Measuring Linguistic Diversity: A Multi-level Metric

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Abstract
This paper proposes a novel approach to the measurement of linguistic diversity. Drawing on the ecological literature, it proposes an adaptation to languages of the classic distinction between “alpha” (intra-setting), “beta” (inter-setting) and “gamma” (system-level) diversity. We begin by discussing some of the general challenges raised by the measurement of diversity. We review received approaches to the measurement of diversity resting on the concepts of richness and evenness, highlighting some limitations that come to the fore when comparing the respective diversity of different settings and systems. In order to overcome some of these limitations, we adapt the concept of “numbers equivalent” to linguistic diversity measurement indices. On this basis, we derive a multi-level approach to diversity measurement. We provide numerical examples to highlight the properties of this model before discussing its application to language policy issues.

1 Introduction

Ethnic, linguistic and cultural (ELC) diversity has become one of the most politically charged issues of our times. In most contemporary societies, the attention devoted to ELC diversity in politics, media and academia is now such that it is easy to forget that it has not always enjoyed such visibility. Rather, the emergence of ELC diversity as an analytically relevant notion to account for social and political change, as well as a useful construct for the purposes of public policy, should be seen as a historical process that has gradually unfolded and picked up pace in the second half of the 20th century (Judt and Snyder, 2012; May, 2012). This has progressively led to the realization that issues such as the rights of ethnonational minorities, the protection of linguistic and cultural groups, the situation of aboriginal communities, and the integration of migrants could be approached as connected facets of a broader, transversal diversity, itself seen as one of the normal hallmarks of mod-
ern societies in a globalizing world (e.g. Ben-Rafael and Ben-Rafael, 2018; Castells, 2009; Knotter, de Lobel, Tsipouri and Stenius 2011; Urry, 2000).

This evolution is reflected in the emergence of new concepts and the coinage of new terms. One that has attracted particular attention is superdiversity, first mentioned in a paper by Vertovec, (2007) in the context of migration studies, in order to capture the new realities created, in receiving countries, by a sharp increase in the number of international migrants. The term was subsequently taken up in sociolinguistics, whether approvingly (e.g. Blommaert and Rampton, 2011) or critically (e.g. Pavlenko, 2019). Of particular interest to us is the concept of complex diversity (Kraus, 2008), which explicitly highlights the fact that against the backdrop of more diverse forms of mobility, the ways in which actors negotiate and assert their ethnic, linguistic and cultural identity have changed. These patterns are best understood if due account is taken of the ensuing re-composition of identities with multiple layers. This is proving useful when revisiting foundational notions of politics in linguistically and culturally plural contexts (Kraus, 2021), and it dovetails with our own approach to the measurement of diversity.

The progressive emergence of ELC diversity as a theme in its own right can also be observed in the more specific area of linguistic diversity, which is the main focus of this paper. Parallel advances were taking place in rational choice, with the first formal explorations of optimality in language policy (Pool, 1991a, b; Selten, 1997; De Swaan, 2000); in political theory, with the examination of the normative dimensions of minority rights (Taylor, 1994; Kymlicka, 1995; Kymlicka and Patten, 2003; Shorten, 2017); and in sociolinguistics, with the advent of the concept of linguistic human rights (see e.g. Skutnabb-Kangas, Phillipson and Rannut 1994; Skutnabb-Kangas and Phillipson, 2016). By the turn of the 21st century, “diversity” was recognized as a relevant object of analysis per se (Grin, 2003; Wood, 2003), even if the bulk of research on linguistic diversity still tends to be devoted to some specific manifestations.

Because societies constantly need to make decisions about ELC diversity, it has also come to be seen as a relevant entry point for policy design. Public policies reflect, but also affect the extent to which diversity is acknowledged, repressed or supported, whether in the internal operations of the various manifestations of the state, in the regulation of the public space, and even in the private sphere. The widespread realization of the pervasiveness of diversity finds expression in the frequency of the association of the words like “policy”, “governance” and “management” with terms denoting ELC diversity (see e.g. Dacyl and Westin, 2000; Gál, 2002; Inglis, 1997; Küchler and Wallmann 2009; Spolsky, 2009).

However, the rise of ELC diversity and diversity management to prominence in the media, politics and academia appears to have taken place with relatively little formal analytical discussion of how it could be defined precisely, let alone operationalized; exceptions to this general pattern include research on indicators of linguistic justice (e.g. Gazzola, 2016, 2017) and multilingual communication (Gazzola, Templin and McEntee-Atalianis, 2020). In this paper, we offer a contribution to the efforts made to fill this gap by proposing a consistent metric for the measurement of linguistic diversity, both for descriptive purposes (particularly in order to facilitate comparison through space and time) and for policy reasons, since the calibration of policies often requires an analytically robust measurement of diversity.

In Section 2, we take a closer look at the need for such a tool and explain our reasons for focusing on linguistic (as distinct from ethnic or cultural) diversity. In Section 3, we review
several traditional diversity indices, most of which had already been applied to linguistic diversity, also highlighting their main advantages and drawbacks. Section 4 brings in reflections on diversity measurement from the literature in ecology. Section 5 is devoted to the entirely novel application to the field of linguistic diversity of a two-level approach distinguishing between a system and its constituent settings. This gives rise to three indicators denoting intra-setting, inter-setting and aggregate diversity. Section 6 provides numerical examples. Section 7 discusses the implications of using this approach and examines possible extensions. Section 8 sums up and concludes, emphasizing why a strong diversity measurement scheme is essential to public policy design and evaluation.

2 Measuring Linguistic Diversity: Why Bother?

The recognition of diversity as a policy object immediately raises standard policy questions: how should diversity be handled? Should it be considered as essentially positive, akin to a merit good, and hence embraced or even encouraged, or essentially problematic, and hence contained or even discouraged?

These questions open up a whole range of positive and normative issues, and addressing them requires us to approach diversity as a vector of advantages and drawbacks, in full awareness of the fact that they encompass not only financial benefits and costs, but also symbolic dimensions (Gazzola, Grin and Vaillancourt, 2020). However, this also involves the very practical need to define precisely what diversity is, and in particular what it means to have “more” or “less” diversity. This question differs from issues that arise when studying the conditions of successful communication in multilingual settings (e.g. Gazzola, Templin and McEntee-Atalianis, 2020), in which the measurement of diversity focuses on agents’ abilities and strategies for overcoming linguistic difference.

The need to understand and operationalize linguistic diversity in its own right has tended to be overlooked. In particular, the examination of how linguistic diversity emerges from the characteristics of the elements that compose it still leaves some important questions open. The reason for this may be that since ethnicity, language and culture are particularly complex elements of human experience, attempts at shoehorning diversity into the mold of some excessively precise definition may appear hopelessly reductionist. Hence, somewhat paradoxically, large tracts of the specialist literature seem content with an equivocal and mostly implicit definition of diversity. “Diversity” often refers to the co-existence, in a given space (a country, a city, a company, a team) of persons or groups who differ from each other, whether in terms of gender, age, native language, religious beliefs, cultural heritage, training, political sympathies, physical appearance, health, abilities, sexual orientation, or possibly other elements of individual biography or collective history. Even when the emphasis is placed on (mostly) intergenerationally transmitted features, which encompass ethnicity, language and culture, the only indicator used generally boils down to the mere presence of people with different ethnic backgrounds, linguistic attributes and cultural heritage.

Nevertheless, policy selection and design requires more than a binary notion of presence vs. absence. Sooner or later, the decisions that need to be made (whether in the provision of public services, the operations of an international organization, the make-up of work teams, etc.), raise questions of comparison between policies intended to respond to, and which may
result in, “more” or “less” diversity. This paper explores the meaning, formalization and implications of the metric required for this purpose.

To a large extent, this problem is the same for most of the intergenerationally transmitted traits often characterized as “ethnic, linguistic and cultural”. However, although language is an immensely complex notion in itself and the notion of “discrete” languages must be used with caution, language actually lends itself reasonably well to various forms of operationalization. By contrast, the mere identification of a clear, unambiguous “ethnic” or “cultural” group as distinct from another is often much more problematic. In order to put the analytical and methodological aspects of measurement in sharper relief, this paper therefore focuses on linguistic diversity.\(^1\) In principle, however, the approach could be transposed, with due regard to the necessary adaptations, to the measurement of “ethnic” and “cultural” expressions of diversity. Moreover, language often, though not systematically, goes hand in hand with culture; hence, the measurement of linguistic diversity can be seen as a proxy for the particularly challenging measurement of cultural diversity, with significant practical implications (Caliendo, Janssens and Slembrouck 2019).

Crucially, this focus on language enables us to propose illustrations of the need, in a policy context, to move beyond relatively amorphous views of diversity, such as the presence vs. absence of different elements in a given setting. Suppose for example that the national authorities, being keen to encourage diversity, set up a scheme whereby certain subsidies to cities or provinces are calibrated on their diversity. More diverse cities, assumed to face higher costs in the delivery of public services because of the diversity of their demolinguistic make-up, would receive more. But what exactly is a “more diverse” city or province? Vague notions of presence and absence are inadequate; the efficient and fair design and implementation of a public policy intended to protect and promote diversity requires a clear concept of what counts as diversity, and how what counts must be counted.

3 Received Approaches to the Measurement of Linguistic Diversity

The literature on linguistic diversity already proposes formalized ways to compare the degree of diversity characterizing two settings. The three key concepts here are richness \((R)\), evenness \((E)\) and distance \((D)\).

3.1 Richness and evenness

Richness refers to the number of unique elements in a set. More richness means more diversity, and assessing linguistic richness comes down to counting the number of different languages present in a given context. This context may be a city, a country, or even the entire

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1. This choice is further justified by the differences that can be observed between the types of policies addressing different manifestations of diversity. Language policies focus on the presence, visibility and use of different languages across various domains (administration, justice, education, media, commerce, etc.), but without necessary reference to ethnicity or culture. In the sphere of ethnicity as distinct from language and culture, the scope of public policies tends to be narrower and their application criteria less clear-cut; for example, affirmative action programs, which usually target ethnic as distinct from linguistic or cultural diversity, raise the difficult problem of defining ethnicity and circumscribing membership in it. As regards policies in the area of culture as distinct from language or ethnicity, they tend to have an even narrower focus (such as the subsidization of museums or music festivals); when “cultural” policy actually regulates language, it can be regarded as a form of language policy.
world, irrespective of the number of people who use a given language, the frequency with which they do, their degree of proficiency in various languages, the forms of language use concerned (written or oral; productive, receptive or interactive), or the domains in which they are used (with colleagues at work, with family at home, with civil servants in the administration, with friends during leisure time, when accessing media services, etc.).

One problem is that $R$ overemphasizes the role of small languages, including those that are used by a tiny fraction of residents. As an indicator of diversity, therefore, it may be an unsuitable criterion for determining, as in the preceding example, the magnitude of a subsidy granted to different cities to help them deliver public services to a linguistically diverse population. Consider two cities with a similar number of residents (say, 1 million) and similar richness (say, $R=5$). They would, however, be in very different situations if city $A$ is home to five language communities in roughly equal proportions, whereas in city $B$, the most important language is spoken by 96% of the population while each of the four other languages is spoken by 1% of residents. This is why a key dimension of diversity is $E$ or evenness, which is an indicator of the extent to which the distribution of different elements is uniform or not.

Many classical diversity indices combine information about richness and evenness, although some specific metrics for evenness exist (see e.g. Maurer and McGill, 2011: 56–57). One of the most popular indicators is based on the notion of concentration as approached in the late 1940s separately by Hirschman, Herfindahl and Simpson. This indicator, which captures the opposite of concentration, is often called the “Greenberg index” ², even though Greenberg himself refers to it the “A index” (Greenberg, 1956: 109), as do Ginsburgh and Weber, (2020: 371). Other names for the same indicator are frequently used, such as the “Simpson index” (Van Parijs, 2011: 177), or the “Gini-Simpson index” (Jost, 2006: 364), the “ethnic fractionalization index” (Desmet, Ortuño-Ortín and Weber 2009). In this paper, it is denoted by “G” in reference to Greenberg:

$$G = 1 - \sum_{i=1}^{R} (p_i)^2$$

where $p_i$ stands for the demographic share of language $i$. A higher value of $G$ implies, all other things being equal, a higher degree of diversity, which dovetails with the interpretation of evenness as the inverse of the probability that two people picked at random in the population speak the same language. The higher the value of $G$, the higher the likelihood of meeting by chance a linguistically different person.³

### 3.2 The role of distance

Another frequently mentioned dimension of linguistic diversity is distance (D), which refers to the magnitude of the differences between the elements making up a more or less diverse

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² This index is commonly used, for example by SIL International, a missionary organization, and by the UNESCO (see https://en.wikipedia.org/wiki/Linguistic_diversity_index, consulted 29 Sept. 2020).

³ This specific interpretation holds only for a given richness. If both richness and evenness vary simultaneously, the comparability of $G$ indices may be subject to restrictions, and a separate assessment of $R$ and $E$ may be preferred, as suggested by Strong, (2016).
setting. It stands to reason that the cities in our example above, $A$ and $B$, may not be equivalentely diverse, even with an identical population of 1 million, identical richness ($R=5$) and evenness (for example with respective shares, in decreasing order, of 64%, 16%, 12%, 5% and 3%, yielding an identical $G$ value of 0.547 for both cities). Suppose that all the languages in city $A$ are northern Slavic languages (say, Russian, Polish, Ukrainian, Czech and Slovak, all languages between which the degree of spontaneous mutual intelligibility is fairly or very high), whereas residents of city $B$ include speakers of Russian (Indo-European, Slavic), Spanish (Indo-European, Romance), Finnish (Finno-Ugric), Tagalog (Austronesian, Malayo-Polynesian) and Tzeltal (Mayan), all languages between which the degree of spontaneous mutual intelligibility is negligible. Few people would dispute the claim that $B$ is more diverse than $A$.

Linguistic distance is a legitimate ingredient in the estimation of a setting’s degree of diversity, but it raises considerable conceptual difficulties. Assuming away the problem of what counts as a language as distinct from another (Fabb, 2016) and starting from an accepted list of “named” languages, the question arises of how interlinguistic distance is best operationalized. It is tempting, in line with Dyen et al. (1992), to rely on lexicon. However, phonological, syntactical and grammatical features may be just as relevant as lexical ones. Alternatively, one might use cladistic distances, which are based on the number of forks in the historical development of languages that result in languages branching off and becoming different idioms. If two languages have only branched off at a relatively late stage, they have, so to speak, survived a high number of potential breaks. They tend to be more similar to each other, and a set comprising these two languages will, other things being equal, embody less diversity than a set comprising two languages that have separated long ago, or two languages that have no common ancestor (linguists disagree as to the existence of a single Ur-language common to all mankind; see Fearon, 2003).

Indexes that address distance tend to belong to a category of their own, and they are only rarely combined with richness and evenness, possibly because of the potentially awkward (and as yet not fully addressed) political implications of using interlinguistic distance at all in policy design (as distinct from using it as an independent variable in explaining patterns of redistribution; see Desmet, Ortuño-Ortín and Weber 2009). Furthermore, the sociological importance of interlinguistic difference may have more to do with perceptions than with objectively measured distance (Montalvo and Reynal-Querol, 2005). However, since this paper explores other directions in the measurement of diversity and the development of relevant indicators, such questions are left out of the rest of our discussion.

4 The Measurement of Diversity in the Ecological Literature

The set of indices discussed in Sect. 3 already enables us to engage in more rigorous comparisons of the degree of linguistic diversity that characterizes different settings, or a given setting at different points in time. In this section, we examine some of the limitations of these indices, as well as the solutions suggested by the ecological literature.
4.1 Limitations of R and G

Let us consider the indices $R$ (richness) and $G$ (which combines richness and evenness). Richness $R$ is easy to understand, but its obvious drawback, as we have seen, is that its emphasis on “small” components of diversity makes it unsatisfactory as a metric for diversity-calibrated policies. By contrast, the Greenberg index raises the opposite problem. Its main weakness is that it is remarkably insensitive to the presence of relatively small components of diversity, and therefore, potentially, to the range of different languages present in a setting. Consider two countries:

- Country A, which uses five languages, with the following distribution: 64%, 16%, 12%, 5% and 3%;
- Country B, which uses ten languages, with the following distribution: 64%, 16%, 12%, 5%, 0.5%, 0.5%, 0.5%, 0.5%, 0.5%, and 0.5%.

Country B’s richness is twice that of country A. However, at 0.54775, country B’s Greenberg index is only very slightly higher than country A’s at 0.547. Therefore, this index is sensitive to the presence of additional languages only if they are spoken by a relatively large proportion of people, but if these languages are only used by very small communities, the index, in effect, ignores their contribution to diversity.

This is why, even though the $G$ index is routinely mentioned in the ecology literature, authors often advise against it because the way it accounts for biophysical diversity is counter-intuitive (Jost, 2007; Maurer and McGill, 2011; Leinster and Cobbold, 2012). These authors recommend using Shannon entropy instead. Its sensitivity to the rarity of different elements of diversity (species in ecology, languages in our case) falls between that of richness $R$ and of the Greenberg index $G$. Shannon entropy $S$ (sometimes called the Shannon-Wiener index) is defined as:

$$S = - \sum_{i=1}^{R} p_i \times \ln (p_i)$$

where $p_i$, as before, denotes the demolinguistic share of language $i$ (obviously, the sum of these shares equals unity). Returning to the example above, country B’s Shannon entropy $S$ is 5% higher than country A’s (its value is 1.142 instead of 1.088), instead of the modest 0.13% difference suggested by the Greenberg index. Shannon entropy, therefore, is less sensitive than richness, but more sensitive than the Greenberg index to the presence of rare languages, making it a relatively more satisfactory operationalization of linguistic diversity than the other two.

4.2 The numbers equivalent or “true diversity”

Unfortunately, even if $S$ is an improvement over $G$, which itself was an improvement over $R$, its response to change remains awkward, as we can see when trying out a few other examples. Suppose that the richness of country B from the example above drops from 10 to 3 (that is, by 70%), and that the three remaining languages have a demographic weight
of 70%, 17% and 13% respectively. Its Greenberg index $G$ drops from 0.54775 to 0.4642 (that is, a change of only 15.3%), while its Shannon entropy goes down by 28.5%. However, these figures, even the last one, do not offer a very intuitive reflection of the fall in country $B$’s linguistic diversity. Could these indices be adapted in order for their response to changes in the raw figures to generate more intuitive and readily interpretable indices?

A solution to this problem was proposed by Hill (1973), who suggested using the numbers equivalent of diversity indices, since these numbers equivalents provide a better quantitative account of the level of diversity in a given context – and, more to the point, a more useful quantitative index of the changes befalling diversity. Following Jost (2007: 2428), let us define the numbers equivalent of a diversity index as “the number of equally likely elements needed to produce the given value of a diversity index”. Jost actually calls this numbers equivalent “true diversity” (ibid.), showing with numerical examples that the numbers equivalent (often denoted by $H$ in the literature) responds to changes in the raw data in a very intuitive fashion. What is more, the numbers equivalent presents various desirable mathematical properties that will be prove useful in the next section.

The intuition behind the numbers equivalent is explained by Jost (ibid.: 2429) as follows: “if two equally large communities (no shared species) each have diversity $X$, and if these communities are combined, then the diversity of the combined communities should be $2X$.” Replace “species” by “languages”, and the same can be said when dealing with linguistic diversity. Unfortunately, of the three indices considered so far ($R$, $G$ and $S$), only $R$ presents this property, whereas $G$ and $S$ do not; however, their numbers equivalents do, thereby displaying what Jost calls “an unexpected unity”. The general formula for the numbers equivalent, which for our purposes is denoted by $Z$, is based on shares $p_i$:

$$Z = \left( \sum_{i=1}^{R} p_i^q \right)^{\frac{1}{1-q}}$$

where $q$ is the “order” of the diversity measure whose numbers equivalent is thus calculated. Richness $R$ is a measure of order 0, and when replacing $q$ by 0 in the equation above, the corresponding $Z$ value $^RZ$ reduces to $R$.

The Greenberg index $G$ is defined as a measure of order 2, since replacing $q$ by 2 in the equation yields the corresponding numbers equivalent $^GZ$:

$$^GZ = \frac{1}{1-G} = \frac{1}{\sum_{i=1}^{R} p_i^2}$$

which is the inverse of the Simpson (or Herfindahl) concentration index.

As to Shannon entropy $S$, it is a measure of order 1. With $q=1$, the exponent in the definition of $Z$ is undefined. However, Hill, (1973: 432) shows that its limit for $q \to 1$ exists, enabling him to define the numbers equivalent $^SZ$ of Shannon entropy as its exponential:

$$^SZ = \exp(S) = \exp\left( -\sum_{i=1}^{R} p_i \times \ln p_i \right)$$
We are now equipped to move on to the next stage of our discussion, for which the concept of numbers equivalent is necessary, and where we adopt a more complex, but also more realistic interpretation of the meaning of linguistic diversity. In what follows, we put aside distance $D$, enabling us to keep the discussion closely aligned with the ecological literature focused on multi-level perspectives.

5 A Multi-level Approach

The operationalization of linguistic diversity proposed in the preceding sections rests on well-established concepts and offers a principled answer to questions that arise when policy selection and design require a transparent metric of the degree of diversity of given settings. The diversity indices discussed so far, however, presuppose a single-level universe, in which diversity is exclusively defined in terms of the different languages present in a given setting, whose equivalent, in the biophysical sphere, would be the different species in a given space.

5.1 Why use a multi-level approach?

The environmental sciences draw our attention to the fact that diversity is not defined solely by the diversity of species, but also by configurations of species, which are often called habitats (Whittaker, 1972). Jost et al. (2011) refer to these configurations as “compositions”. This distinction is commonplace in the literature on biological systems, which identifies alpha ($\alpha$), beta ($\beta$), and gamma ($\gamma$) diversity. Alpha diversity refers to the variety of species within given habitats – more precisely, $\alpha$ is a weighted mean of internal diversities across the habitats considered. Beta diversity denotes the differences between habitats in an ecosystem. The more varied the habitats, the greater the diversity of the system as a whole. Total (i.e., gamma) diversity in the system is a positive function of $\alpha$ and $\beta$. Although its most common definition is $\gamma=\alpha \cdot \beta$, alternative definitions are also encountered, usually $\gamma=\alpha + \beta$.

This two-tier analysis of an ecosystem may be transposed to linguistic diversity. A first parallel can be made between a language and a species, and another between a habitat and a setting, which is defined by the unique combination of languages used in it. Taken together, the settings constitute the system. A typical example would be a city and its neighborhoods, or various cities in a country. Moving to a two-tier analysis has powerful implications, but before we consider them more formally, let us clinch the point with an intuitive example.

A key feature of this model is obviously its distinction between levels, which enables us to see that maximizing diversity at one level does not necessarily maximize diversity at another level. Indeed, the maximization of intra-setting diversity might nudge the system in the direction of a collection of settings all presenting a high degree of internal diversity, but the settings themselves may become interchangeable and their specificity may erode. For instance, London is a multicultural city with every possible choice of ethnic restaurant; but the same can be said of Paris, New York, Berlin, Brussels, Amsterdam, Barcelona, Los Angeles or Singapore and, increasingly, of less cosmopolitan cities too. Paradoxically, the rise of internal diversity within each location or habitat may undermine the diversity that stems from differences between them. In other words, the increase of one manifestation of diversity ($\alpha$) can be detrimental to another ($\beta$).
5.2 Computing $\alpha$, $\beta$ and $\gamma$

Let us now compute these indices. Consider a system with $M$ different settings, each with a demographic weight $n_j (j=1, ..., M)$, with weights summing to unity to cover the entire population in the system, and a richness $R_i (i=1, ..., R_i)$. The linguistic reinterpretation of ecologists’ alpha diversity, using a definition of linguistic diversity encompassing richness and evenness, is given by the numbers equivalent of the weighted average of the respective Shannon entropies over the settings considered:

$$\alpha = \exp \left( -n_1 \sum_{i=1}^{R_1} (p_{i1} \times \ln p_{i1}) - n_2 \sum_{i=1}^{R_2} (p_{i2} \times \ln p_{i2}) - \ldots - n_M \sum_{i=1}^{R_M} (p_{iM} \times \ln p_{iM}) \right)$$

Similarly, the linguistic reinterpretation of ecologists’ gamma diversity, also based on the same definition of linguistic diversity encompassing richness and evenness, is given by:

$$\gamma = \exp \left( -\sum_{i=1}^{R} (n_{1}p_{i1} + \ldots + n_{M}p_{iM}) \times \ln(n_{1}p_{i1} + \ldots + n_{M}p_{iM}) \right)$$

Since the above expressions for $\alpha$ and $\gamma$ are based on the numbers equivalent of a diversity index (in this case, the diversity index used is Shannon entropy), Whittaker’s result (1972) applies, and:

$$\gamma = \alpha \times \beta$$

that is, total diversity is the product of average intra-setting diversity $\alpha$ and inter-setting diversity $\beta$, where not only $\alpha$, but also $\beta$ is the numbers equivalent of a diversity index. Since the raw data generate values for $\gamma$ and $\alpha$, we can compute $\beta$ as the ratio:

$$\beta = \frac{\gamma}{\alpha}$$

It is important to note that these indices display several desirable properties (see e.g. Jost 2007):

1. $\alpha$ and $\beta$ can vary independently of each other;
2. the “amount” of diversity denoted by a given number is the same, whether it describes $\alpha$, $\beta$ or $\gamma$ diversity;
3. $\alpha$ and $\beta$ can never be greater than $\gamma$.

6 Multilevel Model: Numerical Examples

The direct transposition to linguistic diversity of the ecological indices proposed in the preceding section is useful as a tool for comparing the diversity of different locations and for monitoring demolinguistic changes over time. Both uses are relevant for calibrating...
policies, anticipating future policy needs and properly identifying diversity-related social issues. Before discussing these applications, let turn to some numerical examples in order to illustrate the workings of the multilevel approach.

6.1 Transversal comparisons

Consider three stylized cities called A, B and C, whose respective diversity profiles are presented in panels (a), (b) and (c) of Table 1. Each has a population of 4.8 m residents and is divided in four neighborhoods (referred to as $U_1$ to $U_4$). They all have a richness of 4, because four language communities are represented. However, the speakers of these four languages are distributed very differently over their four neighborhoods. Given these distributions, cities A and B have the same gamma diversity of 4, as measured by the $Z$ value of Shannon entropy (computed at the level of the city); by contrast, city C’s gamma diversity approaches 1. This contrast between A and B shows in what way a basic indicator like richness is a poor gauge of diversity.

Moreover, despite their similarities (same $R$, same $\gamma$), cities A and B present deeply different diversity profiles. In city A, diversity is entirely due to the fact that each neighborhood is itself very diverse: all the languages are represented in each neighborhood and their respective demographic weight is the same, which maximizes evenness. However, neighborhoods are indistinguishable from each other precisely because their richly diverse linguistic make-up is similar. City B presents the polar opposite: each neighborhood has a

| City A | L1  | L2  | L3  | L4  |
|--------|-----|-----|-----|-----|
| $U_1$  | 300 | 300 | 300 | 300 |
| $U_2$  | 300 | 300 | 300 | 300 |
| $U_3$  | 300 | 300 | 300 | 300 |
| $U_4$  | 300 | 300 | 300 | 300 |

Alpha 4.00
Beta 1.00
Gamma 4.00

| City B | L1  | L2  | L3  | L4  |
|--------|-----|-----|-----|-----|
| $U_1$  | 1200| 0   | 0   | 0   |
| $U_2$  | 0   | 1200| 0   | 0   |
| $U_3$  | 0   | 0   | 1200| 0   |
| $U_4$  | 0   | 0   | 0   | 1200|

Alpha 1.00
Beta 4.00
Gamma 4.00

| City C | L1  | L2  | L3  | L4  |
|--------|-----|-----|-----|-----|
| $U_1$  | 1199| 1   | 0   | 0   |
| $U_2$  | 1199| 0   | 1   | 0   |
| $U_3$  | 1199| 0   | 0   | 1   |
| $U_4$  | 1200| 0   | 0   | 0   |

Alpha 1.005
Beta 1.001
Gamma 1.006
sharp, unique linguistic profile that distinguishes it from all the others, but each neighbor-
hood is also essentially monolingual – city B has diversity with segregation rather than by
mixing. As to city C, it has minimal diversity despite having the same richness as A and C.

The two-level analysis thus reveals essential contrasts that more common approaches to
diversity tend to hide. More specifically, we can position cities A, B and C in an \{α,β\} two-

Table 2  Linguistic diversity by cities and neighborhoods; cities D, E and F (Residents,
thousands)

| City    | L1  | L2  | L3  | L4  |
|---------|-----|-----|-----|-----|
| City D  |     |     |     |     |
| U1      | 1080| 70  | 50  | 0   |
| U2      | 1080| 70  | 50  | 0   |
| U3      | 0   | 1080| 70  | 50  |
| U4      | 50  | 0   | 1080| 70  |
| Alpha   | 1.48|     |     |     |
| Beta    | 2.13|     |     |     |
| Gamma   | 3.15|     |     |     |
| City E  |     |     |     |     |
| U1      | 900 | 200 | 100 | 0   |
| U2      | 900 | 200 | 100 | 0   |
| U3      | 0   | 900 | 200 | 100 |
| U4      | 0   | 900 | 200 | 100 |
| Alpha   | 2.06|     |     |     |
| Beta    | 1.52|     |     |     |
| Gamma   | 3.14|     |     |     |
| City F  |     |     |     |     |
| U1      | 900 | 200 | 100 | 0   |
| U2      | 0   | 900 | 200 | 100 |
| U3      | 100 | 0   | 900 | 200 |
| U4      | 200 | 100 | 0   | 900 |
| Alpha   | 2.06|     |     |     |
| Beta    | 1.94|     |     |     |
| Gamma   | 4.00|     |     |     |

Fig. 1  Comparing the structure of linguistic diversity, cities a, b and c
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1 dimensional space, as shown in Fig. 1, where the origin is defined by the coordinates (1,1), which is also the location of city C. The set of possible situations can be represented as the area below and including the curve, which may be seen as the maximum value of β as a function of α given a certain richness \( R \) in the system; hence, \( \max(\beta) = R \cdot \alpha^{-1} \). The tips of this area indicate the maximum value that \( \alpha \) and \( \beta \) may take in a given system with a given richness. At both tips and along the convex curve running between them, the value of gamma is maximum, and it corresponds to the numbers equivalent of Shannon entropy; at the same time, the position of A and B at opposite ends of the diagram reveals that the two cities are also opposites in terms of how diversity manifests itself.

Cities A, B and C are, of course, extreme examples, and situations such as those of cities D and E, represented in Fig. 2 (with underlying data in Table 2), are much more likely. Note, however, that given their respective positions, \( \alpha_D \cdot \beta_D = \alpha_E \cdot \beta_E \), yielding almost identical values for gamma (that is, \( \gamma_D = 3.14 \approx \gamma_E = 3.15 \)). Still, these two cities are very different. As shown by the figures in Table 2, every neighborhood in city E has a relatively high internal evenness, but neighborhoods \( U_1 \) and \( U_3 \) on the one hand, \( U_2 \) and \( U_4 \) on the other hand, closely resemble each other, which detracts from the overall distinctiveness of neighborhoods in this city. By contrast, city D has more distinct neighborhoods (only \( U_1 \) and \( U_2 \) are similar), but lower within-neighborhood evenness. Summing up, E offers on average, by comparison with D, more multilingualism within its different neighborhoods, but less distinctiveness between them. Finally, for purposes of comparison, let us present city F, which exhibits both intra-neighborhood evenness and inter-neighborhood distinctiveness; consequently, it also displays a high \( \gamma \), with \( \gamma_F = 4 \).

6.2 Monitoring over time

A two-level approach allows for a finer diagnosis of the processes that unfold when a location’s demolinguistic make-up changes over time. Such changes can stem from various causes, such as (but not limited to) migration flows, social mobility, gentrification, changes
in the legal or political treatment of some languages, or changes in patterns of intergenerational language transmission. Thus, we can reinterpret compositions A, B, C, D, E and F as various possible states, at different points in time, of the same city.

Let us consider a range of examples, keeping richness $R$ unchanged at 4, and begin with composition D. A first possible pattern is that the city progressively shifts towards more uniformity, both within and across its neighborhoods; in this case, D tends towards C (located at the intersection of the two axes; see Fig. 1), where diversity is low by any standard. Another possible shift could take the form of increasing diversity within all neighborhoods, thus leading to an increase in $\alpha$. If this shift entails no change in $\beta$, the composition edges towards case F. If, however, the increase in intra-neighborhood diversity (which causes the increase in $\alpha$), is accompanied by changes that reduce inter-neighborhood contrasts, $\beta$ will go down and the city will find itself moving towards case E. If the increase in $\alpha$ is such that it obliterates inter-neighborhood diversity, $\alpha$ reaches 4 but $\beta$ drops to 1, as shown by the case of city A. Conversely, if the city’s neighborhoods become highly differentiated, we may end up with situation B, where $\beta$ is maximized but $\alpha$ has dropped to 1.

Note that starting from composition D, shifts to F, A or B raise $\gamma$, the city’s aggregate diversity to 4, that is, its highest possible value in this set-up. However, maximum gamma diversity can materialize in very different ways, which is why the mere observation of a shift in total diversity in either direction does not, in and of itself, allow any normative evaluation, even if we assume generally favorable dispositions towards linguistic diversity. For example, the shift from D to A, while increasing aggregate diversity, amounts to a damaging uniformization through the erosion of traditional neighborhood identities. Conversely, a shift from D to B could indicate, despite increasing gamma diversity, a progressive drift towards linguistic segregation and ghettoization.

At the same time, however, a non-extreme increase in average intra-neighborhood diversity ($\alpha$) in most or even all neighborhoods need not lessen the linguistic diversity that was specific to different neighborhoods ($\beta$). This possibility is represented by the shift from D to F. Conversely, an increase in $\beta$, though possibly indicative of a deepening segregation, may also, on the contrary, reflect positive changes. An example is the increase, in a given neighborhood, of the percentage of residents who declare as their L1 a threatened minority language, simply because political repression of this language has abated or stopped, and the language starts being actively promoted and taught at schools.

For simplicity, several issues have been assumed away in this section. However, this implies no loss of generality, and for real-world policy applications, many of these simplifying assumptions can easily be relaxed. Let us consider the number of languages present in the system and the number of units in the system. The number of languages considered may be increased at will; gamma diversity increases up to the level of richness of the system, as do the maximum value of $\alpha$ (when $\beta=1$) and the maximum value of $\beta$ (when $\alpha=1$). The number of units (whether cities, provinces or other relevant jurisdictions) may also vary at will.

### 6.3 Application: assessing the linguistic diversity of Canadian cities

The foregoing can be illustrated with Canadian demolinguistic data. We use census returns on mother tongue by electoral district (ED) for the Montreal, Toronto and Vancouver areas. Using EDs obviates the problem of creating ad hoc divisions that might be arbitrary. Cal-
Calculations have been made for all the languages used as a first language by more than 1% of the resident population of Canada, plus a residual category, yielding the following list: English, French, Arabic, Tagalog, German, Punjabi, Italian, Spanish, Cantonese, Mandarin, and “other”. The resulting set of linguistic diversity indices is presented in Table 3.

Table 3  Linguistic diversity in three major Canadian cities, 2016

| City    | No. of EDs | Gini-Simpson index (G) | Shannon entropy (S) | $\alpha$ | $\beta$ | $\gamma$ |
|---------|------------|------------------------|---------------------|----------|--------|----------|
| Montreal| 18         | 0.70                   | 1.56                | 4.10     | 1.17   | 4.78     |
| Toronto | 25         | 0.66                   | 1.44                | 3.80     | 1.10   | 4.19     |
| Vancouver| 8         | 0.62                   | 1.43                | 3.76     | 1.11   | 4.17     |

Calculations by authors using Statistics Canada data; source: https://bit.ly/3HdON8k

The Gini-Simpson index which, as we have seen, underplays the impact of small language groups on the measurement of aggregate diversity, suggests a constant diversity gradient between the three cities (with a 0.4 increment between them). Shannon entropy offers a different picture, with a minor difference of 0.01 between Vancouver and Toronto, and a noticeably larger difference of 0.12 between Toronto and Montreal, which now stands out more clearly as the most linguistically diverse of the three cities. The $\gamma$ diversity index, which also concerns the aggregate level of a city as a whole, provides similar information.

However, because $\gamma$ is a numbers equivalent, it lends itself to a decomposition of diversity in components that all use the same metric. This decomposition is expressed by the terms $\alpha$ and $\beta$, namely intra-ED and inter-ED diversity respectively. The figures in Table 1 show that while both terms are higher for Montreal, the difference is particularly striking for $\alpha$ diversity, which is 0.30 point higher than in Toronto, and 0.34 point higher than in Vancouver. The differences between the $\beta$ diversity values for all three cities, at 0.07 and 0.06 point respectively, are less pronounced, indicating that Montreal’s higher diversity is not particularly linked to inter-ED diversity (which could be an indicator of ghettoization), and has more to do with the high degree of diversity present within each of Montreal’s 18 EDs.

7 Discussion

The multi-level model presented in this paper is directly applicable to a number of questions, and it also offers a stepping-stone for additional analyses.

Attention to the structure of diversity in a system is useful for calibrating policies. Suppose that the central state allocates subsidies to cities on the basis of their linguistic diversity, in order to enable them to better serve their linguistically diverse residents. As noted before, replacing a blunt measurement like richness by a more elaborate index such as Shannon entropy already constitutes an improvement. However, returning to our earlier example, it may not be optimal to grant the same subsidy to two cities just because they have the same number of residents and the same gamma diversity. These two cities may in fact find themselves in markedly different situations, because the total cost of serving residents in their first language is likely to differ significantly, depending on the relative weight of alpha or beta diversity. For example, coordination and staff costs are likely to be higher, other things being equal, if the education system must, in every neighborhood, operate in all the
languages of the system, than if a certain degree of concentration (lower alpha, higher beta) allows for the use of a smaller range of languages in some neighborhoods. If this holds, the subsidy ought to be different between two cities despite their identical $\gamma$, and be a positive function of the $\alpha/\beta$ ratio. The same reasoning applies, *mutatis mutandis*, for the periodical reviewing of subsidization to a city whose demolinguistic make-up changes over time.

The nature of the categories used when computing the values of $\alpha$, $\beta$, and $\gamma$ may be adapted to the type of policy issue considered. Until now, we have only used discrete categories, as do environmental specialists counting species in different habitats: an alder and a rowan tree are distinct species, and no individual plant can belong to both categories. Likewise, we have assumed so far that individuals were assigned to one language only, and the usual approach, when dealing with the distribution of a population in language groups, is to refer to their native languages and assume that every person can and will choose one.

Operating with such non-overlapping categories is reasonable for many analyses of linguistic diversity and the associated policy applications. A whole range of language rights are calibrated on the languages with which citizens have a primary and lasting association. A typical example is the right to mother tongue education, where research generally shows that even if bilingual streams can (and in many cases, ideally should) be offered, it is beneficial for the child’s cognitive development to access literacy through his or her home language (Phillipson, 2000; May and Hornberger, 2008), which usually coincides with the child’s native language. More generally, access to various services in one’s native language, even for people who speak several languages and could technically access these services in another language, is widely recognized as a right in domains such as administration, the courts, and public media. The actual policy issue is how to effectively implement those rights.

At the same time, a person’s primary and lasting association with a given language is perfectly compatible with bi- or multilingualism (Baker, 2001; Dewaele et al. 2003). For some policy purposes, therefore, assigning persons to one language only may not be satisfactory, if what counts is a person’s linguistic repertoire. In such cases, the four groups in the preceding section, which were respectively defined by their (presumably native) language, may be replaced by a set of up to 15 repertoires, from monolinguals to quadrilinguals, and the population distributed among them. This results in higher-value diversity indicators, if only because the range of repertoires is larger than the range of languages; even with constant total population figures, $\gamma$ goes up. The implications for policy, however, would generally remain minor as long as some monolinguals exist, since the principle of equal access to public service would then mandate the provision of such services in the four languages present in the system.

Another use of the multi-level model is to question widespread interpretations about people’s attitudes towards diversity. Let us disregard the situation where citizens are opposed to linguistic diversity, since the ensuing policy prescription (leaving all ethical considerations aside) would be to opt for policies that steer society towards point C in Fig. 1. Cases where citizens are generally favorably disposed towards diversity are more interesting. However, high $\text{gamma}$ diversity may mean different situations, as can be seen when comparing compositions B, F and A in Figs. 1 and 2; we have also explained, in the preceding section, why it is impossible, in the absence of additional contextual information, to make normative inferences about these compositions, let alone rank-order them, even with the assumption

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4 With $n$ languages, this figure is given by the Mersenne number $2^n - 1$.
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of a generalized preference for diversity. The reason is that preferences for diversity might be defined not so much in terms of gamma as in terms of alpha and beta diversity, an aspect that single-level approaches to diversity tend to overlook.

Therefore, breaking up diversity in its alpha and beta components may help make sense of a substantial amount of consistent, if indirect, evidence. Survey data often reveal *prima facie* ambivalent attitudes in society, with a willingness to accept or even welcome immigration, alongside strong demands for immigrants to adopt the values and codes of conduct of the host society (Grin et al. 2015; Pautz, 2005; Kaufmann, 2018). However, this apparent ambivalence is easier to understand if preferences are defined not in terms of $\gamma$, but in terms of $\alpha$ and $\beta$ diversity, and in particular if citizens prefer $\beta$ not to fall below a certain threshold. For example, the political project of the EU, while insisting on an “ever-closer Union” that implies increased citizen mobility between member states also emphasizes the need for Europe to preserve the specificities of its constituent parts. Hence, even among citizens who are favorably disposed towards immigration (whether intra- or extra-European), some increases in aggregate diversity will elicit negative reactions if the increase in gamma diversity is explained by an increase in alpha diversity while, at the same time, a decrease in beta diversity is taking place. Let us remember that $\beta$ captures the distinctiveness of habitats, and can therefore proxy for people’s sense of place (Debray, 2010; Boix-Fuster, 2015); perceived threats to one’s sense of place may then elicit negative reactions not because of some atavistic rejection of diversity, but precisely because the erosion of beta diversity is seen as harming diversity.

For another example, consider some of the political processes observable in the Canadian province of Québec, which may also, with due adaptation, be understood in this light. Amerindian autochthonous and Inuit communities make up a little over 1% of the resident population of the province, while 77.1% are native speakers of French, 7.5% are native speakers of English, and 12.3%, called allophones, are native speakers of other languages, usually “immigrant” languages. (In addition, 2% of residents describe themselves as native “bilinguals” in the two official languages.) Recent demolinguistic trends in the province, particularly since 2001, suggest an increase in transfers towards English and a decrease of transfers towards French (Castonguay, 2019). In this context, “transfer” refers to a shift by speakers away from their first language (defined as the first language learned at home in childhood and still understood at the time of data collection) to another language, which is the one they most frequently speak at home. In other words, the use of French as an everyday language would be decreasing in Québec (for a contrary interpretation, see Arsenault Morin and Geloso, 2020).

Supporting linguistic diversity in Canada and its provinces could therefore suggest different or even opposing policies, depending on whether diversity is approached with a one-tier or two-tier model. In a one-tier definition of diversity, encouraging diversity implies maximizing the value of linguistic diversity indicators in all the provinces of Canada, including Québec. On this view, the share of French as a native language in Québec may be allowed to decline further, while the presence of other languages should be encouraged. Considering that the protection and promotion of Amerindian languages is a difficult task in which advances, when they occur at all, tend to be modest (Maurais, 1992), increasing diversity

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5 See https://www.autochtones.gouv.qc.ca/nations/population.htm, consulted 20 Sept. 2020; native speakers of the associated languages, however, only make up about 0.6% of the resident population.

6 See https://bit.ly/3xmGYK0, consulted 20 Sept. 2020.
in Québec (as part of favoring diversity in Canada as a whole) would primarily call for the further spread of immigrant languages.

Conversely, in a two-tier definition of diversity, the specificity of habitats, and hence the differences between them, matter just as much as the degree of internal diversity of these habitats. The question then becomes one of identifying the features that make the various provinces and territories of Canada, including Québec, unique as specific linguistic settings (or habitats), and protecting these features, perhaps even at the cost of curbing the (internal) diversity index of some of these settings. In the case of Québec, encouraging diversity, then, would in principle require promoting Amerindian languages and Inuktitut, while supporting the pre-eminence of French over immigrant languages and English, because the linguistic specificity of Québec as a habitat rests on a distinctive composition that combines Amerindian languages, Inuktitut and French. Some parts of such a program, in particular the promotion of French, have been manifest in provincial language policy for more than forty years (Oakes and Peled, 2018; Vaillancourt, 2019), and others, signally the promotion of Amerindian languages and Inuktitut, far less so. A two-tier approach thus puts in sharper relief the trade-offs inherent in the challenges of diversity management.

The two-tier approach to the measurement of linguistic diversity, beyond its immediate applications to the efficient allocation of resources in language policies, is therefore also relevant to the normative debate over the distribution of resources stemming from the implementation of these policies. This can, again, be illustrated with reference to language rights for users of indigenous languages. Preserving the latter usually calls for very specific measures focused on safeguarding settings in which those rights can be genuinely implemented (Skutnabb-Kangas and Phillipson, 2016). As mentioned earlier in this discussion, this may imply curtailing, in specific locations, the presence of non-indigenous languages (such as English and French in the case of Canada). At first sight, this might be perceived as a measure that undermines diversity, making it harder to defend on normative grounds. But a closer look, using the two-tier decomposition presented here, suggests a different interpretation. This move will yield an increase in the level of $\beta$ diversity, without compromising $\alpha$ diversity, thus generating an increase in $\gamma$. This shows that the policy actually strengthens aggregate diversity. The two-tier approach shows that it is therefore fully compatible with a normative preference for diversity in general, and it may even be a condition for meeting certain normative requirements enshrined in language rights instruments.

8 Conclusion

In this paper, we propose an in-depth reconsideration of the tools with which linguistic diversity may be given a quantitative expression. Starting from richness $R$, the most basic and most commonly invoked measure, we have first recalled the importance of other dimensions already present in the literature on linguistic diversity, namely evenness $E$ and distance $D$, which taken together constitute what might be called the “RED” approach. Although these measurements are the object of a substantial literature when taken separately, contributions that actually use all three are few, especially in the language disciplines.

We have then highlighted some of the limitations of classical diversity indices, noting in particular that not all of them account correctly for specific features of diversity. In particular, some are too sensitive, others not sensitive enough to variations in the share of the
smaller languages in a set. Solutions to this problem have been presented in Sect. 5 by adapting, to linguistic questions, some tools developed in the ecological literature. In addition to recommending the use of Shannon entropy instead of the better-known “Gini-Simpson” or “Greenberg” index of diversity, we suggest using its numbers equivalent, because of its highly useful mathematical properties, which have been demonstrated in ecology for the measurement of species diversity.

These properties make it possible to go one step further and to move on to a two-tier approach to the measurement of linguistic diversity. Adapting to language a classic ecological distinction, we propose a new metric for linguistic diversity, which rests on the combined measurement of diversity within settings (alpha diversity), between settings (beta diversity), and in a system as a whole (gamma diversity). Though systematically related, within- and inter-setting diversity may change independently. Making this distinction allows not only for a more comprehensive measurement of linguistic diversity, but also for more precise comparisons of situations in different locations and over time, as a result of social, political and demolinguistic change.

The approach lends itself to a number of promising extensions. Some focus on the use of categories based not on a persons’ affiliation with a given language community, but on their bi- or multilingual language repertoires, opening up new perspectives for the conceptualization of diversity in language education and multilingual communication. Availability of data permitting, other applications may also be considered, in which “language” is replaced by other variables such as ethnicity and culture. As pointed out in the discussion, the range of possible uses of our new metric to diversity management policies is very broad, and applicable not only to policy selection and design, but also in the context of the public debates surrounding them, in areas such as minority language rights, migration, integration, and multiculturalism.

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