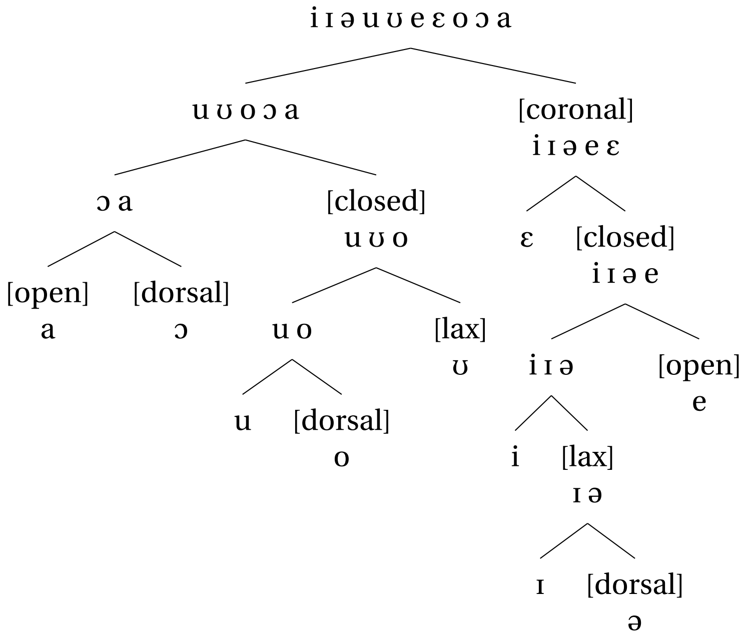


Figure 10: Contrastive hierarchy for South-West Welsh

both Cowper & Hall (2014) and Dresher (2014) suggest that emergent features are compatible with contrastivism, as long as the foundational importance of contrast is also recognized.

Here, I follow the latter line of inquiry, and suggest that the Contrastivist Hypothesis can be made contentful in the context of emergent features by restating it as a condition on inventories. Specifically, I suggest that a set of featural specifications in an inventory is consistent with the Contrastivist Hypothesis if there exists a contrastive hierarchy constructed in line with the Successive Division Algorithm (SDA; Dresher 2009) that assigns that set of specifications to that inventory.

Briefly, the Successive Division Algorithm takes an inventory and uses some feature *F* to divide it into two subinventories depending on whether they bear *F* (or [+*F*] and [−*F*] values, in the binary version), and then recursively repeats that procedure with different features, stopping when a subinventory consists of a single segment. This guarantees lack of redundancy: the algorithm only assigns a feature to a segment if it contributes to distinguishing it from some other segment. However, the SDA is not fully deterministic: the set of features used in a particular language, and the order of subdivisions, are subject to cross-linguistic variation.

Successive division can be applied to both binary and unary features. Figure 10 shows a contrastive hierarchy corresponding to the inventory of South-West Welsh proposed in table 2. It has been constructed following the version of the SDA for privative features described by Hall (2007), with one non-trivial difference.

Hall's (2007) SDA for privative features guarantees that one of the segments in the inventory remains featurally empty, because every cut produces a subinventory where no feature is assigned. I suggest that the presence of such an empty segment is a matter of cross-linguistic variation. It may well be that in some languages there is strong evidence for such empty segments in the phonological grammar. However, it is also possible that no evidence is available for a featurally empty segment: for instance, even if it is theoretically possible in inputs, the grammar may insist on always inserting some features to neutralize it with another segment. I suggest that in such cases the empty segment's place in the contrastive hierarchy may be occupied by another segment specified for a single feature, with the restriction that this feature is also used elsewhere in the hierarchy. Such features are deemed to be available, because they, as our formulation of the Contrastivist Hypothesis has it, are still *necessary* to distinguish (some other) phonemes of the language. If a feature were only assigned to this isolated segment, it cannot be said to be necessary, as the segment would still be distinct if it remained unspecified.

In the case of South-Welsh Welsh, I suggest the segment is [a] and the feature is [open], which is also assigned to [e] fully in line with the algorithm. With this amendment, the inventory of South-West Welsh proposed in table 2 is consistent with the Contrastivist Hypothesis and allows us to successfully account for the behaviour of the categories 'tense' and 'lax' this variety.

4.2 The standard southern system

Applying the criteria for phonological status used in the previous section to the standard southern system shows that the set of categories active in the phonological grammar is essentially identical to that in the south-west. The high vowels //i// and //u// show the same sensitivity to syllable structure — tense in open syllables, lax in closed syllables. Thus, the

[i]/[ɪ] and [u]/[ʊ] distinctions are visible to the phonology. The markedness reasoning also carries over unchanged: [ɪ] and [ʊ] are more marked than [i] and [u].

The status of 'tenseness' in mid vowels is less clear. The distinction interacts with moraic structure, so by the modularity criterion its phonological status is assured. However, there are fewer cues to its featural content, since it is not involved in interactions with other segments. Yet there is an important difference between the standard southern and the south-western system: in the latter, mid vowels are bimoraic *if* they are tense; in the former, mid vowels are bimoraic *if and only if* they are tense. Thus, the argument from restricted distribution cannot be used to decide whether 'tense' or 'lax' mid vowels are more marked, as the restrictions are symmetrical.

One could reason that the mid tense vowels are more marked, since they are associated with the marked context of bimoraicity (much as lax high vowels are marked because they are associated with the marked context of closed syllables). Although such arguments are not particularly decisive, by parity of reasoning I adopt the solution whereby in high vowels it is the lax member that bears an extra feature, and in mid vowels it is the tense member. In any case, as in the south-western system, there does not appear to be positive phonological evidence for treating the 'tenseness' distinction in the mid and high vowels as instantiating the same contrast. Table 4 lays out the proposed analysis, with specifications for the south-western system from table 2 added in grey for comparison. Note that although I use the same feature labels as in preceding section, no phonetic identity or similarity is necessarily implied.

It is worth noting the difference is the specification of [a], which only has the feature [tense], whereas in the south-western system it is [open]. The reason is the different scope of [closed], which only singles out high vowels (and [ə]) in the latter, but does some of the work of [tense] in the former: essentially, in the standard southern system [tense] does the work that [closed] cannot do because there is no phonological relationship between /e o/ on the one hand and high vowels on the other. This has a desirable consequence: if [a] is [tense], then the low vowel is expected not to support the tenseness distinction, agreeing

Segment	[coronal]	[dorsal]	[lax]	[closed]	[tense]	[open]
/i/	✓			✓		
	✓			✓		
/ɪ/	✓		✓	✓		
	✓		✓	✓		
/u/				✓		
				✓		
/ʊ/				✓		
			✓	✓		
/ə/	✓	✓	✓	✓		
	✓	✓	✓	✓		
/e/	✓				✓	
	✓			✓		✓
/ɛ/	✓					
	✓					
/o/		✓			✓	
		✓		✓		
/ɔ/		✓				
		✓				
/a/					✓	
						✓

Table 4: Featural representations for the standard southern system

with the instrumental data available so far: as noted in section 2.1, no instrumental study has yet corroborated the claims of a qualitative difference between short and long vowels.

Figure 11 shows a contrastive hierarchy, drawn up on the same principles as that in the previous section and compatible with the specifications in table 4.

Thus, despite the essentially identical surface inventory, the 'south-western' and 'standard southern' systems differ both in representation (i. e. featural specifications) and computation (i. e. the patterns and rankings that account for them). This supports the position of emergent feature theory, where the symbolic representation of very similar phonetic phenomena can vary cross-linguistically and must be discovered with reference to patterns of distribution and alternation.

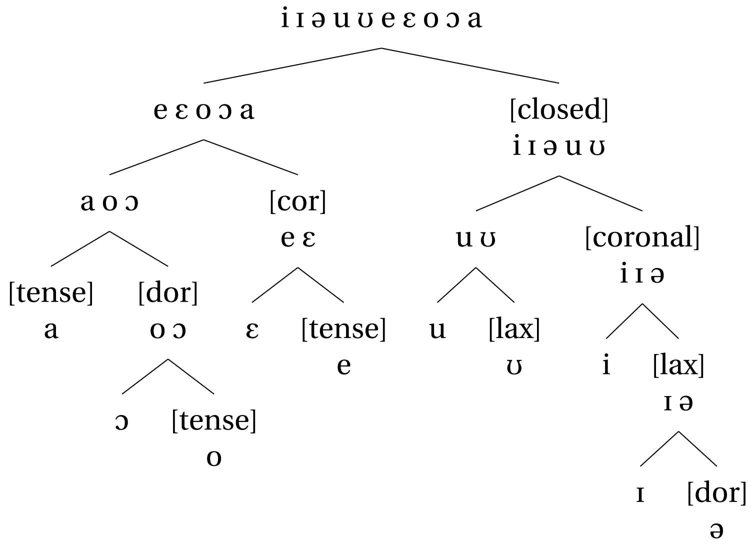


Figure 11: Contrastive hierarchy for the standard southern system

4.3 Featural analysis: summary

The cross-dialectal investigation of quantity-quality interaction in Welsh vowels demonstrates non-trivial cross-dialectal divergences in inventories, the phonological interpretation of very similar phonetic contrasts, and phonological grammars. In all cases, the most important differences concern the status of 'tenseness'.

In the standard southern system, the tenseness distinction covers all vowels (except [ə] and [a]), but it does not create a surface ('s-phonemic') contrast, and there is little positive phonological evidence to connect this distinction in high vowels with the one in mid vowels.

By contrast, in the south-western system the distinction interacts with other features, which provides some evidence as to its nature within the context of the broader grammar. Moreover, in this system 'tenseness' is not just *phonologized*, but also *phonemicized* (Hyman 1976): it appears to be necessary in underlying representations to account for forms like [ˈfɛ̲ː̲nɛst] 'window'. In the next section I discuss the role of the phonologization process in creating these situations.

5 Phonologization, redundancy, and the Contrastivist Hypothesis

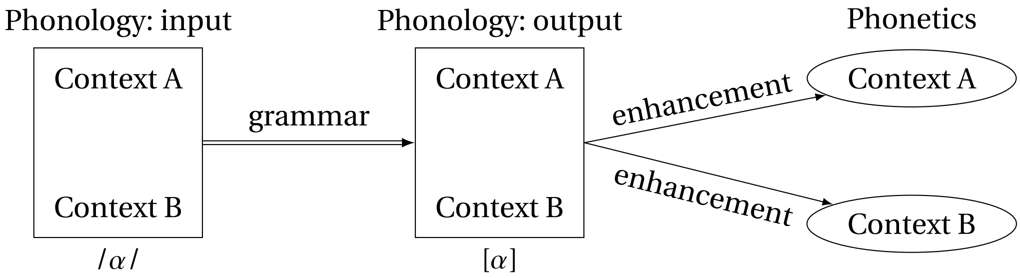
We can now return to the question of whether assigning a phonological 'tenseness' specification to Welsh vowels is consistent with the Contrastivist Hypothesis, using the criteria in section 1.2. To recap, we established the following:

- The set of Welsh phonological patterns $\mathcal{P}$ contains categorical patterns involving proprietary phonological entities such as syllables;
- It is possible to envisage a set of Welsh phonemes $\mathcal{PH}$ where 'tense'/'lax' pairs such as /e/ and /ɛ/ are treated as separate phonemes;
- It is possible to use a version of the Successive Division Algorithm to assign a set of non-redundant specifications for $\mathcal{PH}$ using the feature set $\mathcal{F}$ (that includes, in this case, the features [tense] and [lax]);
- All patterns in $\mathcal{P}$ make crucial reference to features that are *present* in $\mathcal{F}$.

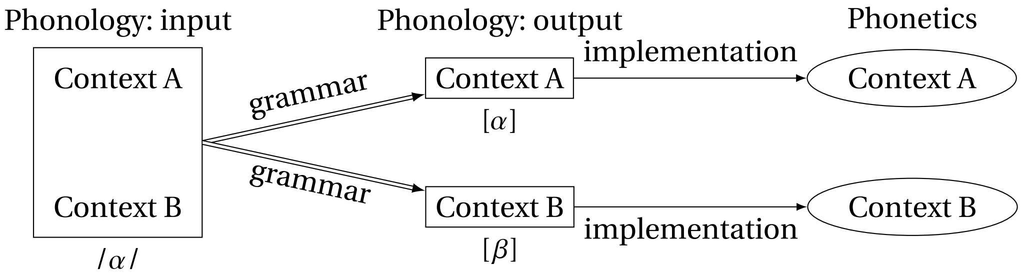
Under these criteria, then, Welsh 'tenseness' does not present a counterexample to the Contrastivist Hypothesis even if quality is also treated as phonologically relevant. This result stands in stark distinction to the traditional analysis that must designate 'tenseness' as an allophonic phenomenon.

The key to the disconnect between the various understanding of contrastiveness lies in the life cycle of phonological processes, and specifically in the process of phonologization. Phonologization represents not so much a change in the observed patterns as a change in their interpretation by the learner. At least in the early stages of phonologization the distribution of newly created categories adheres very closely to the original phonetic conditioning, and thus appears to be 'allophonic' under traditional criteria. This is shown in fig. 12.

Before phonologization, the grammar maps an input category $/\alpha/$ to a single category $[\alpha]$ in the surface phonological representation. However, enhancement (or other phonetic implementation processes) maps that output category $[\alpha]$ to several distinct regions in the phonetic space (contexts A and B). After phonologization, the grammar includes rules mapping input $/\alpha/$ to $[\alpha]$ in context A but to $[\beta]$ in context B, with attendant implementation



(a) Before phonologization



(b) After phonologization

Figure 12: Phonology-phonetics relationships before and after phonologization

mechanisms for [α] and [β]. In both cases, input phonological /α/ corresponds to a similar distribution of the phonetic variants, but the underlying mechanism has changed.

In the case of Welsh 'tenseness', the original 'enhancement' mechanism is the raising of long vowels, still apparently absent in (parts of) the 'non-enhanced' system. This raising must have originally been a pure implementation effect. In the standard southern system, however, this implementation effect coexists with its phonological congener, a categorical tensing rule for long vowels — an example of what Bermúdez-Otero (2015) calls 'rule scattering'.

This framework requires the phonological computation to be able to create fully predictable ('allophonic') distributions of phonological symbols (such as segments) and thus break the link between phonological status and predictability. Indeed, just such a requirement has been at the heart of objections to the taxonomic phoneme — and hence to a privileged role for contrast in phonology since at least Bloomfield 1939. Here, I suggest that even if we recognize that phonological computation can enforce such predictable distributions, a contrastivist approach provides a strong and useful restriction on inventory structure if it is reframed with reference to non-redundant specification implemented with a contrastive hierarchy.

In our definition of the Contrastivist Hypothesis, no phonological pattern can make reference to features that are not necessary to distinguish the phonemes of the language.[13] I suggest here that a feature is 'necessary' for the purposes of this definition if it is used to distinguish between at least one pair of segments without redundancy — that is, within a set of specifications consistent with being constructed by the Successive Division Algorithm. For instance, in the 'standard' Welsh system the features [lax] and [tense] are *not* redundant, since they distinguish between pairs that are otherwise non-distinct (such as [i] / [ɪ]).

The '(non-)redundancy' of a feature is *always* relative to the entire set of specifications for the given language's inventory. A contrastive hierarchy captures the insight that redundancy is always contingent and language-specific. Much work in this area, usefully summarized by Dresher (2009), has shown the range of cross-linguistic variation in contrastive specification. As Dresher (2014) argues, the way each language structures the space of available distinctions determines the patterning of phonological symbols; the constitutive role of contrast, both in phonological and morphosyntactic domains, is also underlined by Cowper & Hall (2014).

How, then, can one falsify the Contrastivist Hypothesis within an emergent-feature framework? Such a falsification requires identifying the set of phonological symbols and phonological patterns, with reference to *independent* criteria for phonological status. I have suggested that categoricity is an important necessary condition, but also argued that it is not *sufficient*, given the possibility of categorical patterns emerging from non-categorical underlying processes, and suggested *modularity* as an additional criterion. Building on this analysis, the featural implementations of the necessary distinctions can be subjected to the contrastivist test: given a proposed phonological grammar $\mathcal{P}$ manipulating (emergent) features $\mathcal{F}$, can the set $\mathcal{F}$ be derived using a contrastivist approach such as successive division?

[13]The definition of 'phonological activity' — whether the grammar 'makes reference' to a feature — depends on the framework. In a rule-based approach, 'activity' must mean being present in the structural description or structural change of some rule. In a constraint-based approach, a feature could be 'active' if referred to by an 'active' constraint, following the definition by Kiparsky (2017): 'a constraint is active at a given level if it is ranked in such a way that it is visible in at least some derivation, i. e. that the output would be different if it were removed entirely'.

The Contrastivist Hypothesis can then be falsified if some independently motivated set of specifications $\mathcal{F}$ cannot be derived in such a non-redundant manner. Such a falsification is, of course, contingent on a fully worked-out analysis of the patterns of the individual language.

6 Conclusion

In this paper I have shown how an approach based on the contrastive hierarchy is compatible with emergent feature theory. As both Dresher (2014) and Cowper & Hall (2014) emphasize, constrastive specification via successive division provides a fundamental mechanism for feature specification, but does not necessarily put substantive restrictions on the nature of the distinctive features involved. An emergent-feature approach goes hand in hand with a theory of phonologization, where symbolic phonological generalizations emerge over the course of the life cycle. Once the categories are identified, the learner must label them. The labelling can be subject both to bottom-up pressures (e. g. the learnability advantage afforded by phonetically coherent categories) and to top-down influence. For the latter category, this paper has focused on morphophonological patterns as an important source of evidence for phonological specification, in line with emergent feature theory and contrastivist approaches.

The study of microvariation in featural specifications reiterates the advantages of emergent features. The varieties examined here have very similar surface inventories, and yet the behaviour of the 'tenseness' distinction differs in the three varieties. Emergent features allow us to not only offer an analysis of the patterns but also capture these cross-linguistic differences in a way that universal feature specifications fail to do, either because they cannot capture the right classes of segments (as in the case of the restriction on [ə ɪ ʊ] in open syllables) or because they predict the existence of classes for which there is no phonological evidence (as in the case of the set of [+tense] segments, which show differing markedness behaviour in the high and mid subinventories).

Further questions remain. One issue, as a reviewer correctly points out, is at what level the 'inventory' $\mathcal{PH}$ relevant for contrastive specification should be determined. In the analysis given here, I have emphasized the phonological visibility of predictable information, which sits rather uncomfortably with the generativist emphasis on inventories of 'm-phonemes' — segments that should be posited in underlying representations, stripped of predictable information introduced computationally.

It may well be turn out to be the case that the right level for generalizations about 'inventories' is what Kiparsky (2017) calls the 'l-phonemic' level: the output of the lexical stratum, which may contain predictable information.[14] By reframing the issue of 'contrast' in terms of lack of redundancy, I have not considered in detail whether the [tense] and [lax] specifications should be present at Kiparsky's 'm-phonemic' level, i. e. whether they are contrastive in the traditional generative sense. For the south-western system, there are indications that at least for the mid vowels this distinction *must* be encoded there ('phonemicized' in the sense of Hyman 1976) given the existence of unpredictable lax long vowels ([ˈfɛ̲ː̲nɛst] 'window'). For the high vowels in the south-western system and all non-low vowels in the standard southern system, however, the distribution still appears fully predictable. Whether 'tenseness' should be encoded 'm-phonemically' in these cases is a separate question that cannot be addressed here in detail. Under certain OT assumptions, it is likely that this could be the case that non-alternating forms lead the learner to postulate a distinction between underlying (say) /ɛ/ and /e/ (for the standard southern system, cf. [ˈweːdi] *wedi* 'after' but [ˈvɛɬi] *felly* 'so'); (cf. Krämer 2012). By contrast, Dunbar, Dillon & Idsardi (2013) argue that fully predictable ('allophonic') variation is factored out during the learning process so that such distinctions are not postulated underlyingly. I leave the exploration of this question to further research.

Another open question is whether the Contrastivist Hypothesis is applicable to *all* aspects of phonological representation, or only to subsegmental features. In the case of Welsh, I have not included moraic or other quantity specifications in the contrastive hierarchy. It is, however, clear that if the analysis of quantity laid out in section 2.2 moraic specifications *are*

[14] See also, for instance, Mackenzie (2016) for discussion of the relationship between contrastive specification and stratal computation.

contrastive in the 'm-phonemic' sense, since moraic and nonmoraic /n l r/ are underlyingly distinct; thus, the case treated here should not be problematic for contrastivist approaches. However, the question remains open in more general terms: for instance, Kiparsky (2017) rejects the Contrastivist Hypothesis as formulated by Hall (2007) precisely because suprasegmental phenomena such as stress or syllabification can be phonologically relevant without being contrastive underlyingly.

To conclude, Dresher (2014) objects to emergent-feature approaches on the grounds that they put too much of an explanatory burden on extraphonological factors and not enough on formal phonological structure. I have argued that both types of factors play an important role in a substance-free analysis. While functional and learnability pressures undoubtedly have an influence, in particular through their role in phonological change (including phonologization), non-trivial formal hypotheses can be formulated and tested within a substance-free approach. In particular, an emergent-feature analysis can shed light on an important challenge to the Contrastivist Hypothesis, and contribute to its reconciliation with the data. The emphasis on phonology-internal evidence inherent in an emergent-feature approach allows us to clearly identify independent, computationally framed criteria for phonologization (phonological status) that put contrastivist approaches on a firmer methodological footing.

References

Adank, Patti, Roel Smits & Roeland van Hout. 2004. A comparison of vowel normalization procedures for language variation research. *Journal of the Acoustical Society of America* 116(5). 3099–3107.

Awbery, Gwenllian M. 1984. Phonotactic constraints in Welsh. In Martin J. Ball & Glyn E. Jones (eds.), *Welsh phonology: Selected readings*, 65–104. Cardiff: University of Wales Press.

Awbery, Gwenllian M. 1986. *Pembrokeshire Welsh: A phonological study*. Llandysul: Welsh Folk Museum.

Ball, Martin J. & Briony Williams. 2001. *Welsh phonetics* (Welsh Studies 17). Lewiston, Queenston & Lampeter: Edwin Mellen Press.

Bermúdez-Otero, Ricardo. 2012. The architecture of grammar and the division of labour in exponence. In Jochen Trommer (ed.), *The phonology and morphology of exponence: The state of the art* (Oxford Studies in Theoretical Linguistics 41), 8–83. Oxford: Oxford University Press.

Bermúdez-Otero, Ricardo. 2015. Amphichronic explanation and the life cycle of phonological processes. In Patrick Honeybone & Joseph C. Salmons (eds.), *The Oxford handbook of historical phonology*, 374–399. Oxford: Oxford University Press.

Blaho, Sylvia. 2008. *The syntax of phonology: A radically substance-free approach.* Tromsø: University of Tromsø dissertation.

Bloomfield, Leonard. 1939. Menomini morphophonemics. *Travaux du cercle linguistique de Prague* 8. 105–115.

Boersma, Paul & David Weenink. 2015. Praat: Doing phonetics by computer.

Botma, Bert & Marc van Oostendorp. 2012. A propos of the Dutch vowel system 21 years on, 22 years on. In Bert Botma & Roland Noske (eds.), *Phonological explorations: Empirical, theoretical and diachronic issues*, 135–154. Berlin: De Gruyter.

Burnham, Kenneth P. & David R. Anderson. 2004. Multimodel inference: Understanding AIC and BIC in model selection. *Sociological Methods and Research* 33(2). 261–304.

Bye, Patrik & Paul de Lacy. 2008. Metrical influences on fortition and lenition. In Joaquim Brandão de Carvalho, Tobias Scheer & Philippe Ségéral (eds.), *Lenition and fortition* (Studies in Generative Grammar 99), 173–206. Berlin: Mouton de Gruyter.

Chomsky, Noam & Morris Halle. 1967. *The sound pattern of English.* New York: Harper & Row.

Clements, G. Nick & Elizabeth V. Hume. 1995. The internal organization of speech sounds. In John Goldsmith (ed.), *The handbook of phonological theory*, 245–306. Oxford: Blackwell.

Cowper, Elizabeth & Daniel Currie Hall. 2014. *Reductiō ad discrīmen*: Where features come from. *Nordlyd* 41(2). 145–164.

Crosswhite, Catherine M. 2000. Vowel reduction in Russian: A unified account of standard, dialectal, and 'dissimilative' patterns. In Catherine M. Crosswhite & Joyce McDonough (eds.), *University of Rochester working papers in the language sciences*, vol. Spring 2000, 107–171.

Dresher, B. Elan. 2009. *The contrastive hierarchy in phonology*. Cambridge: Cambridge University Press.

Dresher, B. Elan. 2014. The arch not the stones: Universal feature theory without universal features. *Nordlyd* 41(2). 165–181.

Dresher, B. Elan, Glyne Piggott & Keren Rice. 1994. Contrast in phonology: overview. *Toronto Working Papers in Linguistics* 14. iii–xvii.

Dunbar, Ewan, Brian Dillon & William J. Idsardi. 2013. A Bayesian evaluation of the cost of abstractness. In Montserrat Sanz, Itziar Laka & Michael K. Tanenhaus (eds.), *Language down the garden path: The cognitive and biological basis for linguistic structures*, 360–384. Oxford: Oxford University Press.

Durand, Jacques. 2005. Tense/lax, the vowel system of English and phonological theory. In Philip Carr, Jacques Durand & Colin J. Ewen (eds.), *Headhood, elements, specification, and contrastivity: Papers in honour of John Anderson* (Current Issues in Linguistic Theory 259), 77–97. Amsterdam: John Benjamins.

Ellis, Nick C., Cathal O'Docharthaigh, William Hicks, Menna Morgan & Nadine Laporte. 2001. Cronfa Electroneg o Gymraeg (CEG): A 1 million word lexical database and frequency count for Welsh. `http://www.bangor.ac.uk/canolfanbedwyr/ceg.php.en`.

Grawunder, Sven, Sabine Asmus & Cormac Anderson. 2015. On the correlation of acoustic vowel and coda duration in modern Welsh C(C)VC monosyllables. In The Scottish Consortium for ICPhS 2015 (ed.), *Proceedings of the 18th International Congress of Phonetic Sciences*. Glasgow: The University of Glasgow.

Hall, Daniel Currie. 2007. *The role and representation of contrast in phonological theory*. Toronto: University of Toronto dissertation.

Hall, Daniel Currie. 2011. Phonological contrast and its phonetic enhancement: Dispersedness without dispersion. *Phonology* 28(1). 1–54.

Hannahs, S. J. 2013. *The phonology of Welsh*. Oxford: Oxford University Press.

Harris, John. 1994. *English sound structure*. Oxford: Blackwell.

Hyman, Larry M. 1976. Phonologization. In Alphonse Juilland (ed.), *Linguistic studies presented to Joseph H. Greenberg*, 407–418. Saratoga: Anna Libri.

Hyman, Larry M. 2013. Enlarging the scope of phonologization. In Alan C. L. Yu (ed.), *Origins of sound change: Approaches to phonologization*, 3–28. Oxford: Oxford University Press.

Iosad, Pavel. 2012. *Representation and variation in substance-free phonology: A case study in Celtic*. Tromsø: University of Tromsø dissertation.

Iosad, Pavel. 2016. Welsh vowels data. Dataset. `http://datashare.is.ed.ac.uk`.

Iosad, Pavel. 2017. The ATR/Laryngeal connection and emergent features. In Bert Botma & Marc van Oostendorp (eds.), *Primitives of phonological structure*. Oxford: Oxford University Press. Forthcoming.

Jakobson, Roman, Gunnar Fant & Morris Halle. 1951. *Preliminaries to speech analysis*. Cambridge, MA: MIT Press.

Jones, Christine & David Thorne. 1992. *Dyfed: Blas ar ei thafodieithoedd*. Llandysul: Gwasg Gomer.

Jones, Glyn E. 1971. Hyd llafariaid yn y Gymraeg. *Studia Celtica* 6. 175–188.

Jones, Glyn E. 1984. The distinctive vowels and consonants of Welsh. In Martin J. Ball & Glyn E. Jones (eds.), *Welsh phonology: Selected readings*, 40–64. Cardiff: University of Wales Press.

Jones, Glyn E. 2000. *Iaith lafar Brycheiniog: Astudiaeth o'i ffonoleg a'i morffoleg*. Caerdydd: Gwasg Prifysgol Cymru.

Kiparsky, Paul. 2015. Phonologization. In Patrick Honeybone & Joseph C. Salmons (eds.), *The Oxford handbook of historical phonology*, 563–582. Oxford: Oxford University Press.

Kiparsky, Paul. 2017. Formal and empirical issues in phonological typology. In Larry Hyman & Frans Plank (eds.), *Phonological typology* (Phonetics and Phonology 23). Berlin: De Gruyter. Forthcoming.

Kniazev, Sergey & Evgeniy Šaul'skij. 2007. Генезис диссимилятивного аканья (в связи с проблемой фонологизации фонетических явлений) [The genesis of dissimilative *akan'je* and the problem of phonologization]. *Russkij jazyk v naučnom osveščenii* 13(1). 210–224.

Krämer, Martin. 2012. *Underlying representations* (Key Topics in Phonology 2). Cambridge: Cambridge University Press.

Lewis, David Gerwyn. 1960. *Astudiaeth eirfaol o iaith lafar gogledd-orllewin Ceredigion*. Aberystwyth: University of Wales, Aberystwyth MA thesis.

Lindblom, Björn. 1963. Spectrographic study of vowel reduction. *The Journal of the Acoustical Society of America* 35(11). 1773.

Mackenzie, Sara. 2013. Laryngeal co-occurrence restrictions in Aymara: Contrastive representations and constraint interaction. *Phonology* 30. 297–345.

Mackenzie, Sara. 2016. Consonant harmony in Nilotic: Contrastive specifications and Stratal OT. *Glossa* 1(1), 12. 1–38.

Mayr, Robert & Hannah Davies. 2011. A cross-dialectal acoustic study of the monophthongs and diphthongs of Welsh. *Journal of the International Phonetic Association* 41(1). 1–25.

Mielke, Jeff. 2008. *The emergence of distinctive features*. Oxford: Oxford University Press.

Morén, Bruce. 2001. *Distinctiveness, coercion, and sonority: A unified theory of weight*. London, New York: Routledge.

Morén, Bruce. 2006. Consonant–vowel interactions in Serbian: Features, representations and constraint interactions. *Lingua* 116(8). 1198–1244.

Morris, Jonathan. 2010. Phonetic variation in North Wales: preaspiration. In *Proceedings of the Second Summer School on Sociolinguistics, University of Edinburgh*. http://www.lel.ed.ac.uk/sssocio/proceedings/Jon.pdf.

Myers, Scott. 2000. Boundary disputes: The distinction between phonetic and phonological sound patterns. In Noel Burton-Roberts, Philip Carr & Gerard Docherty (eds.), *Phonological knowledge: Concepts and empirical issues*, 245–272. Oxford: Oxford University Press.

Odden, David. 2013. Formal Phonology. *Nordlyd* 40(1). 24–43.

Pearce, Mary. 2007. ATR allophones or undershoort in Kera? *UCL Working Papers in Linguistics* 19.

Pilch, Herbert. 1957. Das kymrische Lautsystem. *Zeitschrift für vergleichende Sprachforschung auf dem Gebiete der Indogermanischen Sprachen* 75(1/2). 24–57.

Prince, Alan S. & Paul Smolensky. 1993. Optimality Theory: Constraint Interaction in Generative Grammar. Tech. rep. Rutgers University Center for Cognitive Science & University of Colorado, Boulder.

R Core Team. 2016. R: A Language and Environment for Statistical Computing. Version 3.2.4. R Foundation for Statistical Computing. Vienna, Austria. http://www.R-project.org/.

Scheer, Tobias. 2010. *A guide to morphosyntax–phonology interface theories: How extra-phonological information is treated in phonology since Trubetzkoy's* Grenzsignale. Berlin: Mouton de Gruyter.

Scobbie, James M. 2007. Interface and overlap in phonetics and phonology. In Charles Reiss & Gillian Ramchand (eds.), *The Oxford handbook of linguistic interfaces*, 17–52. Oxford: Oxford University Press.

Sommerfelt, Alf. 1925. *Studies in Cyfeiliog Welsh: A contribution to Welsh dialectology*. Avhandlinger utgitt av Det Norske Videnskaps-Akademi i Oslo. II. Hist.-Filos. Klasse. 192, No. 3. Oslo: I kommission hos Jacob Dybwad.

Strycharczuk, Patrycja. 2012. *Phonetics-phonology interaction in pre-sonorant voicing*. Manchester: University of Manchester dissertation.

Thomas, Alan R. 1960. Ffonemau llafarog tafodiaith Dyffryn Wysg. *Bulletin of the Board of Celtic Studies* 18. 265–270.

Thomas, Alan R. 1961. Ffonemau cytseiniol tafodiaith Dyffryn Wysg. *Bulletin of the Board of Celtic Studies* 19. 193–201.

Thomas, Alan R. 1966. Systems in Welsh phonology. *Studia Celtica* 1. 93–127.

Thomas, Ceinwen H. 1993. *Tafodiaith Nantgarw: Astudiaeth o Gymraeg llafar Nantgarw yng Nghwm Taf, Morgannwg*. Caerdydd: Gwasg Prifysgol Cymru.

Torres-Tamarit, Francesc. 2015. Length and voicing in Friulian and Milanese: Or why rule-free derivations are needed. *Natural Language & Linguistic Theory* 33(4). 1351–1386.

Watkins, Arwyn T. 1967. Some phonological features of the Welsh dialect of Llansamlet (West Glamorgan). In Wolfgang Meid (ed.), *Beiträge zur Indogermanistik und Keltologie: Julius Pokorny zum 80. Geburtstag gewidmet*, 315–322. Innsbruck: Sprachwissenschaftliches Institut der Universität Innsbruck.

Wells, John C. 1979. Final voicing and vowel length in Welsh. *Phonetica* 36(4–5). 344–360.

Wmffre, Iwan. 2003. *Language and place-names in Wales: The evidence of toponymy in Cardiganshire*. Cardiff: University of Wales Press.

Wmffre, Iwan. 2007. Review of Ball & Williams (2001). *Zeitschrift für celtische Philologie* 55. 301–307.

Wood, Simon N. 2006. *Generalized additive models: An introduction with R*. Chapman & Hall/CRC.

Appendix

Word	Expected pronunciation	Gloss
blynyddau	[bləˈnəð·ɛ]	‘years’
boddi	[ˈbɔːði]	‘to perish’
bore	[ˈboːrɛ]	‘morning’
brodor	[ˈbroːdɔr]	‘native (noun)’
brodorol	[brɔˈdoːrɔl]	‘native (adjective)’
bwced	[ˈbʊkʰ·ɛd]	‘bucket’
bwgan	[ˈbuːgan]	‘ghost’
byddin	[ˈbəð·ɪn]	‘army’
caletaf	[kʰaˈlɛtʰ·a]	‘hardest’
cegin	[ˈkʰɛːgɪn]	‘kitchen’
cerrig	[ˈkʰɛr·ɪg]	‘stones’
cigydd	[ˈkʰi·gɪð]	‘butcher’
cludo	[ˈkʰliːdɔ]	‘to transport’
codi	[ˈkʰɔːdi]	‘to rise’
colli	[ˈkʰɔɬ·i]	‘to lose’
copi	[ˈkʰɔpʰ·i]	‘copy’
crwtyn	[ˈkʰrʊtʰɪn]	‘boy’
curo	[ˈkʰiːrɔ]	‘to bear’
cwbwl	[ˈkʰuːbʊl]	‘entire’
cwlwm	[ˈkʰuːlʊm]	‘knot’
cwpan	[ˈkʰʊpʰ·an]	‘cup’
cwpwrdd	[ˈkʰʊpʰ·ʊrθ]	‘cupboard’
cwta	[ˈkʰʊtʰ·a]	‘curt’
cyfan	[ˈkʰəv·an]	‘entire, all’
cyfle	[ˈkʰəv·lɛ]	‘chance’
cyllell	[ˈkʰəɬ·ɛɬ]	‘knife’
cynnal	[ˈkʰən·al]	‘to support’
cyson	[ˈkʰəs·ɔn]	‘regular’
defod	[ˈdeːvɔd]	‘ceremony’
diben	[ˈdiːbɛn]	‘purpose’
dibyn	[ˈdiːbɪn]	‘precipice’
difyr	[ˈdiːvɪr]	‘pleasant’
digon	[ˈdiːgɔn]	‘enough’
dillad	[ˈdɪɬ·ad]	‘clothes’
dilyn	[ˈdiːlɪn]	‘to follow’
diweddar	[dɪˈweːðar]	‘latest’
dwsin	[ˈdʊs·ɪn]	‘dozen’
Ebrill	[ˈɛb·rɪɬ]	‘April’
edrych	[ˈɛd·rɪχ]	‘to look’
enillwch	[ɛˈnɪɬ·ʊχ]	‘win! (pl.)’
ennill	[ˈɛn·ɪɬ]	‘to win’

Word	Expected pronunciation	Gloss
enwocaf	[ɛnˈwɔkʰ·a]	‘most famous’
felly	[ˈvɛɬ·i]	‘so’
ffenestr	[ˈfeːnɛst]	‘window’
ffrwgwd	[ˈfruːgʊd]	‘brawl’
ffyddlon	[ˈfəð·lɔn]	‘loyal’
gelyn	[ˈgɛːlɪn]	‘enemy’
geni	[ˈgɛːni]	‘to give birth’
goddef	[ˈgoːðɛ]	‘to suffer’
gofal	[ˈgoːval]	‘care’
gofyn	[ˈgɔːvɪn]	‘to ask’
gogledd	[ˈgɔg·lɛð]	‘north’
gosod	[ˈgɔs·ɔd]	‘to attack’
Guto	[ˈgɪtʰɔ]	personal name
gwddw	[ˈguːðʊg]	‘neck’
gwella	[ˈgwɛɬ·a]	‘to improve’
gyrru	[ˈgər·i]	‘to drive’
heddiw	[ˈhɛːði]	‘today’
heddlu	[ˈhɛð·li]	‘police’
hollol	[ˈhɔɬ·ɔl]	‘entire’
honni	[ˈhɔn·i]	‘to claim’
hwnnw	[ˈhʊn·u]	‘that’
hybu	[ˈhəb·i]	‘to promote’
Hydref	[ˈhəd·rɛ]	‘October’
ifanc	[ˈiːvaŋk]	‘young’
isod	[ˈɪs·ɔd]	‘below’
llety	[ˈɬɛtʰi]	‘hotel’
llinell	[ˈɬɪn·ɛɬ]	‘line’
llipa	[ˈɬɪpʰ·a]	‘limp’
llogi	[ˈɬɔːgi]	‘to hire’
llonydd	[ˈɬɔːnɪð]	‘contented’
lludw	[ˈɬiːdu]	‘ashes’
llygad	[ˈɬəg·ad]	‘eye’
lwcus	[ˈlʊkʰ·ɪs]	‘happy’
meddwl	[ˈmɛːðʊl]	‘to think’
minnau	[ˈmɪn·ɛ]	‘I (emphatic)’
modryb	[ˈmɔd·rɪb]	‘aunt’
mwdwl	[ˈmuːdʊl]	‘haycock’
Nadolig	[(na)ˈdɔːlɪg]	‘Christmas’
neges	[ˈneːgɛs]	‘message’
nesaf	[ˈnɛs·a]	‘next’
ogof	[ˈoːgɔv]	‘cave’
pecyn	[ˈpʰɛkʰ·ɪn]	‘package’
pennod	[ˈpʰɛn·ɔd]	‘chapter’
personol	[pʰɛrˈsoːnɔl]	‘personal’
plygu	[ˈpʰləg·i]	‘to fold’

Word	Expected pronunciation	Gloss
pobi	[ˈpʰɔːbi]	‘to bake’
pobol	[ˈpʰoːbɔl]	‘people’
popeth	[ˈpʰɔpʰˑɛθ]	‘everything’
posib	[ˈpʰɔsˑɪb]	‘possible’
problem	[ˈpʰrɔbˑlɛm]	‘problem’
pryder	[ˈpʰrədˑɛr]	‘worry’
prynu	[ˈpʰrənˑi] [ˈpʰʊrˑni]	‘to buy’
prysur	[ˈpʰrəsˑir]	‘busy’
pwysicaf	[pʰʊiˈsɪkʰˑa]	‘most important’
pysgota	[pʰəsˈkɔtʰˑa]	‘to fish’
rhedeg	[ˈrʰeːdɛg]	‘to run’
rheswm	[ˈrʰɛsˑʊm]	‘reason’
sefyll	[ˈsɛːvɪɬ]	‘to stay’
seren	[ˈseːrɛn]	‘star’
siglo	[ˈsigˑlɔ] [ˈʃɪgˑlɔ]	‘to shake’
suddo	[ˈsiːðɔ]	‘to sink’
sydyn	[ˈsədˑɪn]	‘sudden’
tebycaf	[tʰɛˈbəkʰˑa]	‘most similar’
tebyg	[ˈtʰɛːbɪg]	‘similar’
tecaf	[ˈtʰɛkʰˑa]	‘fairest’
tipyn	[ˈtʰɪpʰˑɪn]	‘little bit’
tlotyn	[ˈtʰlɔtʰˑɪn]	‘poor person’
tocyn	[ˈtʰɔkʰˑɪn]	‘ticket’
tonnau	[ˈtʰɔnˑɛ]	‘waves’
torri	[ˈtʰɔrˑi]	‘to break’
trefnu	[ˈtʰrɛvˑni]	‘to arrange’
tybed	[ˈtʰəbˑɛd]	‘I wonder’
tyfu	[ˈtʰəvˑi]	‘to grow’
unig	[ˈiːnɪg]	‘only’
wedyn	[ˈwɛːdɪn]	‘afterwards’
wynebau	[ʊjˈneːbɛ] [gwɪˈneːbɛ]	‘faces’
ysbyty	[əsˈpətʰˑi]	‘hospital’

Table 6: Test items

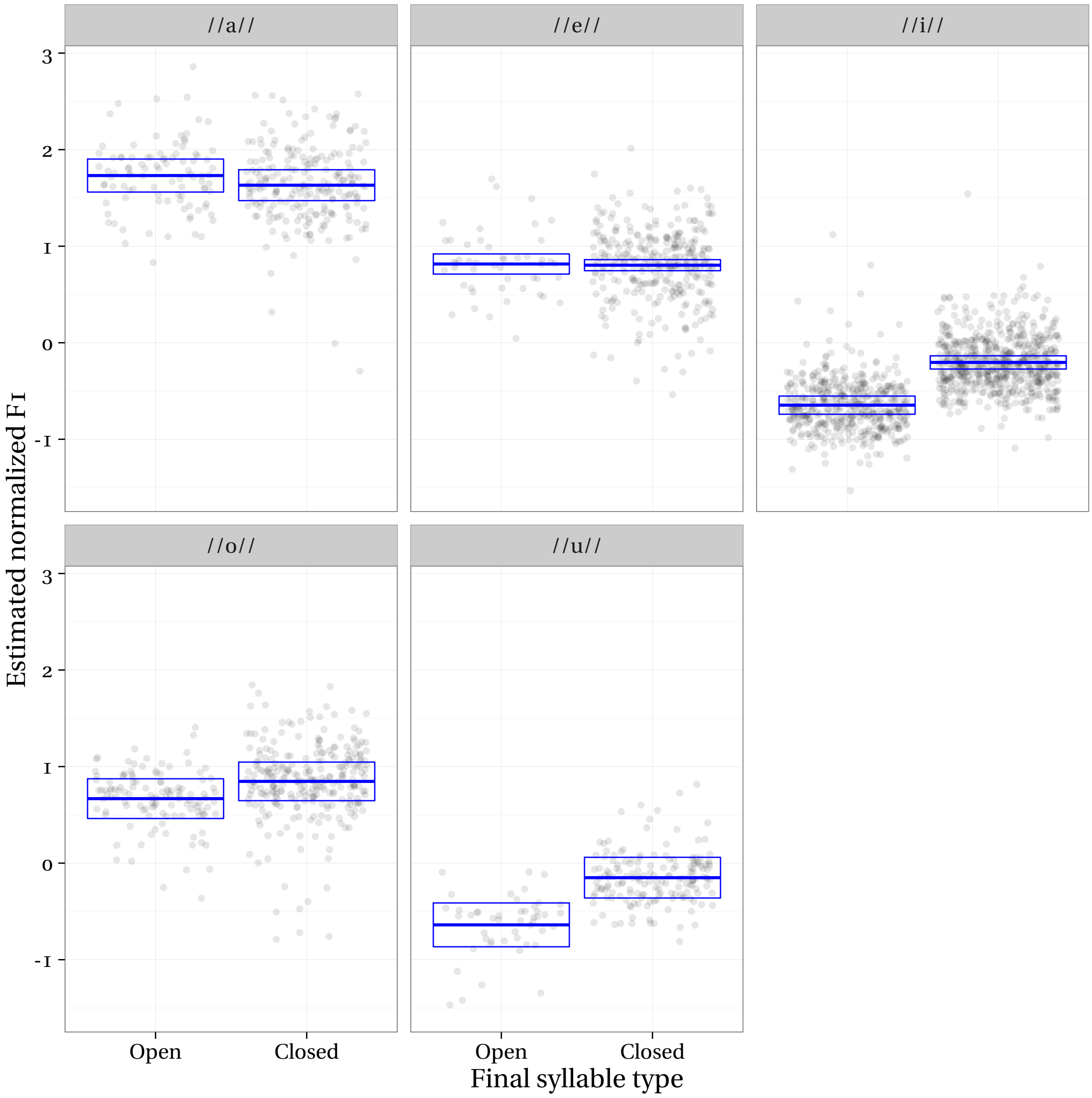


Figure 13: Estimated normalized F1, by final syllable type and vowel

Code	Gender	Age bracket	Place of origin
Sp1	Female	56–60	Carmarthen, Carmarthenshire
Sp2	Male	60–65	Meidrim, Carmarthenshire
Sp3	Male	18–25	Carmarthen, Carmarthenshire
Sp4	Female	50–55	Cardiff, Glamorgan
Sp5	Female	75–80	Goodwick, Pembrokeshire
Sp6	Female	70–75	Crymych, Pembrokeshire
Sp7	Female	25–30	Carmarthen, Carmarthenshire
Sp8	Female	40–45	Aberystwyth, Cardiganshire

Table 5: Participants in the acoustic study

	No duration effect	No length effect	Both duration and length	No random effect
Intercept	8.55^*	8.45^*	8.51^*	8.54^*
	[8.41; 8.70]	[8.30; 8.59]	[8.37; 8.65]	[8.43; 8.66]
//ə//	0.54^*	0.43^*	0.51^*	0.51^*
	[0.33; 0.75]	[0.21; 0.64]	[0.31; 0.71]	[0.34; 0.67]
//e//	0.76^*	0.70^*	0.77^*	0.77^*
	[0.64; 0.88]	[0.61; 0.79]	[0.65; 0.89]	[0.68; 0.86]
//o//	0.88^*	0.79^*	0.89^*	0.81^*
	[0.61; 1.14]	[0.51; 1.07]	[0.63; 1.14]	[0.60; 1.03]
//u//	0.12	0.20	0.10	0.02
	[−0.16; 0.40]	[−0.09; 0.48]	[−0.17; 0.36]	[−0.20; 0.24]
Long vowel	-0.29^*		-0.19^*	-0.21^*
	[−0.46; −0.12]		[−0.36; −0.02]	[−0.35; −0.07]
Long //e//	−0.14		−0.12	-0.13^*
	[−0.30; 0.02]		[−0.27; 0.04]	[−0.25; −0.01]
Long //o//	-0.25^*		-0.23^*	-0.19^*
	[−0.47; −0.03]		[−0.44; −0.01]	[−0.37; −0.02]
Long //u//	0.23		0.24^*	0.30^*
	[−0.02; 0.47]		[0.01; 0.47]	[0.11; 0.49]
F2 smooth	8.77	8.68	8.76	8.71
	[−8.72; 26.25]	[−8.72; 26.09]	[−8.72; 26.24]	[−8.88; 26.31]
Random intercept for word	63.45	76.51	58.88	
	[−146.27; 273.16]	[−141.05; 294.06]	[−150.84; 268.59]	
Duration smooth		3.24	3.14	3.17
		[−3.84; 10.33]	[−3.79; 10.07]	[−4.00; 10.34]
AIC_c	-327.97	-310.40	-337.98	-322.74
AIC	-380.23	-382.63	-388.17	-325.85
BIC	-64.24	-19.67	-77.70	-241.76
Log Likelihood	272.33	285.75	274.86	184.80
R^2	0.95	0.95	0.95	0.93
Num. obs.	345	345	345	345

* 0 outside the confidence interval

Table 7: Models for $\log_2(F1)$ for speaker Sp1

	No height effect	No interaction	Model with interaction
Intercept	−1.01*	−1.06*	−1.00*
	[−1.24; −0.77]	[−1.29; −0.83]	[−1.18; −0.83]
//ə//	0.70*	0.65*	0.79*
	[0.44; 0.97]	[0.38; 0.91]	[0.58; 1.00]
//e//	1.54*	1.43*	1.58*
	[1.28; 1.81]	[1.16; 1.70]	[1.35; 1.82]
//o//	1.59*	1.51*	1.54*
	[1.27; 1.91]	[1.19; 1.83]	[1.26; 1.81]
//u//	0.26	0.14	0.29
	[−0.09; 0.60]	[−0.20; 0.49]	[−0.04; 0.62]
Long vowel	−0.22	−0.28*	−0.25*
	[−0.49; 0.05]	[−0.56; −0.01]	[−0.47; −0.04]
Long /e/	−0.26	−0.17	−0.83*
	[−0.62; 0.10]	[−0.52; 0.19]	[−1.15; −0.52]
Long /o/	0.00	0.06	−0.38*
	[−0.35; 0.36]	[−0.29; 0.42]	[−0.68; −0.08]
Long /u/	0.34	0.34	0.35
	[−0.09; 0.76]	[−0.09; 0.76]	[−0.16; 0.85]
Duration smooth	1.86	1.53	2.23
	[−2.70; 6.42]	[−2.17; 5.24]	[−3.16; 7.61]
F2 smooth	3.34	3.48	3.79
	[−4.05; 10.73]	[−4.06; 11.01]	[−3.97; 11.56]
Speaker (random)	4.41	4.43	4.35
	[−5.39; 14.21]	[−5.37; 14.23]	[−5.45; 14.15]
Word (random)	98.08	96.93	76.56
	[−117.51; 313.68]	[−118.67; 312.52]	[−123.35; 276.48]
High post-tonic vowel		0.27*	0.05
		[0.15; 0.38]	[−0.27; 0.36]
//e// before high			−0.08
			[−0.46; 0.29]
//o// before high			0.02
			[−0.35; 0.38]
//u// before high			−0.18
			[−0.60; 0.24]
Long vowel before high			0.03
			[−0.35; 0.41]
Long //e// before high			1.06*
			[0.58; 1.54]
Long //o// before high			0.82*
			[0.35; 1.30]
Long //u// before high			0.05
			[−0.59; 0.69]
AIC_c	2113.37	2105.94	2085.73
AIC	2098.96	2091.61	2074.11
BIC	2761.47	2752.27	2670.42
Log Likelihood	-931.78	-928.44	-931.12
R^2	0.79	0.79	0.79
Num. obs.	2057	2057	2057

* 0 outside the confidence interval

Table 8: Models for normalized F1, south-western speakers

	No duration effect	Duration effect	Model with interaction
Intercept	345.73*	381.57*	345.09*
	[286.15; 405.32]	[327.99; 435.16]	[271.91; 418.28]
//ə//	99.06*	88.54*	155.20*
	[33.17; 164.95]	[30.06; 147.02]	[67.97; 242.42]
//e//	294.38*	250.44*	277.96*
	[234.12; 354.65]	[199.97; 300.90]	[203.94; 351.98]
//o//	197.05*	114.78*	191.61*
	[93.96; 300.13]	[19.17; 210.40]	[79.28; 303.94]
//u//	47.06	31.88	59.40
	[−50.98; 145.11]	[−57.61; 121.37]	[−48.50; 167.30]
Long vowel	13.43	−12.86	8.24
	[−44.22; 71.08]	[−40.49; 14.77]	[−51.54; 68.01]
Long /e/	−2.26		−19.40
	[−77.03; 72.51]		[−96.29; 57.50]
Long /o/	−63.91		−74.77
	[−143.35; 15.53]		[−157.25; 7.72]
Long /u/	4.19		37.05
	[−81.50; 89.88]		[−51.42; 125.53]
F2 smooth	2.77	2.76	2.81
	[−3.63; 9.17]	[−3.60; 9.11]	[−3.66; 9.28]
Word (random)	17.86	21.02	16.89
	[−193.82; 229.54]	[−196.53; 238.58]	[−194.79; 228.56]
Duration smooth		2.05	
		[−2.86; 6.96]	
Duration for //i//			1.49
			[−2.02; 4.99]
Duration for //e//			1.00
			[−0.96; 2.96]
Duration for //o//			1.40
			[−1.87; 4.68]
Duration for //u//			2.86
			[−3.59; 9.31]
AIC_c	4107.10	4090.27	4093.57
AIC	4100.75	4082.94	4083.92
BIC	4217.76	4208.36	4226.97
Log Likelihood	-2019.75	-2008.64	-2004.52
R^2	0.67	0.69	0.69
Num. obs.	337	337	337

* 0 outside the confidence interval

Table 9: Models for F1, Sp8