Complexity Theory: Applications to Language Policy and Planning

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Complexity Theory: Applications to Language Policy and Planning

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by

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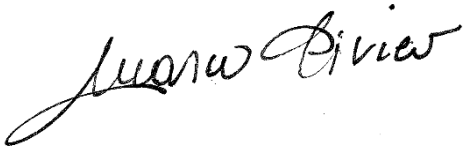

"Indeed, if there really is some day discovered a formula for all our desires and caprices – that is, an explanation of what they depend upon, by what laws they arise, how they develop, what they are aiming at in one case and in another and so on, that is a real mathematical formula – then, most likely, man will at once cease to feel desire, indeed, he will be certain to."

Fëdor Dostoevskij, *Notes from Underground*, 1864

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Abstract

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Due to the fact that phenomena such as globalization, integration, migration, and progress in information and communication technology have all contributed to making the world a much more complex place than it used to be, there are strong reasons for considering complexity as a key aspect of various topics of interest for the social sciences. The overall objective of this PhD dissertation is to explore the possibility of approaching language policy and planning (LPP) from the perspective of complexity theory. The research work is structured as follows:

1. In a first step, I provide a definition of complexity and put it an LPP perspective. I introduce the notion of "complexity", trying to spell out its basic characteristics. I plan to discuss how and why it is receiving increasing attention in the social sciences.

2. In a second step, I look at selected LPP issues and reinterpret them under the lens of complexity theory by applying its tools and methods.

This research work was developed as part of the MIME project, which was financed by the European Commission's Directorate-General for Research and Innovation in Framework Program 7. It draws inspiration from it and shares its basic assumptions and values. It aims to contribute to its objectives, which, broadly speaking, are to reconcile mobility and inclusion in the multilingual context of the European Union, and to formulate policy orientations in accordance with its findings. While the MIME project lies at the heart of the fundamental questions of this dissertation, the case studies go beyond it and are not confined to the type of situations analysed as part of this European project.

The complex approach has come to be very important, if not indispensable, in the analysis of a wide range of phenomena in an increasingly interconnected and complex world. Over the last ten to fifteen years, the tools of complexity theory have been applied to a wide variety of topics in different disciplines, ranging from the natural sciences (such as biology and ecology) to the social sciences (e.g., economics and sociology) and the humanities (e.g., linguistics). However, it has only seldom been applied to language policy. It is precisely this gap that my dissertation tries to fill.

The first part of the thesis presents the theoretical core, upon which all other discussions build. It is devoted to the description of the theoretical background of my research. I plan to investigate the range of language policy implications of the complexity paradigm. My goal is to provide an overall introduction to complexity theory and a typology of its analytical concepts and tools, on the basis of their features and usefulness. The dissertation devotes special attention to those aspects of complexity that are of particular relevance for the study of LPP. Following this review of key aspects of complexity theory and its application to LPP, I link it up with the general principles of public policy, in order to provide an integrated perspective on LPP as a case of complex policy area.

In the second part of this research, I move on to examine a range of practical case studies in LPP, using the results of the theoretical work carried out in the first part. The selection of the case studies is intended to guarantee a sufficiently wide scope in order to illustrate how complexity theory can contribute to LPP in all its aspects. I revisit a range of classical LPP themes from the perspective of complexity theory. I plan to explore both past and current cases with their established practices and prospective cases with a potentially wide spectrum of complex policy solutions. The topics retained for application are the following:

1. the management of multilingual communication in linguistically diverse organisations (whether in the private or public sector);

2. the protection and promotion of minority languages;

3. the challenges of second/foreign language education in the context of the European Union and their consequences in terms of linguistic disenfranchisement.

A final section of the thesis is devoted to a synthesis consolidating the theoretical findings. General conclusions are derived from the theoretical

work and case studies, in order to identify structuring elements and to firmly anchor LPP in the framework of complexity theory.

Acknowledgements

This thesis is the result of many years of research, but it is also much more than that. It is the material embodiment of and testimony to many years of ups and downs, good and bad news, moments of satisfaction and disappointment. As strange as it may sound, writing a thesis forces you to experience a very wide range of emotions. Some days you feel like you can change the world with your ideas. Other days you go to bed and spend the night thinking that you have absolutely no idea of what you're doing. Sometimes you start numbering all the things that are wrong with your research (and with your life) and that list is always in your mind, right between the grocery list and the delay for that abstract submission. Then one day, right when you're down to your last bit of hope because of that rejection, you attend a conference, meet someone who compliments you on the presentation that you just powered through, and your confidence is fully restored. This emotional roller coaster can be overwhelming and can easily make you lose sight of the objective. As to me, I was lucky enough to have some incredible people around me who never failed to make me feel their continued support.

The first person that I want to thank is Professor Grin, François, a demanding supervisor and a dear friend. He trusted me from day one and walked me along this path with care and patience. He taught me how to do research, how to find my spot in the academia, and, above all, he taught me to believe in myself and to learn from my mistakes.

I want to thank the members of my jury, who took their time to read and comment my thesis. In particular, I would like to thank Professor Hofstede, who welcomed me in his research group as a visiting PhD student. I want to thank my family for trusting me and supporting me unconditionally at every moment of this journey. Though far, they always felt very close. Sometimes a few good words can tell more than a thousand hollow ones.

I want to thank my dearest friends and colleagues, who were always close to me, both physically and emotionally. Not only do I have some incredible friends who have been with me most of my life, but I also had the chance to meet a bunch of extraordinary people in the past few years, who enriched me with bits of their personalities and allowed me to evolve and grow as a person more than I ever thought possible.

Last, I think I need to thank myself, as I was able to hold tight on this roller coaster and to get to the end of this amazing ride called a PhD.

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To my family and loved ones,
who believe in me more than I do myself.

Chapter 1

An Overview of Complexity Theory

1.1 Introduction

As a consequence of large-scale phenomena such as globalization, integration, migration, and progress in information and communication technology, the world has become a much more complex place than it used to be. Today, social systems, which I shall define as *collections of interacting components*, are much more interconnected, and actions within and outside these systems can (and often do) give rise to unexpected (or deliberately overlooked) reactions in terms of "what is reacting to what" and "with what intensity". As a consequence, it is essential to understand in depth such manifestations of *complexity* when analysing a wide range of activities, such as business and policy making. Let us look, for example, at public policy. First, policy interventions can produce consequences in apparently unrelated fields because of connections that have been overlooked or were simply unknown. Second, the issue that a specific intervention aims to address might have roots elsewhere, and therefore be resistant to policy intervention until these connections are clearly identified. Therefore, policy interventions in a complex environment are often effective only if they are designed with a degree of complexity that matches that of the issue they are addressing (Bar-Yam, 2015), lest societies collapse under a level of complexity that is no longer sustainable (Tainter, 1988). Clearly, this is true also for language policy issues. Besides, identifying a *correlation* between phenomena, which can sometimes prove a surprisingly easy task with today's statistical tools, is often not enough to tell the whole story. Nevertheless, policy makers may be tempted to draw conclusions based on simple correlations. Careful policy makers should always

look for *causal* links, which are much harder to define and call for a deep understanding of several related phenomena. In these circumstances, an analysis that takes complexity into account is crucial.

The complexity of human language can be hardly denied. Hidalgo (2015) argues that the ability to use language is one of the key aspects of humans that differentiate them from other animals. Besides, he links language to other manifestations of human complexity. In particular, he relates it to the ability to create complex tools. He provides two arguments to support this idea. First, the ability to put pieces together to produce a complex tool requires an inner understanding of how different pieces can be assembled to generate a new object, much like we put words together to create sentences. This capacity can be seen as a primitive form of grammar and it has been found to trigger similar patterns of brain activity. Second, he argues that the knowledge required to produce complex tools is conveyed more efficiently through language. In this sense, technological progress since prehistory can be seen as proof of some early form of human language. Indeed, one might easily go as far as to argue that culture is the way human intelligence and ingenuity are passed on across generations. This idea is also found in Gellner (1983), who argued that formal education and linguistic standardisation became crucial after the First Industrial Revolution, in that the workforce of the industrial era could no longer be trained by merely showing what was needed, as used to be the case in the context of agriculture-based economies. Given that the skills and knowledge needed to perform a task had become more complex and were no longer unchanging, communication (and, therefore, a common language) became suddenly crucial for economic development.

In this first chapter, which can be considered a general introduction, I present the fundamentals of complexity theory[1] and I show how complexity is an omnipresent characteristic of language-related issues. This is a necessary starting point, as the science of complexity, coupled with language policy, provides the theoretical backbone of the second (and applied) part of this dissertation. Besides, as complexity theory is a relatively recent paradigm of research, not everyone is familiar with it. Hence, the goal of this chapter is also didactic, in that it provides readers with an overall introduction to complexity science and a typology of its analytical concepts and tools, on the basis of their features and usefulness. To do this, I adopt a stepwise approach.

[1] Throughout this dissertation I use the expressions "complexity theory" and "complexity science" interchangeably.

First, I introduce the notion of "complexity" along with some preliminary clarifications. I briefly review the history of the development of complexity and complexity theory. I spell out the basic characteristics of "complexity" in order to show how it is conceptually different from "complication" and "complicatedness".[2] I resort to several examples to explain the characteristics of complexity. Whenever fitting, I propose examples from language-related issues.[3] I also discuss how and why it is receiving increasing attention in the social sciences. Second, I present some of the major analytical tools of complexity theory, paying special attention to those which are applied in the following chapters of this dissertation. Finally, I consider some practical examples of complexity in the social sciences, including cases from the private and the public domain, in order to provide justification for an application of complexity theory to language policy. In particular, I refer to multilingualism in the European Union as an example of a complex issue, first introducing it and then re-interpreting it from a complex perspective. By the end of this chapter, it shall be clear that complexity is *everywhere* in language-related issues, whether one speaks of sociolinguistic phenomena or of stricly linguistic matters such as grammar and vocabulary. Therefore, the discussion below provides justification for a complexity theory approach in the language sciences.

1.2 The science of complexity: Preliminary clarifications

Complexity theory, or "the science of complexity" as it is often referred to, is better described as a way of approaching the analysis of certain phenomena, a paradigm of study, rather than a theory *strictu sensu*. One should think of it more as a way of re-thinking things and phenomena, looking at them through a convex lens which enlarges the vision field. As we shall see in the following pages, complexity theory integrates a set of concepts and ideas

[2]Note that the word "complexity" can be opposed to both "complication" (that is, the act of complicating or an element that complicates) and "complicatedness" (the quality or the condition of being complicated), in that it can refer both to "something that makes things complex" and to "the quality of being complex". As a matter of fact, the words "complexification" and "complexness" as parallels of "complication" and "complicatedness" appear in some dictionaries, but their use is not frequent and is avoided in this dissertation to prevent confusion, except when they come in particularly handy. The meaning of each of these words is usually clear from the context.

[3]It should be noted, however, that complexity can be explained through countless examples of all different sorts, not only language-related.

derived from different disciplines and fields of research that give up a mechanistic view of the world in favour of a holistic approach, whereby the object of study is often characterized by a level of uncertainty. At the same time, this approach de-emphasizes linearity and predictability (Grobman, 2005). It places itself in direct opposition to the philosophical position of "reductionism", which supports the idea that all processes and phenomena can be reduced to a collection of simpler basic parts. However, this does not amount to saying that complexity theory rules out the possibility of deducing larger macro-dynamics from individual micro-cases, quite the opposite. It simply states that a constant application of a strictly inductive logic risks being fallacious. The same applies to the continuous attempt to fit phenomena into pre-established models. Indeed, Mikulecky (2001) quite suitably observes that

> "[c]omplexity is the property of a real world system that is manifest in the inability of any one formalism being adequate to capture *all* its properties. It requires that we find distinctly different ways of interacting with systems." (p. 344) [emphasis added]

Therefore, a complex approach does not completely rule out the possibility of resorting to formal models. Rather, it supports the idea that a complex phenomenon cannot be explained by a single model and/or from a single perspective. It calls for a combination of methodologies and an interdisciplinary perspective. This idea is explored in depth in the coming pages.

However, before I move on to a detailed discussion of complexity theory, two important points require clarification. The first one concerns the notion of "uncertainty". Over time, uncertainty has been used (and misused) to convey somewhat different ideas. At times it has been given a more probabilistic connotation, whereby uncertainty would result, for example, from sampling errors or observational errors. The usual approach to cope with this kind of uncertainty consists in the use of statistical tools that allow for a margin of error (such as setting different levels of confidences or using factors of correction for finite populations). At other times, uncertainty has been associated with the property of being impossible or hard to determine with precision. In this sense, the notion is better expressed by the term "indeterminacy" or, in Heisenberg's words, "*unbestimmtheit*". Heisenberg used this expression in relation to quantum mechanics, stating that it is impossible to measure with

absolute precision both the position and the momentum (mass times velocity) of a particle at the same time (Mitchell, 2009, p. 20).[4] Indeed, increasing the level of precision in the measurement of one dimension inevitably decreases the precision in the measurement of the other. Heisenberg's *unbestimmtheit* is probably closer to what scholars of complexity theory mean by "uncertainty".

The second point that requires clarification concerns the actual meaning of the word "complex". First of all, let us recall that "complex" does not (necessarily) mean "complicated", although the two words are often used interchangeably in non-specialized contexts. Seeing the difference between these two words and their related notions is a fundamental step in understanding complexity science. A complicated system (or object, process, organism, organization...) is made up of several different parts that work together in order to bring about one or more results. One can think of a watch as a clear example of a complicated system (in this case, a piece of machinery). It is composed of tens, sometimes hundreds of components of various sizes that have to work in perfect coordination to do their job, i.e. show time (and whatever other piece of information they can reasonably express).[5] However, such a piece of mechanical engineering is not *complex*, but "merely" *complicated*. A complicated system possesses a great number of components which work in a *patterned* and therefore *predictable* way. It is hard to assemble it, it is hard to find the right combination that makes it work, but eventually the device will function *without any uncertainty*. It is nothing else but the *sum of its components*, organized in a specific way. Therefore, if a component stops working, it is possible to fix the whole system by simply intervening on that specific component, whose function is already known and predictable. The idea is similar to the plumber checking a washing machine that has recently stopped working, and stating with confidence that a particular piece needs to be replaced.

This idea echoes French scholar Pierre de Laplace's strongly deterministic (though strictly theoretical) view of the universe. In his "Essai philosophique

[4] More precisely, Heisenberg's principle of uncertainty (in German *Unbestimmtheitsprinzip*) states that the position and the momentum of a particle cannot be simultaneously determined with precision. The more precise the determination of the position, the less precise the measurement of its momentum can be, and vice versa (Heisenberg, 1927).

[5] As of today, Swiss watchmaker Vacheron Constantin claims to have created the most complicated watch ever, the Reference 57260, which has 57 complications, including carillons, alarms, 26 different calendars, on top of six time measurements functions. All features in a timepiece providing information beyond hours and minutes are quite rightly referred to in the jargon of horology (the art or science of measuring time through devices) as "complications" and not "complexities".

sur les probabilités" he writes:

> "Une intelligence qui, à un instant donné, connaîtrait toutes les forces dont la nature est animée et la situation respective des êtres qui la composent, si d'ailleurs elle était suffisamment vaste pour soumettre ces données à l'analyse, embrasserait dans la même formule les mouvements des plus grands corps de l'univers et ceux du plus léger atome ; rien ne serait incertain pour elle, et l'avenir, comme le passé, serait présent à ses yeux."[6] (Laplace, 1814, p. 2)

Conversely, a complex system is characterized by a degree of *unpredictability*. Sargut and McGrath (2011) observe that with a complicated system, one can usually predict outcomes by knowing the starting conditions, while with a complex system, the same starting conditions can lead to radically different outcomes, depending on existing interactions. This observation echoes what mathematician Henri Poincaré stated in his essay "Science et méthode", first published in 1908, which can be seen as an extension of Laplace's idea to include the concept of unpredictability:

> "Une cause très petite, qui nous échappe, détermine un effet considérable que nous ne pouvons pas ne pas voir, et alors nous disons que cet effet est dû au hasard. Si nous connaissions exactement les lois de la nature et la situation de l'univers à l'instant initial, nous pourrions prédire exactement la situation de ce même univers à un instant ultérieur. Mais, lors même que les lois naturelles n'auraient plus de secret pour nous, nous ne pourrons connaître la situation initiale qu'approximativement. Si cela nous permet de prévoir la situation ultérieure avec la même approximation, c'est tout ce qu'il nous faut, nous disons que le phénomène a été prévu, qu'il est régi par des lois ; mais il n'en est pas toujours ainsi, il peut arriver que de petites différences dans les conditions initiales en engendrent de très grandes dans les phénomènes finaux ; une petite erreur sur les premières produirait une erreur

[6] "Given for one instant an intelligence which could comprehend all the forces by which nature is animated and the respective situation of the beings who compose it - an intelligence sufficiently vast to submit these data to analysis - it would embrace in the same formula the movements of the greatest bodies of the universe and those of the lightest atom; for it, nothing would be uncertain and the future, as the past, would be present to its eyes." (Translation by Frederick Wilson Truscott from "Théorie Analytique des Probabilités", originally published in 1814.)

> énorme sur les derniers. La prédiction devient impossible et nous avons le phénomène fortuit."[7] (Poincaré, 1947, p. 68)

Indeed, in complexity theory, systems are seen as evolving entities, in which internal initial conditions do not provide sufficient information to foresee future developments. Besides, it should be noted that the word "system" itself, as opposed to loose synonyms such as "collection" or "aggregate", hints at non-trivial properties which do not belong to the single components and therefore implies a certain level of complexity. Larsen-Freeman and Cameron (2008) propose the example of secondary school as a system. Students are not just a collection of individuals. They may, among other things, share certain values and be influenced by their teachers, therefore creating a system that is unique.

1.3 A history of complexity: From the natural sciences to the social and language sciences

Tracing back the origin of the notion of complexity is not an easy task. The difficulty is amplified by the fact that the terms "complex" and "complexity" are used (and sometimes misused) to express their general, non-technical meaning, *even* in the academic context. Therefore, it is not straightforward to single out those contributions to research that actually deal with complexity in the specific sense that I am discussing here. However, since complexity is a relatively recent scientific paradigm, a dissertation dealing with it has to discuss it also from a historical perspective. In this section I present the history of the notion of complexity. I start by discussing the theories that first dealt with it. Then I review the specific contributions from different scientific disciplines that provided the theoretical basis for the notion of complexity, bridging the natural sciences with the social sciences by means of examples (also) from language studies.

[7] "A very small cause which escapes our notice determines a considerable effect that we cannot fail to see, and then we say that that effect is due to chance. If we knew exactly the laws of nature and the situation of the universe at the initial moment, we could predict exactly the situation of that same universe at a succeeding moment. But, even if it were the case that the natural laws had no longer any secret for us, we could still only know the initial situation approximately. If that enabled us to predict the succeeding situation with the same approximation, that is all we require, and we should say that the phenomenon had been predicted, that it is governed by laws. But it is not always so; it may happen that small differences in the initial conditions produce very great ones in the final phenomena A small error in the former will produce an enormous error in the latter. Prediction becomes impossible, and we have the fortuitous phenomenon." (Translation by Francis Maitland from "Science et Méthode", originally published in 1914).

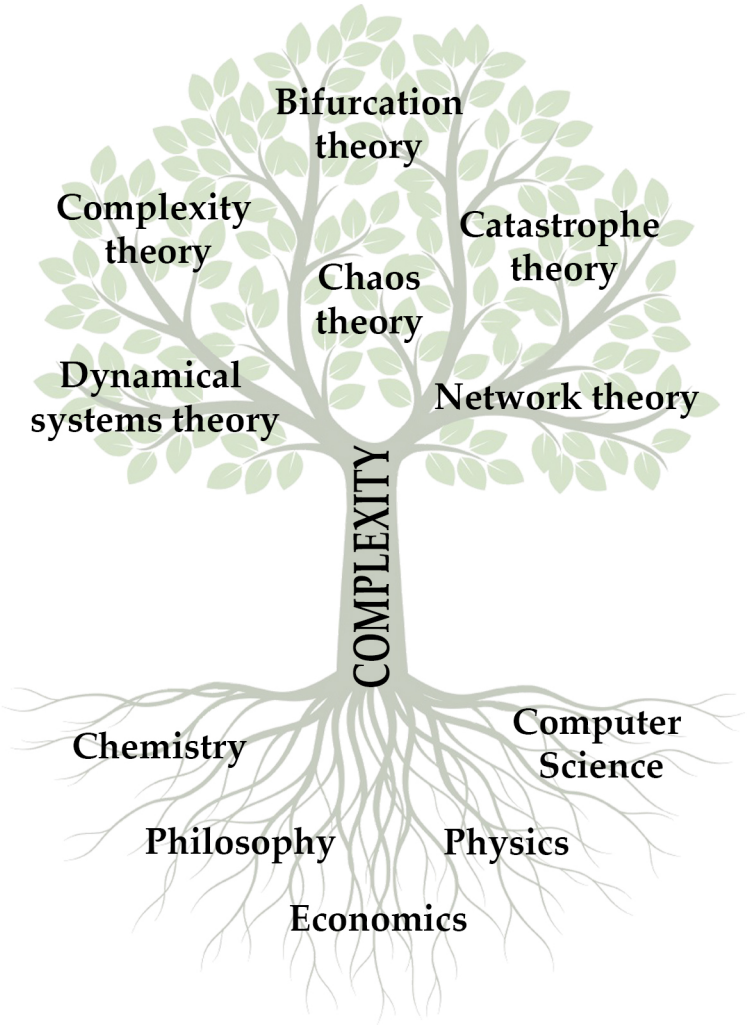


FIGURE (1.1) The genesis of complexity.

The genesis of complexity could be thought of as a tree, in that it started out as a number of different roots (i.e. the contributions from various disciplines) that eventually converged into a robust trunk (complexity). This image is particularly useful also to convey the idea that several disciplines still continue feeding the notion of complexity. Besides, this picture could be further refined by including branches and sub-branches, which represent the different disciplinary developments and treatments of the notion of complexity (e.g. complexity theory, chaos theory, dynamical systems theory, bifurcation theory, catastrophe theory, network theory).[8] The resulting picture would approximately look like Figure 1.1.

Bifurcation theory can probably be considered one of the first important

[8]Some notions or graphic representations brought forward by cognates of complexity theory can come in handy in this chapter to explain the basic ideas of complexity. In such instances, a few introductory words are devoted to presenting other theories.

theories that addressed the issue of complexity. First introduced by Henri Poincaré (1885), bifurcation theory studies the changes caused by small variations in certain parameter values (called bifurcation parameters) within a system. The point where two or more alternative paths can be followed by a system as a consequence of a change in one or more parameter values is called a bifurcation. Interestingly, bifurcation can be triggered by a change in one variable as well as in n variables at the same time (in which case we speak of bifurcation with co-dimension n). In particular, a sub-branch of bifurcation theory called catastrophe theory, largely based on the contributions by French mathematician René Thom in the 1960s, studies specific cases of bifurcation that can potentially bring about dramatic changes in the behaviour of a function.

Another important antecedent of complexity theory is chaos theory, which studies systems whose behaviour is heavily dependent on initial conditions. It should be noted, however, that chaos is not to be confused with randomness. In fact, in chaos theory, the behaviour of systems can be completely deterministic. The focus is on the fact that approximately similar initial conditions can lead to drastically different future scenarios. As a matter of fact, it would not be nonsensical to speak of deterministic chaos. The mathematical counterpart of chaos theory is dynamical systems theory, which studies the behaviour of complex dynamic systems by means of difference and differential equations.

Although the idea of complexity was analysed from several theoretical perspectives, locating when and where it was first brought forward as a scientific notion is not an easy task. This is especially true because the development of complexity theory did not follow the path from the natural sciences to the social sciences that characterised several other theories, such as Newtonian mechanics, thermodynamics and Darwinian evolution. Each of these prominent natural science paradigms and theories inspired, at different times, new ways of approaching research in the social sciences and provided arguments for methodological justification. A classical example is that of the gravity model of trade, which, drawing from Newton's law of universal gravitation, explains the size of trade flows between two countries as a function of their economic "masses" and of the geographical distance between them. In the case of complexity, a number of different sciences co-evolved around the same ideas that eventually provided the founding principles of

complexity theory (Room, 2011, p. 15). Speaking of natural sciences in complexity theory, Russian-Belgian chemist Ilya Prigogine is traditionally considered one of the major contributors. During the 1970s, he carried out studies on thermodynamics applied to complex and far-from-equilibrium systems. Larsen-Freeman and Cameron (2008) also mention Chilean biologists Humberto Maturana and Francisco Varela as important contributors to the evolution of complexity theory (as well as to systems theory and sociology). In the early 1970s, they proposed the idea of "autopoietic" systems referring to living organisms that continuously change and redefine themselves while maintaining their identity (Maturana and Varela, 1972).

In the social sciences, Austro-Hungarian born economist and philosopher Friedrich Hayek largely contributed to the development of the notion of complexity, introducing it in many different fields. In particular, he worked on the idea of spontaneous order arising in complex systems (which is discussed at greater length in the next section). Hayek (1964) observed that there is an important distinction between "a prediction for the appearance of a pattern of a certain class" and "a prediction of the appearance of a particular instance of this class". In other words, there exists a non-negligible gap between the formal description (of the development) of a general phenomenon and the specific circumstances that eventually come about. For example, it is one thing to predict that a certain phenomenon (say, the course of celestial bodies) will follow the mechanics described by a certain (mathematical) formalisation, but it is another thing to predict the manifestation of a specific instance of such mechanics. Hayek goes on to say that this gap is especially significant for issues of life, mind, and society, in that they imply a higher level of complexity and unpredictability than physical phenomena. Conversely, physical issues can be described effectively by means of relatively simple formulae. In other words, the minimum number of variables that need to be included in a model in order to reproduce the characteristic patterns of a phenomena is lower for physical matters than it is for social matters. However, this does not mean that the additional challenges raised by social phenomena could and should be addressed by adding more variables, quite the opposite. The extremely high number of variables that would need to be taken into consideration rules out the possibility to rely exclusively on statistical methods and makes it therefore impossible to work out very precise predictions. Interestingly, some have gone as far as to say that it does not make any sense to speak of "variables" when it comes to the description of social phenomena, as systems are so complex and dynamics so nested and intersected that

scientists should only look at the system as a whole without trying to break it down in several variables in the hope of coming across some causal links (Byrne, 2002).

Hayek's research contributed particularly to the field of economics. He received the Nobel Prize for, among other things, his contributions concerning the notion of self-organization and the emergent properties of markets. In particular, he adopted the word "catallaxy" to describe "the order brought about by the mutual adjustment of many individual economies in a market" (Hayek, 2013, p. 269). A similar idea was brought forward by English anthropologist and linguist Gregory Bateson, who was among the first to argue that systems have a multi-layer structure. In particular, speaking of ecological anthropology, he supported the idea of a world made of systems structured on several levels (individuals, societies, and ecosystems) and characterized by mechanisms of continuous adaptation and feedback loops that depend on several variables (Bateson, 1972) (these notions are discussed in greater detail in the next section).

One of the earliest scientific contributions to complexity theory that made the link between the natural and social sciences was given by Warren Weaver, mathematician and, among other things, one of the pioneers of machine translation. He talked about complexity to show how research in biology and the medical sciences were essentially different from research in the physical sciences during the seventeenth, eighteenth, and nineteenth centuries (Weaver, 1948). The physical sciences, he argues, focus on studying phenomena maintaining constant all but a couple of variables of interest. However, research in biology and medicine could not adopt the same methodology, as it is seldom possible to maintain things constant in living organisms to allow for an isolated observation of the variable(s) of interest. Therefore, measuring effects and variations is often made harder by the confounding effect of other variables. Interestingly, and quite ahead of his time, Weaver also discusses in the very same essay the crucial distinction between *disorganized* and *organized* complexity. He argues that problems of disorganized complexity are characterized by a very large number of variables having a behaviour which is individually erratic. Conversely, when speaking of organized complexity, the same large amount of variables display interrelated patterns which make them an *organic* whole. Besides, Weaver also extends the idea to the social sciences, asking questions such as: "To what extent is it safe to depend on the free interplay of such economic forces as supply and demand?" or "How can one explain the behaviour pattern of an organized group of persons such as

a labour union, or a group of manufacturers, or a racial minority?" (Weaver, 1948, pp. 539-540). These speculations clearly laid the ground for future applications of the notion of complexity in the social sciences. Again quite ahead of his time, Weaver observes that problems of organized complexity can be effectively treated in essentially two ways:

1. by means of electronic computing devices (which were in their earliest stages at the time) able to simulate complex processes, and

2. through mixed teams of scholars from different disciplines able to provide insights on the same issue from different analytical perspectives.

Not surprisingly, these two methodologies are still today two of the main pillars of complexity science. Incidentally, one of Weaver's concluding statements would prove true several decades later, when complexity science would finally reach language disciplines:

> "Communication must be improved between peoples of different languages and cultures, as well as between all the varied interests which use the same language, but often with such dangerously differing connotations." (Weaver, 1948, p. 544)[9]

Concerning the specific case of machine translation, Weaver was among the first (if not the very first) to recognize its complex nature. In his famous 1949 "Translation" memorandum, he supported the idea of applying the high speed, capacity, and logical flexibility of (then) modern computing devices to translation tasks (Weaver, 1955). The proximity of Weaver's proposals to today's founding ideas of machine translation is remarkable, especially considering that they date back to the first half of the last century. Among other things, he had two proposals of particular interest for this discussion on complexity theory. First, he rejected the idea of a word-for-word approach, as a word might have several translations in another language. Instead, recognizing that the meaning of a word is highly dependent on the words along which it occurs, he supported the idea of deciding on a translation by looking at the context, a number n of words occurring in proximity of the word to be translated. If n is large enough, then it is possible to translate the word with reasonable accuracy. Therefore, computing devices represent a major ally in the translation job as they can handle a large corpus of co-occurrences. He called the study of statistical co-occurrence of words and the application

[9] As a matter of fact, this very observation served also as an important source of inspiration for this dissertation.

of statistical methods to translation "statistical semantics". Second, he proposed that translation should be approached as a problem of cryptography. This idea was probably the result of his participation in World War II as a mathematician. He suggested that a text to be translated from language A to language B should be seen as a text in language B coded into the "A code". He starts his discussion by telling the anecdote of a mathematician (whom Weaver simply refers to as "P") who had spent a period of time at the University of Istanbul and had learnt the Turkish language. P was asked by a colleague who had come up with a deciphering method to write down a text and then encode it into numbers. P wrote a message in Turkish and then gave the encoded version to his colleague. The day after the colleague came back with a text that, although not perfect, was accurate enough to be understood with no much pain by someone who spoke the language well. What Weaver found remarkable was that the person who decoded the numerical text was neither aware that the original text was in Turkish, nor could he or she speak the language. Weaver goes on to observe that human beings have all the same physical endowment to cope with their communication needs (i.e. to come up with a language). As different as languages can be, they share some traits that he names "invariants", which are largely independent of the language used, such as letter combinations, letter patterns, and so on. Therefore, he purports the idea that machine translation should build on the notion of "invariants" as they represent the key to decoding across different languages.

In 1984, the Santa Fe Institute was founded. Located in Santa Fe, New Mexico, United States, the Santa Fe Institute is a non-profit theoretical research institution whose mission is to "understand and unify the underlying, shared patterns in complex physical, biological, social, cultural, technological, and even possible astrobiological worlds" in order to "promote the well-being of humankind and of life on earth".[10] As of today, the Santa Fe Institute is deemed to have played a key role in the development, consolidation and diffusion of the notion of complexity (Room, 2011, p. 16).

1.4 What do we call "complex"?

Over the last decades, complexity has been defined in a number of different ways, each definition stressing one aspect or another. A complex system has a *large number* of *heterogeneous*, independent and *interacting components*, able

[10] More on their mission is available at the address https://www.santafe.edu/about.

to evolve along *multiple pathways*. Its development is very *sensitive to initial conditions* or to small perturbations, and it is analytically described through *non-linear* differential equations (Whitesides and Ismagilov, 1999). On top of being inherently complicated, complex populations are rarely deterministic, and predisposed to *unexpected outcomes* (Foote, 2007). The major problems for those who get to deal with complex systems are *unintended consequences* and the difficulty of making sense of a situation (Sargut and McGrath, 2011). All of the words emphasized in the previous sentences are highly recurrent in theoretical and applied texts dealing with complexity theory. At times, each one of these aspects have been highlighted as the key characteristic of a complex system. In the next few paragraphs I present the fundamental features of complex systems. The discussion focuses on the following features, which seem to constitute a *fil rouge* across numerous publications in the field of complexity:

1. non-linearity;
2. non-Gaussian distributions;
3. power laws;
4. presence of attractors;
5. feedback loops;
6. spontaneous order;
7. lack of central control;
8. emergence;
9. hierarchical organisation;
10. recursivity;
11. openness.

The reader should be aware of the fact that different authors may use different words to refer to basically the same characteristics. This is mainly due to the different academic backgrounds of the scholars who have contributed to complexity theory at different times. The following discussion is based on a long process of literature review and a thorough work of harmonization of various contributions from a wide range of disciplines. Besides, some

of these features can be quite rightly seen as overlapping at times. Therefore, the reader should bear in mind that this examination is not meant to be exhaustive. It aims at defining the idea of complexity and at showing that a complex system is not just "complex" in the broader sense of the word. Rather, it is complex "in a specific way", in that it displays a precise set of characteristics. I now move on to an in-depth analysis of these characteristics, which is a necessary starting point towards the constitution of a general framework that will eventually allow us to distinguish between complex and non-complex language policy issues in a consistent way.

1.4.1 Non-linearity

By non-linearity, specialists often mean precisely that a system displays a fundamental disproportionality between cause and effect (Homer-Dixon, 2010). In a simple (linear) system, a small disturbance implies a small change, while a big disturbance leads to a big change. On the contrary, complex systems do not necessarily exhibit such proportionality. Small changes could imply dramatic effects and big ones could have only marginal implications. In mathematics, a system or a function is called linear if it complies with two principles, additivity (1.1) and first-degree homogeneity for any scalar value (1.2), often combined in the so-called "superposition principle" (1.3):

$$f(x+y) = f(x) + f(y) \tag{1.1}$$

$$f(\alpha x) = \alpha f(x) \tag{1.2}$$

$$f(\alpha x + \beta y) = \alpha f(x) + \beta f(y) \tag{1.3}$$

These equations simply state that

1. the variation of a system following an external input can be described as the sum of the variations in its components, and

2. the variation of the components and the overall variation of the system are linearly related by a constant.

The basic form of a linear equation is:

$$y = mx + q \tag{1.4}$$

where y and x are the dependent and the independent variables, while m and q are constants and represent respectively the slope of the line and the

intercept. Without going into further detail, it is enough to notice that linear equations are those that do not contain products between the variables, powers of the variables and any transcendental function involving the variables (such as logarithms, exponentials, and trigonometric functions). For example, it is very easy to see that the function $f(x) = x^2$ is not linear (in fact, it is a quadratic function), in that it does not respect neither the additivity principle nor the homogeneity principle. Indeed, we observe that

$$f(x+y) = x^2 + y^2 + 2xy \tag{1.5}$$

while

$$f(x) + f(y) = x^2 + y^2 \tag{1.6}$$

In the same way, we observe that

$$f(\alpha x) = (\alpha x)^2 = \alpha^2 x^2 \tag{1.7}$$

while

$$\alpha f(x) = \alpha x^2 \tag{1.8}$$

In case of failure of the superposition principle (i.e. statement 1 and/or statement 2 above do not hold), the system is said to be non-linear. Scheffer et al. (2001) propose an interesting example from ecology to explain non-linear responses to external stimuli. They note how an ecosystem (in particular, they focus on the eutrophication process of shallow lakes, i.e. the process by which shallow lakes become overly enriched with nutrients, therefore inducing excessive growth of algae) may appear to remain unchanged or only slightly changed up to a certain critical level of human intervention (which they name "stress"), beyond which follows a catastrophic transition to a new state. However, a switch back to the previous state (in the case studied by Scheffer et al. 2001) requires going back much more than the simple restoration of the stress level preceding the collapse. Another good example is desertification. Increasing grazing intensity can incrementally destroy vegetation, but once desertification occurs, it is not enough to reduce (or even remove) grazers in order to stop it and restore the previous level of vegetation.

A language-related example could be the process of acquiring new vocabulary. Indeed, vocabulary learning begins at a very slow rate, which then increases and eventually slows down again (Larsen-Freeman and Cameron, 2008). If we were to plot this pattern on a graph with time on the x-axis and vocabulary size on the y-axis, we would not draw a line but an S-shaped

curve. At the beginning it is reasonable to find it difficult to acquire new words, especially if they are substantially different from the vocabulary of one's native language. One might find it hard to memorize new and possibly unfamiliar sounds and orthography, which make the acquisition process very slow. However, as the process goes on, one becomes more and more familiar with pronunciation and spelling and might even start making connections between words sharing the same root or having the same prefix or suffix. Besides, it is very likely that a person interested in learning vocabulary in a new language is exposed to that same vocabulary in other ways, both actively and passively, for example hearing it at the grocery store, reading it on billboards, and so on. When talking specifically of young children in the process of learning their native language, MacWhinney (1998) factors in growing cognitive capacity as an additional interaction variable. All this clearly accelerates the acquisition process. However, as one reaches a wide vocabulary, the process slows down again and approaches a horizontal asymptote. This can happen for a number of reasons. For example, it becomes less likely that one hears or reads less frequently used words; or, being able to count on a wide vocabulary and sufficient fluency to make oneself understood, one might feel less and less in need of looking up a specific term on the dictionary, eventually missing out on least common synonyms.

Analytically speaking, the previous discussion amounts to saying that vocabulary (computed as the amount of words known) as a function of time (years of learning or age) cannot be fitted in a straight line. Rather, it will resemble a logistic function. Let us assume that we have a variable V indicating the level of vocabulary (i.e. the number of words known by an individual) as a fraction of N (the total amount of words in a language or, alternatively, the individual's *carrying capacity*, i.e. the number of words that one can possibly acquire given one's cognitive limits) acquired over time t. Given our previous considerations on the different stages of acquisition (slow-fast-slow), this model is formalized by the following differential equation:

$$\frac{dV}{dt} = rV\left(1 - \frac{V}{N}\right) \tag{1.9}$$

where the constant r represents the rate of growth.[11] According to Equation 1.9, the variation in the level of vocabulary over time (which can only take on positive or, at least, null values) is initially represented by the first term (rV) and, as V is still small, the overall variation is small as well. This

[11] For the proof of Equations 1.9 through 1.11, see appendix A.

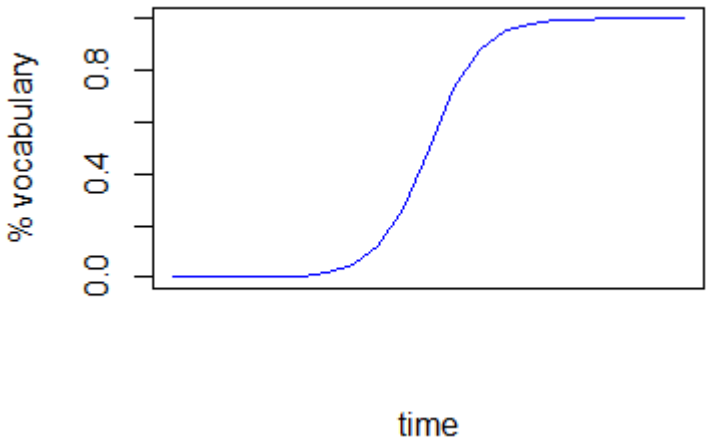


FIGURE (1.2) Acquisition of new vocabulary as a logistic function of time (N = 1).

represents the initial slow part of the process. As V increases, so does the variation. This is the part where the acquisition of vocabulary accelerates. However, this increase starts being compensated by the value of the second term ($-\frac{rV^2}{N}$), whose modulus increases in V (N is constant and greater than V by definition). As a consequence, the value between parentheses tends to 0 as V increases. This reduces the relative impact of rV on the overall variation. In other words, when the vocabulary is large enough, the acquisition process slows down and reaches maturity. The standard formula of the logistic model is:

$$V(t) = \frac{N}{1 + Ae^{-rt}} \tag{1.10}$$

which is graphically depicted as in Figure 1.2. If we set $A = \frac{N-V_0}{V_0}$, we find the general solution to Equation 1.9:

$$V(t) = \frac{NV_0e^{rt}}{N + V_0(e^{rt} - 1)} \tag{1.11}$$

where V_0 is the initial vocabulary endowment.

From Equation 1.10, it is easy to see that

$$\lim_{t\to\infty} V(t) = N \tag{1.12}$$

This means that, as was obvious to guess, the asymptotic term of our vocabulary acquisition function is N, defined as the total number of words in a language or, alternatively (and perhaps more reasonably), the amount of words that one can possibly acquire or memorize at a given moment in time. Indeed, as mentioned above, the value N is the so-called *carrying capacity*, a

term often used in ecology to define the capacity of an environment to sustain a certain number of individuals given its resource endowment.

Before moving on, it is worth spending a few words on the $\frac{V}{N}$ term in Equation 1.9, which is called *intraspecific competition* and makes so that the behaviour of the logistic function switches from exponential-like to logarithmic-like. Indeed, if N is infinite, the growth function is exponential. The understanding of this term is straightforward in ecology: it indicates the competition between individuals of the same species for the resources available in an environment (food, shelter, mating opportunities, etc.), as opposed to competition with other species, which is called *interspecific competition*. Small values of intraspecific competition indicate that there is large room for growth. An increasing population provides, among other things, more mating opportunities, mutual protection, and, as a consequence, greater potential for growth. However, as V approaches N, the environment slowly reaches saturation. Values of V greater than N are not sustainable, and therefore the population will stabilize at N and all excess individuals will die out because of lack of resources. Concerning our discussion on vocabulary acquisition, the intuition is probably easier to grasp if one interprets N as the amount of words that an individual can possibly learn, or, in other words, its cognitive limits in terms of vocabulary acquisition. As long as there is "usable storage space" in one's brain, one can learn new words relatively fast. As grammar knowledge and vocabulary increase, one is able to make connections and create new words which are likely to exist (e.g., provided that one has already acquired a certain amount of grammatical notions in, say, English, once the word "patient" has been learned, one can reasonably assume that also the words "patiently", "impatient" and "impatiently" exist). However, as one's cognitive limits are approached, words start competing with each other to keep their place in one's memory, making it hard to learn new words. One's vocabulary eventually stabilizes at the limit value and extra words will simply slip out of one's mind or, at best, replace least used words. It should be noted, however, that in real life this situation is not an equilibrium. Rather, this point could be seen as a maximum that could be followed by a downward slope. Indeed, the level of vocabulary tends to decrease unless a continuous injection of energy (in this case, constant language practice) is applied, a concept on which I come back later.

One of the first scholars to approach the idea of minor changes implying major consequences was US mathematician and meteorologist Edward Lorenz, whose work was greatly inspired by Poincaré's ideas (Bütz, 1997).

Lorenz, along with a number of other meteorologists of the time, was convinced that weather conditions could be predicted with accuracy by simply inputting enough data in a computer and projecting weather patterns. According to a famous anecdote, Lorenz tried to replicate a simulation that he had performed previously on a different computer using the same initial conditions. To his surprise, the simulation gave wildly different results. When looking into the matter, he realized that he had given a value of 0.506127 to one of the variables during the first simulation, while he had only inputted 0.506 when he tried to replicate the simulation. He then realized that an apparently insignificant change (of about 0.025%) in the initial conditions caused huge differences in the output. It followed that predictions of weather conditions, especially over the long term, were all but impossible. In his renowned 1963 paper, Lorenz developed a mathematical model to describe atmosphere convection (Lorenz, 1963). The model links three variables x, y and z (proportional, respectively, to the intensity of the convective motion, the temperature difference between the ascending and descending currents, and the vertical variation in temperature) to three parameters σ, ρ and β, which capture some physical properties of the fluids under study. Without getting too technical, the system of differential equations proposed by Lorenz looks as follows:

$$\begin{cases} \frac{dx}{dt} = \sigma(y - x) \\ \frac{dy}{dt} = x(\rho - z) - y \\ \frac{dz}{dt} = xy - \beta z \end{cases} \tag{1.13}$$

Lorenz chose values of σ, ρ and β equal to, respectively, 10, 28 and 8/3, and noted that, for these values and values falling in a small neighbourhood around them, the systems has a chaotic behaviour. Figure 1.3 displays the so-called Lorenz attractor, a set of chaotic solutions of the Lorenz equations. The figure shows the evolution of the system in a three-dimensional plot with initial conditions x, y and z all equal to 1.[12] Figure 1.4 displays the solution to system 1.13, that is, the evolution of x, y and z (again with initial values of 1) as a function of t. It is interesting to notice how the dynamic system represented by the Lorenz equations is *locally unstable* yet *globally stable*: once they have entered the sequence, the values of x, y and z can diverge significantly, but they never depart from the attractor.

To see how an apparently insignificant variation of the initial conditions

[12] For more on attractors, see Subsection 1.4.3

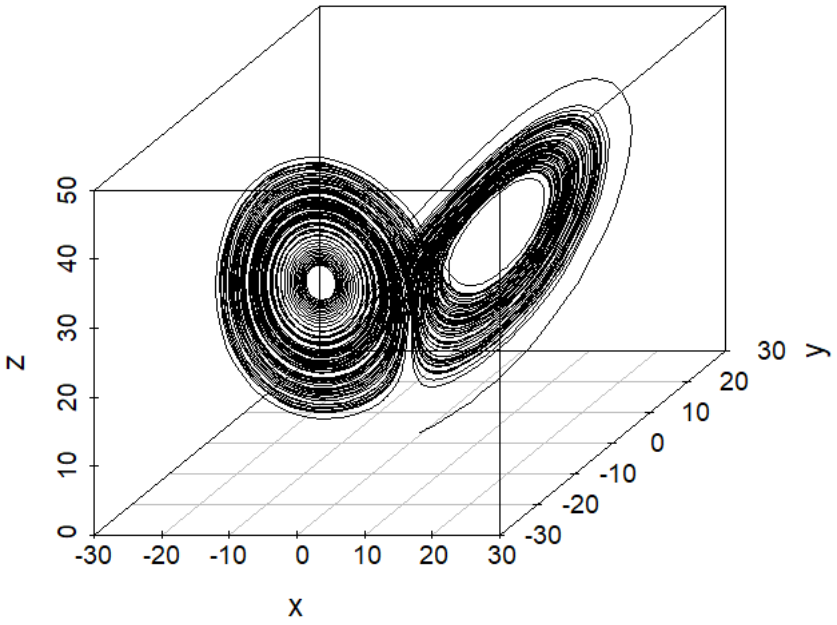


FIGURE (1.3) Lorenz attractor with initial conditions $x, y, z = 1$.

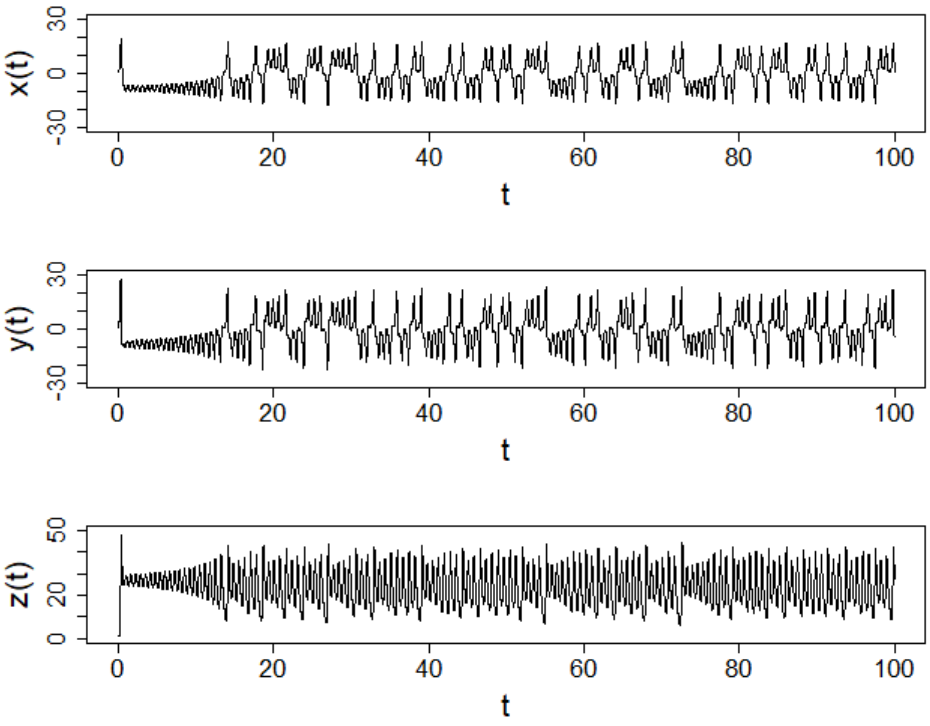


FIGURE (1.4) Evolution of the values of x, y and z as a function of t.

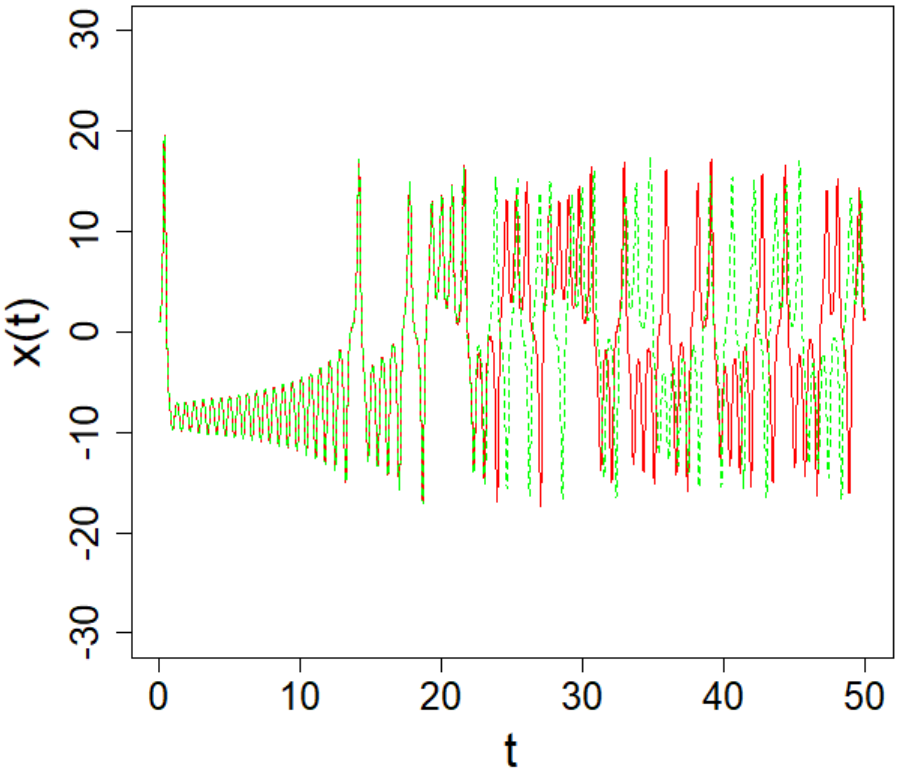


FIGURE (1.5) Evolution of x in the Lorenz equations, with initial conditions $x(0) = 1$ (red, solid) and $x(0) = 1.0001$ (green, dashed).

can dramatically change the results, Figure 1.5 plots the values of the x variable for $x(0) = 1$ and $x(0) = 1.0001$ (the initial values of y and z being the same). We can notice immediately that the two curves overlap for a short while and then take two radically different paths. The effect observed by Lorenz is often referred to as the "butterfly effect" or, in more technical terms, "sensitive dependence on initial conditions". The metaphoric parallel is straightforward: something as apparently insignificant as a butterfly flapping its wings can cause a tornado miles away, pretty much as an apparently negligible change in a variable can affect significantly the behaviour of the whole system.

1.4.2 Non-Gaussian distributions and power laws

Herbert (2006) notes that, within a complex system, events do not follow a normal (Gaussian) distribution. To understand what this means, I shall devote a few paragraphs to explaining what a normal distribution is. The

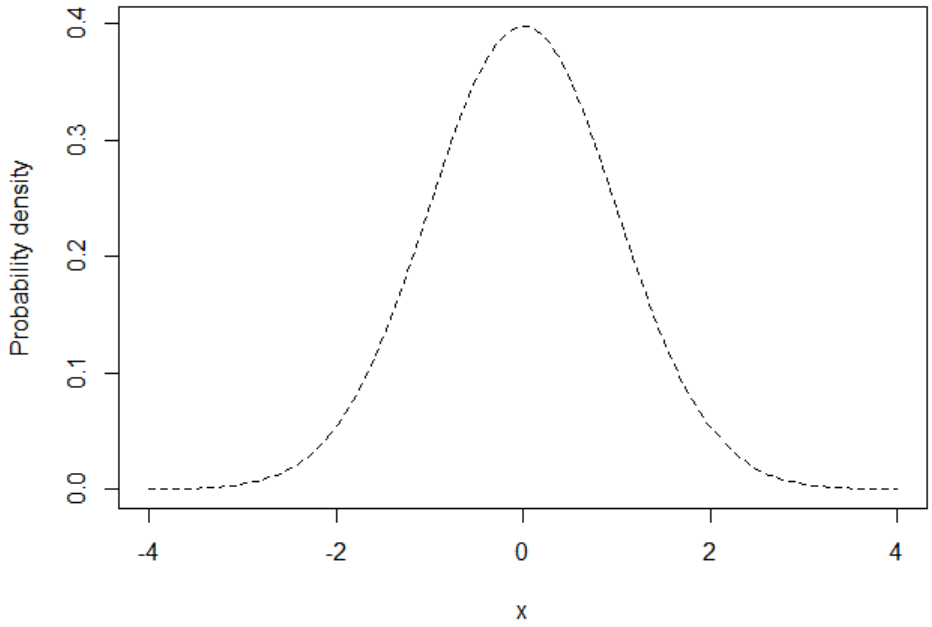


FIGURE (1.6) Density function of the standard normal distribution.

normal distribution has the following probability density function:

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \tag{1.14}$$

where μ is the mean of the distribution (as well as its median and mode), σ is the standard deviation and σ^2 is the variance. Graphically, the normal distribution is bell-shaped, as depicted in Figure 1.6. Among other properties, two of the most salient characteristics of the normal distribution are symmetry around the mean and unimodality (i.e. the fact of having only one mode). Concerning this last property, it should be noted that, strictly speaking, also non-normal distribution having several recurring values but only one that is more recurring are to be considered unimodal. Technically, one should speak of bimodal or multimodal distributions only when there are values that recur "equally often". The normal distribution, however, has only one mode in its largest sense. Indeed, bearing in mind that the mean of a normal distribution is equal to its mode, its first derivative is positive for all values of x lower than the mean, negative for all values of x greater than the mean and null only when x is equal to the mean. Besides, it has two inflection points (where the second derivative is zero and changes sign), located one standard

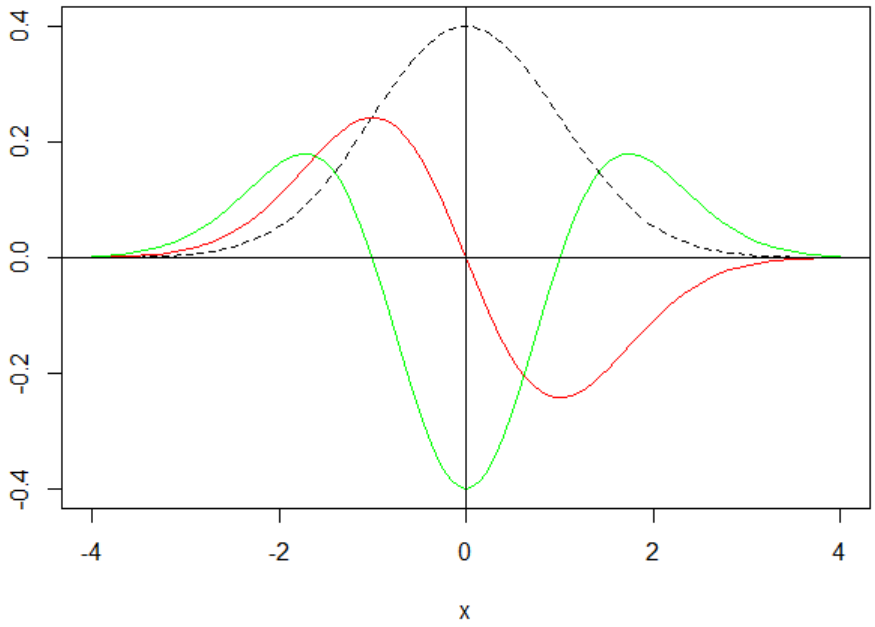


FIGURE (1.7) Density function of the standard normal distribution (dashed), with its first derivative (red) and second derivative (green).

deviation below and above the mean. This is easier understood by looking at Figure 1.7. These characteristics make sure that the likelihood of deviations from the mean declines as we move away from the centre of the distribution and that this decline is the same on both sides. In practical terms, this tells us that we can reasonably neglect deviations from the mean, especially extreme ones. However, a Gaussian distribution does not actually deny the existence of extreme cases, it only assumes that they are extremely unlikely. The peculiarity of the normal distribution (and the reason of its success) is that it can "rule out" the importance of extreme cases thanks to the central limit theorem. This theorem says that, under certain (fairly) common conditions, the sum of independent random variables tends to be normally distributed, even if the original population is not normal. We can easily understand this idea by throwing a die several times and summing up the results. If we throw one die once, results ranging from 1 to 6 are equally likely to occur (or uniformly distributed), with each result having a probability of $1/6$. However, as we increase the number of throws (or of dice thrown at the same time) and sum up the resulting numbers, we will notice that central values are more likely than extreme values. If we throw two dice, the probability of getting numbers

summing up to 7 is three times the combined probabilities of getting numbers summing up to either 2 or 12 (specifically, 1+6, 2+5, 3+4, 4+3, 5+2 and 6+1, versus 1+1 and 6+6). With only one repetition, an originally uniform distribution is now much less uniform. As we increase the number of dice, we eventually approximate a normal distribution, as we can see in Figure 1.8.[13]

In the case of complex phenomena, extreme events occur more frequently than a Gaussian distribution would predict and, most importantly, they carry more weight than one could expect. Besides, if we concentrate on the average of the observed values, we might be missing an important part of the story.[14] In complex phenomena, seemingly unlikely events are not that unlikely and can have dramatic repercussions. In general, one might be tempted to use historical observations to make predictions, assuming the existence of predetermined patterns which will eventually repeat themselves over time, in a cyclical fashion. This is not the case for complex systems, where outliers often have significant consequences. In relation to complex systems, scholars have sometimes spoken of "black swans"[15] to define those occurrences that are believed not to be possible until they actually occur. Besides, it can be argued that these events are the only ones that can seriously affect a system and have a long-term impact (such as sudden shocks in the financial markets).

I shall devote a few words to clarifying the difference between non-linearity and non-Gaussianity, as they can be easily mistaken. Both ideas focus on the fact that apparently minor issues can have important consequences. However, non-linearity is about the magnitude of the impact of small events, regardless of their likelihood or frequency. Non-Gaussianity, conversely, only reminds us that, in complex systems, one cannot rule out extreme events, if only because they are often the ones that imply the most significant impacts. As I discuss later, many complex social and physical phenomena do not follow the assumptions of Gaussianity. Probability in complex systems often

[13] Cmglee CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0), via Wikimedia Commons: https://commons.wikimedia.org/wiki/File:Dice_sum_central_limit_theorem.svg.

[14] This idea can also be explained by a simple but quite telling joke. I shall leave to the reader any further considerations. The joke goes like this: "A physicist, a mathematician and an econometricians go out hunting, and come across a large deer. The physicist fires, but misses, by 50 centimetres to the left. The mathematician fires, but also misses, by 50 centimetres to the right. The econometrician doesn't fire and shouts triumphant: 'We got it!'"

[15] The expression "black swan" is attributable to the Latin poet Juvenal, who wrote: "Rara avis in terris nigroque simillima cygno" ("A rare bird on Earth, very much like a black swan", my translation). Being common in Southwestern and Eastern Australia, black swans were presumed not to exist by the Latin scholars who coined the phrase. For more on the idea of black swans, see Taleb (2007).

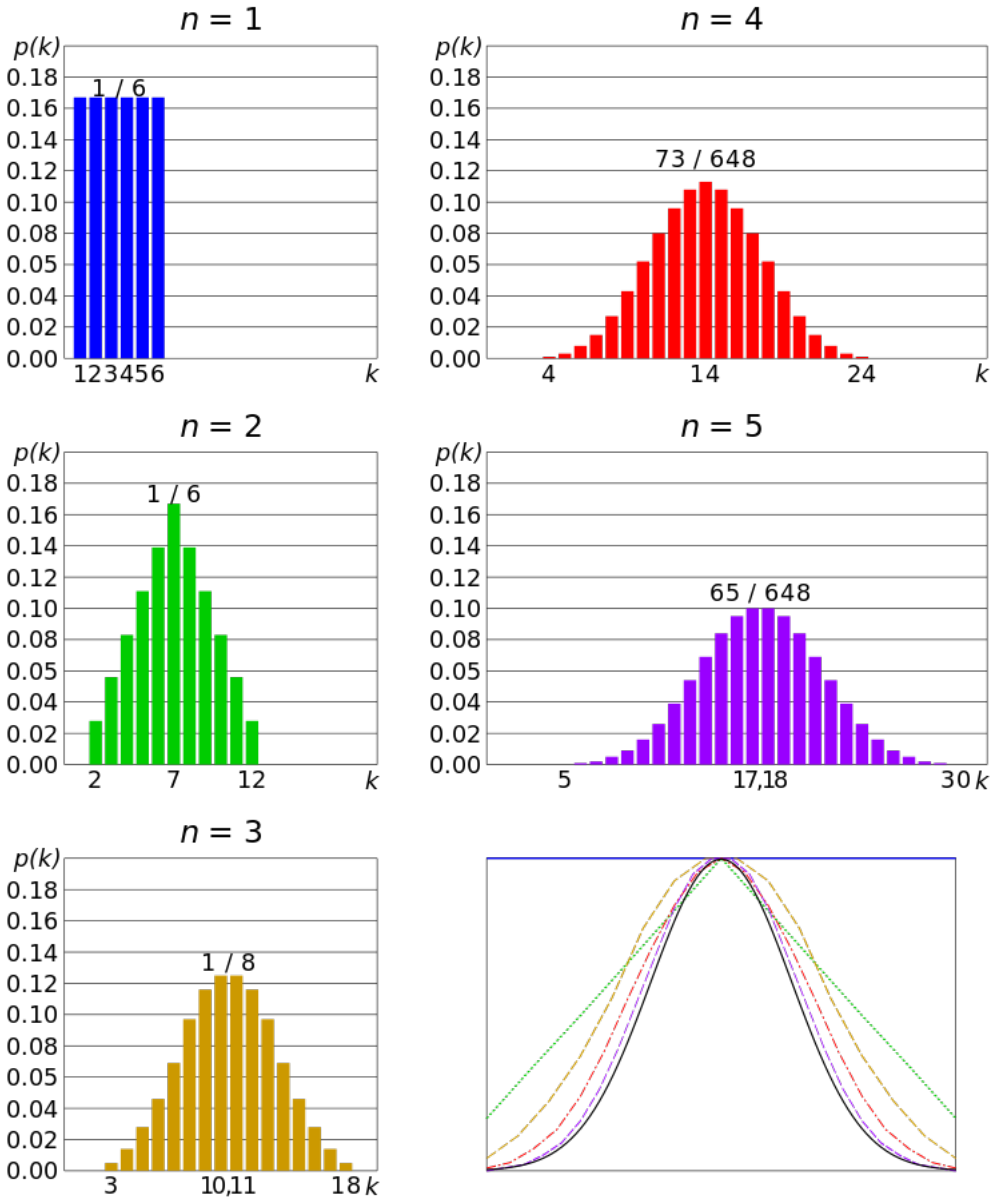


FIGURE (1.8) Comparison of probability density functions, $p(k)$ for the sum of n fair 6-sided dice to show their convergence to a normal distribution with increasing n, in accordance to the central limit theorem.

follows *power law distributions* rather than Gaussian distributions. It has been shown that power laws occur in several instances in both natural and social phenomena. Newman (2005) notes that power laws are impressively ubiquitous and mentions several phenomena that display power laws, such as city populations, the magnitude of earthquakes, the intensity of solar flares, number of battle deaths in wars, the frequency of use of words in human languages, the number of times papers are cited, the number of hits on web pages, the numbers of species in biological taxa, people's annual incomes. A power law is described by the following function:

$$f(x) \propto ax^{-k} \tag{1.15}$$

where the symbol $\propto$ denotes direct proportionality. This formula simply states that the value of $f(x)$ is proportional to x by a factor a and an exponent k.[16] In other words, one value varies as a power of the other. For example, the volume of a cube varies as the third power of (or scales cubically with) the variation of the length of its side (e.g. if we double the length of the side, the volume will increase eight times). The property of power laws that makes them so interesting is the so-called *scale-invariance*. Generally speaking, something that is scale-invariant does not change when scales of different variables are multiplied by the same factor. In other words, it keeps its properties (or, more specifically, it is self-similar) at all levels of zooming. Graphically, it is easy to notice the scale-invariant property of power laws by simply noting that, given a power law, we can take the logarithm of both sides and obtain the equation of a line on a log-log plot:

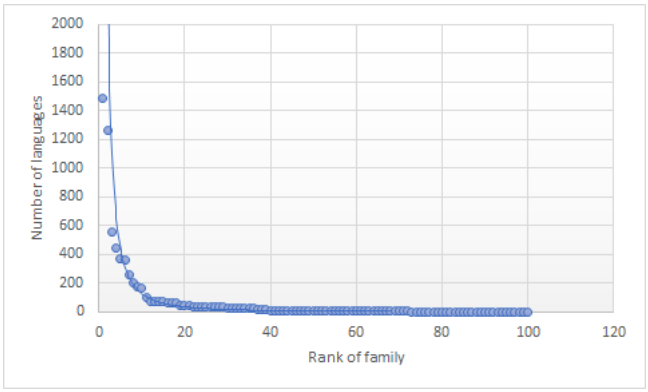
$$y = ax^{-k} \tag{1.16}$$

$$\log(y) = \log(ax^{-k}) \tag{1.17}$$

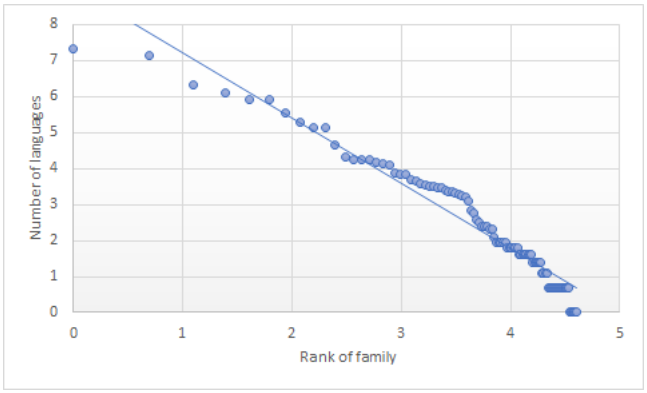
$$\log(y) = \log(a) - k\log(x) \tag{1.18}$$

Therefore, a power law with exponent $-k$ can also be represented as a line with slope $-k$ on a log-log plot. This means that, at any level of zooming on the function, the relationship between successive elements in the power-law distributions is unchanged. Let us look at a practical example. Figure 1.9 reports a plot of language families in decreasing order of number of languages belonging to each family, and the same rank-frequency plot on a log-log scale

[16] The minus sign of the exponent is not compulsory, but convenient given the negative slope of the functions that we are going to study.



(A) Language family sizes.



(B) Language family sizes (log-log plot).

FIGURE (1.9) Language family sizes display a power-law type of relation.

to show linearity[17] (Wichmann, 2005) (not to be confused with our previous discussion on non-linearity of complex systems).

Interestingly, one of the first who observed the properties of power laws in rank-frequency relations was American linguist and philologist George Zipf.[18] He was one of the pioneer of the field of quantitative linguistics and contributed significantly to other disciplines with his findings. In his renowned book "Selected Studies of the Principle of Relative Frequency in Language", Zipf (1932) explains that the frequencies of words in the corpus of a text in any natural language, when ranked in decreasing order, display

[17] Although it is not technically accurate to speak of "rank-frequency" plot in this case as the quantities that we are measuring are not frequencies but the number of languages, it is customary to speak of "rank-frequency" plots also for such cases. The plots were produced by simply sorting families in decreasing order of number of languages in them, ranking them starting from the first (i.e. the largest family), and finally plotting the latter as a function of the former. For the log-log plot, the natural logarithm of the two variables was used.

[18] Before Zipf, Italian economist Vilfredo Pareto had observed power laws in an attempt to describe wealth distributions in nineteenth century Italy. Indeed, power-law distributions are also known by the names of "Pareto distributions" or "Zipf distribution", depending on how variables are displayed on the axes (for more on this, see http://www.hpl.hp.com/research/idl/papers/ranking/ranking.html).

an inverse power relation with their rank.[19] He observed that the n^{th} word recurs roughly $\frac{1}{n}$ times as often as the most frequent word (Manaris et al., 2006). This idea is captured by the following formula:

$$f(n) \propto \frac{1}{n^a} \tag{1.19}$$

This formula states that the probability of the word of rank n appearing in a text (or the frequency with which it recurs in a natural corpus) is proportional to its rank raised to a certain exponent $a \approx 1$. In other words, if we order words in decreasing order of frequency in a text, we will observe that the most frequent word ($n = 1$) has a frequency proportional to 1, the second most frequent word ($n = 2$) has frequency proportional to $\frac{1}{2^a}$, the third ($n = 3$) has frequency proportional to $\frac{1}{3^a}$, and so on. Mandelbrot (1953) later proposed a reviewed version of Zipf's law:

$$f(n) \propto \frac{1}{(n+\beta)^a} \tag{1.20}$$

where β is a factor that "shifts" the rank in order to better fit empirically observed frequencies. Piantadosi (2014) notes that the simple fact that words vary in frequency is a non-trivial property of language. Besides, it is unclear why this frequency distribution is relatively well approximated by such a simple mathematical relation, especially if we note that this law in no ways accounts for intrinsic aspects of languages, such as the meaning of words and syntax rules. Piantadosi (2014) goes as far as to say that it is "unreasonable" that the intricacies characterizing language processes end up generating word frequency distributions that follow such simple statistical laws. Most of the research work on this topic focused on increasingly more precise derivations of the law; this does not say much about the underlying cognitive processes leading to such a law. Numerous explanations for this relation have been proposed, but there is still much debate about whether any of these attempted explanations is on the right track.

1.4.3 Fixed points and attractors

Another recurrent key property of complex dynamics is the presence of "attractors". Informally speaking, attractors can be defined as values towards

[19] Interestingly, it was found that Zipf's law also holds for constructed languages, such as Esperanto (Manaris et al., 2006), and yet undechiphered languages, such as Meroitic (Smith, 2007).

which a system tends to go. Mathematically, an attractor is an n-dimensional vector in an n-dimensional space made up of the values towards which the n variables in the systems tend. For example, within a linguistic community, this vector could be made up of two variables, i.e. the number of speakers of a certain language and the average level of fluency. If there exist values to which these two variables tend simultaneously, the resulting two-dimensional vector is an attractor.

Intuitively, attractors can be thought of as statuses of a system in which it is in equilibrium. Moving away from these points requires an injection of energy into the system. One can think of a ball rolling along a wavy surface. As long as the ball keeps enough momentum, it will be able to enter and exit the "pits". However, as energy dissipates as a consequence of friction, it will eventually find a hill that it won't be able to climb and it will stop inside one of the pits. In particular, the immediate surroundings of an attractor are often referred to as "basins of attraction", which can be thought of as a neighborhood of an attractor whose conditions will eventually lead to (or, more technically, be iterated into) the attractor. Going back to the ball-and-pits example, the surroundings of the bottom of a pit are its basin of attraction, in that, if the ball finds itself in that position and does not have enough energy to escape, it will roll back and forth and eventually stop at the bottom. Strictly related to the notion of attractor are also those of *repeller* and *saddle point*. A repeller is the exact opposite of an attractor. It is also a fixed point, but a very unstable one, from which the system is pushed away with even a slight amount of energy (as opposed to moving away from an attractor, which requires a great amount of energy). One can think of the peaks between the pits from the previous example. If the ball is perfectly placed at the top of the peak, it will not move. However, as soon as the slightest stimulus is applied to the ball (say, a slight gust of wind), it will move away from that point. A saddle point is a hybrid between an attractor and a repeller, in that it is stable in one dimension, but unstable in another. As the name suggests, one can think of a ball rolling on a saddle. The ball will run towards the middle of saddle on one axis, but away from it on its orthogonal axis.[20] The behaviour of the ball with respect to a plane made of attractors, repellers and saddle points is easily explained by Figure 1.10 which represents the topology of the different states of the ball. The arrows indicate the

[20]Those familiar with optimal control might associate the notion of saddle point to a specific type of multivariate optimization, in which the problem consists in locating a point where one dimension is maximized and the other one is minimized, such as the point where production is maximized and its relative cost is minimized.

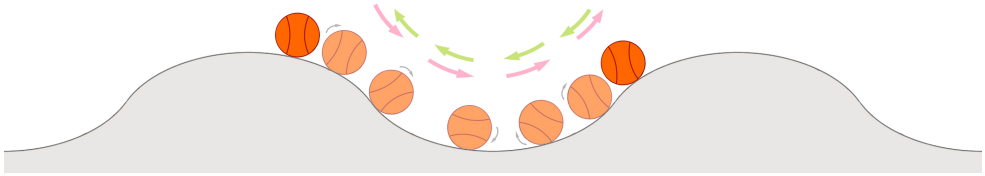


FIGURE (1.10) Ball rolling on a wavy surface.

directions in which the ball will run depending on its current state.

We can distinguish among several types of attractors. The most recurring types are fixed points, limit cycles and chaotic attractors. We speak of a *fixed point* attractor when there exists a single point towards which the system tends in the long run regardless of the initial conditions (such as the bottom of the pit in the previous example, or the central position of a pendulum that swings in the presence of friction). If a system oscillates periodically between several attractors, or, in other words, when the attractor is represented by a loop to which the system tends, we speak of a *limit cycle* (such as a planet orbiting around a star). Finally, when a system is very sensitive to initial conditions and its behaviour is very unstable and hard to predict, we speak of *chaotic* attractors. It should be noted that chaotic does not mean random. In the case of chaotic attractors, the system is still dependent on initial conditions and therefore has a pattern. However, the system is so highly dependent on initial conditions that every infinitesimal perturbation can affect dramatically its development, making it very hard or simply impossible to predict.

While social systems in reality do not tend towards chaotic attractors, they sometimes find themselves in a position called the *edge of chaos*, which displays traits of chaos. Larsen-Freeman and Cameron (2008) provide a very interesting example of a chaotic situation in a speech community. One can think of a speech community made up of adolescents that communicate in English and play with the language as a chaotic system. Vocabulary and grammar are treated with increased flexibility and are susceptible to variation at every exchange, new words and abbreviations are constantly added. Besides, this new language spreads quickly (or, to use another complexity theory term, non-linearly) through several IT devices. Nevertheless, this situation is only on the *edge* of chaos, in that an individual from that community will quickly revert to a more stable area of its language state space as soon as she has to communicate with someone from outside the community or in a formal context where a prescribed way of speaking is expected.

To explain further the idea of attractor, I resort once again to the logistic

function introduced above. More precisely, I refer to the *logistic map*, which is the discrete counterpart of the continuous logistic function. The logistic map is a polynomial map of order 2 and is often used as an example of chaotic behaviour generated by a simple non-linear dynamic equation. The equation of the logistic map is:

$$n_{t+1} = rn_t(1 - n_t) \tag{1.21}$$

where n is the ratio between the current population and the maximum population (what was previously referred to as carrying capacity), t is an index of the iterations, and r is a parameter that captures the combined impact of natality (birth) and mortality within the population. It is easy to check using a simple calculator that the behaviour of this system is highly dependent on the rate r. If the value of r is between 0 and 1, the population dies quickly. For values between 1 and 2, the value of n quickly approaches the value $\frac{r-1}{r}$. The same happens for values of r between 2 and 3, although the attractor is reached by fluctuating around it for a variable number of iterations. For values greater than 3, n will not stabilize at one value. Rather, it will oscillates around two or more attractors, creating a limit cycle. The number of attractors redoubles as r increases. In this case, it is said that the system displays periodic behaviour, with a period equal to the number of attractors. For values of r greater than approximately 3.57, the system displays chaotic behaviour. For values greater than 4, almost all initial values will eventually diverge beyond the [0,1] interval. This trend is graphically captured by the so-called bifurcation diagram (Figure 1.11). On the x-axis there are the values of r, while on the y-axis there are the values of the attractor. At each bifurcation we can see a redoubling of the number of attractors. The ratio of the length of successive intervals between bifurcation points tends to the Feigenbaum constant, $\delta \approx 4.6692$.

To explore further the relationship between the variable r and the behaviour of the logistic map, we can resort to the so-called cobweb diagram, or Verhulst diagram, depicted in Figure 1.12. The four plots depict the logistic map for different values of r. The parabola (which describes Equation 1.21) is plotted together with a 45° straight line, which represents all those points where $f(n) = n$. Clearly, the points where the parabola and the line cross are fixed points (i.e., points where $n_{t+1} = n_t$). To study the behaviour of the logistic function given a certain starting point n_0, one simply needs to locate the point n_0. As explained above, we can observe different patterns depending on the value of r (n_0 being equal to 0.2 in all panels). Panels A and B display trends for values of r equal to 0.8 and 1.8, respectively. The population

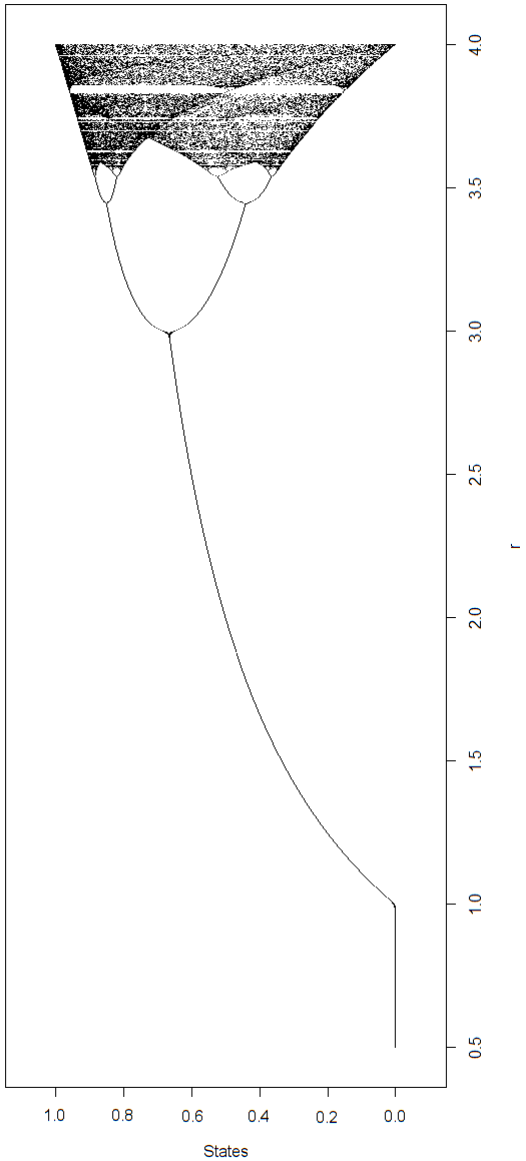
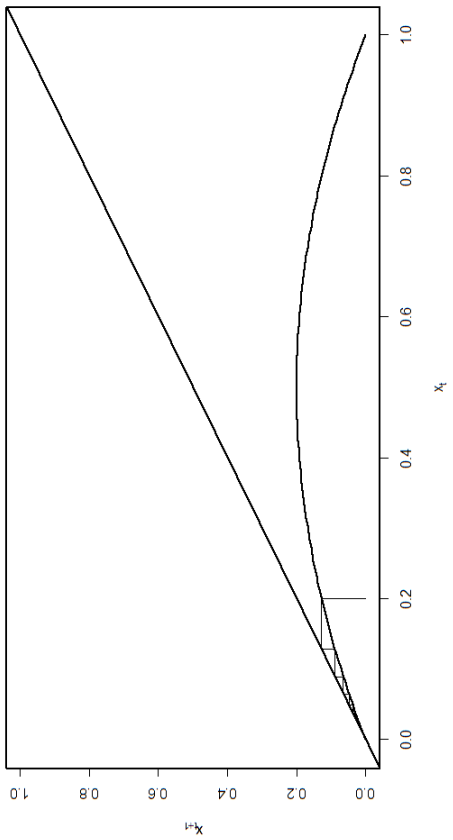
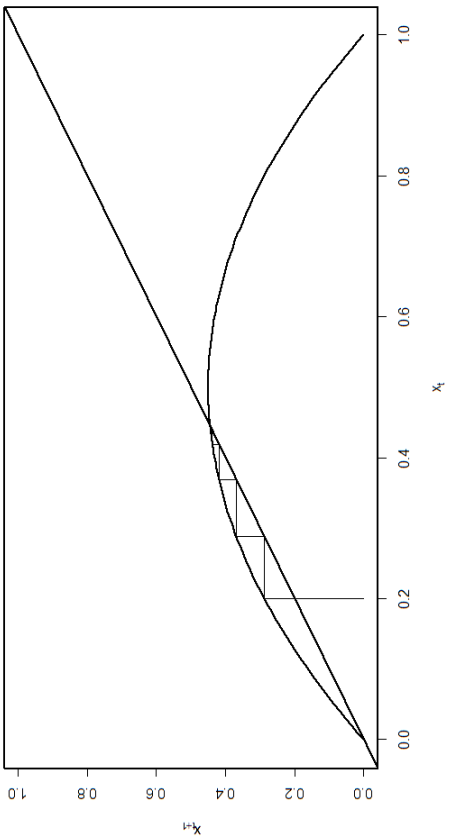


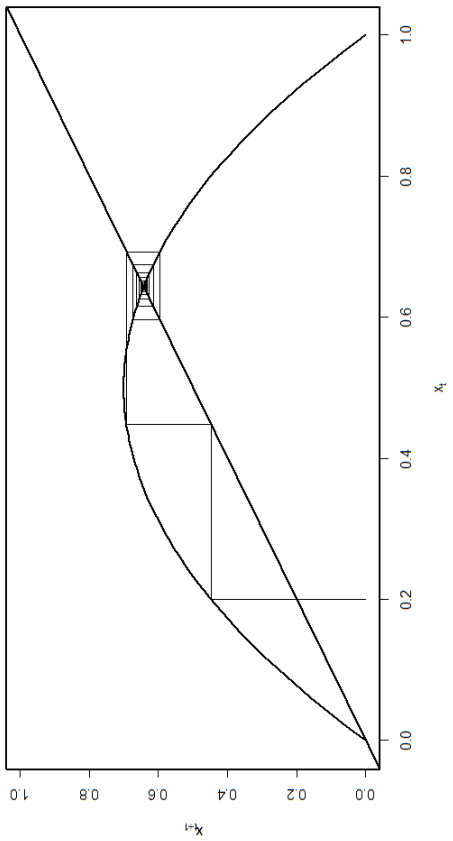
FIGURE (1.11) Bifurcation diagram of the logistic map.



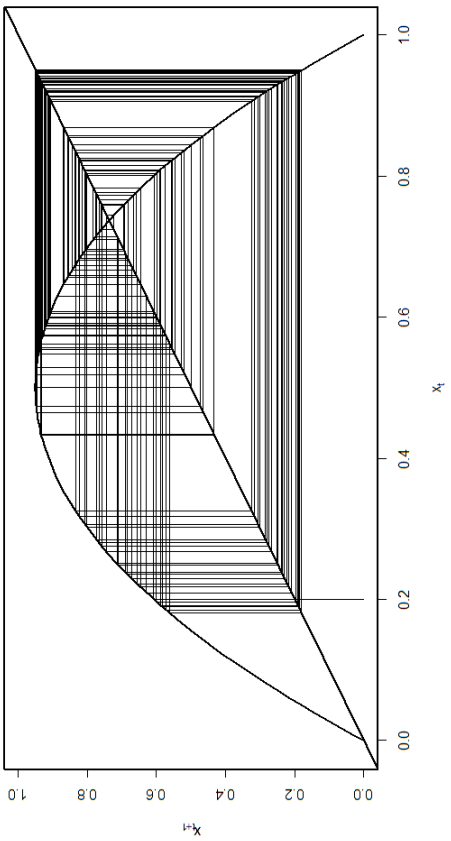
(A) $n_0 = 0.2$ and $r = 0.8$.



(B) $n_0 = 0.2$ and $r = 1.8$.



(C) $n_0 = 0.2$ and $r = 2.8$.



(D) $n_0 = 0.2$ and $r = 3.8$.

FIGURE (1.12) Cobweb plots with $n_0 = 0.2$ and various values for r.

dies out (A) or stabilizes at some specific value (B) within a few iterations. In panel C, which displays the trend for $r = 2.8$, the population stabilizes at a specific value, but it gets there in a very different way with respect to B, i.e. by oscillating around it for numerous iterations. In cases A, B and C, the fact that the population stabilizes is showed by the fact that the it converges to a value were the parabola crosses the 45° line, that is, where $n_{t+1} = n_t$. This is not the case for the trend depicted in panel D, where $r = 3.8$. The population never reaches a stable point. Rather, it keeps jumping across different values, displaying chaotic behaviour.

1.4.4 Feedback loops

The presence of feedback mechanisms is a necessary condition for a system to be complex. A feedback loop is defined as a loop in which the output of a system turns itself into an input for that same system. A very intuitive example is that of heating systems. The system generates heat and the temperature rises. This higher temperature is "fed back" to the system which interprets it as a signal to stop generating heat when the temperature reaches a certain threshold (normally set by the user). Feedback loops are of two types: *negative*, in which the effect of the input is reduced (as in the example of the heating system), or *positive*, in which the input effect is amplified (as, for example, in the case of lactation, where consumption by the new-born stimulates the organism of the mother to further produce milk). Those familiar with economics (especially financial economics) can think of a selling panic in the investment market as an example of feedback mechanism, or to expectations leading to a boost of the financial markets that, in turn, has a positive impact on expectations. It should be noted that the words "negative" and "positive" are not meant to indicate, respectively, "worse/lower" or "better/higher", as common sense might suggest, but only whether the direction of the output is opposed to that of the input or not. In the case of the heating system, we would still speak of a negative feedback if we considered the case of a lower threshold being surpassed indicating that the temperature should be increased.

1.4.5 Spontaneous order and lack of central control

One might be tempted to believe that complex systems should not display any sort of order or self-organizing dynamics. However, it should be noted that pure randomness and total order would equally imply no complexity at

all (Ladyman, Lambert, and Wiesner, 2013). If we were to plot order against complexity on two axes, the resulting function would approximately resemble a concave parabola (that is, opening downwards). Complex systems are characterized by internal patterns which arise naturally as a response to external inputs. However, these patterns are not defined at a central level. This order, being distributed rather than centralized, is said to be robust, in that it is not vulnerable to the malfunctioning of some key elements (Ladyman, Lambert, and Wiesner, 2013). This, however, is a necessary yet non-sufficient condition for complexity as also non-complex systems may have no form of central control.

It should also be noted that complex systems are located in what some scholars name "the edge of chaos" (Langton, 1990), which is the subtle zone between complete randomness and perfectly structured order.[21] Therefore, neither total lack of order nor its opposite could define a complex system.

1.4.6 Emergence and hierarchical organisation

Emergence is probably one of the (if not the single) most important characteristic displayed by complex systems and would probably deserve a whole discussion to itself. Here, however, I only offer a general introduction.

A system is characterized by emergence if it exhibits novel properties that cannot be traced back to its components (Homer-Dixon, 2010). Some scholars call these properties "emergent properties" (Bunge, 2003; Elder-Vass, 2008). The adjective "emergent" refers to the fact that such properties are not present at the individual level, but only "emerge" as we move on to consider higher levels of aggregation. To understand this idea one could think of utterances as sets of words. Words have their own properties (such as meaning and syntactic function) and, put together, they can form sentences. However, a sentence is more than the simple sum (or succession) of the words that it contains. It has its own meaning that emerges only when its components are put together and is also dependent on extra-verbal contextual elements.[22] For a quick (and very unsophisticated) example, think of the profound difference

[21] Some have noted that the "edge of chaos" areas abound in the natural world, such as the transition area at $0°C$ between ice and water. These situations are constantly falling away from equilibrium and require continuous injections of energy to remain stable (Prigogine and Stengers, 1984).

[22] Note that a language is a complex system in that it is also located in the "edge of chaos" previously mentioned. Words have to respect precise patterns of expression, which are provided by the grammar and are generally shared and understood by all speakers. Nevertheless, they are at the very same time subject to arbitrary use by the speakers.

between the words "yeah" and "right" and the utterance "yeah, right" (especially if accompanied by a sarcastic intonation).

A good example from the natural sciences is the saltiness of sodium chloride (i.e. table salt), which is not attributable neither to chloride nor to sodium individually. Saltiness *emerges* as a consequence of a (1 to 1) combination of the two elements. Elder-Vass (2008) goes on to stress that an emergent property is not only one that is not possessed by any of the parts individually, but also one that would not be possessed by the compounded entity if there were no structuring set of relations between the individual parts (and it is therefore not due to the mere co-presence of these elements). This reasoning echoes what Nobel laureate Herbert Simon argued much earlier:

> "Roughly, by a complex system I mean one made up of a large number of parts that interact in a non-simple way. In such systems, the whole is more than the sum of the parts, not in an ultimate, metaphysical sense, but in the important pragmatic sense that, given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole." (Simon, 1962, p. 468)

One could conclude that all other characteristics of complex systems are indeed emergent properties. As a matter of fact, that is far from being incorrect. Spontaneous order and self-organisation, discussed in the previous subsections, are indeed emergent properties. They emerge only as a consequence of the existing interactions between parts and they are not inherent to any of them. Talking specifically about spontaneous order, Hayek defined it as "orderly structures which are the product of the action of many men but are not the result of human design" (Hayek, 2013, p. 36). Market dynamics leading to equilibria (in the absence of a central coordinating body) are quite an eloquent example of emergent (orderly) behaviour (Petsoulas, 2001).

Discussing emergence, one should also mention the hierarchical organisation of different levels of observation. When we adopt a "micro" perspective, we are focusing on the individuals, on the rules that direct their behaviour, and on the efficiency, efficacy, and socio-psychological rationale underlying the origination and adoption of these rules. Conversely, when we switch to a "meso" perspective, we move away from such a detailed vision and focus on "meso units", which can be defined as a population of actualizations (Dopfer,

Foster, and Potts, 2004).[23] In other words, we are looking in a unitary way at a collection (or population) of elements sharing a similar characteristic (such as belonging to a determined category) or behaviour (e.g. having a specific preference). To put it in algebraic terms, we could say that a meso-unit is equal to:

$$ME_j = \sum_{i=1}^{n} MI_i \tag{1.22}$$

where ME is a meso-unit, MI is a micro-unit. This means that a meso-unit is the sum of n micro-units. Therefore, in this specific case, we would have a meso-unit j made up of n observations i sharing a similar characteristic (or behavioural rule). We can also say that there exist as many meso-units as there are rules. Summing up over meso-units we obtain a macro-unit:

$$MA_z = \sum_{j=1}^{m} ME_j = \sum_{j=1}^{m} \sum_{i=1}^{n} MI_{ij} \tag{1.23}$$

The relationship linking the macro and the meso level is of the same kind as the one linking the meso to the micro-level. If we put together a number of meso-units sharing a characteristic, we could say, of higher order (in other words, a characteristic that is the same for everyone, even though they are different as we reduce the scale), we obtain a macro-rule. It should be noted that this algebraic representation describes only the number of elements, and not their characteristics.[24] Therefore it should not be confused with another statement that I made elsewhere, i.e. that a higher-order complex system is not just the sum of its elements. This latter statement clearly refers to the novel characteristics that the elements display when added up together.

To take a simple example, we could think of individuals as micro-units, the sum of individuals attending the same educational institution as a meso-unit, and the sum of the schools in the same level of education as a macro-unit. It is obvious that there is no strict positioning of the micro, meso, and macro-levels. Reconsidering the same example, we could switch the school

[23] The authors use the term "actualization" to refer to various ideas. In our case, the term can be described as the sum of "carriers of a rule", where a carrier is an agent whose behaviour follows some specific rule. The aggregation of these carriers, that is, of the multiple realizations of a specific behavioural rule, is then seen as the actualization of such rule.

[24] In this regard, we should note that *numerosity* of elements has also been mentioned as a basic characteristics of complex systems (Anderson, 1972), in that complex dynamics can only arise from the interaction between more than a bunch of individual elements. Besides, this is a major difference with respect to *chaotic systems*, which can have very few interacting sub-units, whose interactions, though, are such that they produce very intricate dynamics highly dependent on initial conditions (Rickles, Hawe, and Shiell, 2007).

to the macro-level and make all students belonging to the same class a new meso-unit. What I would like to stress here is not that there exist three levels of observation that always correspond to the same kind of entities, but rather that there are levels of observation that fall along the micro-macro continuum, which I call meso-levels. This is always true, in that even an individual can be seen as a macro-unit made up of atomic and sub-atomic particles, being, respectively, the meso and the micro-level. When we move to a higher perspective we are able to concentrate on the dynamics concerning aggregations of elements rather than the details characterizing individuals. Pool (1991a, p. 7) notes that some detail tends to disappear while other characteristics of the issue at hand appear or become much more evident as we move from a micro perspective to a more macro scale. Alternatively, from the opposite perspective, some crucial detail risks being overlooked when we are at a macro-level but becomes evident once we switch to a micro perspective. However, we should also understand that meso and macro-level dynamics can be embodied in individuals that we could be tempted to consider micro-level actors (this idea will be clarified in a moment). Besides, one may be tricked into believing that the determinants of interest (and, therefore, of optimal behaviours) are the same at all scales, basically replicating their structure as we move up and down the scale levels (in the same way as fractals have a recursive self-replicating structure). What distinguishes higher-order units (i.e. the macro from the meso and the meso from the micro) is the fact that, as often stressed throughout these pages, they are not just the sum of their constituent parts. Therefore, complex systems are not fragmentable, in that a decomposition into smaller parts would inevitably amount to a loss of properties (particularly, those appearing only at the highest levels of aggregation).

1.4.7 A definition of complexity

After this in-depth examination of the various characteristics of complexity, I can now propose a definition of complex system, which is largely based on the one provided by Mitchell (2009) and takes into consideration all the aspects discussed above: "A complex system is a system in which large networks of components with no central control give rise to (i) non-trivial emergent behaviour at different levels of aggregation, (ii) sophisticated information processing, (iii) non-linear and/or unexpected effects, (iv) processes of self-regulation, and (v) adaptation via learning and evolution".

1.5 How does complexity arise in socio-economic systems?

In this section I look at real-life manifestations of complexity in social systems. As often mentioned in the previous pages, reality is rich in examples of complexity in all sorts of domains, ranging from the physical laws governing the natural world to the social conventions governing interactions between humans. Concerning social systems, it is easy to see that they are made up of heterogeneous elements, whose conditions are highly dependent on the conditions of others. Therefore, they can be seen as complex environments, where interactions can bring about global dynamics that are more than the sum of individual behaviours.

So far I have considered examples from different spheres. Henceforth I limit the discussion to cases which might be of interest to the social sciences to see why and how complexity came to be considered by policy makers. I briefly discuss how complexity arises in business contexts and then I move on to consider the case of the public sphere in greater detail. In general, I pay greater attention to language-related cases.

1.5.1 Complexity in business and management

The issue of complexity has largely been explored by scholars in business and management since the early 1990s, especially from an organizational behaviour perspective (see, for example, Simon 1962; Stacey 1996; Levinthal 1997; Anderson 1999; Kelly and Allison 1999; McKelvey 1999; Chiles, Meyer, and Hench 2004; Gruhn and Laue 2006; Gharajedaghi 2011; Straub 2013). Complexity theory is of particular interest for strategy choices in large corporations characterized by interconnected structures. However, some authors noted that complexity theory is still struggling to become a fully accepted approach to business management. Straub (2013) suggests that this is in part due to the reluctance of managers to accept a complexity approach in that it would inevitably make their job dramatically harder.

Traditionally, corporate strategy has been treated as a centralized activity, under the responsibility of corporate executives who are often supposed to be in possession of all critical information and to have the right incentives to make decisions for the good of the company as a whole (Eisenhardt and Piezunka, 2011). Besides, many large companies have a business-unit (BU) structure, whereby BU-executives have information limited to their own BU

and make choices accordingly (Hill, Hitt, and Hoskisson, 1992). This definition reflects an approach to business management as a complicated issue, as opposed to a complex one, whereby an optimal strategy of local units is expected to lead to optimality for the company as a whole. Concerning complex strategies in multinational corporations, Eisenhardt and Piezunka (2011) (quoting Chandler 1962) propose the telling example of the large chemical company DuPont, which turned from a single-business firm into a large multinational company operating in several markets in the post-War period. Initially, the company retained its strongly centralized organisation, which led to poor performance. As a reaction, executives restructured the company into several loosely-linked units, which resulted in a significant performance boost. As another example, they also mention the case of General Motors, which was initially a group of several independent producers. Only when the company started organising these units in such a way as to create links among them did the company reach high levels of performance.

Multinational companies (or, better, companies dealing with people from different cultural backgrounds, which are not necessarily multinational)[25] often find themselves in the situation of having to decide on language issues for internal and external purposes. As is discussed more at length in Chapter 2, a constantly recurring issue is the trade-off between prioritizing the use of a single language and continuously adapting to the local context, especially when managing the aftermath of a merger or acquisition. On the one side, unrestricted multilingualism can cause severe inefficiencies. On the other side, though a common language could boost cross-border collaboration, it can come at a very high price, such as, shadowing talented workers who are not proficient in it. Besides, it can (quite paradoxically) generate misunderstandings due to non-proficient use. Neeley and Kaplan (2014) mention the detrimental promotion of a Japanese worker in a US company's Japanese subsidiary exclusively based on his fluency in English. Only later did it appear clear that he was not the best performer and most deserving employee, and that his promotion, based on a severely biased view, had generated discontent among his peers. Besides, a common language does not amount to a common culture and definitely not to a common set of values and underlying assumptions when it comes to handling interpersonal relationships. Researchers call "cultural clash" the phenomenon of disruptive tension experienced by individuals when they have to interact in a second language and

[25] This is the case of many national companies working in multilingual countries, though the "one-nation-one-state-one-language" ideology is still somewhat resistant.

adopt the ways of another culture (Berry, 1983). Many scholars found that intercultural interactions are very likely to generate misunderstandings, in that individuals are used to (sometimes radically) different social customs and rules (Calori, Lubatkin, and Very, 1994; Weber, Shenkar, and Raveh, 1996; Vaara, 2000).

Besides, language issues develop in different ways at different levels. In fact, micro-linguistic behaviours can differ significantly from those at the macro level. Even if we conceived language choices and behaviours simply as the strategy that guarantees optimality of communication overall, it is easy to see that accommodating one's own individual needs is very different from meeting the need of a large (and possibly linguistically and culturally diverse) community. Besides, discussing the scale of complex phenomena, some authors found it suitable to mention also a meso-level (as defined in the previous pages), recognizing that the micro-macro dichotomy is better described as a continuum rather than two separate points (see, for example, Kaplan and Baldauf 1997).

1.5.2 Complexity in public policy

Most policy decisions more and more frequently concern complex systems. Their effects spread all over the system concerned through multiple actions and reactions (Bankes, 2011). For example, environmental policies are never strictly environmental, in that they are introduced in a system that has several other characteristics (political, cultural, demographic, economic...). This is a rising trend. Government officials and policy makers deal with very diverse systems involving a large number of interacting parts (OECD, 2009). Therefore, complexity science constitutes a valuable approach to policy making and policy evaluation, especially once we recognize that the questions the policy is trying to answer as well as their effects are better described in probabilistic rather than deterministic terms, in order to provide room for randomness. Nevertheless, the fact that the object of interest is complex does not amount to saying that a complex approach is being applied. As a matter of fact, complexity theory is only seldom applied to policy making. Indeed, evidence-based policy making often assumes linearity and stability (Room, 2011) or, in the words of Friedman (2005), a flat world, in which globalisation processes have contributed to the homogenization of behaviours. On

the contrary, one might as well argue that globalisation has most likely increased complexity, in that it has drastically reduced global "viscosity",[26] to put it in physical terms. Changes in today's world are much more likely to reverberate over a way wider area than where they have strictly taken place.

Examples of applications of complexity theory in the public domain are numerous. When studying the patterns of contagion of certain epidemic illnesses, it is often assumed that a population is homogeneous, i.e. each individual has the same probability of being infected (OECD, 2009). This somewhat unrealistic assumption can be easily overcome by applying the tools of complexity theory, allowing to take into consideration heterogeneous populations and to make more reliable predictions. Another example concerns the management of traffic networks. Recognizing that predictions were not allowing for enough flexibility to account for every possible human interaction, complexity theory was applied to make more accurate transport predictions (Marshall, 2004; Avineri, 2010). Advanced complexity-based modelling taking human cognition into consideration has been used also to predict human traffic behaviour, in order to avoid stampedes and to locate emergency exits during highly crowded events (Bonabeau, 2002).

Complexity theory provides a new way of looking at policy matters, where dynamic (rather than static) effects play a major role. How does the complex approach differ from the traditional tools of policy making and policy evaluation? First, complex systems science re-orient the focus of policy makers. While traditional policy making is centered on making accurate predictions of events, a complex approach puts more emphasis on trends and probabilities. In other words, as said before, it introduces an element of randomness when modelling phenomena. In algebraic terms, it switches from a generic form $y = mx$ to $y = mx + \epsilon$, where ϵ is a term capturing random and unpredictable events. Second, the complex approach recognizes that cause-and-effect chains cannot be thought of as independent, parallel processes. Rather, they should be conceived as a tightly meshed network where causes and effects are intertwined. Finally, the complex approach abandons the safety of a strictly quantitative understanding and shifts the attention of policy makers towards the underlying patterns and mechanisms that make certain phenomena complex. The complex approach recognizes that it makes no sense to look for a one-to-one cause-and-effect relation. It studies behaviours and reveals the subtle links connecting the world in sometimes non-obvious ways.

[26] Viscosity of a fluid is the property that describes its resistance to deformation. Simply put, a less viscous liquid is one in which it is easier to swim, such as water, as opposed to one that poses much more resistance, such as honey.

1.6 The multilingual challenge: a complex issue?

"Multilingual challenge" is an expression often used to refer to the collection of difficulties encountered during communication when multiple languages co-exist in the same context. As is discussed in greater detail in Chapter 4, this challenge presents itself in numerous shapes. We encounter challenges in the family, educational, institutional, professional and scientific contexts.[27] Communication-related issues are recurring ones. Here are a few examples of contexts where you might encounter a language challenge, in (tentatively) ascending order of complexity:

- trying to order in a restaurant abroad during holidays;
- families with adopted children with different linguistic backgrounds;
- neighbourhoods where immigrant communities with different backgrounds live together;
- education providers (at different levels) handling a diverse student body;
- big multinational corporations having culturally and linguistically diverse teams and foreign subsidiaries;
- large international and supranational organizations.

Besides, the multilingual challenge can be interpreted as referring to all those dynamics concerning the spread and endangerment of languages. However, what I mean here by "multilingual challenge" refers to the specific context of the European Union. In this sense, the multilingual challenge relates mainly to the communication difficulties and language dynamics posed by the fact that the European Union is an extremely linguistically diverse territory. As of today, it numbers 27 members and 24 official and working languages,[28] a great number of minority languages, and important waves of immigration further complicating its linguistic landscape. This has all sorts of implications, including institutional communication problems, business relations, rights of minorities, and so on. These issues are usually dealt with by means of language policies. In the next few sections I provide a definition of language policy, outline multilingualism in the European Union, and try to

[27] For more on the various aspects and multi-faceted nature of the multilingual challenge, see Jessner-Schmid and Kramsch (2015).

[28] At the moment of starting this dissertation, the EU had 28 member states, as the UK was still a full-fledged member. Hence, many of the considerations discussed in this dissertation assume a 28-member EU.

understand why the multilingual challenge represents a complex matter (in the sense presented in the previous sections) and why, therefore, complexity theory is a valuable asset for language policy makers.

1.6.1 What is language policy?

What is *language policy*? This question is rather simple and might pop up spontaneously in the mind of those who are not technically involved in it. However, language policy is something that affects everyone, passively and actively. It is fundamental to understand that almost anything involving communication and language use is the result (at least in part) of different combinations of language policy measures, from the choice of providing certain services in a given language to the drafting of school curricula. Sometimes, even the linguistic identity that an individual assigns to herself and her community might be influenced by policy measures. Besides, language policies have repercussions on society which might affect people's life so profoundly that it is often very hard to isolate them. Suffice it to say that numerous researchers in the social sciences (and not only) often find themselves facing language issues in their daily work and have a hard time managing them. The non-negligible impact of language policies on people calls for sustained research efforts completely focusing on them. Furthermore, it is impossible to deny the importance of language policy and its very existence, as there is no reality involving communication between humans with "no language policy" – as a matter of fact, the simple fact of declining to take decisions concerning language issue *is* a form of language policy (which is being, anyway, communicated in a certain language). Following this line of reasoning, it is important to note that language policy is in no way a "new thing". For example, education curricula in Ancient Rome were made thoroughly bilingual (Latin and Greek) as a clear policy choice. For socio-cultural and homogenization reasons, pupils were expected to read and express themselves in the two major languages of the time throughout Roman territories (Pacal, 1984). Furthermore, those in charge of education policy were well aware of the fact that Greek gave access to the highest level of education, i.e. philosophical studies (Hornblower and Spawforth, 1996).

However, providing an answer to the questions concerning the very existence of this field of research (such as: Why is it necessary? What are the objectives? What are the material results of this research?) has proved, over the last few decades, somewhat difficult. The cause of this is the lack of a

generally accepted comprehensive theory of language policy. However, this is not the consequence of superficial research, but rather the opposite. Language policies are so entrenched in everyday life that they are acknowledged and practiced in all societal domains. As Ricento puts it,

> "[w]hile [language policy (LP)] as an organized field of study is a relatively recent development, the themes explored today in LP research have been treated in a wide range of scholarly disciplines in the social sciences and humanities over the years." (Ricento, 2006, p. 19)

Several academic disciplines can have a say in the study and application of language policies. As several other fields of study related to languages, language policy remains hitherto a rather fragmented discipline, deeply rooted in specific sciences such as, to mention but a few, linguistics, sociology, law, political sciences, geography, economics, and many of their sub-fields.

It is worth recalling here that economic theory, far from being limited to dynamics involving monetary transactions, attempts to describe actions and interactions of individuals and institutions, paying special attention to the fact that resources (of any sort) are limited and that their use needs to be optimized. Language is, among other things, a mechanism of communication and, as a basic function of social interaction, the study of its optimization falls in the domain of economic analysis (Rubinstein, 2000). It might be interesting also to look at the relationship between economics and language in the other direction. We could say that no science, including economics, would exist without language. There would be no way to produce and accumulate knowledge, and scholars would lack the basic means to perform critical thinking. Language is so deeply enmeshed in people's life that a "languageless" world is a cognitive reality that goes well beyond the reasoning possibilities of most people.[29]

As mentioned, economics plays an important role in the study of language policy. The economics of language is a relatively recent field of research which lacks a universally shared definition (as it was the case for language policy). However, Grin attempts to provide a definition of this discipline, trying to strike a balance between its wide reach and the rigour that academic norms require:

[29] In this context, however, it is worth mentioning an extremely fascinating stream of research across linguistics and anthropology studying cases of individuals who have grown up learning no language of any sort (see, for example, Schaller 1991; Downey 2010).

> "The economics of language refers to the paradigm of mainstream theoretical economics and uses the concepts and tools of economics in the study of relationships featuring linguistic variables. It focuses principally, but not exclusively, on those relationships in which economic variables also play a part." (Grin, 1996, p. 6)[30]

In other words, scholars of language economics apply the traditional (mostly mathematical) methods of economics to provide an explanation to specific socio-economic dynamics by putting them in relation with linguistic variables, which can, on a case-by-case basis, be exogenous or endogenous to the model. Generally speaking and looking at the relevant literature, economics can contribute to the discourse on language studies in various ways, including:

- studying the relationship between language and labour income;
- defining language dynamics of spread and decline;
- identifying the role of language in economic activities;
- supporting language policy decisions and analysing their impact (Grin, 2010).[31]

These four orientations are often intertwined. Language policy decisions are not meant to happen in a vacuum. They are always made to address specific societal dimensions relating to languages. Canada's well-established academic tradition of studying earning differentials between Anglophones and Francophones is a good example of this.[32] Canadian scholars involved in this kind of research deal with issues that go well beyond the simple statement that speaking English offers an advantage over speaking French (as an L1 or L2). They deal with one language being dominant and another being dominated. They shed light on the prominence of certain languages in economic contexts. They provide a handle on ethical issues, such as fairness and equality of opportunities for minorities.

[30] It is worth noting that this definition is not strictly limited to languages. It aims to include the concept of "ethnicity" within its reach, and it does so by referring simply to language as much of the literature on ethnicity uses the former as a marker of the latter.

[31] Recently a new stream of research has come to the fore as an application within the field of behavioural economics, which tries to identify the effects of language characteristics on economic behaviour (see, for example, Chen 2013).

[32] See Vaillancourt (1996) for an overview.

Why is language an object of public policy in the first place? Public policy can be defined as "*an intentional course of action followed by a government institution or official for resolving an issue of public concern*. Such a course of action must be manifested in laws, public statements, official regulations, or widely accepted and publicly visible patterns of behaviour" (Cochran et al., 2009, pp. 1-2, emphasis in original). The expression "of public concern" reveals the collective nature of the issue at stake. As noted above, language is the natural means of communication, which is an inevitable part of modern (as well as ancient) societies.[33] As a consequence, language issues and all their social, political, and economic implications deserve the attention of public policy practitioners and scholars. The role played by policy analysis in the field of language policy has been evident to scholars (in particular to sociolinguists) since the 1970s (Jernudd, 1971; Rubin, 1971; Thorburn, 1971). Nevertheless, it received greater attention only starting from the 1990s, when a number of scholars from political science and economics started to apply policy analysis models to language policy (Grin and Vaillancourt, 1999; Grin and Gazzola, 2010; Gazzola, 2014).

In the following section I discuss how policy analysis is applied to language issues. In particular, I explore the case of European multilingualism, a theme that is discussed in greater detail in Chapter 4.

1.6.2 European multilingualism: Friend or foe?

According to Archibugi (2005), the revival of the interest for language issues in our times is the result of two main phenomena:

- the increased interdependence between communities, i.e. a process more often labelled as "globalisation"; and
- the increased importance of individual rights, as a consequence of both a broadening of rights in democratic states and an increase in the number of states that embrace democratic values.

The problem of linguistic rights can be regarded as happening at the same time *inside* and *outside* the state. Historically, domestic language problems are typical of multilingual communities, such as (in different ways and for

[33] The word "society" came to English through French from Latin "societas", a derivative of "socius", which means "companion, friend". Therefore, it can be literally translated as "companionship, friendly association with others".

different reasons) Switzerland, Canada, and Belgium. On the contrary, external language problems (i.e. across state communities) are much more recent (obviously, as they require the existence of interacting communities as a premise). One of the most interesting examples of such phenomenon is the European Union's language regime.[34] Kymlicka (2001, p. 214) states that "democratic politics is politics in the vernacular" and that "[t]he average citizen feels at ease only when he discusses political questions in his own language". This statement enshrines one of the basic principles on which the European Union (a self-proclaimed democratic institution)[35] has based its language regime. Linguistic diversity is one of the cornerstones of the European project. This idea is further emphasised in the legal corpus of the European Union.[36] The Union recognizes the value of multilingualism as key for intercultural dialogue, social cohesion, prosperity, lifelong learning, media, information technologies, and for the EU's external relations.[37] Foreign languages are essential to ensuring mobility within the European Union (another one of the founding principles), and they can represent a barrier to participation in society, and may prevent marginalised language groups from being represented and included in society. In this sense the European Commission coordinates and collaborates[38] with the national governments to achieve the objectives of the language strategy,[39] which pursues a multilingual scenario.

To give an idea of the extent of multilingualism within the EU institutions, I shall consider the example of the European Parliament. At the time

[34] In this chapter, I only provide an overall review of the issue, since it is discussed at greater length in Chapter 4.

[35] Article 6 of the Treaty on European Union says: "The Union is founded on the principles of liberty, *democracy*, respect for human rights and fundamental freedoms, and the rule of law, principles which are common to the Member States" (emphasis added).

[36] Article 22 of the European Charter of Fundamental Rights states that "[t]he Union respects cultural, religious and linguistic diversity". This idea is recalled and reinforced by Article 3 of the Treaty on European Union, which says that "[i]t shall respect [Europe's] rich cultural and linguistic diversity, and shall ensure that Europe's cultural heritage is safeguarded and enhanced."

[37] For more on this, see the "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - Multilingualism: an asset for Europe and a shared commitment", available at http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52008DC0566.

[38] It is worth noting here that the European Union has no right to intervene directly in the language policy of member states, therefore it can only work as a harmonizing body in this sense.

[39] See http://ec.europa.eu/languages/policy/language-policy/index_en.htm.

of writing, the Union adopts a full-multilingualism (sometimes called *panarchic*) regime with 24 official and working languages,[40] in which every language is translated (or interpreted) in every other language. This system is fixed by Council Regulation No. 1, which identifies the languages to be used by the European Economic Community and by the European Community for Nuclear Energy, and which has been amended along with successive enlargements of the Union. The number of translation and interpretation (T&I) directions in such a system is given by the following formula:

$$L = n(n-1) \tag{1.24}$$

where L is the total number of language directions and n is the number of official and working languages. This means that language services in the European Union are currently working with 552 language directions.[41] Implications are far from negligible under several aspects. On the one hand, this regime accords equal dignity to every language and complies with the non-hierarchical rationale underlying the Union. Besides, it grants every citizen of the European Union the potential to be actively and passively involved in the political life of the Union, by providing official documents in all languages and full interpretation during conferences and other official events. However, the flip side of linguistic democracy is a huge amount of translation and interpretation activity, bearing a certain cost and often topping an already cumbersome bureaucracy (Fidrmuc and Ginsburgh, 2007). It is important to stress the difference between official and working languages within EU institutions. All European institutions have adopted the 24 languages as official languages. However, these languages are also working languages only for the Parliament, the Council, the Economic and Social Council, and the Committee of the Regions. The Commission and the Court of

[40] The languages are: Bulgarian, Croatian, Czech, Danish, Dutch, English, Estonian, Finnish, French, German, Greek, Hungarian, Italian, Irish, Latvian, Lithuanian, Maltese, Polish, Portuguese, Romanian, Slovak, Slovene, Spanish, and Swedish.

[41] For an in-depth review of the different language regimes see Gazzola (2006a). A number of considerations are necessary. First of all, it makes sense to speak of directions (that is, from language A into language B and from B into A are counted as two separate directions) in that it is common practice that language professionals translate or interpret into their own native language. Therefore, unless one is perfectly bilingual, one that translates or interpret from A into B will not be translating or interpreting from B into A. Second, 552 is the number of existing directions and not the directions that are constantly offered by the interpretation service. In fact, not all parliamentary sessions need interpretation towards and from all languages. Finally, interpreters often make use of pivot languages when the direct combination is not available (for example, interpreting Finnish into Maltese passing through English and vice versa).

Auditors use exclusively English, French, and German for internal communication purposes (and, in practice, essentially English), while the European Court of Justice uses only French for its deliberations.[42] For this reason it is more appropriate to talk about "controlled multilingualism" rather than "full multilingualism".

The multilingual nature of the European Union (and, in general, of Europe) has often been regarded as a treasure[43] and a curse at the same time. Gazzola (2006a) provides an interesting overview of the reasons working in favour and against full multilingualism in the European Union, mentioning a number of previous studies on this subject.

First of all, legal issues should be considered. Given the direct impact of Community law on the legal system of member states, it is important to debate the acceptability of legal texts drafted in a certain language being enforced in countries where that same language is not official. If that were the case, it would provide a justification to the general principle of presumed knowledge of the law, enshrined is the most famous expression "ignorantia iuris non excusat", which roughly translates to "not knowing the law does not provide an excuse".[44] Besides, providing that citizens should acquire knowledge of a law in a language they do not master would impair the basic principle of equality of rights (Fenet, 2001; De Elera, 2004). Therefore, a number of political issues are at stake, i.e. democratic participation in political life, equal treatment of state representatives, and respect of the prestige of member states.[45] Finally, cultural variables also play a role. As mentioned earlier, the European Union openly supports multiculturalism and, therefore, multilingualism.[46] Mayer and Palmowski (2004, p. 582) noted that multiculturalism is precisely the nature and trademark of the European cultural identity.

Nevertheless, full multilingualism has a number of drawbacks, which are also worth exploring in this brief overview of the subject. First of all,

[42] However, proceedings before the ECJ can be conducted in any EU official languages, according to different rules (Council of the European Union, 2012, art. 36 and 37).

[43] The idea of multilingualism as a source of wealth is usually intended in rhetorical terms, as it does not have a quantifiable monetary value (Grin, 1997).

[44] In countries with a tradition of Roman law, this formula is often replaced by an expression from Aristotle translated into Latin: "nemo censetur ignorare legem", which roughly translates to "nobody can be assumed to ignore the law".

[45] For an overview see Bourdieu et al. (2001), Starkey (2002), and Buchmüller-Codoni (2012).

[46] On this subject, see Kastoryano (2009).

Fidrmuc (2012) notes that full multilingualism represents a muddled mechanism which often involves delays and is often not adequate, especially during emergencies. A continuous work of translation and interpretation (often making use of relay translation and/or interpreting)[47] results in a loss of quality. Finally, this huge machine obviously involves a non-negligible cost. The exact amount of money spent on language services in the EU is hard to compute. The European Commission declares spending 330 million euros for translation services only.[48] Fidrmuc and Ginsburgh (2007) estimate a cost of about 1 billion euros per year in the wake of the 2004 enlargement.[49] Nevertheless, these last two points can be easily rejected. Indeed, it easy to note that the loss of quality due to translation is not comparable to the lack of precision which might arise from a non-proficient use of a language by non-native speakers, not to mention the consequences in terms of unequal treatment. Concerning the cost of full multilingualism, the EU's English-language website reports that the cost of its full multilingual regime represents only 1% of the EU budget and amounts to slightly over 2 euros per citizen.[50] Furthermore, these complaints result from the confusion between "expensive" and "too expensive". In other words, if society finds that the cost of something (in this case, full multilingualism) is proportionate to its subjective value, there is no reason to complain that it is excessive (Grin, 2004, p. 4). Finally, one must note that cutting T&I costs does not amount to saving money *tout court*. It rather implies a shift of costs from the EU to its member states. In other words, if the EU does not cover for costs of T&I, it is up to member states or even private citizens to invest in language education, as giving up communication within the EU institutions is probably not an option.

As mentioned above, the "language issue" has traditionally attracted the interest of scholars from different disciplines. Nevertheless, only recently has it gained more attention from the academic community. A conspicuous research effort was devoted to carrying out an in-depth exploration of the European multilingual issue. It is no surprise that the continuous (linguistic, for our purposes) enlargement process of the European Union was followed by a growing body of research on this subject. After all, multilingualism is part of a greater idea of mutual respect, which needs to be defended to keep

[47] For more on this, see http://ec.europa.eu/dgs/scic/what-is-conference-interpreting/relay/index_en.htm.

[48] See http://ec.europa.eu/dgs/translation/faq/index_en.htm.

[49] Figures refer to a full multilingual regime with 20 languages, but it is reasonable to assume that the present cost with 24 official and working languages is not significantly different. Therefore, the line of reasoning would not be affected.

[50] See http://europa.eu/rapid/press-release_MEMO-12-703_en.htm?locale=en.

the Union project going. Scholars noted that it would be hard to see it differently, as the history of the Union is quite different from the process that brought about the rise of European nations during the nineteenth century (Baggioni, 1997; Gazzola, 2006b). What is more, language issues cannot be ignored. Language policy scholars noted that a *laissez-faire* policy on language is not an option, not only in the sense that it is advisable that institutions make an effort in this direction, but also that they cannot avoid using a language as a means of communication (Grin, 2005; Gazzola, 2014). The same idea is found in De Schutter (2007), who says that, though the State can be neutral with respect to religions, it cannot be neutral with respect to language use. Language planning of any sort (corpus, status, acquisition) are inevitable as language is indispensable whenever the State is involved in policy making, administering society, communication, i.e. everyday. However, it has also been noted that globalization is in a sense weakening the control of language dynamics by the State. This means also that the role of supranational and international organisations is being strengthened in this respect (Gazzola, 2014). Therefore, it is not possible to "let it be". The multilingual issue is there, it cannot be ignored, and it is more and more in the hands of international and supranational entities, such as, respectively, the United Nations and the European Union.

1.6.3 Is it a complex issue?

I will now try to put together everything that has been discussed so far. I reconsider language policy and the multilingual challenge from a complex perspective. I show that language issues display the aspects of complexity discussed in the first section and, therefore, that they "qualify" to be considered and treated as complex issues. The direct consequence of the acknowledgement that language issues are complex implies that language policies have to be drafted in a way that takes the principles of complexity theory into account. This does not mean "changing language policies", in that a policy is not something that exists autonomously, in its own right. A policy is an answer to a specific problem, without which it has neither reason nor legitimacy to exist. Therefore, a policy answer should reflect the characteristics of the object being treated. If we recognize that language issues are complex, the policy maker needs to adopt a complex approach to draft an answer. I provide examples illustrating different language issues. My objective is to

prove that language issues are complex in their nature and therefore should be addressed by means of complexity theory.

Non-linearity and feedback loops

Non-linearity is probably one of the most recurring characteristics of language issues. Several instances of non-linear patterns have been detected by scholars in language policy and economics of multilingualism. A well-known example is that of the threshold in the process of language shift, i.e. the process whereby a speech community traditionally speaking language B, gradually replaces it with language A (Grin, 1992) (this topic is discussed in greater detail in Chapter 3). A threshold is a stage in this process where "it is too late" to go back, a point where language B will now inevitably give way to language A. Ambrose and Williams (1981) discuss the case of Welsh. Distinguishing between Welsh-speakers (including bilinguals) and Welsh monoglots, they argue that there exists a "language loss line" (slightly below 50% of monoglots, according to their empirical findings) under which the entire Welsh-speaking population starts to drop and eventually disappears. Grin (1992) further explored this intuition from a theoretical perspective, noting that there is no single threshold point. Rather, several (or better, an infinite number of) "points of no-return" exist, depending on the interaction of demographic and linguistic variables, such as the distributions of speakers across languages (in its turn affected by migration flows as well as birth and death rates) and the attitudes of people towards these languages (depending, among other things, on the availability of opportunities to use a specific language). Language survival can be attained through policy intervention. The function linking these variables tends to be non-linear. Besides, a small variation in the initial condition leads to drastic changes in the stable equilibrium eventually attained. Therefore, any action drafted by policy makers should take this non-linearity into consideration. In the same study, the author identifies a feedback loop characterizing the level of language survival (defined by a variable called "language vitality"). In particular, the latter is quite clearly influenced by intergenerational transmission as well as individual loss and acquisition because they determine the percentage of speakers of each language. At the same time these two variables are functions of language vitality. A decreasing level of language vitality can induce a decline in the level of intergenerational transmission, as well as in the level of acquisition, which eventually cannot make up for the loss of speakers over

time (of course, the opposite is also true, in that an increase in language vitality increases the interest to transmit of acquire the language). Grin (1992) notes, however, that language vitality does not necessarily feed on itself. This idea is discussed in further depth in Chapter 3.

Non-Gaussianity

As mentioned, a non-Gaussian distribution is characterized by a higher-than-normal likelihood of extreme events, which can bring about unexpectedly big effects. The fact that extreme and unexpected events can have important consequences on language issues is easy to see. In the previous pages it was briefly mentioned that migration flows play a role in the definition of the linguistic landscape of a region. This is true both in the long term and in the short term. In the long term, one can think of colonization processes that made four European languages (English, French, Spanish and Portuguese) the major languages of the contemporary Americas, virtually annihilating indigenous languages. Concerning the short term, one can think of the emergence of non-indigenous communities across Europe over the last few decades (either non-native to the country of settlement, such as the Romanian community in Italy, or to Europe in general, such as Latin American or African communities). This clearly has implications from a number of perspectives. One can think of the EU directive that ensures the right of suspected or accused persons to interpretation and translation in a language that they understand during criminal proceedings.[51] As a consequence, member states have an obligation to provide interpreters and translators to people speaking a language different from the local one(s). Complying with this principle is straightforward. Locating and anticipating needs is relatively easy, and so is preparing and eventually providing competent professional to meet the requested services. However, this is only simple as long as the language landscape remains constant or changes in a "predictable" way. Nevertheless, such a system may collapse very easily under the pressure caused by an (apparently) unlikely and unforeseeable event. Current migration flows seem to confirm this. Because of unexpected events (terrorism and war in the Middle East), migration flows towards Europe have dramatically increased

[51] Directive 2010/64/EU of the European Parliament and of the Council of 20 October 2010 on the right to interpretation and translation in criminal proceedings. This directive draws on Article 14 of the International Covenant on Civil and Political Rights, which, among other things, ensures the right of an individual involved in a proceeding "[t]o have the free assistance of an interpreter if he cannot understand or speak the language used in court" (International Covenant on Civil and Political Rights, 1976, art. 14.3).

during the last few years, boosting the presence of non-indigenous people on European soil, from all sorts of different cultural and linguistic backgrounds. Such an unpredicted shock can easily undermine the functioning of the administration (not to mention socio-economic repercussions). A sudden increase in the volume and diversity of migration is not easy to cope with when it comes to granting T&I services, among other things. The receiving country may not be prepared in terms of staff to deal with incoming people. As a consequence, policy interventions in this domain should aim at boosting systemic resilience by making it flexible and able to quickly adapt to external shocks. Policy makers dealing with language policy and planning (LPP) should be aware of the complex nature of language issues. They should switch from a static approach, whereby only the current situation is addressed, to a complex and dynamic approach, which leaves room for randomness and unexpected occurrences.

Spontaneous order and lack of central control

Spontaneous order and lack of central control are possibly the easiest complex characteristics to spot, concerning both language itself and language use. A language evolves over time, developing a rich vocabulary and a complex syntax with every speaker (often unconsciously) contributing to it (Cantor and Cox, 2009, p. XI). Speakers reciprocally give up a part of their linguistic liberty (intended here as the ability to pronounce different sounds) to "meet halfway". They define common words and rules in order to be able to understand each other (Adelstein, 1996) (it is worth reminding here that Adam Smith considered language an essential tool for social cooperation). However, these rules are created, followed and broken continuously. As was observed above, a living language is never in equilibrium. Rather, it fluctuates around an "equilibrium region", determined by a spontaneous tendency to maintain mutual intelligibility among speakers, and by individual use, whose peculiarity are often defined at a decentralized level. Besides, it should be noted that languages are often resistant to central control, i.e. the attempts of language scholars to regularize speech patterns (Cantor and Cox, 2009, p. XII). If, say, a language regulator prescribed the use of a specific word or grammar rule, it is not obvious that speakers would respond positively to the imposition. It is the case, for example, of adjective agreement in many Romance languages, such as French. While the Académie française, the central institution that deals with matters pertaining the French language, prescribes the use of the masculine agreement when an adjective refers to a

number of nouns with different genders, some users display a preference for a more inclusive language by using, among other things, the so-called "accord de proximité" (proximity agreement). Such type of agreement provides that adjectives should agree in gender with the closest noun.[52] Therefore, it is evident that a random element can coexist with a spontaneous order and a weak form of central control.

A notable example of lack of central control in language matters is provided by the so-called "Greek language question", a very controversial dispute about the official language of Greece that stretched over the 19th and 20th centuries. In particular, this case is an example of resistance to central control. The dispute concerned the marked diglossia between the vernacular language commonly spoken by Greek people, called *dimotikí* or Demotic Greek, and a cultivated imitation of Ancient Greek, called *katharevousa*. There never was one standard version of *katharevousa*, but multiple versions that were closer in grammar and vocabulary to either Ancient Greek or to Demotic Greek. Although the issue would call for a dissertation specifically dealing with it, it can be summarized as follows. In the immediate aftermath of the regained independence of the Greek State from the Ottoman Empire, many intellectuals advocated a move away from the vernacular language, deemed uncultivated and heavily influenced by foreign languages, and a revitalization of Ancient Greek, with a view to bringing back the political and cultural vitality of their ancestors. Greek intellectuals were convinced that Greek people would naturally pick up elements of Ancient Greek if continuously exposed to texts written in *katharevousa*. Over time, they believed, *katharevousa* would take over Demotic Greek not only in the writing, but also in the speaking as everyday language. However, by the end of the 19th century it was clear that the stubborn attempt to impose archaized structures on people only resulted in an increasingly strong separation between the spoken and the written language. Indeed, if some people were able to understand (or, at least, figure out) the content of a text written in *katharevousa*, only a very small minority was also able to use it actively. This brought even famous linguist and defender of *katharevousa* Georgios Hatzidakis to recognize in 1883 that "in our struggle to render the written language more noble, we

[52] For a different example, the fact that the General Delegation for the French language and the languages of France ("Délégation générale à la langue française et aux langues de France", DGLFLF) proposed the use of the word “courriel” since June 20, 2003 (Journal officiel du 20 juin 2003), never stopped people from using the words “mail” and “e-mail”. It should be noted, however, that the DGLFLF only provides lexical resources which are meant as simple terminological recommendations and not as a way force people to use certain specific words.

are allowing the Greek people to become more uncouth". Notwithstanding the continued effort of many intellectuals to impose an artificially cultivated version of Greek, a marked diglossia kept existing. In 1885, renown writer and *katharevousa* supporter Emmanouil Roïdis observed that even members of the Parliament switched from *katharevousa* in prepared speeches to Demotic during debates. This situation of diglossia persisted throughout the first half of the 20th century, although Demotic Greek slowly started gaining some popularity among intellectuals. The last strong attempt to impose *katharevousa* on people came in the late Sixties and early Seventies, under the authoritarian regime of the Colonels. In 1968 *katharevousa* was made the official language, while the use of Demotic in schools was officially banned. Supporters of Demotic were accused by the regime of communism and of working against the State. However, all support for *katharevousa* eventually crumbled along with the collapse of the regime in 1974 and Demotic Greek was made the official language of Greece in 1976.

Emergence and hierarchical organisation

To explain emergence within language issues, I consider the issue of clashing interests at different levels, which underlines the importance of also taking the meso level into consideration. In general, recognizing the complex nature of the multilingual challenge and adopting a tripartite perspective becomes crucial for policy makers. Let us look at another practical example, building on a discussion by Grin (2015) on the use of different languages in a higher education context:

- at the micro level, a researcher walking in an (at least moderately) culturally diverse university will immediately notice that individual students have different backgrounds, different language profiles, and use all sorts of different communication strategies (speaking their own language, speaking the interlocutor's language, code-switching, code-mixing, intercomprehension, and so on) and that these strategies are adopted by users with no external restriction;

- at the meso level, a researcher will notice that universities make choices about the use of one or another languages for different purposes (e.g.: choice of languages taught as subjects; choice of language(s) of instruction, including exams and, possibly, educational materials; choice of language(s) for internal administrative purposes; choice of language(s)

for external communication) and that these choices do not necessarily corresponds to micro-level strategies in terms of diversity;

- at the macro level, an LPP researcher's interest will typically concern the general choices made by the authorities (assuming we are dealing with a publicly-funded education system) regarding the language(s) of instruction in universities (as well as in other educational contexts).

Let us also note that interests may actually coincide between the micro and the macro levels and that therefore we would be missing a big side of the story if we ignored meso-level entities. Let us consider country X, where X is the official language, though Y is also spoken by a newly-formed community, whose members are not always fluent in X. Besides, country X has significant trade relations with country Z. Let us also consider the information written on the packaging of goods for sale in country X's supermarkets. Such information includes ingredients, conservation methods, origin, etc. A breakdown of the interests at stake in this scenario based on the three levels of perspective will be as follows:

- MICRO: individual A, speaking exclusively language X, doing shopping in the local supermarket. She is clearly interested in understanding what is written on the packaging and, therefore, she wants and, as a national of country X, *expects* information to be provided in a language that she speaks, i.e. language X. In another aisle of the same supermarket, individual B, belonging to the immigrant community and speaking language Y, *would like* to have information in language Y, but is willing to struggle with language X.

- MESO: the CEO of a company based in country X producing goods to be sold in supermarkets. Incidentally, the CEO is also part of the immigrant community, her native language is Y, but she is also fluent in X. As she acts on behalf of a private institution, it is reasonable to assume that her sole interest is to generate profit for the company and, therefore, she would want to limit packaging costs as much as possible, including printing information. Initially, she would avoid completely adding information in another language, but she fears that the company might lose clients. In country Z, another CEO is facing a similar situation. She would like to market the company's product in country X, but this would imply translation costs (towards X? Y? Both X and Y?), packaging reconfiguration and, therefore, an increase in production costs.

- MACRO: the president of country X's consumer protection authority. She was appointed by the newly-elected government, a notable a supporter of minority rights. Her main interest is, obviously, that consumers are protected and, therefore, constantly aware of their consumption choices. She works to push the parliament of country X to pass a law that obliges companies selling products in country X to provide information in language X on the packaging, whether the company is local or based abroad. At the same time, she is working on another proposal that would introduce an obligation to add information in a non-official language spoken as a unique language by more than a certain number of tax-payers. However she did not put it in the law about language X because she did not want to provoke a negative reaction from the opposition.

We can discuss a number of considerations on the basis of this example. We note that interests at the micro and macro levels are somewhat converging, in that in both cases the optimal solution would be to have information in the language(s) spoken by the residents of country X. If one skipped the meso perspective, one would be tempted to believe that this is where the story ends, but we would be overlooking a whole other set of interests. At the meso level we find entities such as corporations who have completely different objectives and might even consider the request for multilingual information a nuisance. It is evident that the fact that the micro and macro interests converge is not enough and that intervention at the meso level is needed. One might argue that the companies of the example are private actors and that their behaviour cannot be determined through policy making (as far as language use is concerned). This is only partially the case. True, these private institutions have freedom to make decisions about language use as far as internal processes are concerned. Nevertheless, the government can (and often must) intervene to regulate the relationships between these companies and the people, including the use of language. Finally, we should note that the company's profit is of interest for every individual in the company, our meso-unit, whether they are nationals, foreigners, speakers of language X or Y. Indeed, the company's success (or failure) has substantial repercussions on its workers' conditions. Therefore, we can note how, as mentioned, a meso level characteristic (in this case, the interest for corporate profit and the subsequent strategies) comes into existence only when the meso level aggregation takes place.

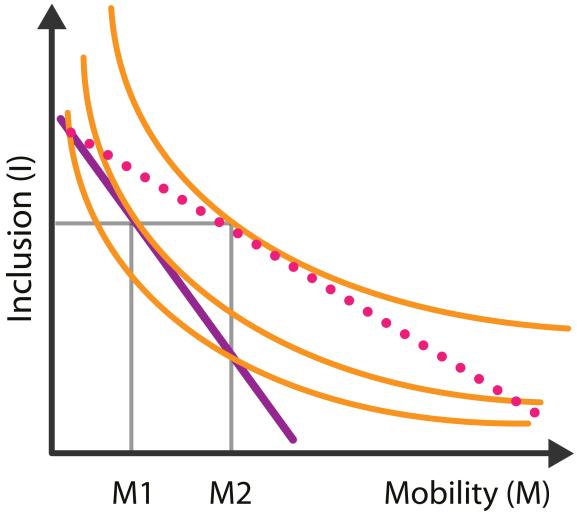


FIGURE (1.13) The trade-off between mobility and inclusion.

1.6.4 The trade-off between mobility and inclusion

In the introduction it was mentioned that one needs to pay particular attention to causal links when implementing a policy addressing a complex issue. The reason for this is that there might exist links between apparently unrelated variables. Therefore, actively affecting one variable might accidentally affect other variables. In this section I discuss, both analytically and in practice, how policies addressing seemingly unrelated issues could work in opposite directions, practically cancelling their respective effects. In particular, I draw from Grin (2018a) and consider the example of mobility and inclusion in multilingual Europe. By "mobility" I refer to the fact that people are nowadays more and more likely to move throughout their lifetime for various purposes. By "inclusion" I refer to people's feeling of belonging in a given context or within a given community.

Mobility and inclusion might pull in non-converging (potentially opposite) directions. Investing resources to increase one dimension could affect the other in a negative way. An individual or society can at best strike a balance between mobility and inclusion, so that utility (i.e. the level of satisfaction or, in this case, the aggregate value accrued to society) is maximized under a specific constraint. The combination of mobility and inclusion defines a certain level of utility within society. Reasonably, an efficient or cost-effective use of resources is preferred to any other, as it guarantees the highest possible result given a certain resource endowment. This trade-off can be graphically represented as in Figure 1.13, drawn from Grin et al. (2014, p.17).

It is easy to see that this is the best possible result because any movement along the constraint would provide people with less desirable conditions. Any other pair along the constraint is indeed sub-optimal, as it could be matched by other pairs providing the same level of satisfaction and consuming less resources.

This whole idea of the trade-off can be rewritten in analytical terms. By creating a model, one usually means to use simple mathematical representations to fit the relationship between mobility and inclusion just discussed. One can think of mobility and inclusion as the elements of a two-good economy and some form of social value as the utility resulting from a combination of them. For simplicity, one can think of the relation between these three variables (utility, mobility, and inclusion) as a two-input Cobb-Douglas function (more specifically, I discuss utility as a function of mobility and inclusion):

$$U(M, I) = kM^{\alpha} I^{\beta} \tag{1.25}$$

where U, M, and I represent, respectively, utility, mobility, and inclusion, k is a positive constant, and α and β are constants whose values are included between 0 and 1.[53] Basic calculus tells us that the behaviour of this function with respect to its variables is described by the following first-order partial derivatives:

$$U_M = k\alpha M^{\alpha-1} I^{\beta} > 0 \tag{1.26}$$

$$U_I = k\beta M^{\alpha} I^{\beta-1} > 0 \tag{1.27}$$

The fact that both first-order derivatives are positive tells us that, if either mobility or inclusion increase while the other dimension is kept constant, the level of utility increases (though we have not specified in what proportion). In other words, the marginal contribution of either dimension is positive.

The second-order partial derivatives are:

$$U_{M,M} = k\alpha(\alpha - 1) M^{\alpha-2} I^{\beta} < 0 \tag{1.28}$$

$$U_{I,I} = k\beta(\beta - 1) M^{\alpha} I^{\beta-2} < 0 \tag{1.29}$$

$$U_{M,I} = U_{I,M} = k\alpha\beta M^{\alpha-1} I^{\beta-1} > 0 \tag{1.30}$$

[53] Note that in many cases, especially those concerning production functions, the sum of the exponents α and β is also defined, in that exponents summing up to a value lower, equal, or higher than one imply, respectively, diminishing, constant, and increasing return to scale However, I am not interested here in cardinality properties, which are key in production functions. What matters here is that our function preserves ordinality of preferences (utility).

What do the signs of the partial derivatives tell us? The unmixed second-order derivatives are both negative, suggesting that the contribution of one dimension, though being always positive, diminishes when the other is held constant. However, the sign of the mixed second-order derivatives (which are equal, by Young's theorem) is positive. This tells us that mobility and inclusion are complementary goods and that more of one increases the marginal utility of the other.[54]

Is it reasonable to think of the relationship between inclusion and mobility in this sense? The indifference curves resulting from this conceptualization are downward-sloping and convex, as depicted in Figure 1.13. The negative slope represents the willingness to make a trade-off, i.e. to exchange mobility for inclusion and vice versa. The convexity of these curves tells us that there exists a preference for variety between inclusion and mobility. Besides, the shape of the curves makes sure that corner solutions (where one dimension is completely abandoned in favor of the other) are not possible. The underlying assumption is that policies "going all-in" on either one or the other dimension are in no way satisfying. A completely mobile society, with no inclusion, and a sclerotic though extremely inclusive society are equally unfavorable conditions. Besides, if the indifference curves were concave, society would be ready to give up more and more of one dimension for less and less of the other. In other words, for example, people would be ready to give away an increasing amount of mobility to make society only slightly more inclusive. However, again, I do not contemplate extreme positions favoring one dimension over the other. As said, these curves are characterized by diminishing marginal rates of substitution. It means that people's preferences are characterized by a decreasing willingness to give up one dimension for the other. Simply put, it means that if an individual (or society) has already a very little amount of, say, inclusion, a further reduction can be compensated only by a great increase in mobility. In a symmetrical way, when inclusion is abundant, it will not be a problem to give up a greater portion of inclusion to have a little more mobility. In analytical terms, the marginal rate of substitution is equal to the ratio of the two first derivatives:

$$MRS_{M,I} = \frac{U_M}{U_I} = \frac{k\alpha M^{\alpha-1} I^{\beta}}{k\beta M^{\alpha} I^{\beta-1}} = \frac{\alpha}{\beta}\frac{I}{M} \tag{1.31}$$

[54] However, it should be noted that, by this reasoning, mobility and inclusion cannot be considered *perfect* complements, i.e. goods that *must* be consumed together in a fixed ratio. In that case, more of one good does not imply that the marginal utility of the other increases.

As said, the marginal rate of substitution (how much inclusion we need to give up to increase mobility while keeping the level of satisfaction intact) decreases in the variable M, meaning that the more mobility we get, the less inclusion we will be ready to give up. Needless to say, the symmetrical trend is also true, both analytically and intuitively. Finally, it can be easily shown that the elasticity of substitution of these indifference curves is constant and equal to one. This metric describes the willingness of people to substitute one dimension for the other. As a general rule, if elasticity tends to infinity, the goods are considered substitutes, while if it tends to zero, they are complements and substitution is less and less possible (or welcome). A unitary elasticity of substitution means that people are willing to obtain utility by switching between the two dimensions based on their relative costs, but there is a preference for a diverse bundle rather than extreme solutions.[55]

We could theoretically find an infinite number of combinations of inclusion and mobility and, in virtue of the non-satiation principle, the more, the better. However, the indifference curves are just a way of showing that, given a certain level of utility, we have an infinite number of equally satisfying combinations, and that all of these combinations lie on the geometric locus described by the curve. Shifting to another curve means moving to a whole different set of combinations which are more or less satisfying than the previous one (which is why indifference curves can never intersect). To sum up, moving along the curve means choosing among different combinations that guarantee the same level of utility accruing to society, while jumping from one curve to the other means not only changing the combination (although the relative proportions might well stay the same), but also switching to a different (lower or higher) level of social utility.

Indifference curves alone say nothing about the limitations to utility provided by constraints of different nature. Indeed, these curves only inform us about the "behaviour" of individual (on a micro-level) and social (on an aggregate macro-level) preferences with respect to the goods that consumers are provided with (inclusion and mobility, in this case), given a pre-specified amount of utility. Therefore, the next step in the formulation of our mobility-inclusion model is giving a formal definition to the constraint. This step is fundamental to define the pre-specified amount of utility just mentioned and

[55] Of course, this is a strong assumption, as one may as well argue that certain societies prefer mobility over inclusion (or the other way round). Note, however, that this assumption can be easily relaxed by switching from a Cobb-Douglas to a common constant-elasticity-of-substitution (CES) function.

find an optimal combination of inclusion and mobility. Describing a constraint means defining the relative cost of either dimension in terms of the other at any moment, i.e. how much, say, inclusion must be given up to increase mobility by one unit (assuming that we have a unit of measures for either dimension). It should be noted that, although this argument might sound similar to the one just made about the indifference curves, it is not the same thing. In the case of indifference curves, I was referring to people's preferences, what makes them satisfied and how. On the contrary, I am now referring to the trade-off caused by the fact that measures supporting one dimension often clash with measures supporting the other. Here are some examples drawn from Grin et al. (2014):

- Encouraging the acquisition of language skills to sustain mobility risks amplifying social differences, causing eventually the exclusion of a part of the population. This is especially the case when opportunities to acquire language skills (as many other professional skills) are associated with better socio-economic conditions (i.e. better-off people have more chances to acquire these skills), such as when languages are mostly acquired through private means. If a policy maker fails to see this connection, implementing a mobility-enhancing policy that exclusively relies on the acquisition of language skills risks exacerbating the social divide, causing further social fragmentation (that is, less inclusion).

- Strengthening the association of a territory to one (or more) specific languages (the so-called "territoriality principle") may work in favor of a cohesive society. Measures such as teaching the local language are generally recognized as very effective tools to foster inclusion, especially of immigrants. However, relying extensively on such policies to include people reinforces the relation between one place and one language, and therefore it may actually hinder mobility, not to mention the fact that it might be considered anachronistic in a highly mobile world.

The reason why it is important to define a constraint is that it helps us understand how consumers can maximize their utility, given a certain availability of resources. We can think of the constraint as a line or a curve that lies on the same plane as our indifference curves, crossing some of them and being tangent to only one. Individuating the point of tangency means maximizing the level of utility in terms of the two dimensions. In analytical form:

$$\max_{s.t.B(M,I,p_M,p_I)} U(M,I) \tag{1.32}$$

or, in explicit terms:

$$\max_{s.t.B(M,I,p_M,p_I)} kM^{\alpha}I^{\beta} \tag{1.33}$$

In the expression $s.t.$ stands for "subject to" and $B(M, I, p_M, p_I)$ is a function that describes the constraint in terms of mobility, inclusion, and their respective prices, all being positive values.[56] What does the constraint mean? As mentioned, the constraint is placed in the same plane as the indifference curves. However, it does not show all the equivalent pairs of goods, but individuates all affordable pairs, which are those in the area between the constraint line (the purple line in Figure 1.13) and the axes. Intuitively, the closer the constraint to the origin, the fewer the affordable pairs. Any increase in the budget will shift the constraint line further from the origin (the dotted line in Figure 1.13), increasing the range of choice (this can also be the consequence of a fall of the cost of one or both dimensions). Maximizing our utility function simply means finding the pair lying at the same time on the constraint and on the highest possible indifference curve. In terms of our analysis, (monetary and non-monetary) resources to push mobility and inclusion are limited and need to be allocated (ideally, in an optimal way) between the two. In theory, corner pairs (resources being completely allocated on one of the two) are available in the case of the constraint, but the possibility of these extreme solutions is anyway ruled out by the shape of the indifference curves.

Up until now, we have been thinking of the constraint as a linear function, mostly for the sake of simplicity. However, the price to pay for simplicity is often a loss in terms of realism. As a matter of fact, the constraint we are dealing with is rather complex and is definitely best described by non-linear functions. It is easily understood that price of either mobility or inclusion is a function of their relative quantities. The shape of the constraint is pivotal for our maximization problem: a line or a convex (upward) curve would guarantee the existence of a single pair that maximizes utility, while a non-convex curve would allow for several possibilities, such as multiple local and global optima.[57] The latter case is particularly interesting: as the maximization problem is solved and policy makers come up with equally optimal

[56] Note that I keep the function describing the constraint in implicit terms and avoid using a simplistic additive form such as $B = p_M M + p_I I$. For a discussion on non-linear budget constraints, see Quigley (1982).

[57] It should be noted that the word "convex upward" is used here to refer to a specific property of certain real-valued functions, for which the following inequality holds true for all x and y in their domain:

$$f((1-\alpha)x + \alpha y) \geq (1-\alpha)f(x) + \alpha f(y), \qquad \forall \alpha \in [0,1] \tag{1.34}$$

solutions, choice could be driven not just by the political climate but also by the preferences of the government currently in charge. As a matter of fact, right-wing and left-wing parties have different positions concerning mobility and inclusion. Thinking of the constraint of policy making processes in linear terms would be inevitably reductive, given the extremely changing environment in which they take place and the high level of interaction between policies at all levels. Policy makers need to tackle ever more complex and sometimes not well understood problems, in terms of both causes and consequences. It is important to note that the constraint is further complicated by the geographical scope of the policy. If the policy is to target a very wide and socio-economically diverse area, the number of elements making up the constraint increases and things that can be taken for granted in certain areas may be completely different in other areas. We could say that these differences can be attributed to different social archetypes. By this I mean that different societies, as those making up complex organizations like the European Union, possess different collectively-inherited ideas that shape different social patterns of thought and behaviour with respect to specific issues. In other words, different social entities might react differently to similar situations on the basis of underlying hypotheses internal to their group, non-universally shared and which have existed for a long time. Besides, current conditions in a different jurisdiction translate into different needs and constraints. As mentioned, different policies are in constant interaction. Therefore, a complete harmonization of a specific policy across a wide area is seldom possible, unless the different authorities agree on a larger view. This, however, would be somewhat unrealistic at the moment. For this reason, a complex language policy should not aim at finding a one-fits-all solution. It should rather offer an algorithm or a model that could elaborate on the information provided and come up with an optimal strategy on a case-by-case basis.

If the equality is never satisfied, we can speak of *strict* upward convexity. This is equivalent to saying that, if we traced a segment connecting two points of the convex upward curve, the segment would always sit below the graph of the function between the two points. Note that "convex upward" is synonymous with "concave".

1.7 Conclusions

This chapter aimed at, first, reviewing complexity and, second, showing that the multilingual challenge and language issues in general qualify to be considered complex matters. Therefore, it is legitimate to apply a complex approach to language matters. I have shown that language issues display non-linear behaviours, featuring feedback loops, spontaneous order and emergence. Besides, extreme and unlikely events can have dramatic repercussions. Consequently, policies dealing with language issues should be drafted adopting a specific complexity approach. This is particularly true considering that simulations are a good substitute for real-life experiments when these are potentially expensive and burdensome.

The literature on complexity theory offers a good number of examples of applications of complexity theory to public policy matters. However, complexity theory is only seldom applied to language policies. Therefore, as of today there is no such thing as a complex framework to implement language policies, able to address language challenges in a flexible and adaptive way, taking all non-trivial aspects into consideration. In particular, in the coming chapters I adopt an agent-based modelling and sensitivity analysis approach. The general idea is that, due to the non-negligible presence of randomness, language policies (and, in general, policies addressing situations where the future is unpredictable) call for a complex approach. Therefore, traditional quantitative and qualitative methods need to be complemented by other research methods, such as computer-based simulations. Agent-based models have the great advantage of relating the heterogeneous micro-behaviours of agents[58] with different information, decision rules, and situations to the macro-behaviour of the overall system (Lempert, 2002). My objective is to show that a complex framework is a valuable ally for policy makers. I present some traditional language policy issues and show how they can be studied from a complexity theory perspective. I run simulations in different contexts calibrating the simulators according to different inputs so as to answer questions such as: given a certain set of initial conditions, what is the long term tendency of language use? How does it change following specific kinds of interventions?

[58] I shall clarify here that, throughout this dissertation, I the use the word "agent" as a synonym of "actor" in a simulation model, as is customary in the relevant literature.

Chapter 2

The Complexity of Knowledge Sharing in Multilingual Corporations: Evidence from Agent-Based Simulations

2.1 Introduction

As was discussed in depth in Chapter 1, in the past few decades, scholars of all sciences have been paying increasing attention to aspects of complexity that characterize matters of both nature and society, which gave an interdisciplinary spin to much of the research effort reflected in the literature. The world has always been a complex place, but people were on average less aware of this fact. In his famous book "Turbulence in World Politics: a Theory of Change and Continuity", Rosenau (1990) argues that, until the 50s, people were on average less educated and in general less concerned with global issues as a consequence of limited information availability. As education and access to information have both dramatically increased, people have become increasingly aware of global issues. This has led to the somewhat deceptive impression that, over the decades, the world has become a more complex place. Nevertheless, social systems have indeed become arguably more complex, or at least more complicated. Indeed, they are much more interconnected today than they used to be in the past as a result of the massive progress in information and communication technologies. Scholars in the management and economic sciences have been exploring the issue of complexity since the early 1990s.

In this chapter I argue that complexity theory and agent-based modelling can provide a great support to the research on language issues. This was

quickly mentioned in Chapter 1 and will be discussed in greater detail in this (and the following) chapters. In particular, in this chapter I explore the potential application of agent-based modelling to the study of communication in multilingual workplaces. I analyse the features of communication within multilingual businesses to show that it is an intrinsically complex issue and that it deserves being studied by means of the tools and concepts of complexity theory. In particular, using the software NetLogo, I develop an agent-based model (ABM) that simulates different scenarios, in order to detect macro-dynamics generated by different individual micro-behaviours and corporate policies. First, I review the ideas of complexity and language problems. Then, I present multinational corporations as multilingual complex entities. Finally, I concentrate on the processes of knowledge sharing, knowledge creation and knowledge accumulation within a multilingual working environment.[1] In particular, I focus on the potentially unbalanced accumulation of knowledge across different language groups within corporations as a function of language skills.

The objective of this chapter is first and foremost to explore the potential of agent-based modelling as a tool of complexity theory to study the dynamics of language systems. As a matter of fact, ABMs have been used extensively to explore all sorts of social phenomena in the past few years. Nevertheless, they have only been rarely applied to language issues, and virtually never to issues of language policy. My objectives are therefore to develop an ABM of communication in a multilingual context and to show that ABMs lend themselves very well to the analysis of language matters. Besides, I will discuss the limitations of the model presented here and how they could be addressed in the future. In general, this chapter wishes to contribute to the fields of language policy and language economics by expanding its research methodologies. Although this is mostly a theoretical discussion, whenever possible, I will try to contextualize my analysis with examples from Europe or the European Union. In particular, I draw on several cases from the Swiss context to provide validation to the model. The reason behind this choice lies in the fact that Switzerland, being a multilingual country, provides numerous examples that match well the underlying assumptions of the model.

[1] As is customary, I will use the word "multilingual" to refer to a context where several languages are spoken and "plurilingual" to describe individuals able to speak more than one language.

2.2 Complexity Theory and Language Issues

The effects of the increased level of complexity are tangible and can be observed all around us. Diversity is one of its manifestations. Indeed, one can think of the increased level of cultural and/or linguistic diversity to which one is exposed on a daily basis nowadays and compare it to the rather homogeneous societies of our recent past. In many cities today it is rather common to see entire neighbourhoods where a different language from the majority/official one(s) is spoken, as well as highly diverse districts where several dozens of different languages are spoken.[2] This seems to contradict the generally acknowledged idea that the world is becoming more linguistically homogeneous, as a consequence of the disappearance of numerous small languages. As a matter of fact, many languages are less and less used. Several languages have already "died out", and many more eventually will by the end of this century. To explain this seemingly paradoxical situation, Grin (2003a) distinguishes between *objective* and *subjective* diversity. He speaks of objective diversity to refer to the effective amount of diversity (in several forms, including linguistic, cultural and religious diversity) that exists at a given moment in time throughout the world. Conversely, he speaks of subjective diversity to refer to the amount of diversity to which individuals, on average, are exposed. Once this distinction is made, it is easy to see how the former is decreasing, while the latter is increasing, solving the apparent paradox just mentioned.

Among other things, the global economy has also become a much more interconnected system. As a consequence of global political and trade agreements, contemporary corporations often operate in several countries and have become multilingual entities. This in turn has called for the development of language strategies by those corporations. Indeed, the share of sociolinguistic literature specifically dealing with multilingualism is impressive. Nevertheless, academic contributions by researchers in the management sciences up until the 1990s have often disregarded language-related issues (MacLean, 2006). Furthermore, research specifically focused on the role of communication has often failed to take language into consideration, despite the fact that it has often been cited as a major cause of misunderstandings and a barrier to smooth international information flows (Marschan-Piekkari, Welch, and Welch, 1999). Piekkari, Welch, and Welch (2014) add to this the

[2] This clearly does not mean that this is the case everywhere. Many areas, especially outside large urban conglomerates, have remained to a great extent culturally and linguistically homogeneous or only have a small allophone population.

fact that language has often been subsumed under the larger umbrella of culture without acknowledging its specificities. As noted by Iannàccaro, Gobbo, and Dell'Aquila (2018), an individual's ease in speaking a given language is dependent not only on her linguistic skills, but also on several other factors, such as the knowledge of the social norms that rule the use of different varieties and registers. They also note that languages do not serve only a communicative function, but also a symbolic one, related to aspects of self-identification. Both Spolsky (2009) and Cooper (1989) highlight the fact that dealing with language issues always involves several non-linguistic variables, which have to do, to mention but a few, with the social, political, economic and even religious situation of the community of interest. Besides, as I will show later in this chapter, language problems have a cross-disciplinary nature that makes it hard to come up with a shared set of concepts and definitions. Let us also point out that the undisputed predominance of English-speaking (particularly American) researchers, often insensitive to or unaware of language-diversity issues, could also be an underlying cause of the fact that language issues were often left aside. Nevertheless, MacLean (2006) notes how, from the late 1990s onwards, language issues have received increasing attention within the academic community, roughly at the same time as the transnational model of the global corporation explored by Bartlett and Ghoshal (1992) started to emerge.

Languages form an important aspect of the complexity of the global economy and deserve being studied as a stand-alone variable in the field of complexity theory. As mentioned, multinational companies often find themselves facing language-related issues in their daily management. This "language challenge" often forces companies to confront a trade-off between prioritizing the use of a single corporate language and constantly adapting to the local context and its linguistic landscape. This trade-off stretches over a spectrum that has unrestricted multilingualism on the one extreme and a common corporate language on the other. However, they both come at a significant cost. Unrestricted multilingualism can cause severe inefficiencies in terms of cross-border collaboration, while a common language can shadow talented workers who are not proficient in the selected common language and, quite paradoxically, generate miscomprehensions as a consequence of a non-proficient use (Neeley and Kaplan, 2014). In addition, micro-linguistic behaviours (such as a conversation between two employees) can differ significantly from those encountered at the macro level (such as drafting a financial report for stockholders). Even if we conceived language choices and

behaviours simply as the strategy that guarantees optimality of communication overall, it is easy to see that accommodating one's own individual needs is different from meeting the need of a large and possibly linguistically and culturally diverse community such as a multinational corporation. Managing communication in a multilingual context is a highly complex issue, as it is rooted in a number of pre-existing conditions, it involves several agents co-existing in a heterogeneous environment and has non-negligible repercussions that are hard to trace back to their causes.[3]

The study of language policy and the evaluation of language policy measures has a long-standing tradition. Grin (2003b, p. 30) defines language policy as "the systematic, rational, theory-based effort at the societal level to modify the linguistic environment with a view to increasing aggregate welfare". He goes on to say that "[i]t is typically conducted by official bodies or their surrogates and aimed at part or all of the population living under their jurisdiction". Language policy can also be seen as "the deliberate attempt to change an individual's or community's use of a language or languages or a variety or varieties" (Kennedy, 2011, p. 24). The impact of language policies on people is undeniable and non-negligible and calls for specific research efforts completely focusing on them. Nevertheless, as discussed in Chapter 1, scholars in this domain have not yet agreed on a comprehensive theory of language policy. Language policies are omnipresent in everyday life and they are acknowledged and practiced in all social domains (Ricento, 2006). There is no single academic science that can claim that language policy is an object of analysis falling within its exclusive domain. Language policy remains hitherto a rather fragmented field of research, deeply rooted in specific sciences such as, to mention but a few, linguistics, sociology, law, political sciences, geography, economics, and many of their sub-fields. Many studies concern communication strategies within private business, and many of them acknowledge the complex nature of this issue. However, these studies seldom adopt a genuine complexity theory approach. A notable exception is represented by a position paper by Beckner et al. (2009), in which the authors examine in depth the reasons why languages and language-related issues are intrinsically complex. Among other things, they note that languages simultaneously shape and are shaped by social behaviours and interactions. Therefore, language is at once a manifestation of the complexity of human cognitive abilities (in that it results from communication among individuals,

[3]For an in-depth review of the characteristics of complex systems, readers can refer to Chapter 1 of this dissertation.

an articulate coordination process that involves, among other things, formulating a message in a way that maximizes simultaneously the clarity of its content and the potential for the listener to interpret it correctly) and a factor that can shape human cognition. In light of the numerous considerations made by Beckner et al. (2009), a complexity theory approach that uses agent-based modelling to analyse language matters seems justified.

2.3 Corporations as complex multilingual entities

As mentioned, the process of globalisation resulting from the numerous political and trade agreements of the past decades has led to the redefinition of corporations as large-scale, organizationally complex and culturally diverse entities. Besides, progressively wider free-trade areas, such as the European common market or NAFTA, have increased opportunities for businesses to expand their customer base, which nowadays often extends over the entire globe even for small- and medium-sized enterprises.[4] In particular, in cases such as the European common market, widening the free exchange area comes with an exponential growth of diversity both in cultural and linguistic terms (27 member states, 24 official languages plus several regional and minority languages, since 1st February, 2020), as opposed to less linguistically heterogeneous areas, such as Mercosur in the South-American sub-continent, with four full members, seven associated countries, one suspended member and two observers, but only three official languages (Spanish, Portuguese, and Guaraní).[5]

Many researchers have noted that corporations can be placed on a spectrum that stretches from local and centralized companies to global realities in which it is hard to locate one or even more centres. As early as the 1980s, Porter (1986) spoke of several typologies of international corporations, whose

[4] To show to what extent doing business with customers can be an extremely multilingual activity, Tietze et al. (2016) mention a study from the University of Manchester discussing, among other things, how commercial signage in Chinese, Urdu, Polish, Arabic and Bengali and other languages is a common business practice within the city of Manchester.

[5] Clearly, this remark only refers to those languages that have an official status in South America, *de facto* or *de iure*, the most recurring being Spanish and Portuguese, followed by Guaraní, and, to a lesser extent, English, French, and Dutch. Autochthonous languages of South America only have regional recognition, if any. The only notable exception to this is Bolivia, whose constitution explicitly lists Spanish along with 36 indigenous languages (some of which even extinct) as official. Besides, it should be noted that the multilingual nature of the European common market is a consequence of the fact that Europe has been a multilingual continent long before any integration process was started, and not the other way around. Each small expansion of the European Union (and of the common market) came almost systematically with the addition of at least one new language.

strategy and structure is highly dependent on the type of industry they operate in. These industries can be multi-domestic (one which is present in many countries but in which competition occurs on a country-by-country basis, implying the adoption of strategies based on local conditions), global (where the competitiveness of a firm is interconnected with and highly affected by firms in other countries and where strategies cannot neglect global conditions) or any nuance between these two extremes. As a consequence, corporate strategies also vary along an equivalent spectrum, from essentially country-centred strategies for multi-domestic companies to globally coordinated actions for global corporations. Referring to the typology of multinational corporations (ethnocentric, polycentric and geocentric) in terms of their identification, information flow and complexity proposed by Perlmutter (1969), MacLean (2006) notes that the same typology can be used to discern among different approaches to language management. On the one side, language is seen as a minor issue in ethnocentric and polycentric corporations, in that communication will mostly happen in the home language or in the subsidiary language. On the other side, language is a much more complex issue in geocentric corporations, as the continuous flow of information across countries and within a linguistically diverse workforce necessarily calls for a better designed approach. In a world where business tends towards a transnational model, language obviously takes on a crucial strategic value for key issues such as knowledge management. Likewise, it is likely that managers will no longer see language diversity as a nuisance, but rather as an element of competitive advantage, provided that internal communication is managed effectively. Indeed, the fact that employees are proficient in the corporate language does not imply that their customer base is too. As a matter of fact, the value added deriving from, say, the ability of employees to address customers in their native language might more than compensate the costs of managing linguistic diversity. On the contrary, a staff that is only proficient in the corporate language might reduce communication costs within the corporation, but it might hinder communication with the outside. Yanaprasart (2016) notes that the approach to language management also varies along a spectrum that stretches from monolingualism to multilingualism. Looking at a number of Swiss corporations with a linguistically diverse staff and customer base, she notes that different models of corporate language management are associated with different combinations of corporate, official, administrative and national languages and are strongly

dependent on the specific setting.[6] She notes that every strategy comes with its set of advantages and disadvantages. On the one side, having a single international language, such as English, as a working language at a corporate level gives access to a pool of talents that stretches beyond the boundaries of the country where the headquarters are located. On the other side, multilingual communication seemingly allows for a richer and more critical discussion among employees. Besides, it avoids putting non-native and native-speakers of the corporate language in an "us vs them" situation. However, unrestricted multilingualism risks seriously hampering knowledge transfer, whereas imposing a single corporate language is often associated with the creation of language hierarchies to the detriment of those who have limited proficiency in the *lingua franca*.[7] It should also be noted that arguments in favour of monolingualism as a way to facilitate information flow and provide a sense of unity among employees are often based on the somewhat unrealistic and deceptive assumption that everyone is fully fluent in the corporate language. Even in those contexts where the use of a single language is officially mandated, it is not unusual to observe that communication among employees, especially informal communication, happens in a collection of different languages, leading to situations of marked diglossia and/or bilingualism.[8] In any case, regardless of the approach chosen and its pros and cons,

[6] These results stem from a purely qualitative study, so they should not be immediately extended to the entire Swiss context. However, they fit well in this discussion and support the point that multilingual strategies are often the result of a trade-off.

[7] In this regard, there seems to be a certain awareness of the psychological and power implications of language imbalance. Bruntse (2003) discusses the case of the Danish-Norwegian-Swedish airline SAS which explicitly opted for an informal mix of the three languages (known as "SASperanto") as a working language rather than specifically one of them in order to avoid power imbalances. This case is an interesting example of intercomprehension. For more on this, see Section 2.6 of this chapter.

[8] In short, diglossia refers to those situations in which two languages are spoken within a community for different purposes (such as Swiss German and Standard German in German-speaking Switzerland). Conversely, bilingualism describes those situations in which two languages are spoken within a community with no differences in terms of purposes or prestige (such as French and Dutch in Belgium). Diglossia and bilingualism are not mutually exclusive. For more on this, see Fishman (1967). Interestingly, diglossia and bilingualism (whose definitions are much more articulate then those presented here) provide fertile ground for the development of an *ad hoc* agent-based model. Indeed, both diglossia and bilingualism can be broken down into a number of individual properties and behavioural rules (such as the frequency with which one language is used rather than the other, the perceived status of each language, and the level of fluency in each language) that then bring about results at community level. One could also go as far as to argue that diglossia and (societal) bilingualism could be conceived as "emergent properties" of individual bilingualism combined with a specific set of behaviours. As mentioned in Chapter 1, systems are said to display "emergence" when they exhibit novel properties that cannot be traced back to their individual components (Homer-Dixon, 2010), but that result from their interaction. More in this regard will be discussed in Chapter 3.

language-related issues must be addressed, one way or another. Appointing a language officer to manage the language strategy is therefore a necessary measure in multilingual realities (Piekkari, Welch, and Welch, 2014). Such an officer, or "language champion" as Piekkari, Welch, and Welch (2014) label her, would be in charge of the articulation and implementation of the language strategy and would be involved in all language-sensitive corporate activities and initiatives, such as mergers and acquisitions and entry into new markets. The presence of a high level officer directly involved in language issues would make sure that such problems are not overlooked or dismissed as unimportant by the top management.

As rightly pointed out by Sanden (2015), corporate language policies are an inherently interdisciplinary matter firmly rooted both in the management and in the language sciences. Indeed, interdisciplinarity (or, rather, the need to be studied through an interdisciplinary approach) is a recurrent trait of complex issues. Besides, language policies have an inner articulation that distinguishes between different types. At a general level, we can already distinguish between public and private policy. Then, we can go on to make increasingly more precise categorizations based on a number of factors, such as the domain in which policy interventions fall (e.g. education, judicial authorities, cultural activities, trade) or their type of planning (i.e. status planning, which concerns the social role of the language, or corpus planning, which concerns, among other things, vocabulary and grammar).[9] Corporate language policies, in particular, are a context-specific kind of policy, in that they are language policies specifically developed in the context of business organizations or business units within an organization (Sanden, 2015). In this concern, a good definition is provided by Sanden (2016, p. 274): "corporate language management can be described as an approach where a company plans, designs and implements a language regulation based on a strategic evaluation of the language needs of the organisation". It is worth noting that, in management practices, the notion of corporate language policy often boils down to mandating the use of English as a *lingua franca* within a multilingual corporation. The focus of these policies is on communication and knowledge transfer and, as observed by Piekkari and Tietze (2011), the major driver is often the "one language fits all" idea. Yet, as I argue in the rest of this chapter, this practice is not a remedy for all communication issues in multilingual corporations. Quite to the contrary, this practice can lead to issues of power

[9] For more on the classification of language policies, see Grin (2018b).

imbalance and hierarchization across language groups, loss of important information, and exclusion of some employees (Lønsmann, 2017).

It is clear, then, that today's businesses, especially multinational corporations, need to manage a linguistically more diverse personnel (within and across branches), as well as to meet the demands of a multilingual customer base. However, multinational corporations are not simply adapting to an increasingly globalised world. The process of adaptation triggers a feedback loop in which corporations also affect the societies in which they operate by putting more and more pressure on employees to become multilingual and by selecting them on the basis of their level of fluency in different languages. This in turn has an impact, among other things, on education, increasing the importance of language skills in school curricula and the demand for language courses. Therefore multinational corporations exist in a complex environment. This might sound hardly surprising to some, but providing arguments to support this fact was a necessary step towards the application of a complexity theory approach.

2.4 Knowledge management and the process of knowledge accumulation and sharing

Knowledge has become one of the key assets of successful firms and a crucial element in the process of value creation (Grant, 1996). According to Floridi (2010), it is at the core of a scientific revolution that changed how humans see themselves and the world, as was the case for the Darwinian, the Copernican and the psychoanalytic revolutions. This has become especially true following the fast-paced development of communication technologies, which led people to rely on information exchange much more than they used to in the past. Floridi (2010) goes as far as to say that individuals are informationally embodied organisms, the "inforgs", that populate a world dominated by information, the so-called "infosphere". In this reality, the barrier between the offline world and the online world, where information lies, tends to become thinner.

Grant (1996) notes that one of the main characteristics of knowledge is its transferability, especially when speaking of *explicit* knowledge (that is, knowledge which is codified and can be communicated, as opposed to *tacit*

knowledge, which is not codified and can only be observed through its application or once it has been codified and externalized). Knowledge transferability is highly dependent on the absorptive capacity[10] of the recipient, which, in turn, depends on a number of criteria, such as language. Grant (2009) notes that knowledge aggregation is greatly enhanced when knowledge can be expressed in a common language.[11] Likewise, the lack of a common means of communication is seen as a major barrier to the introduction of knowledge-intensive manufacturing techniques. Finally, knowledge is often treated by economists as a public good and, consequently, due to its non-rival nature, he or she who owns knowledge can decide to share it with someone else without actually losing any of it.[12] All of these characteristics of knowledge are particularly evident if one takes a cognitivist perspective on knowledge, which views knowledge as a quantifiable amount of information that can be stored and shared.[13] As I discuss in the next section, this characterisation of knowledge lends itself particularly well to our modelling purposes. In this regard, it should also be noted that there is no agreement among researchers on whether knowledge and information have different meanings and whether they should be treated as two different notions, the former having a wider scope than the latter (Wang and Noe, 2010). To our purposes and for the sake of simplicity, no such distinction shall be made.

A technical definition of information that lends itself very well to our modelling purposes is provided by Floridi (2011). He states that σ is an instance of information if and only if:

1. σ consists of one or more data;
2. the data in σ are well-formed;
3. the well-formed data in σ are meaningful.

For the purposes of this chapter, parts 1 and 3 of the definition are taken for granted, i.e. I assume *a priori* that the piece of information that one wants to convey consists of facts and that the data contained in it are meaningful to the listener. Part 2 focuses on how the information is constructed, stating that

[10] Absorptive capacity is defined by Levinthal and Cohen (1990) as "[the] ability to recognize the value of new information, assimilate it, and apply it to commercial end".

[11] It should be noted that his definition of language is not strict and includes, for example, statistical and accounting indicators.

[12] Admittedly, though, one might lose the exclusivity of a specific piece of information, where much of the value of information may indeed reside.

[13] For a thorough review of the different ways of defining knowledge, see Venzin, Krogh, and Roos (1998).

"the data are clustered together correctly, according to the rules (syntax) that govern the chosen system, code or language". Although Floridi clarifies that the concept of syntax should not be interpreted in a strictly linguistic sense, in our case it is immediate to see that a poorly formulated message caused by limited language skills has an impact on information and its transferability. As I discuss in the next section, this is taken into account in the model of knowledge transfer presented here by means of a specific parameters that captures the level of fluency of each agent.

Knowledge sharing is an essential practice within organisations and it is crucial for keeping a competitive advantage. Therefore it is always highly encouraged by managers, albeit with much difficulty (Bock et al., 2005). For the purposes of this chapter, I shall refer to knowledge sharing (or knowledge transfer) as defined in Ajith Kumar and Ganesh (2009): "a process of exchange of explicit or tacit knowledge between two agents, during which one agent purposefully receives and uses the knowledge provided by another". I shall also point out that the expressions "knowledge sharing" and "knowledge transfer" have often been used interchangeably in the literature (Renzl, 2008). Ajith Kumar and Ganesh (2009) go on to define agents as "an individual, a team, an organizational unit, the organization itself or a cluster of organizations". As we shall see in detail in the next section, the basic agents of the model presented here are individuals. The exchange process involves the act of giving knowledge by one agent (the source) and the act of receiving knowledge by the other (the recipient). It goes without saying that a shared means of communication is a necessary requirement for this process to take place. Indeed, Lønsmann (2017) observes that failing to consider language competence issues can seriously hinder communication and knowledge transfer.

2.5 An agent-based model of knowledge sharing and accumulation

The use of agent-based modelling to explore the dynamics of complex systems has slowly established itself as a common practice in the last few years, first in the natural sciences and then in the social sciences. Some scholars have developed models to explore language dynamics (for example, Vogt

and Haasdijk 2010), as well as the process of knowledge sharing within corporations (for example, Wang et al. 2009). For language policy-making purposes, computer-based simulations can help, for example, with the prediction of language needs and the subsequent design of language services accordingly. Also, they can be used to produce long-term projections and to compare between different scenarios where different measures are (or are not) implemented. However, agent-based modelling has never been applied to explore the dynamics of knowledge sharing within corporations resulting from the interaction individuals speaking different languages. Even though it seems rather obvious that knowledge sharing mainly occurs through communication and that language is a key element of communication, there are only quick and superficial references to it, if any, in most studies on knowledge sharing. This is surprising, as languages influence knowledge-related dynamics in several ways. Referring to a number of different studies, Chua (2002) mentions three ways in which a shared language influences the conditions for the sharing and development of knowledge:

1. it facilitates access to others and their information;
2. it can provide a common conceptual apparatus in the context of knowledge creation;
3. it enhances the capability of sharing, transferring and combining knowledge.

Before I move on to present the model, a few clarifications about the use of ABMs in general are necessary. Possibly the single most important value added of ABMs is that, being based on iterated equations, they allow for a good deal of randomness and even account for chaotic solutions, with no need to make the model convoluted. On the contrary, ordinary differential equations cannot do that, while systems of stochastic differential equations can only do that with a great deal of complication. Another value added of ABMs is that they are explicit models, in that all the assumptions and the logical relations among variables are completely transparent and can be checked for consistency or modified by all users. It is possible to calibrate the variables to reflect real cases (Epstein, 2008). Consequently, ABMs are particularly useful for sensitivity analysis. Finally, it should be noted that, although they can be used for prediction, ABMs are particularly suited for exploratory purposes, for example to spell out causal links and clarify relationships among variables.

Concerning specifically the model presented in this chapter, a few clarifications are also necessary. First of all, it starts with a context that is *a priori* multilingual. Although the model can be easily calibrated to replicate a monolingual context and compare it to a multilingual one, my goal here is to explore the dynamics of knowledge exchange and accumulation within a context that already *is* multilingual, resulting, for example, from a cross-border merger or acquisition. Besides, I start from the acknowledgement that the world in which large multinational companies exist and operate is indeed multilingual. I do not speculate here on how a monolingual world would function and whether a monolingual world would be better or worse. Therefore, I speak here neither in favour nor against linguistic diversity, it is taken as a given. Concerning the value of language, language is approached here only in terms of its instrumental value, i.e. as a tool for communication. I do not consider the cognitive added value of being multilingual, nor the synergy that stems from multicultural collaboration. In regard to the latter point, one might think of people speaking different languages but sharing a similar cultural background. Both aspects can be modelled by adding specific variables that could be included in future versions of the model. However, as the objective of this model is to show the potential of using ABMs to deal with language-related issues rather than making accurate projections, it is, for the time being, kept as simple as possible.

Finally, having mentioned the advantages of computational models, it is also necessary to present their main limitations. Although an in-depth discussion of the epistemological limitations of computer-based approaches is far beyond the scope of this chapter (as well as of this dissertation), a few words on this matter are necessary in order for the reader to have a better understanding of this type of modelling strategies.[14] Ever since the introduction of computational models, scholars have asked themselves to what extent one could rely on them as the epistemological core of future research. One of the common concerns associated with the application of computational models to society is that, just as any other formal model, they are reductionist and unable to replicate the complexity of the human mind. This criticism can be addressed by pointing out that computational modelling is often done in a reconstructionist perspective, by which the researcher breaks a complex phenomenon down into smaller pieces and then put them back

[14] More on the limitations of agent-based modelling is said in Chapter 5.

together to replicate it. Although I recognize the limitations of computational modelling, the model presented in this chapter does not attempt to explain the cognitive processes underlying multilingual knowledge exchange. Rather, it takes the exchange of information as a given and tries to see how multilingualism affects the flow of knowledge. This can certainly be seen as too much of a mechanistic approach. However, as shall become clear in the following pages, my objective here is not to give a full explanation of the process of multilingual knowledge transfer, but only to integrate and contribute to a wider discussion, which is clearly much more articulate and should be addressed by multiple methodological perspectives.

2.5.1 Model specifications

The characteristics of the model are as follows:

1. the environment of the model is a multinational environment (for example, a corporation) where multiple individuals coexist and interact;

2. the linguistic environment is allowed to vary between monolingualism and multilingualism (up to 5 different languages) – the multilingual environment can be thought of as the result of a recent merger or acquisition;

3. each individual is assumed to have one native language (L1) and to be fully competent in it;

4. initially, the distribution of L1s is (almost) uniform, i.e. the amount of speakers of each L1 is roughly the same;

5. individual agents are allowed to be either monolingual or plurilingual with foreign language skills ranging from 0 (no competence) to 1 (full competence) based on a truncated normal distribution (only allowed to take on values between 0 and 1) whose mean and variance can be calibrated – for the sake of simplicity, a plurilingual individual in a multilingual context with n languages is able to speak $n - 1$ foreign languages (beyond her L1, in which she has competence equal to 1) at the same level of fluency with no distinction between receptive and productive skills (in other words, in a trilingual scenario, she speaks her L2 as well or as poorly as her L3);

6. each individual agent possesses a level of knowledge that increases by interacting with other individuals up to a maximum, which we can see as her "knowledge maturity" level;

7. if the "retire?" option is on, when old enough, an individual retires;

8. based on a layoff rate, individuals who have accumulated less knowledge than the average of their peers with the same amount of time in the corporation might be laid off;

9. when one leaves, a new one is hired on the basis of the strategy implemented:

    - if a diversity-saving strategy is adopted, for every person of a given language group that leaves, a new one from the same language group is hired – this strategy keeps the level of diversity constant and equal to the moment when it is implemented;
    - if a knowledge-maximizing strategy is adopted, for every person who leaves, one is hired whose L1 is one of the languages of the individuals who have a higher-than-average level of knowledge – this means that, if the majority of individuals with greater knowledge speaks language A, there is a higher probability that the new one is selected among speakers of A;
    - if a random strategy is adopted, the new employee is hired at random.

I should devote a few words to commenting the "diversity-saving" strategy, which might sound peculiar to some. Indeed, it is probably more usual to see companies that are committed to making no discrimination on the basis of a number of characteristics, including language background. This is, however, quite different from the overt willingness to maintain a specific distribution across language groups. As a matter of fact, this is not an unusual practice at all and the Swiss Confederation is an example of that. Article 20 of the Federal Law on the National Languages and Understanding between the Linguistic Communities states that:

> "La Confédération veille à ce que les communautés linguistiques soient représentées équitablement dans les autorités fédérales [...]."[15]

[15] For the full text of the law, see https://www.admin.ch/opc/fr/classified-compilation/20062545/index.html.

> "The Confederation ensures that linguistic communities are equitably represented within the federal authorities [...]."[16]

Article 7 of the Ordinance on the National Languages and Understanding between the Linguistic Communities (of which an unofficial English translation is available on the website of the Federal Government) provides practical details:

> "The representation of linguistic communities in the federal administrative units [...] must aim to achieve the following ranges [...]:
>
> a) German: 68.5 - 70.5%
>
> b) French: 21.5 - 23.5%
>
> c) Italian: 6.5 - 8.5%
>
> d) Romansh: 0.5 - 1.0%
>
> [...] When recruiting personnel, the employers [...] shall ensure that candidates from all linguistic communities progress from the preselection phase to the interviews, provided they fulfil the objective criteria. Where candidates have equal qualifications, priority shall be given to those who belong to a linguistic community that is underrepresented in the administrative unit in question [...]."[17]

The idea here is clearly that the personnel of the public administration should approximately mirror the overall population in terms of language distribution.

The second hiring strategy, which I labelled "knowledge-maximizing" for the results to which it should reasonably lead, implies a preference for hiring individuals who speak the language of the most knowledgeable individuals as a native language. This means hiring people who have direct access to a greater amount of knowledge. In this concern Vaara et al. (2005) speak of language-based networks, referring specifically to the case of the banking sector merger between the Finnish Merita and the Swedish Nordbanken. Based on the model code, this strategy does not mean hiring people whose native language is the one spoken by the group with the greater amount of

[16] My translation.

[17] For the full text of the law, see https://www.admin.ch/opc/en/classified-compilation/20101351/index.html.

group-wise *aggregate* knowledge (i.e. the sum of the knowledge of each individual belonging to a given group). Rather, the model looks at employees with individual knowledge greater than the overall mean (of all groups) and then selects one of their languages to hire the new employee. Considering that the initial distribution of languages is roughly uniform, the effects of this policy are negligible at first but tend to increase rapidly over time. Eventually, it is able to turn a slight numerical advantage into an overwhelming superiority for a specific group, whose language becomes the *de facto* corporate language. Peltokorpi and Vaara (2014) speak of language-sensitive recruitment when language skills and, in particular, fluency in the corporate language represent a crucial determinant in the hiring process. Such a practice is often considered the quickest and most effective way to get rid of barriers to knowledge transfer due to multilingualism (Lester, 1994). Nevertheless, Peltokorpi and Vaara (2014) discuss certain fallacies related to such a practice. Specifically, they mention:

1. the case of the South Korean and Japanese subsidiaries of an MNC having trouble finding highly proficient English speakers due to a shortage on the local market, and

2. the case of a German MNC that faced difficulties because of its continued practice of hiring employees on the basis of their English rather than their technical competences.

2.5.2 Interactions

When the simulation is started, the following happens:[18]

1. at every time step, individuals move towards a randomly assigned group to work together – the number of groups and their dimension can be calibrated. One can think of these groups as brainstorming meetings or focus groups, whose participants have some knowledge on a given topic and are called to work together on a specific issue;[19]

2. when all the groups are formed, each group agrees on a language to use for communication based on a simple rule: the language chosen is always the L1 of the majority within each group – in the (admittedly rare)

[18]The complete code of the model is available in appendix B.

[19]The part of the code concerning the grouping motion is largely based on the "Grouping Turtles Example" model developed by Uri Wilensky and available in the library of the NetLogo software.

case of two equally represented languages, one of the two is randomly selected;

3. thereafter, individuals communicate – each group member contributes to the process of knowledge creation as a function of her L1 and of the language chosen for communication according to the following formula:

$$C_i = r_{in} \frac{K_i}{K_{max}} \tag{2.1}$$

where C_i is the contribution to knowledge creation of individual i, r_{in} is the level of competence of individual i in language n (which is 1 by default for her L1, and ranges between 0 and 1 for her non-L1 languages), K_i is her level of knowledge and K_{max} is the maximum amount of knowledge that an agent can acquire, that is, the level of knowledge where an agent reaches maturity (the same for everyone). Equation 2.1 roughly captures two phenomena. First, the variable r captures the fact that one's ability to contribute to a discussion is inevitably dependent on one's ability to articulate a speech in a given language. Second, the K_i-to-K_{max} ratio captures the idea that more knowledgeable individuals will most likely lead the discussion and contribute more to the process of knowledge creation as a function of their own experience, and also that groups whose components are on average more knowledgeable produce relatively more new knowledge.[20] In a group of m individuals, total shared knowledge T will be equal to:

$$T = \sum_{j=1}^{m} r_{jn} \frac{K_j}{K_{max}} \tag{2.2}$$

4. at the same time, each member acquires an amount of knowledge equal to the sum of contributions minus her own contribution. The theoretical justification for this is a bit more subtle than the ones provided so far. According to the theory of knowledge by Nonaka and Takeuchi (1995), new knowledge is created through a process that turns each individual's *tacit* knowledge into *external* or explicit knowledge, which then

[20] As has been stressed, the goal of this chapter is not to make predictions about *how much* new knowledge is created within multilingual corporations. My goal here is to look at different language strategies and how they compare in the process of knowledge sharing and accumulation, beyond exploring the potential of ABMs to study language-related issues. As a consequence, it is not crucial to have accurate numbers, as long as the way in which knowledge creation happens is reasonable.

gets shared and reinternalized. As a consequence, it is reasonable to assume that each person reinternalizes only that part of tacit knowledge that was externalized by the others. This also accounts for the intuitive fact that less knowledgeable individuals acquire more new knowledge with respect to more expert colleagues (for the simple reason that there are more things that they do not know). Once again, how much knowledge one is able to gain depends on her L1 and on the language chosen for communication. All the knowledge that was expressed in a given language has to be "filtered" through the receiver's understanding of that language. Therefore, each individual acquires new knowledge L equal to:

$$L_i = r_{in} \sum_{j=1, j\neq i}^{m-1} r_{jn} \frac{K_j}{K_{max}} \tag{2.3}$$

5. after communication has taken place, all agents are dispersed, assigned to a new group and the process starts again.

To see how knowledge sharing and acquisition happen within groups as a function of each member's L1 and of the chosen language for communication, I shall consider the case of a two-person group. Pairwise, if we consider two individuals, a and b, with full competence in their L1 and, respectively, levels r_a and r_b (with $0 \leq r_i \leq 1$) in their non-L1 languages, we will witness the dynamics presented in Table 2.1.

		a gives	
		$LC = L1$	$LC \neq L1$
b gets	$LC = L1$	$\frac{K_a}{K_{max}}$	$r_a \frac{K_a}{K_{max}}$
	$LC \neq L1$	$r_b \frac{K_a}{K_{max}}$	$r_a r_b \frac{K_a}{K_{max}}$

TABLE (2.1) Knowledge sharing between two individuals

Let us consider the two columns under "a gives" first. If the language chosen for communication (LC) is a's L1, she will contribute to the "shared knowledge pot" with 100% of what she is able to give (the value of the variable r for her L1 is always 1). Conversely, if LC is different from her L1, she will be able to contribute by an amount that depends on her level of competence in LC (r_a) which can vary between 0 and 1. Symmetrically, if we look at the "b gets" rows, we will see that b is able to get 100% from the knowledge pot if LC is her L1, while she will be able to take away a portion r_b if LC is not her L1. If LC is the L1 of neither a or b, a will only be able to give r_a

of knowledge and b will get r_b of it (that is, $r_a * r_b$).[21] No need to say that each member is both giver and taker of knowledge. Therefore, in this case, a symmetrical discussion can be made about b passing some knowledge to a (meaning that we could construct a second matrix with roles reversed).

One can think of this process as the idea that an individual will be able to express 100% of her thoughts, in terms of precision, nuances, completeness, etc., only if she is fully fluent in the language that she is using, not to mention the feeling of linguistic unease when speaking a different language that might affect the quality of one's speech.[22] At the same time, the recipient of a message will inevitably miss a certain amount of detail or nuances if she is not fully fluent in the language being spoken. Indeed, Marschan-Piekkari, Welch, and Welch (1999) have discussed at length the fact that communication across cultural borders is often associated with misunderstandings caused by language and other barriers. The larger the distance between the two cultures involved, the harder it will be for the members of these cultures to understand each other, increasing the risk of communication problems. They discuss similar findings from studies on internationalization processes, suggesting that cultural and language differences are a form of hindrance for international flows of information.

2.5.3 Results

Before executing and commenting the simulations, it is important to verify the model, i.e. to check whether it performs computations the way we want it to. Indeed, it is easy to overlook minor inaccuracies in the code that can easily corrupt the model and generate data that are inconsistent with our assumptions. ABMs are often verified through a procedure called "tracing", a type of dynamic testing that consists in comparing the results produced by the computer with the values computed manually by the analyst (Wang et al., 2009). The tracing procedure did not show any inconsistency between

[21] This latter case is obviously only theoretical, in that in a two-person group, LC has to be the language of at least one of them, based on the rules explained above.

[22] On this topic, it is worth mentioning Iannàccaro, Gobbo, and Dell'Aquila (2018), who distinguish between linguistic *insecurity* and linguistic *unease*. The former refers to a feeling of perceived inadequacy of one's own language variety with respect to a socially expected standard norm. The latter refers to a "set of situation[s] in which the speaker's linguistic knowledge is not adequate to the linguistic needs of the moment", that is, whenever the speaker feels that her linguistic competence is not adequate for the linguistic task that she needs to perform (but might be adequate for other linguistic tasks). In our analysis, this would mean that her knowledge of the language is not enough to support her communicative needs, therefore causing a sense of unease that affects her communicative performance beyond her limited language skills.

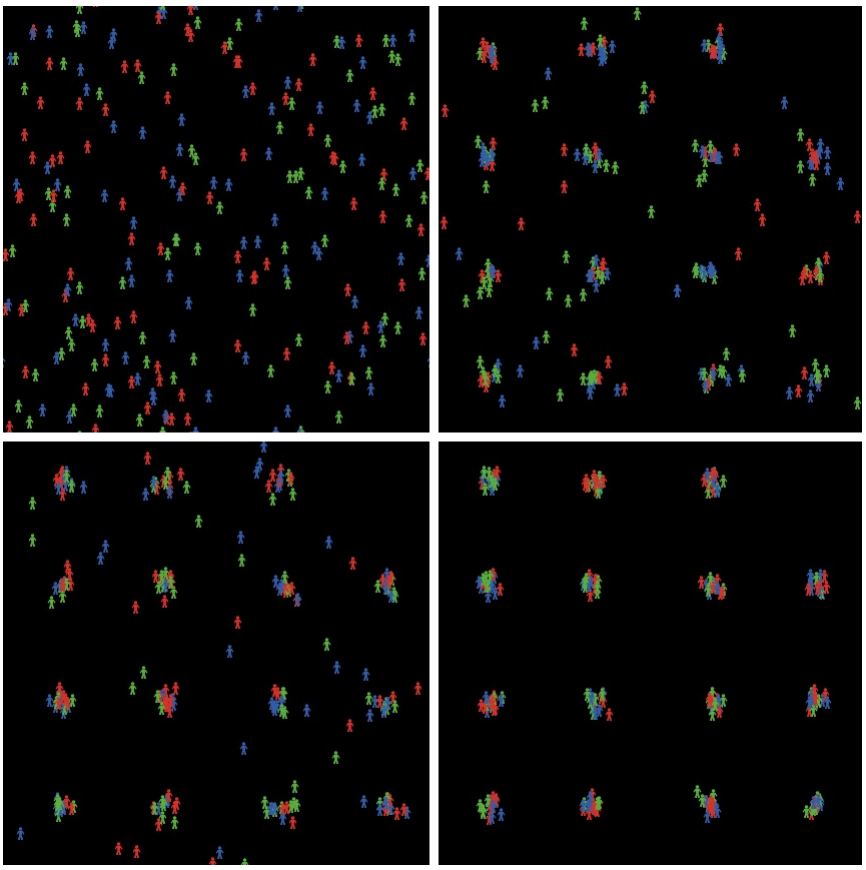


FIGURE (2.1) Grouping motion of individuals.

the code and the expected result. Therefore, I now go on to comment the results of simulations with different starting conditions.

I start by looking at a company with a population of 240 employees where three languages are spoken. I select a grouping strategy based on the number of groups, set equal to 15, therefore we will have 15 groups of 16 individuals. The level of knowledge maturity is arbitrarily set at 100. When the simulation is launched, individuals (who are initially spread over the surface) start grouping up (the motion is presented in Figure 2.1).

When all groups are formed (as in the bottom-right quadrant of Figure 2.1), the members of each group agree on a common language for their group based on the rule explained above and converse. In the first simulated scenario, every individual is only able to speak her L1. This means that only people who speak the majority language of their group will be able to participate in the conversation and, consequently, share and acquire knowledge. For the time being, I keep the layoff rate at zero and do not put any limit to working age. Consequently, I am not interested in selecting different hiring strategies. The reason why I do this is that I want to look at the process of short-term knowledge accumulation for each language group. I present the

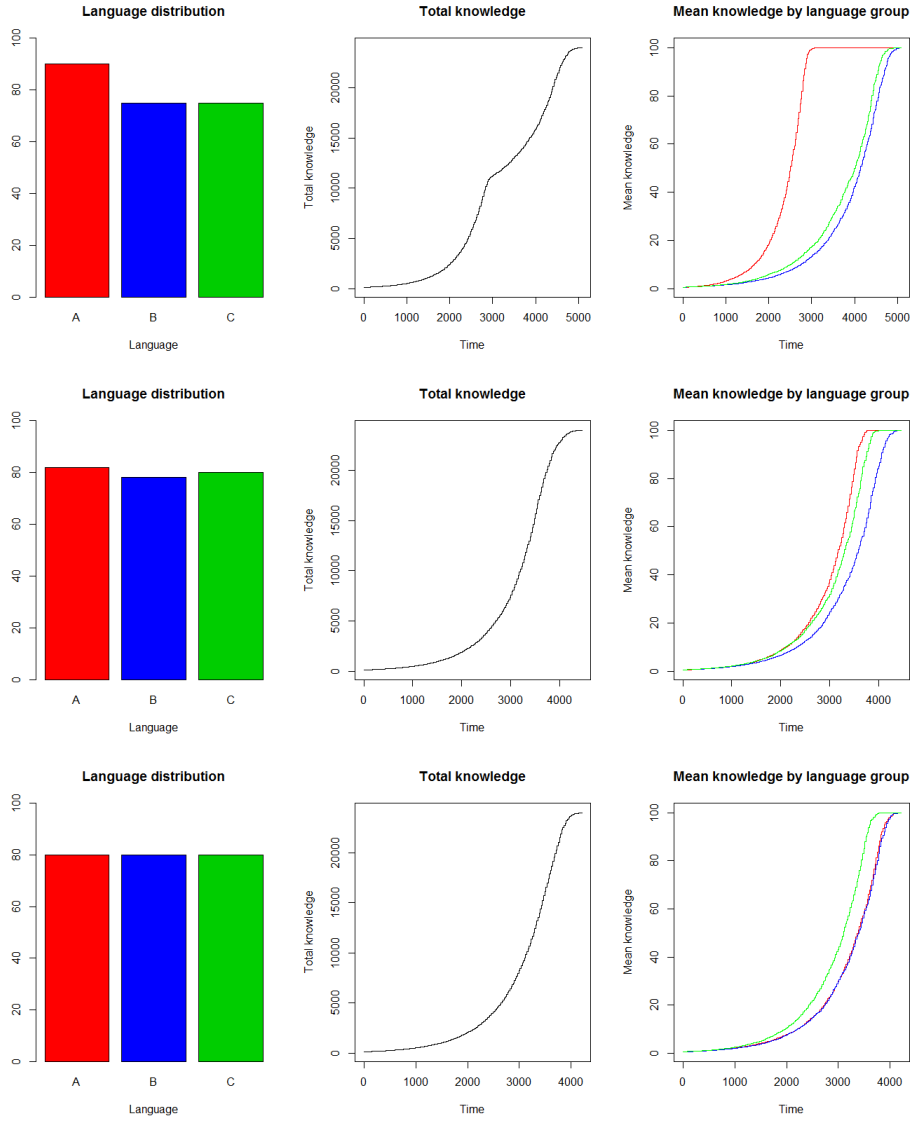


FIGURE (2.2) Monolingual employees, different simulations of short-term knowledge accumulation.

results of different simulations in Figure 2.2.

Each line of plots represent a different simulation with very similar initial conditions in terms of language distribution across employees (reported each time as a bar chart in the first plot). The second plot in each simulation reports the value of total knowledge existing in the company at every time step,[23] while the third one reports the average level of knowledge across language groups. We can notice immediately that, even with negligible differences in terms of language distribution (a few employees), the slightly overrepresented groups reach knowledge maturity much more quickly. Besides, the system displays extreme sensitivity to initial conditions, a typical

[23] With 240 employees and an arbitrary maximum value of knowledge maturity of 100, the maximum total knowledge that can be possibly achieved is 24000.

trait of complex systems. Indeed, differences in knowledge growth increase dramatically with increasingly skewed distributions. Differences in times-to-maturity are also detectable in the total knowledge plot. When differences are small, overall knowledge growth displays a smooth s-shaped curve, typical of learning processes (Kucharavy, Schenk, and De Guio, 2009), as in the second and third sets of plots. Conversely, if different groups reach knowledge maturity at very different moments, overall knowledge growth will display a somewhat irregular trend, as in the first line of plots.

Let us now switch to a context in which individuals are allowed to have multilingual skills. The only difference with the one presented above is that agents here are plurilingual. As mentioned, this implies that they are fully proficient in their L1 and also have a variable level of competence in their L2 and L3 (that varies across individuals, but not across languages for the same individual). The level of each individual is assigned randomly, but remains constant over time. In the following simulations most employees have either no or very limited language skills in their non-L1s (normally distributed around a mean of 0.3). As a consequence, many individuals have now an opportunity to participate in the conversation and acquire new knowledge, though in a very limited way. Results are reported in Figure 2.3.

Beside the characteristics discussed above, we note that language skills, even when limited, make the process of knowledge accumulation in the multilingual environment much more resistant to initial conditions. Even with skewed distributions (as in simulations 1 and 3), growth remains relatively similar across language groups. As shown in Figure 2.4, this is even more the case when average language proficiency is increased from 0.3 to 0.5 (top) and 0.7 (bottom) (for example, as a result of language training among employees). We can also note that, when one language group is larger than the others, knowledge accumulation seems to run faster (as in the three plots on top). This could be due to some sort of "pulling" effect, by which knowledge is created and transferred efficiently among speakers of the same languages and is then quickly passed on to smaller language groups.

Let us now focus on long-term dynamics. In the following simulations employees retire after 35 iterations. The initial distribution of iterations spent in the company is random and normally distributed around 10. The hiring strategy is "diversity-saving" and the layoff rate is again set on 0. In Figure 2.5, I compare (from top to bottom) the monolingual scenario and two plurilingual scenarios with levels of average language skills equal to 0.3 and

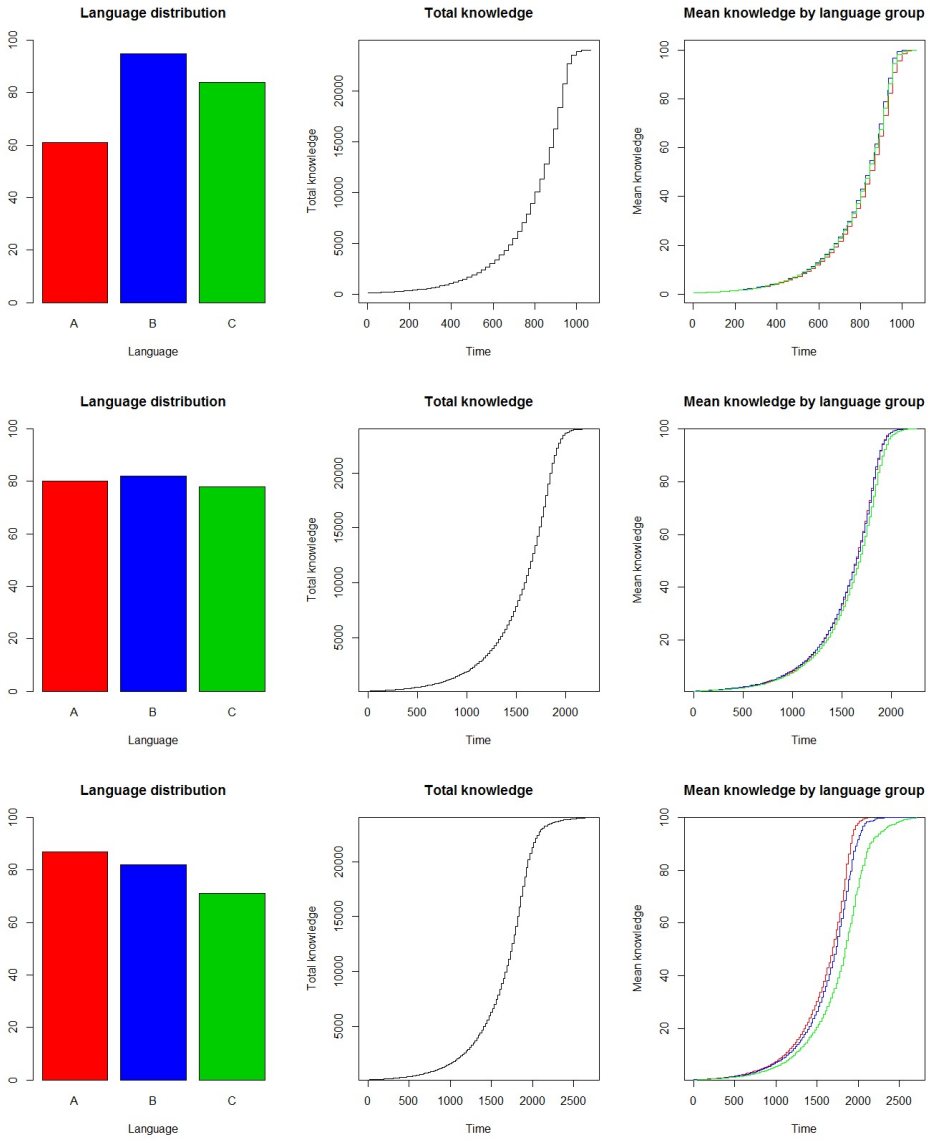


FIGURE (2.3) Plurilingual employees with low skills, different simulations of short-term knowledge accumulation.

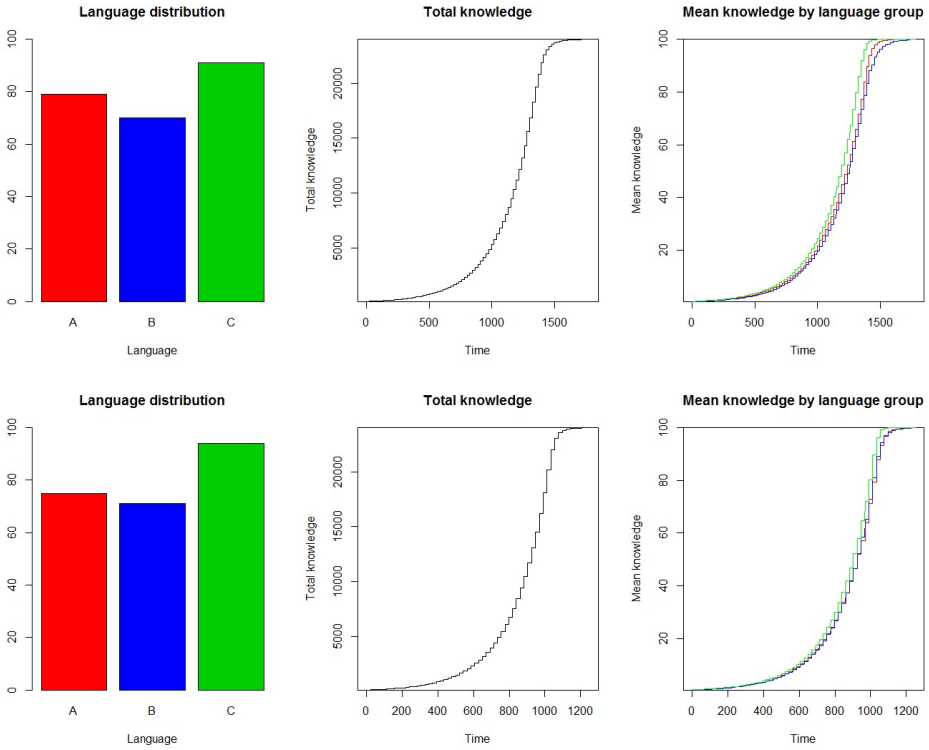


FIGURE (2.4) Plurilingual employees with average skills, different simulations of short-term knowledge accumulation.

0.6.[24]

We notice immediately that the level of knowledge quickly approaches a cyclical trend in all scenarios. Indeed, people acquire new knowledge while they stay at the company, increasing total knowledge as well as its mean value. However, upon leaving, each individual takes her knowledge away with her. This has a particularly strong impact in these simulations in that the only people who leave are retirees, who clearly have a great share of total knowledge. If we look at the monolingual scenario (top), we notice that communication is so weak that people are not working at the company long enough to reach knowledge maturity (arbitrarily set equal to 100). Besides, if we look at mean knowledge by language group, we notice that, even if the distribution of language groups is almost uniform, the language group that had slightly more employees ended up having more knowledge in their hands (the highest line in the third plot), skewing the process of knowledge distribution. Moving on to the other two simulations (plurilingual scenarios), we can observe that language skills are necessary to reach knowledge maturity in a multilingual context within the given time framework, but only if

[24]Note that the scale in the first two graphs of the first and the second simulation is different from the others for legibility reasons.

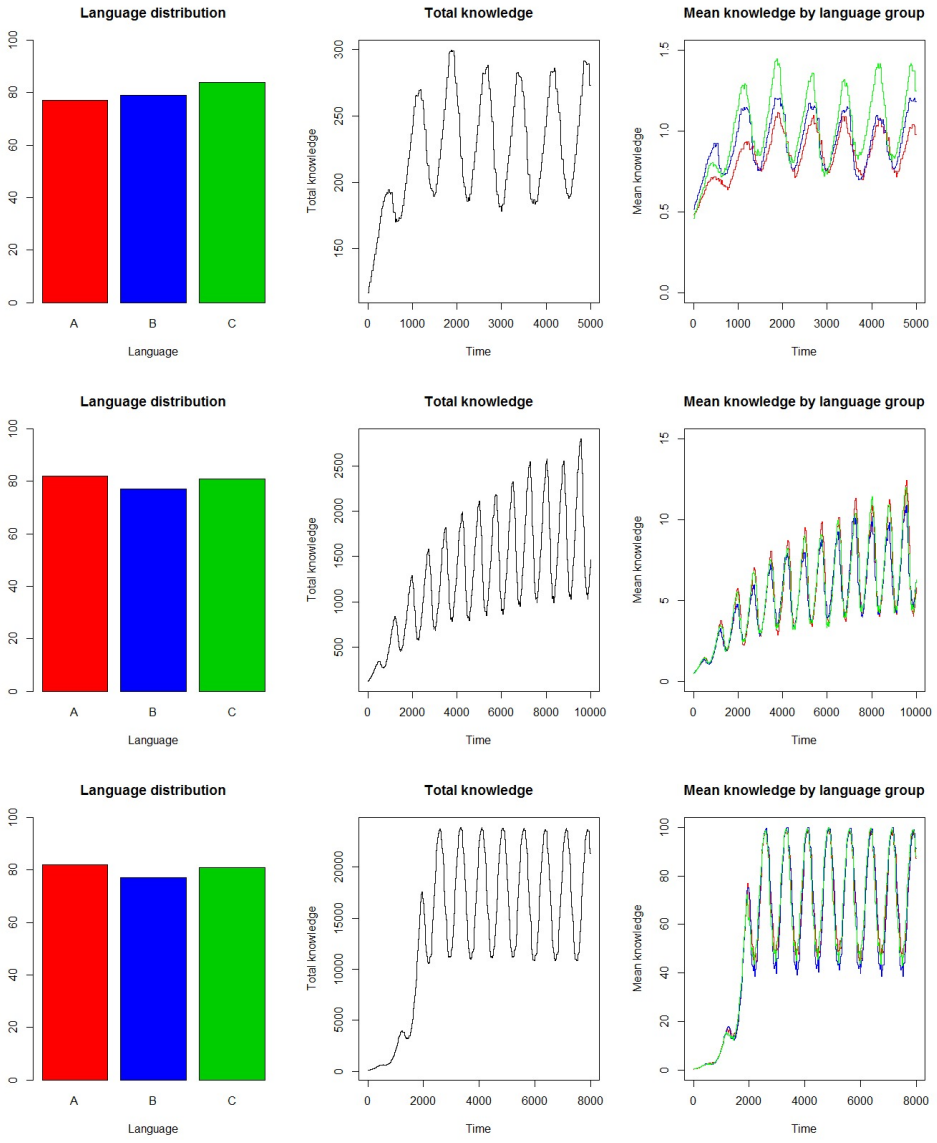


FIGURE (2.5) Trends of long-term knowledge accumulation, monolingual (top) and plurilingual employees with different levels of average language skills (middle and bottom).

they are at least average. Indeed, paying attention to the different scales, we can notice that in the second simulation (middle), where people have only poor language skills (an average of 0.3), the mean level of knowledge never exceeds 15. Conversely, in the third simulation (bottom), where people have fair language skills (an average of 0.6), the mean reaches 100, implying that all employees grow quickly enough to reach maturity.

Let us now look at the consequences of adopting a "knowledge-maximizing" hiring strategy on the company's linguistic landscape. Figure 2.6 shows a comparison between four scenarios. It shows the trend of the Greenberg index.[25] In the first scenario (top-left) agents are monolingual, while in the other agents are plurilingual with average language skills of 0.2 (top-right), 0.5 (bottom-left) and 0.8 (bottom-right). Other conditions are identical and the same as above.

In all cases, the value of the index eventually drops to 0 (perfect uniformity, i.e. one single language group), but in very different ways (for the diversity saving strategy, the index is clearly constant and equal to 0.66, i.e. three equally represented language groups). In the monolingual case, this happens very quickly, in that it reaches zero after about 2500 time steps (x-axis). Besides, it seems to remain constant for a while and then it abruptly plunges to zero after a "no-return" point is reached. Very little language skills do not seem to make any significant difference. Conversely, in the medium and high language skills scenarios, the index decreases in a much more gradual way and, in the scenario with the highest value of average language skills, it only reaches zero after more than 21000 time steps, more than 8 times as long as the monolingual scenario. It should also be noted that these patterns tend to be very consistent and by and large independent from the initial

[25]The Greenberg index is one of the simplest metrics used to compute the degree of linguistic diversity. It is also referred to as the "linguistic diversity index" and was put forward by Greenberg (1956). If we consider a community where n languages (with $n > 1$) are spoken, each individual speaks only one language, and the proportion of speakers of language i is p_i (with $i = 1, 2, \ldots, n$ and $0 < p_i < 1$), the total probability of randomly picking two individuals who have the same L1 is given by the sum of the probabilities of this event happening for each single language (i.e., picking two individuals whose native language is 1, two individuals whose native language is 2, and so on), that is:

$$\sum_{i=1}^{n} p_i^2 = p_1^2 + p_2^2 + ... + p_n^2 \tag{2.4}$$

The Greenberg index, being a metric of diversity rather than uniformity, is then equal to:

$$G = 1 - \sum_{i=1}^{n} p_i^2 \tag{2.5}$$

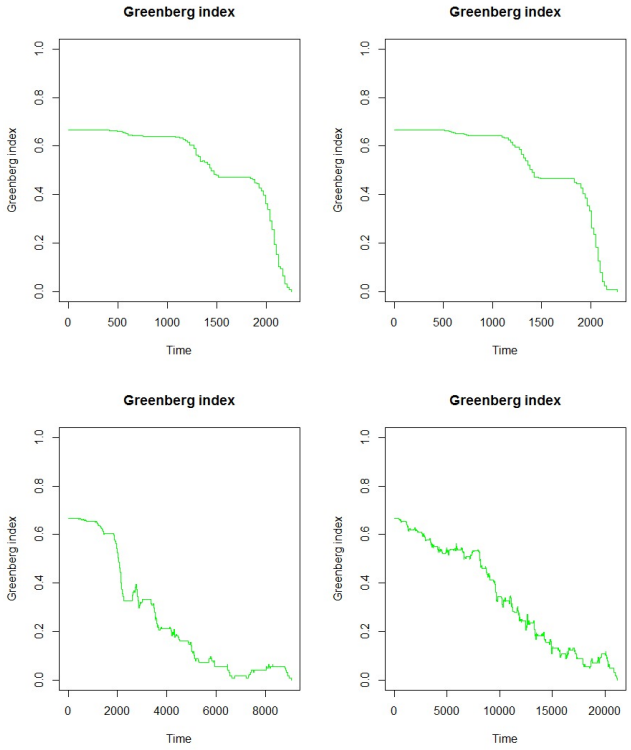


FIGURE (2.6) Trends of the Greenberg index in different scenarios.

distribution of language groups.

2.6 Discussion and future research

Many more simulations with different initial conditions can be performed. In particular, it is worth pointing out that the simulations presented here considered situations where a substantial level of multilingualism was already present at the beginning. I recognize that it is often the case that many multinational corporations are mostly monolingual or strongly biased towards the home language in the initial phases of going international. However, the choice of considering a roughly even distribution of languages among employees as an initial condition is mainly due to the fact that this chapter is partly focused on how different hiring strategies can cause language diversity to disappear over time. As a matter of fact, due to NetLogo's in-built stochasticity, initial distributions are never exactly even and it was noted that even a slightly more represented language group can quickly turn into an overwhelming majority. Therefore, the "uneven distribution" case is already included in the pattern that stems out from the "even distribution".

All in all, we can conclude that agent-based modelling lends itself particularly well to the exploration, among many other things, of language-related dynamics. It can simulate quite effectively communication processes and their implications. The mechanics of the model presented here are based on actually observed practices, such as the hiring practices in the Swiss public administration, aiming at a specific distribution of language groups, and the language-based networks resulting from the Merita-Nordbanken merger, in which new social networks and power imbalance stemmed from specific language policy measures. Besides, a relatively simple model such as the one presented here seems to replicate dynamics actually observed in empirical studies. For example, Neeley (2012) discusses at length the case of a French high-tech multinational firm mandating the use of English for communication. Regardless of this imposition, she observed that different languages were selected for communication depending on the native language of the people involved in information exchange processes, similarly to what happens in the ABM presented here. This eventually resulted in some employees being left out of the information flow. Besides, these dynamics were often associated with a feeling of frustration. Neeley's observations, stemming from a qualitative study, go in the same direction as the results of the model presented here. She not only documented the perceived loss of professional status among non-native English speakers with respect to their English speaking peers, but also the anxiety and subsequent diminished performance due to limited language skills. The model accounts for these conditions in its underlying algorithm. Neeley notes that French-speaking employees with a less-than-full knowledge of English might go as far as to refrain from participating in meetings or calls held in English. This clearly causes discrepancies in the process of information flows, as predicted by the model presented here.

The model can be refined in a number of ways for further research. For example, we could develop the code in order to allow each individual to have different levels in their L2 and L3. Besides, the model presented here can be explored by other users to simulate all sorts of case-scenarios not addressed in this chapter. For example, one might want to investigate how group dimensions affect knowledge exchange, or how personnel turnover affects the cycle of knowledge accumulation. Besides, the model also contains an "intercomprehension" scenario, which is not commented here. Generally speaking, intercomprehension is a multilingual communication strategy in which speakers of different languages rely on their receptive skills

in other languages to understand one another.[26] In our simulation, such a scenario would imply that all agents have full receptive skills (and no productive skills) in their non-L1 languages and are therefore allowed to always express themselves in their own language without fear of not being understood. In such a scenario it would be possible to rule out both the feeling of unease discussed above and the reduced amount of knowledge acquired by or passed on to others due to limited competence in the language being spoken. This should boost the process of knowledge transfer within the organisation. Further discussion of this scenario is left for future research.

Furthermore, the model can be made more realistic. Indeed, the model only considers one simple rule when it comes to language choice, i.e. the language of the majority always wins. However, this can be refined by adding some considerations about the relative importance of individuals. For example, it could be possible to observe strategies that tend to favour more senior employees or that try to be as inclusive as possible in order to maximize the number of participants in a meeting.

As I mentioned, at the present stage, the model does not account for the cognitive added value of plurilingualism and it does not consider the synergy that comes from multicultural collaboration. Besides, it does not include sociolinguistic aspects such as the perception of language status or the reluctance to speak certain languages. Alternatively, a potentially interesting development could be the introduction of a certain degree of homophily, i.e. the tendency of individuals to create bonds with similar others (McPherson, Smith-Lovin, and Cook, 2001) and, in our case, to have a preference for communicating with individuals who share the same linguistic and cultural background. This could be useful to see whether language differences lead to some segregation patterns. Bramoullé et al. (2012) proved theoretically that agents (or, in general, nodes of connections) tend to group more densely with other agents who share a common attribute rather than with those who do not have that attribute. The model presented here could be further developed to include an element of grouping strategy based of homophily. As said, in the model presented here, grouping happens randomly. This choice

[26] It should be noted that, although intercomprehension is often emphasized between related languages (for example, between Romance or Scandinavian languages), a degree of mutual intelligibility between the two languages is not a necessary condition. Indeed, intercomprehension can also rely on previously acquired receptive knowledge of the other language. For more on the topic of intercomprehension in the context of multilingual organisations, see Grin (2008a). However, some authors prefer to use the term *lingua receptiva* to refer to those cases in which mutual comprehension does not only happen between related languages, but also between unrelated languages of which the interlocutors have receptive proficiency (ten Thije, 2013).

was driven by the fact that I was mainly interested in looking at the overall process of knowledge accumulation within the corporation from a macro-perspective. However, it would be interesting to develop a new parameter that increases the likelihood for people who speak the same language to stick together. Alternatively, this could be implemented as a self-reinforcing mechanism by which, every time two people who share the same language meet, the chances that they end up being in the same group again rise. In either case, the main object of interest here would be to see to what extent different levels of homophily (i.e. a greater or lower tendency to group up with similar others) can lead to patterns of segregation and hinder a smooth flow of knowledge across language groups.

Also, it could be interesting to integrate results from qualitative studies of knowledge creation dynamics in order to refine the simulation. This could not be done here mainly for space reasons and the consequent need to keep the discussion narrowly focused on the technical characteristics of the ABM. However, inputs from qualitative studies could provide a way to add realism to the way in which the agents behave. Finally, based on previous research by Kharkhurin (2012) and Fürst and Grin (2018), a variable that models increased individual creativity resulting from multilingualism and multiculturalism could also generate interesting results.

All these features can be accounted for by modifying the source code of the model. Nevertheless, this should be done with caution, in that adding too many details might shadow our variable(s) of interest. Besides, the objective of ABMs is not to provide an accurate computer copy of the real world. Quite paradoxically, assuming we had enough computing power to produce it, this copy would be just as complex as the world that we are trying to explain and we would end up needing a model to explain our model. It is clear, then, that computing power is not *the* solution to all problems. As was mentioned throughout the chapter, language issues call for a complex approach that draws on multiple disciplinary traditions. Computational modelling contributes to the study of language issues by providing a technical configuration to the numerous inputs provided by qualitative studies. If used appropriately, it can incorporate results from a qualitative reasoning, help researchers by providing order to the overall discussion around languages and favour qualitative reasoning in a virtuous circle.

Chapter 3

The Dynamics of Language Minorities: An Agent-Based Model of Language Contact

3.1 Introduction

Language scholars speak of language contact to refer to all those situations in which speakers of different languages (or different varieties of the same language) get to interact with one another and, eventually, influence each other's linguistic behaviour (or, at least, one influences the other). In particular, Thomason (2001) stresses the interaction aspect. The mere juxtaposition of speakers of different languages is indeed not enough to speak of language contact. Interaction is key for one language group to have an impact on the other, be it exchanging linguistic features across speakers or pushing one group to deviate from its usual speaking behaviour (e.g., switching to another language). Among the numerous social and linguistic implications of language contact, *language shift* is one of the most commonly observed phenomena. It can be defined as the process whereby, for a number of reasons, a community shifts to speaking a language different from its own. As a matter of fact, close language contact and perceived lower status are often the cause of language decline and, eventually, language extinction. Nelde (2010) rightly observed that language contact is inevitably followed by some form of conflict, which often comes to the detriment of some less powerful, possibly minority-language community. The idea of conflict should not be strictly interpreted as a violent clash between groups. Rather, it should be seen as a form of competition over limited resources, such as funds devoted to media in one or another language or time spent speaking one language or another.

Hornberger (2010) defines language shift as the gradual displacement of one language by another in the lives of the community members. She notes

that factors contributing to it are complex and diverse. They have been observed to be of political, social, economic, cultural, and, clearly, linguistic nature (Conklin and Lourie, 1983). Over time, governments have implemented numerous policy interventions concerning language decline. Often, the cause of failure has been the presence of non-linguistic variables which were not addressed by policy intervention and eventually played a crucial role in the decline process (as discussed in Section 3.6).

Language contact is a recurring phenomenon in population dynamics and its implications for regional and minority languages represent a complex issue. As I shall argue in the rest of this chapter, the implications of language contact depend on many variables simultaneously at play. The direct consequence of this is that traditional approaches to language issues, which are often studied from one disciplinary perspective at a time, often fail to detect all the factors at play in language dynamics. Surprisingly, the acknowledgement that language issues have implications in social, political and economic terms did not automatically lead to an interdisciplinary approach. In the past few years, many scholars have come to the conclusion that language issues are complex and call for an interdisciplinary approach in order to look at all dimensions simultaneously.[1] Language dynamics are ultimately linked to the complexity of individual language behaviours and their continuous interplay, which develops into collective behaviours and eventually decides the fate and fortunes of every language. Collective behaviours are often hard to predict and disentangle and thought experiments often represent an important tool, in that they go beyond classical observation methods and switch the focus from correlation to causation (Gabbriellini, 2018). Nevertheless, thought experiments may be hard to perform, especially when they concern phenomena that involve somewhat unintuitive or unexpected dynamics. In this context, computer simulations allow to systematically explore the implications of intuition and can make us aware of unpredictable patterns that we would otherwise overlook. In this chapter I develop an agent-based model (ABM) that describes language dynamics as the result of complex interactions. ABMs simulate all sorts of dynamics based on the interactions of individuals acting within a system in which new variables can be added, subtracted and modified to project different scenarios.[2] These variables do not only represent standard information such as the number of individuals and

[1] For an in-depth discussion on the transversal character of language issues, see Grin et al. (2014)

[2] Examples are numerous and include simulations of social identity dynamics leading to group formation (Smaldino et al., 2012), the evolution of grammar and vocabulary (Lekvam,

their linguistic endowments and skills, but also situational conditions, such as social relations, people's attitude towards socio-cultural differences, their propensity to pick up a new language, government intervention in the education system, and so on. Besides, ABM programming tools allow for the calibration of such variables, which respond to - and with - different levels of intensity. As a consequence, ABMs can not only help sketch the current situation and its future dynamics, but also provide an idea of the consequences to which different policy interventions might lead. Indeed, ABMs are most typically developed to either increase our understanding of the mechanics of real-world systems, or predict how changes in different factors can affect the dynamics of the real-world systems (Williams, 2018).

The rest of this chapter is structured as follows. First, I introduce the notion of language contact by briefly reviewing the relevant literature and discussing the various aspects of language contact that allow us to consider it a complex issue in the formal sense of the term (Section 3.2). Second, I briefly introduce agent-based modelling and explain why it is useful in the study of population dynamics (Section 3.3). Third, I present a model of language contact developed in the NetLogo programming environment (Wilensky and Rand, 2015) and its underlying hypotheses (Section 3.4). Finally, I discuss the simulations performed, the statistical methods used to analyse the data and the results of the analyses (Sections 3.5 and 3.6). The main contributions of this chapter are, first, to show that macro-level language contact dynamics can be explained by relatively simple micro-level behavioural patterns and, second, to provide further support to qualitative discussions already presented in previous studies. The resulting model can then be used to make projections of short- and long-term trends of language decline and to estimate the relative impact of a number of different factors, including those that are "policy-actionable", i.e. that can be addressed through policy.

3.2 Language contact and bilingualism

A simple yet effective definition of language contact is provided by Thomason:

> "[L]anguage contact is the use of more than one language in the same place at the same time." (Thomason, 2001, p. 1)

Gambäck, and Bungum, 2014; Sierra-Santibáñez, 2014), and income distribution and wealth accumulation across different social classes (Russo, 2017).

This definition effectively highlights a first fundamental element of language contact, i.e. *coexistence*. For language contact to happen, two languages need to "exist" concurrently. However, Thomason herself immediately points out two problems with such a trivial definition. The first issue is that two (groups of) speakers of different languages in the same place at the same time may ignore each other. In that case, no transfer of linguistic features would occur and we could only speak of language contact in its purely literal sense. Therefore, coexistence is a necessary but not sufficient condition. Indeed, some form of *interaction* is a second crucial condition for language contact to have sociolinguistic consequences. The second issue is that this definition does not clarify what is meant by "language". One might simply assume that language contact occurs when speakers of different *codified* languages interact with one another, which would be far from incorrect. However, linguists tend to speak of language contact in a broader sense to include also interactions between speakers of different variants of the same language. Different syntax patterns, deviations from some specific pronunciation, the use of slang and local terms can all cause individuals to have trouble understanding one another, even if they are indeed speaking the same language. Besides, I shall point out that the expression "in the same place" should not be interpreted too strictly, especially at a time when information technology allows communication to happen smoothly over long distances. Thomason (2001) does not provide a strict spatial definition. Indeed, language contact can happen at different level on a spectrum that stretches from micro (e.g. two individuals speaking different languages working in the same office) to macro (e.g. along the language border within a bilingual country).

Appel and Muysken (2005) note that some form of bilingualism is a common (though not systematic) consequence of language contact. They speak of two types of bilingualism, *individual* and *societal*, to distinguish between bilingualism as the individual ability of speaking two languages from bilingualism as a feature of a society where two languages are spoken. Furthermore, they identify three types of societal bilingualism, generally described as follows:[3]

1. two languages are spoken by two different groups and each group is monolingual, typical, for example, of early colonial settlements, where the colonizer and the colonized would each speak his or her own language;

[3]Note that Appel and Muysken (2005) speak of the case of two languages, but their categorization can be easily extended to the case of more than two languages.

2. two languages are spoken and everybody is bilingual, a situation often found in many African countries, where individuals often have command of the language of the former colonizer in addition to one or more local languages;

3. two languages are spoken, but one group is monolingual and the other is bilingual. An example of this type might be Ireland, where virtually everyone has full command of English and some are also able to speak Irish, though at different levels of fluency. A similar example is to be found in Friesland, a region in the North of the Netherlands, with Dutch and West Frisian.

Interestingly, Switzerland provides examples of each of the mentioned typologies (all of which, however, need to be taken with a pinch of salt, in that the categorization of multilingual communities is rarely as clear-cut as presented above):

1. First, the country has four national languages, and for three of them (German, French and Italian) it is possible to identify areas with relatively clear-cut borders. Although language regions have no legal recognition whatsoever, keeping in mind that cantons have sovereignty on all matters except those that are shared with or *delegated upwards* to the Federal government, linguistic communities are fairly independent from one another. Indeed, out of 26 cantons, only three are officially bilingual (French-German) and one officially trilingual (German-Italian-Romansh). As a matter of fact, it is rather common for Swiss people to live most of their life on their side of the linguistic border and only use their language for most of their time.

2. Second, in German-speaking cantons, standard German (*Hochdeutsch*) is the official language,[4] but many German-speaking Swiss, though proficient in standard German, would consider their local Swiss German dialect (e.g. *Baseldytsch*, *Bärndütsch* or *Züridütsch*, respectively the dialects of Basel, Berne and Zurich) to be their native language.[5]

[4]It should be noted that Articles 4 and 70 of the Swiss Constitution simply speak of "German" (*Deutsch*) as being a national and official language, but it is normally interpreted to mean "High German" (*Hochdeutsch*), which is also informally referred to as the "written language" (*Schriftsprache*) in the Swiss context. This applies also to the French, Italian and Romansh (equally official) versions of the Constitution.

[5]From here on, I use the term "German" to refer indifferently to High German and Swiss German.

3. Third, the Swiss canton of Grisons is the only one where Romansh is an official language, along with German and Italian. Being a very small minority that has been shrinking over the last century, virtually all Romansh speakers have full command of another Swiss language, most of the time (Swiss) German, since childhood. Clearly, the reverse does not apply to German-speaking and Italian-speaking residents of Grisons, who are only seldom fluent in Romansh.

Each of these cases would call for an *ad hoc* study, and therefore it was necessary to make a choice. Throughout the rest of this chapter I concentrate on the third typology of societal bilingualism.

Speaking of bilingualism, there is no overall agreement of whether a bilingual individual should be one who has native-like command of both of her languages, or simply anyone who has some knowledge of a second language, or anything in between.[6] For the purposes of this chapter, I call "bilingual" any individual who alternatively uses one of two languages depending on the situation, *regardless* of her level of fluency. As said, it is assumed that all minority-language speakers are fluent in the majority language. It follows that any minority-language speaker qualifies as a bilingual in our simulated environment, even if they have very limited knowledge of the minority language.

Some authors (for example, Sperlich and Uriarte 2014; Grin 2016) have noted the *competitive* nature of language choice for plurilingual individuals and compared the dynamics surrounding language use to *market-like* dynamics of scarce resource allocation. Indeed, individuals need to allocate a limited amount of resources (in particular, time) over the languages they speak, whether it means having a conversation or reading a book in one language or another. Clearly, every individual tries to allocate her resources in order to maximize her utility (defined here as a measurement of the satisfaction that an individual gains from an activity that can be performed in different languages). However, the allocation process does not operate independently of certain constraints. For example:

1. the use of a specific (probably majority) language might be expected or even mandatory at work or in education, implying that during certain hours, individuals are not free to choose what language to use;

[6] For a review of the various definitions of "bilingualism", see Paradowski and Bator (2016).

2. leisure opportunities in the minority language(s) might be few compared to those in the majority language and/or more costly, due for example to limited availability of translated books or dubbed films;

3. the utility provided by activities in the minority language (just as in any language) is highly dependent on the level of fluency of individual speakers. Indeed, supposedly pleasant activities, such as conversing or reading a book in a minority language, might as well result in a feeling of frustration if they are not backed by sufficient fluency.

Uriarte (2016) defines language contact as the most extreme form of language competition, whose pressure is particularly felt by the minority-language community. Indeed, we can identify several factors that will influence (if not effectively shape) the linguistic behaviour of minority-language speakers. In a seminal paper, Giles, Bourhis, and Taylor (1977) discuss the idea of "language vitality" and classify the factors affecting it in three categories:

1. *status factors*, which include variables such as the socio-economic conditions of speakers, the perception of the language in terms of prestige (or lack thereof), and the socio-historical weight of the language;

2. *demographic factors*, which include variables such as the absolute number of speakers and rates of emigration and immigration;

3. *institutional support factors*, which include the formal and informal support to the language provided by various institutions, such as legal recognition and language education programs.

As I discuss in Section 3.4, the model of language contact presented in this chapter takes into consideration variables from all of these categories. From the first category, I consider the likelihood for minority-language speakers to reveal their cultural background, which is clearly influenced by how the language is perceived by society. For example, if a certain minority language is generally linked to backwardness or lower social classes, people may prefer not to be associated with it. Therefore, they might hide their cultural background from their interlocutor if they are not certain that they are speaking to another minority-language speaker. Conversely, if a language is perceived as having a certain prestige, minority-language speakers might

be happy or even proud to show it by addressing people directly in the minority language.[7] Concerning the second category (i.e. demographic factors), the model includes variables such as the initial total population, the proportion of minority-language speakers, population growth rates and life expectancy. Finally, concerning the third category, the model allows for the implementation of language education programs specifically addressed to minority-language speakers with a view to boosting their skills in the minority language. I shall also point out that, although I do draw on the typology of factors proposed by Giles, Bourhis, and Taylor (1977), I do not strictly abide by their view on them. Their discussion on the implications of these factors and the causal links between them and language vitality have been discussed and by and large criticized by Grin (1990) and Grin (1992). In particular, he suggests that a higher level of language vitality is not necessarily related to a higher likelihood of survival. As we will see, this chapter partly confirms the idea that language decline might happen regardless of its initial level of vitality (see Section 3.5).

3.3 Agent-based modelling and population dynamics

Agent-based modelling has been an important methodology in the study of population dynamics and, in the past decade, it has known renewed fame as a consequence of the massive progress in information technology and computational power. Generally speaking, researchers use agent-based modelling to describe population dynamics by relying on theories from other disciplines and translating them into behavioural rules to apply in the context of computer-based models. As van Bavel and Grow (2017) note, population studies have always been characterized by a "closed" approach where populations are treated as entities with their own macro properties. This top-down approach prioritizes the description of population by means of indicators representative of the whole nation.[8] The "closed" approach has

[7] There are numerous studies that show how languages (or varieties thereof) can be associated with a more or less favourable perception in certain contexts. For example, see Ros (1984) for a discussion on the different perception of Castillian-speakers and Valencian-speakers in the Valencian Community in Spain.

[8] The use of the term "nation" is not unintentional. Indeed, as noted by Kreager (2009), the "closed" approach was closely connected with the rise of the idea of the nation state, whose population is defined by a number of shared characteristics such as territory, language and history.

proved very successful and laid much of the theoretical groundwork of the discipline. However, Kreager (2015) points out that this approach comes at the expense of a more "open" approach that would prioritize the study of the processes and networks arising from the interactions among heterogeneous agents and their environment. The focus of such an approach would be on the study of the mechanisms behind patterns of association among individuals. However, such an open approach inevitably calls for a reorientation of the research paradigm from an exclusively macro-level perspective to one that also looks at the micro level. More precisely, it requires the analysis to take on a perspective that stretches along a micro-to-macro spectrum. Indeed, macro-level dynamics are inevitably the result of interactions among micro-level agents. Nevertheless, many of these dynamics cannot always be inferred directly from looking only at what happens at the micro level. In complex phenomena such as population dynamics, it is unsurprisingly the case that the macro level displays properties which are more than the simple sum of its micro-level components.

Agent-based modelling provides the right amount of flexibility to handle such complexity, as it allows for an effective representation of the feedback cycle between the micro and the macro level. Referring to Hedström and Swedberg (1998), van Bavel and Grow (2017) explain the link between the micro and the macro level by means of a three-step *macro-micro-macro* model, widely known as "Coleman's boat" (Coleman, 1990). The first step describes the situational mechanisms, that is, how the characteristics of the macro level shape the context in which individuals interact. The second step looks at the action formation mechanisms, i.e. the individual interactions at the micro level and how they are affected by the situational mechanisms defined at the macro level. Finally, in the third step the analysis moves on to study the transformational mechanisms, i.e. the way in which individual actions and interactions affect the macro context and bring about social change. It is exactly this third step that Billari (2015) considers the most interesting and challenging for scholars in the field of demography. The macro-micro-macro model can be graphically represented as shown in Figure 3.1 (adapted from van Bavel and Grow 2017). This three-step process can be easily adapted to the structure of the model presented in this chapter. First, we look at the macro-level elements embodied in the model, including not only demographic conditions such as total population and growth rate, but also the linguistic landscape, i.e. the fact that two languages are spoken according to a certain distribution. Second, we give agents behavioural rules to manage

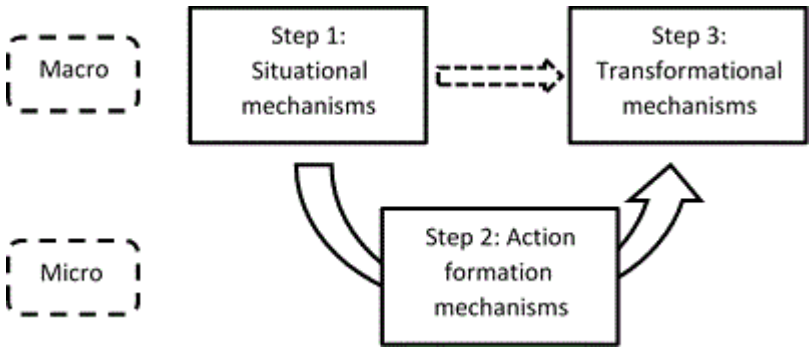


FIGURE (3.1) The macro-micro-macro model.

language use, given the macro-level conditions. Third, we look at how their behaviour affects the macro-level context, in particular the language distribution.

One of the reasons why many scholars advocate the use of computational models in the study of population dynamics is that they lend themselves particularly well to sensitivity analysis, with which we can evaluate the relative impact of different parameters on the output of the model (Grow, 2017). In particular, the model presented here can be used mainly in two ways:

1. to make projections starting from existing conditions;
2. to estimate the potential impact of policies addressing one or more of the factors included in the model.

I shall point out that the model presented here is to be seen as a first step in this direction and that, for policy-making purposes, it would need to be further developed and informed with sociolinguistic data.

Before I move on to present the details of the ABM presented in this chapter, I discuss in short some notable examples of modelling language contact and explain in brief how they differ from the model developed here.

3.3.1 Modelling language contact

The tradition of modelling language contact is not recent. Indeed, the literature on this topic is rich and wide. An in-depth discussion of this literature is well beyond the scope of this chapter, but a short review seems due in order to provide the reader with a bird's eye view on the topic. In particular, many models of language competition take on a differential equation approach. Simply put, these models try to develop a mathematical formulation that is able to describe observed trends in language growth or decline (i.e. the rates of change, whence the use of differential equations). One of the

earliest examples of such approaches is provided by Grin (1990), who models minority languages as a function of several variables, such as government subsidies, the increase of wage rates in minority language areas are spoken and the level of exposure to the minority language. Another notable example is provided by Abrams and Strogatz (2003). They describe the case of a community where two monolingual groups co-exist and develop a concise yet effective model that describes the rate of change of speakers of languages X and Y in terms of the probabilities of switching from one language to the other. These probabilities are in their turn dependent on the relative amount of speakers and the perceived status of each language. The authors go on to show how their formulation fits well historical data from several instances, such as the case of Scottish, Quechua and Welsh. Isern and Fort (2014) build on the model by Abrams and Strogatz and add a spatial dimension to it. By adapting the reaction-diffusion model, most commonly used for modelling the change of concentration and spread of chemicals, they estimate the speed at which a language spread over a geographical area replacing the local language.

Minett and Wang (2008) are among the first to move the focus from differential equations to agent-based modelling, recognizing that differential equation models work well in so far as individual behaviour can be neglected so that one can focus on aggregate trends. The authors explore the effect of language status and education policies on the maintenance of a minority language. Another related example of modelling language contact is provided by Castelló, Loureiro-Porto, and San Miguel (2013), who also take on an agent-based modelling approach. Starting from the acknowledgement that language contact is a complex phenomenon, they develop and ABM that explores the dynamics of a community where two languages are spoken, each with a share of monolingual and bilingual speakers. They pay particular attention to how language status and individual likelihood to shift to another language impact language growth and decline. However, the main focus of their study is on the spatial dimension of social networks, i.e. they explore the impact of different types of spatial configuration on language dynamics (in terms, for example, of language segregation). Networks are an important element in the study of language contact, as noted by Milroy (1980). Therefore, Castelló, Loureiro-Porto, and San Miguel (2013) provide one of the first attempts to combine a quantitative approach with a sociolinguistic perspective.

Another interesting example is provided by Patriarca et al. (2012), who,

on top of providing a very interesting review of different methodologies used in the study language contact, also consider the possibility of adopting a game-theoretical approach. For this purpose, they discuss two different strategies encountered among minority-language speakers, i.e. addressing people in the minority language or not. As I discuss later, this kind of reasoning also serves as basis for one of the behavioural rules of the agents in the ABM presented here. The authors acknowledge that, regardless of the methodology adopted, a clear understanding of the mechanisms underlying language contact is still missing and that more empirical work is needed to inform modelling. They suggest that future research should focus, among other things, on the impact of variables such as language prestige and language policies on patterns of local interactions. The model that I present here follows by and large this rationale. In this chapter, I try to bridge the gap between the purely economic thinking and the sociolinguistic perspective. Abrams and Strogatz (2003), as well as most of the mathematical models that build on theirs, refer to a non-better defined "transition rate", which, in turns, depends on a variable taking on values between 0 and 1 that should reflect the advantages that the languages gets from a higher status. This latter variable is, in my opinion, somewhat obscure, possibly as a consequence of a relative disregard of the sociolinguistic literature. It is indeed not the status that eventually decides the fate of a language, but rather how this status translates into practice. For example, a language might be official, and therefore enjoy "high status". Yet, if people do not have a desire, an opportunity or simply the capacity to speak it, a high status will not save it from extinction Grin (2003a). By treating status as a single variable, a model can provide valuable insights, yet it often remains obscure as to what exactly affects the vitality of a language. By combining the economic and the sociolinguistic approach, I try to break down the status variable into a more "operationable", more transparent set of variables. This line of reasoning is not brand new in the literature of language contact. For example, this is also the view of Zhang and Gong (2013). They argue that the variables usually found in the mathematical models of language competition are too abstract and that such studies should focus on more concrete parameters. It is not unexpected that such observations come from two authors that are well versed in the language sciences.

3.4 An ABM of language contact

Before presenting the details of the model, I discuss its underlying assumptions. The model assumes that the two communities differ only in the languages they speak, one being able to speak only the majority language and the other being able to speak both the majority and the minority language. As discussed previously, a community in which two languages are spoken can be, generally speaking, either a community with an ethnolinguistic minority within it (such as the Arbëreshë, speakers of a variant of Albanian living in some villages of Southern Italy, or Romansh speakers in German-speaking Switzerland) or an ethnically homogeneous community where only some individuals are able to speak a certain language (for example, Irish speakers in Ireland). In particular, I assume that minority-language individuals are perfectly integrated and that it is not possible to single them out on the basis of a peculiar accent or some physical traits. Besides, an important implicit assumption made by the model is that minority-language speakers are willing to bear a certain level of frustration in order to speak (and therefore support the maintenance of) the minority language.

I conceptualize the utility of conversing with another individual as depending on two variables: the level of proficiency of the interlocutors and the preference for one specific language. Concerning the first variable, it is reasonable to assume that more proficient speakers will be able to discuss a broader range of topics with no difficulty. As I said, every individual in the environment is fully proficient in the majority language. Therefore, if we conceived utility *only* as a function of proficiency, following the principle of least effort in efficient communication (Zipf, 1949), we would conclude that minority-language speakers:

1. are indifferent between speaking the majority or the minority language, if both interlocutors are fully fluent in both languages;

2. prefer to communicate in the majority language (in which they are assumed to be fully fluent), if at least one of the interlocutors has less-than-full knowledge of the minority language.

Formally, we could write

$$u(A) \geqslant u(B) \tag{3.1}$$

where $u(A)$ and $u(B)$ are the minority-language speakers' utility functions of communicating respectively in the majority language A and in the minority language B. As I said, the amount of utility depends on the level of fluency

of both interlocutors. Therefore, the equality is only verified when two fully proficient minority-language speakers get to meet. Whenever this is not the case, $u(A)$ is greater than $u(B)$.

However, as said, I conceptualize utility as being also a function of the specific language used to communicate. Minority-language speakers of our virtual community will always be willing to speak the minority language when presented with the opportunity, regardless of their level of fluency. Therefore, I am implicitly assuming that there exists an additional utility stemming from the mere fact of speaking the minority language. This additional utility is always more than enough to compensate the fact that minority-language speakers are not always able to hold a fully satisfying conversation in it. Formally, it reverses the inequality as follows:

$$u(A) < u(B) \tag{3.2}$$

This additional benefit can be seen as a non-linguistic consequence most likely related to the emotional attachment of minority-language speakers to their language. Indeed, it is reasonable to assume that minority-language speakers are happy to have an opportunity to speak and, therefore, support their language. Obviously, this greater utility is only accessible if both interlocutors speak the minority language. If one of the interlocutor is a monolingual majority-language speaker, the minority-language speaker is forced to choose the majority language.

3.4.1 Model specifications

The model has the following characteristics:

1. The environment in which the agents live, though visually represented as a square by the NetLogo interface, has a *toroidal* topology, i.e. all of the edges are connected to another edge in a doughnut-like shape. Therefore, agents are free to move in any direction at any time. The choice for an open environment over a closed one is made to avoid that agents get stuck in corners or against the edges, which could distort the results.

2. The environment is a multilingual community in which two languages are spoken, majority language A and minority language B. The initial proportion of individuals of either community can be determined before launching the simulation. The two languages are assumed to

be linguistically distant, so that mutual intelligibility is excluded and mixed conversations (i.e. happening partly in language A and partly in language B) are not possible. Besides, it is assumed that there are no migration flows.

3. For the reasons discussed in Section 3.2, every individual is assumed to be fully fluent in the majority language and some individuals are also able to speak the minority language with varying degrees of fluency. Following Grin, Sfreddo, and Vaillancourt (2010), the initial distribution of fluency among speakers of the minority language follows a doubly-truncated normal distribution, with lower and upper limits of 1 (almost no useful knowledge of the language) and 100 (full proficiency), around a mean that can be determined through the model interface before launching the simulation.

4. Depending on their personality type, some minority-language speakers are always willing to start the conversation in the minority language (*reveal* type), while others will prefer to speak the majority language and switch to the minority language in case they find out that their interlocutor is also a minority-language speaker (*hide* type). The ratio of reveal-to-hide individuals can be determined before launching the simulation.

5. Every time step represents one year.[9]

6. The population grows at a certain rate which can be calibrated and differentiated between the two communities. Women aged between 14 and 50 are "fertile" and, depending on a fertility rate, might give birth to a child.[10] By analogy with communication behaviour rules, minority

[9] It is worth recalling here that time is one of the most delicate elements to model in agent-based modelling. It is indeed very hard to find a precise correspondence between real-life time and simulated time. I consider one iteration of the model to be equivalent to one year in real life, but this should not be interpreted too strictly. What really matters here is "relative" time, rather than "absolute" time. In other words, if the reader does not agree with the assumptions that led me to consider an iteration equivalent to one year, he can focus on the relative number of iterations. For example, should the model find that the minority-language community disappears in n years under certain conditions and in $2n$ years under other conditions, we can still draw the conclusion that it took twice as much time to reach extinction in the second scenario.

[10] Admittedly, one may argue that a smaller age range, such as 20 to 45, might have been more sociologically relevant. However, I decided to stick to the definition of "women of reproductive age" of the World Health Organization. See https://www.who.int/data/maternal-newborn-child-adolescent-ageing/indicator-explorer-new/mca/women-of-reproductive-age-(15-49-years)-population-(thousands).

children born to families where both parents speak the minority language also speak the minority language and inherit the level of fluency of their mother. As I assumed that communication between minority-language speakers and majority-language speakers can only happen in the majority language, babies born to mixed couples are assumed to be majority individuals with no fluency in the minority language.[11] This (admittedly strong) assumption is a simplification largely based on the observations of Solèr (2004), who discusses in depth different linguistic behaviours in various family scenarios and goes on to distinguish many more cases. Besides, Lüdi et al. (1997), speaking of the case of Switzerland, note that German tends to impose itself as the only communication language in German-Romansh families even in areas with a high presence of Romansh speakers.[12] The likelihood of exogamous pairing can be determined before launching the simulation by the exogamy rate variable.

7. Individuals die when they reach a certain age, which can be manually set. All other causes of death are not taken into consideration, in that there is no reason to believe that the incidence of fatal events is different between the two communities.

8. The government can decide to put in place special education plans specifically intended for minority-language speakers aged between 6 and 18 in order to boost their language skills (during these years, their fluency increases by ten units at every time step). The policy can either be in place at all times or activated only if the proportion of minority-language speakers falls below a certain threshold. Besides, it can be addressed to all minority-language speakers or only a part of them. By

[11] A rather different kind of support for the idea of higher-status male-specific language transmission is provided by Forster and Renfrew (2011). They found that prehistoric language death and replacement correlates with immigration of males but not necessarily females, according to a global analysis of modern mtDNA (which is inherited from mothers only) and Y chromosomal patterns. This suggests that prehistoric women may have preferred to adopt and pass on the language of immigrant males, especially if they displayed military prowess or a perceived higher status, yielding the language/Y-chromosome correlation observed today.

[12] Another example of such behaviour is presented in a study by the Canadian office of statistics on language use in different family configurations (see www150.statcan.gc.ca/n1/pub/75-006-x/2015001/article/14301-eng.htm). In short, the study shows that in communities where both French (minority) and English (majority) are spoken, families in which both parents have French as a mother tongue are much more likely to use French as a home language than English, as opposed to couples where only one parent has French as his/her main language.

the end of the program, students are assumed to have reached full proficiency, regardless of their initial level.

Model specifications are an intentionally simplified version of real-life dynamics. Indeed, one of the objectives of this chapter is to show that it is possible to propose an explanation of complex macro-level patterns by tracing them back to relatively simple micro behavioural rules. Support for this claim is provided by validating our ABM through real-world data.

Before moving on, I shall devote a few words on the communication dynamics within mixed households, whose impact on the minority language is captured by the exogamy rate variable. One could argue that this assumption does not seem to be reasonable, in that it is not unusual to observe bilingual households. However, relaxing this assumption would mean splitting the exogamy rate variable in two, one variable defining the likelihood that a female minority-language speakers picks a majority-language partner and the other defining the likelihood that the minority-language is passed on to the offspring of such mixed couples. The exogamy rate is conceptualized as the probability with which minority-language women have a child from a majority-language man. However, in practical terms (i.e. in the source code) it is the probability with which the offspring of a minority-language woman is not a minority-language speaker (e.g., if the exogamy rate is 30%, then there is a 30% chance that the offspring born to a minority-language woman is a majority-language speaker only, as, implicitly, the baby is born to a majority-language father). However, this can also be interpreted to mean that, even in mixed households, the minority language is passed on with a certain probability (for example, if the exogamy rate is 0%, it could mean that, even in mixed households, the minority language is always passed on to the next generation). Obviously this could be treated differently. We could split this in two parts: first, modelling the actual probability of minority women to choose a majority partner, and second, adding an extra parameter to model the probability with which the child born to a minority mother and a majority father acquires the minority language. However having two nested distributions vary simultaneously would not provide more insights than having one distribution (as defined above) vary, as long as its meaning is clearly laid out. The reason why I decided to code it this way is because I wanted to keep a direct relationship between the impact of each parameter and potential policy measures. In other words, I tried to model directly the net impact of the two variables. I tried to define the parameters in a "policy-actionable" way, so that, once we have defined their impact, we can evaluate the extent that

our potential policy intervention should have. Indeed, as I argue at the end of the chapter, one cannot really influence (democratically, that is) people's choice of a partner to have a child, but one can influence the communication behaviour in their household. Influencing the attitude of mixed households would in fact amount to influencing the exogamy rate variable defined the way I do.

3.4.2 Types of minority-language speakers

As Uriarte (2016) points out, communication can be thought of as a so-called *cheap talk* game, originally introduced by Crawford and Sobel (1982). Cheap talk models are rooted in game theory and are used to describe communication between players. They are opposed to *signalling* processes, in that in the latter sending messages may be costly for the sender and can happen in several possible ways, while in the former it is free and happens mainly through ordinary talk. The setting of the model is a game where an informed individual communicates a piece of private information to an uninformed decision-maker. The idea is that the two individuals may have diverging interests, so one may decide to convey more or less information to persuade the other to make a certain decision. Crawford and Sobel (1982) describe specifically the following setting:

- there are two players, a *sender* (S) and a *receiver* (R);
- S has some information about θ, a certain state of the world, described by a value over a closed interval $[0, 1]$, which is unknown to R;
- S can decide to send a message to R at no cost, which can correspond exactly to θ or deviate from it by a parameter b (if $b \neq 0$ the two players have different objectives, and b can be interpreted as conflict of interest);
- on the basis of the information received, R takes action y (also described by a real number) that maximizes her utility (u_R).

The payoffs of the two players are described by the following quadratic utility functions (Ganguly and Ray, 2012):

$$u_S(y, \theta, b) = -(y - (\theta + b))^2 \tag{3.3}$$

$$u_R(y, \theta) = -(y - \theta)^2 \tag{3.4}$$

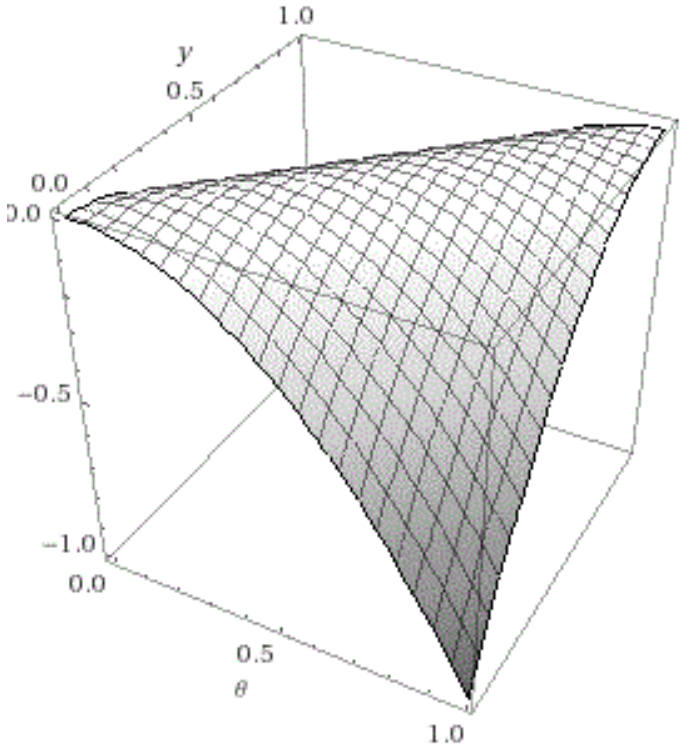


FIGURE (3.2) Graph of the utility function of the receiver

The sender S conveys the amount of information that causes the receiver R to react in a way that maximizes the sender's utility (u_S). The parameter b represents the divergence of interests between the two players, or bias. The receiver wants to take the action that matches the state of the world in order to maximize u_R. Indeed, we can take the partial derivative of u_R with respect to y, the only parameter that R can control, and get

$$\frac{\partial u_R}{\partial y} = 2\theta - 2y \tag{3.5}$$

To find the maximum of the function, it is enough to set this derivative equal to zero and check that the second derivative is negative. It follows that u_R is maximized for $y = \theta$, as the second derivative is negative (and equal to -2). This can be seen in Figure 3.2. Conversely, the sender maximizes her utility u_S by choosing how much information to reveal in order to get the receiver to take an action that matches the state of the world plus a certain deviation (obviously, she could also decide not to share information θ at all, meaning that $b = -\theta$. Indeed, S can control parameter b, and if we differentiate u_S with respect to it, we get

$$\frac{\partial u_S}{\partial b} = 2y - (2b + 2\theta) \tag{3.6}$$

Therefore, u_S is maximized for $y = \theta + b$.

In the specific case discussed here, we could assume that there is no conflict of interest between two players who speak the minority language, in that, as explained above, I assumed that every minority-language speaker is willing to speak the minority language whenever presented with the opportunity. Therefore, we have a case in which $b = 0$ and both utilities are maximized when the sender fully discloses the state of the world θ (i.e., reveal that she speaks the minority language by addressing her interlocutor in it) and the receiver reacts accordingly (by replying in the minority language). Indeed, the sender's utility is maximized when she can speak the minority language (see Equation 3.2) and she has an interest in revealing that she is a minority-language speaker, as this might lead the interlocutor to reply in the minority language, if she is also a minority-language speaker. By the same reasoning, the interlocutor has an interest in replying in the minority language if she is a minority-language speaker. Therefore, we could conclude that minority-language speakers have an interest to always speak the minority language as a first choice.

Nevertheless, minority-language speakers might also meet a monolingual speaker, who, by definition, is only able to speak the majority language. According to linguistic politeness theory (Brown and Levinson, 1987), individuals will choose a communication strategy that minimizes confrontation. Indeed, addressing someone directly in the minority language might be perceived as a *face-threatening* act, in that the interlocutor might be forced to reveal her lack of knowledge of the minority language. As a consequence, the sender wants to avoid this kind of situation. In other words, her utility would be reduced if it turned out that the interlocutor did not speak the minority language, as she would feel that she has been "impolite" by addressing the non-minority interlocutor in the minority language. This matter is largely cultural and can vary greatly across different societies. For example, the seriousness of face-threatening acts depends largely on the level of power distance that exists in a given society, defined as "the extent to which the less powerful members of organizations and institutions accept and expect that power is distributed unequally" (Hofstede, 2011, p.9). Indeed, face-threatening acts are perceived as much more serious in societies characterized by higher levels of power distance, such as Asian and African countries, than it is in societies where it is less pronounced, such as Northern European countries. Note that this behaviour could also be seen as a specific form of

communication accommodation. We speak of communication accommodation when people make behavioural changes in their communication strategy to converge or diverge from their partner. For example, accommodation can be used to reduce the perceived socio-cultural distance between two individuals by making one's speech pattern more similar to one's interlocutor. Conversely, one might stress some aspects of one's own way of speaking to highlight the very same differences. In the case of the model presented here, the decision by a minority-language speaker not to address her interlocutor directly in the minority language can be seen as a form of linguistic convergence to reduce distance.[13]

To strike a balance between the economic reasoning presented above and the considerations on linguistic accommodation, I distinguish between two categories of minority-language speakers:

1. those for whom the reduction in utility stemming from being "impolite" is greater than the extra utility deriving from speaking the minority language – these individuals will not address people in the minority language, unless they are sure that their interlocutor also speaks the minority language;

2. those whose extra utility more than compensates the potential reduction – these individuals will always try to speak the minority language.

Therefore, following Sperlich and Uriarte (2014), I distinguish between these two types of minority-language speakers according to their personality. Speakers of the minority language can be willing either to reveal their linguistic background or to hide it. Uriarte (2016) defines them as individuals who are, respectively, *strongly loyal* or *weakly loyal* to the minority language. In the model presented here, a reveal-personality individual will always start the conversation in the minority language and only switch to the majority language if her interlocutor cannot speak the minority language. Conversely, a hide-personality individual will always start the conversation in the majority language and will only reveal her background if another minority-language speaker addresses her in the minority language. The background of the person starting the conversation is not important, in that it is assumed that a reveal-personality minority speaker will reply in the minority language even if she is addressed in the majority language and then switch to the majority language if it turns out that her interlocutor speaks only the majority language. Intuitively, a graphic representation of this process could be as

[13] For more on communication accommodation theory, see Giles (2008).

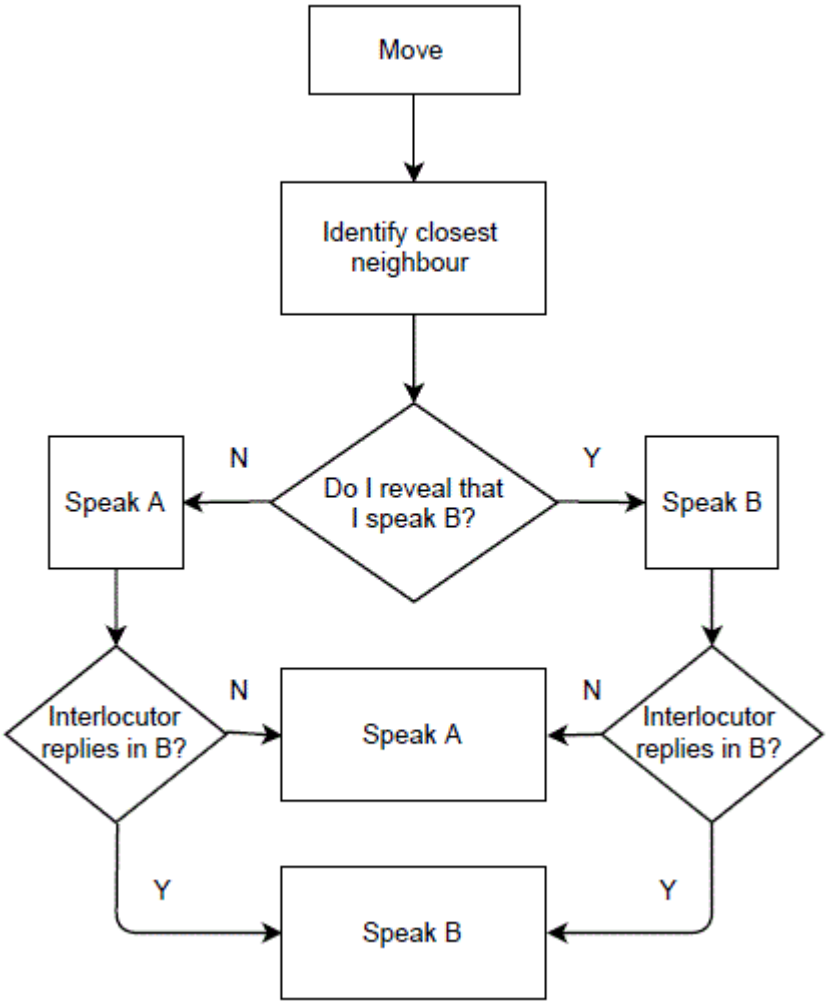


FIGURE (3.3) Flowchart of communication behaviour of minority-language speakers

presented in Figure 3.3. Obviously, the communication behaviour of (monolingual) majority-language speakers is much less articulate, in that they will always speak language A.

3.4.3 Interactions

Starting from the age of 6, every individual explores the environment and interacts with her closest individual at every time step. Every time step can be seen as one year. Interactions happen according the following rules:

1. if two majority-language speakers meet, they will converse in language A and nothing happens in relation to language B;

2. if a minority-language speaker meets a majority-language speaker, they will converse in language A and the proficiency in language B of the former will be slightly reduced;

3. if two language-B speakers meet, the way they interact depends on their personalities:

    - if two hide-personality individuals meet, they will not know that they are both able to speak the minority language and they will converse in the majority language, causing their level of fluency in the minority language to be reduced;
    - if at least one reveal-personality person is involved, the conversation will be held in the minority language and the level of fluency increases for both.

At every time step (i.e. at every iteration of the model), every minority-language individual locates her closest agent and, depending on whether the closest agent is a minority-language speaker or not, adjusts her level of knowledge of the minority language, respectively positively or negatively by one unit. This is a mechanical way of conceptualizing the fact that interacting in the minority language will increase one's fluency in it, while not doing it does the opposite. At every time step, if there are n minority-language speakers, there are going to be n such interactions (majority-language speakers are always assumed to speak the majority language, so nothing happens to their fluency). Obviously, in real life it is not one single conversation that makes a significant difference in one's level of fluency. For this reason, I try to capture in one interaction the effect of a long series of conversations, which is why I characterize a time step as one year. For a minority-language speaker, one interaction with a majority- (minority-)language speaker can be seen as a year in which one used the majority (minority) language more often than the other. Indeed, there would be no practical gain in breaking down this effect in hundreds and hundreds of micro-interactions, which would each have a micro-impact on the level of fluency and which, summed up, would give a net negative or positive overall impact. Simple as they are, these interactions capture the idea that, throughout a year, minority-language speakers might have more or less frequent opportunities to use the minority language, which will eventually affect their level of fluency. If their level of fluency reaches

zero, they are assumed to be completely assimilated in the majority community and are considered simple majority-language speakers from then on.[14]

In the following sections I first validate the model and then I present the results of a number of simulations. I concentrate on the likelihood of survival of the minority language as a consequence of variables such as the proportion of minority people having a reveal-personality, education policies and the threshold at which they are put in place. I also devote a few words to discussing the impact of these variables on the level of fluency of minority-language speakers.

3.4.4 Model validation

Before discussing the results of the simulations, the model needs to be validated by comparing its results with real world data, in order to make sure that the assumptions on which it is based and the trends that it estimates are in a sense illustrative of reality. In the domain of computer simulations, a model that is a good representation of the real system is said to have *face validity* (Carson, 2002). It could be easily argued that, given the need for simplifications, models are unrealistic anyway. However, agent-based modelling, just as any type of modelling, should be seen as an instrument to gain insights into a phenomenon and not as a truthful representation of reality. Even if based on drastic simplifications of reality, models can help gain better understanding of a phenomenon, which can in turn help our intuition to explain it or make predictions about it. As the objective of this chapter is to provide an idea of the relative impact of the variables taken into consideration on the decline of minority languages, it is not crucial that numbers are exactly right. Nevertheless, a close approximation of observed data is still desirable.

As discussed in Section 3.2, Switzerland provides various examples of language competition. In particular, I compare the model presented here with the situation of Romansh speakers in the trilingual canton of Grisons. As mentioned, Grisons is Switzerland's largest canton in terms of surface, the only officially trilingual one and the only one where Romansh is an official language.[15]

[14] The complete code of the model is available in appendix C.

[15] "Romansh" is actually a collection of five mutually understandable Romance languages, each with its own written standard. They belong to the same language sub-family as Ladin and Friulan, which are spoken in Northern Italy. In 1982 a unified Romansh language with a shared written and spoken standard was introduced by the *Lia Rumantscha* (Romansh League), called *Rumantsch Grischun* (Grisons Romansh).

As they constitute a shrinking minority, virtually all Romansh speakers (with the possibly sole exception of very young children) are proficient in the majority language of the canton, i.e. German (along with the local Swiss German dialect) (Liver, 1999; Solèr, 2004). According to the Swiss Federal Statistical Office, only 0.5% of the resident population of Switzerland declares Romansh as a main language (De Flaugergues, 2016). The Romansh language has an important cultural and identity value for Romansh people. According to Solèr (2004), in areas where Romansh is spoken, it is very common for Romansh speakers to meet allophones, mostly German speakers, and Romansh is only used with other Romansh speakers. In this regard, he notes that Romansh speakers often face a dilemma, in that (i) being upfront about their background and constantly choosing to address people in Romansh without knowing if they speak the language is often considered rude, and (ii) constantly giving up Romansh in favour of German to accommodate allophones may be perceived by others as an act of betrayal towards not only one's own native language, but also one's own cultural heritage. The Romansh-speaking and the German-speaking communities live together with a high level of integration in virtually all areas where Romansh is spoken. Solèr (2015) notes how there exists virtually no Romansh-only areas and this has been especially the case since 2010, when many officially Romansh-monolingual municipalities started being merged with other German-monolingual municipalities to create larger bilingual administrative units. Besides, mixed couples made up of a Romansh speaker and a German speaker are also a common feature of Romansh-language communities (Osswald, 1988). Considering all of the above, it is possible to conclude that Romansh-speaking areas in the canton of Grisons are by and large well represented by the simulated environment of the model and can be used as a source for validation.

The next step in our validation process is to check whether the trends estimated by the model are comparable to the trends actually observed. In order to do this, the model needs to be calibrated so as to reflect actual contextual data of the region taken into consideration. As a consequence, historical data from the canton of Grisons were averaged over the period considered for validation, i.e. from 1960 to 2000, and used to calibrate the model before launching the simulations. Then, I compared the results generated by the simulations in terms of the decline in the relative number of Romansh speakers with the actual trends observed over the same period. In order to account for the intrinsic stochasticity of agent-based models, I ran 100 simulations

with the same initial conditions and averaged the results.

Some data were not directly available and needed to be estimated. Taking into consideration only Romansh speakers and German speakers (excluding italophones and other allophones), the former represented 31.52% of the combined Romansh- and German-speaking population of Grisons in 1960, while the latter represented 68.48%.[16] According to the World Bank,[17] the average fertility rate in the canton of Grisons between 1960 and 2000 was 1.81,[18] which I assumed to be the same for both language communities. Average life expectancy, which rose from slightly more than 71 in 1960 to almost 80 in 2000, was 75.4. According to Osswald (1988), in 1960, couples involving at least one Romansh speaker involved another Romansh speaker in 60.75% of the cases and an allophone in the rest of the cases. This value had decreased linearly to 57.47% in 1970 and 52.14% in 1980. However, these values consider all possible combinations, including Italian speakers and other allophones. These data are complemented, and partly contradicted, by the data provided by the Swiss Federal Statistical Office, which allow to distinguish different types of combinations. If we consider only households where Romansh and/or German are spoken, regardless of whether a third language is also spoken, we obtain estimates that vary roughly between 60% and 65% between 1970 and 2000. Therefore, I combined the two sets of data and considered an average rate of endogamous pairing of roughly 60% between 1960 and 2000. The proportion of reveal-to-hide personality individuals is hard to estimate, therefore I simply assumed that the two personality types are equally represented in the community, as everybody faces the dilemma explained earlier. Concerning education policies in support of the Romansh language, I kept them inactive for these simulations in that the use of Romansh in schools was significantly increased only in 1990, at the end of our simulated period, when, on average, roughly 54.5% of students living in the traditional Romansh-speaking areas used Romansh as a communication language (Lüdi et al., 1997, p. 269). However, the use of Romansh in education varies significantly across the different Romansh-speaking communities. In 1990, the use of Romansh in school varied from less than 10% of the students in the Sutsilvan area to almost 90% in the Vallader area (Furer, 2005).

[16] These numbers were calculated using data published in Coray (2008).

[17] https://data.worldbank.org/country/switzerland

[18] According to the CIA World Factbook, fertility rate is defined as "the average number of children that would be born per woman if all women lived to the end of their childbearing years and bore children according to a given fertility rate at each age" (see https://www.cia.gov/library/publications/the-world-factbook/fields/356.html).

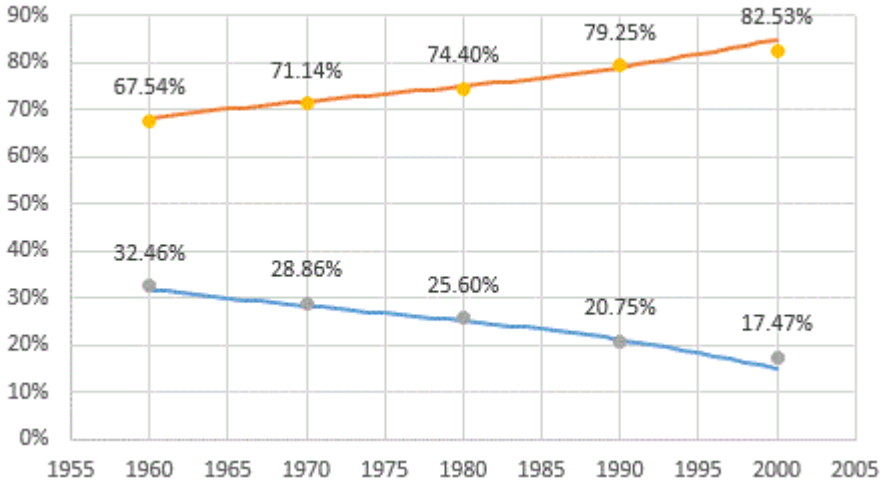


FIGURE (3.4) Comparison of simulated trends (blue and orange curves, respectively for Romansh and German) with actually observed data (grey dots for Romansh and yellow dots for German)

Figure 3.4 shows the average of the simulated trends of Romansh speakers (blue curve) and German speakers (orange curve) proportions between 1960 and 2000 based on the conditions explained above. The trends are compared to the proportions actually observed (yellow and grey dots). The estimates were adapted from Coray (2008), taking into consideration only Romansh and German speakers. Surveys for the period 1960-1980 asked people about their "mother tongue", while those for the years 1990 and 2000 allowed respondents to distinguish between "main language" and "language of common use".[19] As the latter option is much less restrictive than the former, for the sake of consistency, I decided to stick to the estimates of speakers of Romansh as main language, which was defined in the survey as the language of which respondents have the best command. Therefore, I consider "main language" more akin to the idea of "mother tongue" than "language of common use". The model seems to project actual trends quite well. Therefore, we can consider the analysis of the results produced by the model as reasonably reliable, even if it is based on relatively simple behaviour rules.

3.5 Data generation and analysis

In this section I first explain how I used the model to perform simulations and generate data, then I review the statistical methods used to analyse the data

[19] The two options in German were "Hauptsprache" and "Umgangssprache". Another possible translation for "Umgangssprache" could be "language of social interaction".

Parameter	Value (range)	Meaning
Initial population	200	Agents at the beginning of the simulation
Initial proportion of minority speakers	40%	Proportion of the population able to speak the minority language
Growth rate of the majority community	2%	-
Growth rate of the minority community	2%	-
Life expectancy	80	-
Exogamy rate	0% to 100% (in steps of 10%)	The likelihood with which a female minority individual gives birth to a baby with a majority individual
Reveal strategy	0% to 100% (in steps of 10%)	The proportion of minority-language speakers that are willing to reveal that they speak the minority language
Education	0% to 100% (in steps of 10%)	The proportion of minority-language speakers in school age that receive education in the minority language, if a language education plan is in place
Minority threshold	0% to 50% (in steps of 10%)	The threshold under which the proportion of minority has to fall before a language education plan is put into place

TABLE (3.1) Summary of the parameters used for the simulations

and produce results. I concentrate on the impact of different variables on the proportions of minority-language speakers. I also briefly discuss the impact of the same variables on the level of fluency of minority-language speakers. However, as statistics on people's language skills are harder to obtain and less reliable as often based on self-assessment, the model was only validated for the proportion of minority-language speakers. Consequently, results concerning the level of fluency should be taken with a pinch of salt. Nevertheless, I considered it useful to add them to the discussion of the model, in that they can still provide some interesting insights. Finally, I briefly present some results concerning the relationship between vitality and long-term survival of minority languages.

The specifications used in the simulations performed for the first analysis are summarized in Table 3.1. The first five parameters are necessary because they provide the model with dynamics, but I set them on arbitrary values because I am not interested in their impact. The last four are allowed to vary and were combined to create different scenarios to simulate.[20] Each combination of variables was simulated ten times to account for variations due to the intrinsic stochasticity of ABMs.[21] A time limit of 1,000 time steps was set. The number of scenarios simulated was 7,986, each of which, as said, was repeated ten times, making the total number of simulations 79,860.

The first analysis puts the decline of minority-language speakers in relation with the variables mentioned above. It is divided in two parts. First, I run a linear regression using the number of steps until extinction of the

[20]The value of zero for "minority threshold" was included to simulate the impact of absence of policy. Values over 50% would have skewed the results, in that values from 50% to 100% are all above the initial proportion of minority speakers.

[21]Due to the stochastic nature of ABMs, outcomes for the same model will vary across runs, *ceteris paribus*. For this reason, it is common practice to run ABMs multiple times to average out the effect of stochasticity (Groff, Johnson, and Thornton, 2019).

minority-language community (i.e. until the proportion of minority-language speakers to total population reaches zero) as a dependent variable and the variables mentioned above as independent variables. Second, I run a logistic regression to estimate the probability of surviving in the long term depending on the same independent variables as for the first part.

For the first part, I only look at the sub-sample of populations where the minority community disappeared within 1000 steps, which corresponds to roughly 95% of the total sample. Therefore, the new sample consisted of 75,541 observations. A quick look at the data shows a few issues that need to be taken into account before moving on to the analysis. By taking a look at the average number of steps-to-extinction per level of each variable, we immediately notice that the impact of all variables, especially the rate of exogamy, is non-linear. I shall note in passing that non-linearity is a common feature of complex systems, as discussed at length in Chapter 1. To account for this curvature, I do two things. First, as it is common in these cases, I center the predictors about their mean values and include the square of each predictors. Centring data is done to avoid that the linear and the quadratic term correlate with one another. Second, I take the logarithm of the number of steps and use it as a dependent variable. This is a common transformation used to linearize non-linear relations. Besides, this helps hedge another issue, heteroscedastic data, i.e. a situation where the residuals vary systematically with the size of the dependent variable. Indeed, while the absolute size of the residuals might increase with the dependent variable, it might be more stable in percentage terms. However, to account for any heteroscedasticity left in data, I shall still use robust standard errors to compute more reliable test statistics and their related p-values. The resulting regression equation is the following:

$$\begin{aligned} ln(y) = \beta_0 + \beta_1 exogamy.rate + \beta_2 reveal.strategy + \beta_3 education + \\ + \beta_4 minority.threshold + \beta_{11} exogamy.rate^2 + \beta_{22} reveal.strategy^2 + \\ + \beta_{33} education^2 + \beta_{44} minority.threshold^2 + \epsilon \end{aligned} \tag{3.7}$$

The results of the regression analysis are reported in Table 3.2. The (adjusted) R^2 of the model is 0.829, meaning that the regressors can explain almost 83% of the variance in the dependent variable, while the remaining 17% can be traced back to the intrinsic stochasticity of complex systems. Bearing in mind that the high number of predictors included in the model tend to inflate the value of the R^2, we can say that the model is a good fit for the data. All of the

	Estimate	**Std. Error**	**t-value**	**Pr(>|t|)**	**Sig.**
(Intercept)	5.584000	0.002355	2370.99	<2e-16	***
Exogamy rate	-0.018260	0.000032	-569.94	<2e-16	***
Reveal strategy	0.001711	0.000030	56.79	<2e-16	***
Education	0.002651	0.000030	87.81	<2e-16	***
Minority threshold	0.005303	0.000056	95.08	<2e-16	***
(Exogamy rate)^2	-0.000065	0.000001	-56.84	<2e-16	***
(Reveal strategy)^2	-0.000043	0.000001	-40.24	<2e-16	***
(Education)^2	-0.000052	0.000001	-47.77	<2e-16	***
(Minority threshold)^2	-0.000260	0.000004	-68.04	<2e-16	***

TABLE (3.2) Results of regression analysis (dependent variable: logarithm of time steps until extinction)

predictors are statistically significant. However, given the great amount of data, statistical significance was almost expected and is not very informative. Interpreting the estimated coefficients when quadratic terms are included is somewhat less intuitive than it is for usual regression with linear predictors only. Indeed, each linear predictor needs to be interpreted together with its corresponding quadratic term. Besides, for the sake of easier interpretation, I re-transform the coefficients to account for the fact that I used the logarithm of time steps as a dependent variable. The impact of the independent variable x on the predicted value y is the change in the predicted value when x changes by some amount δx, *ceteris paribus*, i.e. when all other variables are held constant. We start by looking at the fitted model (for the sake of simplicity, I stick to the case of one linear predictor and its corresponding quadratic term):

$$ln(\hat{y}(x)) = \hat{\beta}_0 + \hat{\beta}_1 x + \hat{\beta}_{11} x^2 \tag{3.8}$$

where the "hats" on the beta terms indicate estimated values. Plugging in $x + \delta x$ for the change in x and subtracting the initial value of $ln(\hat{y})$ gives

$$ln(\hat{y}(x+\delta x)) - ln(\hat{y}(x)) = \hat{\beta}_0 + \hat{\beta}_1(x+\delta x) + \hat{\beta}_{11}(x+\delta x)^2 - \hat{\beta}_0 - \hat{\beta}_1 x - \hat{\beta}_{11} x^2 \tag{3.9}$$

which can be rewritten as

$$ln\left(\frac{\hat{y}(x+\delta x)}{\hat{y}(x)}\right) = \hat{\beta}_1 \delta x + \hat{\beta}_{11}(2x\delta x + (\delta x)^2) \tag{3.10}$$

Note that this last passage is the same regardless of the number of predictors included in the model. As they are kept constant in order to compute the impact of the variable x only, they cancel out, as was the case for $\hat{\beta}_0$.

Provided that the change in x is small and that size of $\hat{\beta}_{11}(\delta x)^2$ is insignificant compared to the remaining terms on the right-hand side (that is, when $|\hat{\beta}_{11}\delta x| \ll |\hat{\beta}_1 + 2\hat{\beta}_{11}x|$, where $\ll$ means "much less than"), we can rewrite equation 3.10 as

$$ln\left(\frac{\hat{y}(x+\delta x)}{\hat{y}(x)}\right) \approx (\hat{\beta}_1 + 2\hat{\beta}_{11}x)\delta x \tag{3.11}$$

The left-hand side of equation 3.11 is the logarithm of the relative change in the predicted response $\hat{y}(x)$. The right-hand side is a multiple of the (small) change δx in the regressor. The relative change in $\hat{y}$ is going to be

$$\frac{\hat{y}(x+\delta x)}{\hat{y}(x)} \approx \exp((\hat{\beta}_1 + 2\hat{\beta}_{11}x)\delta x) \tag{3.12}$$

As can be seen, the relative change depends on the value of x with which one starts. In other words, the change in the response is not constant and depends on the value of the regressor. Therefore, contrary to linear-linear regression, the estimated coefficients in log-linear regression do not represent the slope of the curve. Finally, we can observe that, for small values of δx and given that $e^0 = 1$, the right-hand side of the previous equation can be rewritten as

$$\exp((\hat{\beta}_1 + 2\hat{\beta}_{11}x)\delta x) \approx 1 + (\hat{\beta}_1 + 2\hat{\beta}_{11}x)\delta x \tag{3.13}$$

Consequently, combining equations 3.12 and 3.13, we can write

$$\frac{\hat{y}(x+\delta x)}{\hat{y}(x)} \approx 1 + (\hat{\beta}_1 + 2\hat{\beta}_{11}x)\delta x \tag{3.14}$$

which is equivalent to

$$\hat{y}(x+\delta x) \approx \hat{y}(x)(1 + (\hat{\beta}_1 + 2\hat{\beta}_{11}x)\delta x) \tag{3.15}$$

This means that the ratio between successive fitted values of y is linear in x or, alternatively, that the new value $\hat{y}(x+\delta x)$ is approximately equal to the previous value $\hat{y}(x)$ times a change of $100\% * (\hat{\beta}_1 + 2\hat{\beta}_{11}x)\delta x$. This linear approximation helps us interpret the results of the regression analysis in a more intuitive way. If we consider positive unit changes (i.e., $\delta x = 1$), we can find, for example, the range of variation in the impact of each variable from their minimum to maximum value,[22] reported in the last column

[22] Technically, as explained earlier, the range of values is not from 0 to 100 (or 0 to 50 for the minority threshold variable), but from -50 to 50 (and -25 to 25 for minority threshold). Indeed, in order to account for the potential collinearity between linear and quadratic terms,

	Impact of linear predictor	Impact of quadratic predictor	Range of relative change
Exogamy rate	-1.826%	-0.007%	98.82% - 97.54%
Reveal strategy	0.171%	-0.004%	100.60% - 99.75%
Education	0.265%	-0.005%	100.79% - 99.76%
Minority threshold	0.530%	-0.026%	101.83% - 99.28%

TABLE (3.3) Impacts of linear and quadratic predictors and variation of relative change when $\delta x = 1$

of Table 3.3. Table 3.3 is interpreted as follows. The first two columns are simply the beta coefficients in percentage terms, the same reported in Table 3.2. The last column indicates the ratio between successive fitted values of y, the dependent variable. Values above 100% mean that successive values increase, while values below 100% indicate a negative evolution. Values very close to 100% imply that successive values are very close to one another or virtually unchanged. The exogamy rate seems to be by far the strongest predictor. Consecutive fitted values of y, the proportion of minority-language speakers, are initially about slightly less than 99% of the preceding value when x, the independent variable, increases by one unit. As x increases, this decrease tends to accelerate (as it could be guessed from the fact that the coefficients of the linear and quadratic terms are both negative). Indeed, when x is high, a unitary increase causes successive values to be between 98% and 97.5% of their preceding values. All other predictors have a positive but relatively weak impact on the long term survival of the minority community. Among them, minority threshold seems to be the strongest. Therefore, teaching the minority language to minority individuals to make them fluent seems to have a positive impact, especially if we consider that the variable education also has a positive coefficient. When the minority threshold is low (i.e. when the proportion of the minority community has to be very small before education plans are put in place), each unitary increase causes successive values of y (time steps to extinction) to be almost 102% of the preceding value. However, as suggested by the negative coefficient of the quadratic term, this effect tends to wane as the threshold increases. Successive values tend to be very close to one another, as indicated by a relative change very close to 100%. The same applies to the other two predictors.

For the sake of completeness, I also show a graphic representation of the impact of each predictor. The graphs in Figure 3.5 plot the average number of time steps until extinction of the minority community for each separate variables. The other variables also vary, but the contribution of one variable at a time is displayed. As can be seen, each variable contributes to the variation

the variables were centered on their mean, as it is customary in these cases. This does not imply any difference in interpretation. For more on this, see Afshartous and Preston (2011).

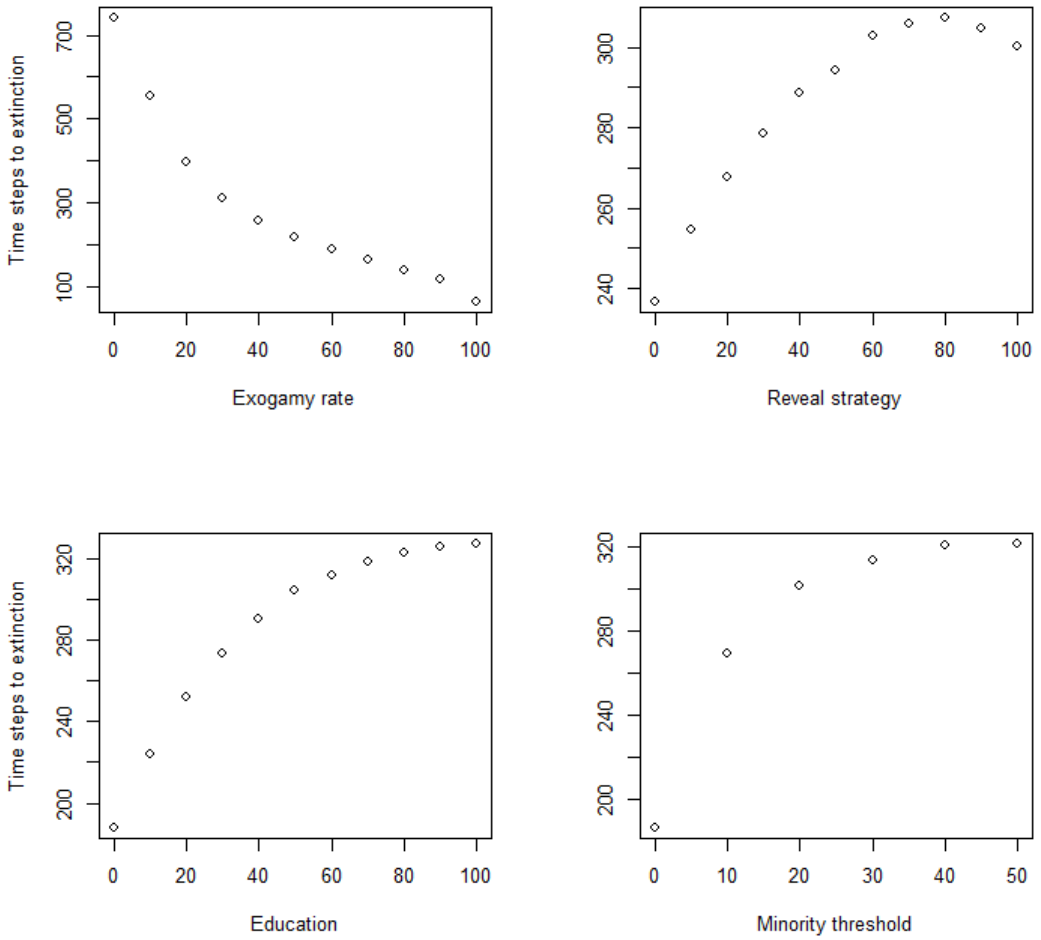


FIGURE (3.5) Average number of time steps until extinction for various levels of each predictor

in time to extinction of the minority community. The plots also confirm the sign and the relative impact of each variable (note the different scale for the exogamy variable), exogamy being clearly the strongest, and the other predictors having a smaller, yet non-negligible, effect. Besides, the curvatures of these trends justify the choice to add quadratic terms to the regression equation.

The second part of the first analysis consists in using logistic regression to provide further confirmation of the estimated impact of the variables mentioned above on the likelihood of long-term survival of the minority-language community. In this part, I use the same database as that generated for the first part, but I do not exclude those simulations where the minority community went extinct within 1,000 time steps. Indeed, I am interested here in comparing simulations where the minority community survived with those where it did not. As mentioned, the minority-language community survived in only 5% of the simulations. To increase the proportion of surviving communities for comparison purposes, I looked at those communities that were still alive after 500 time steps. The proportion of simulations in which the minority community survived beyond 500 was about 14% of the total. Therefore, the question that I am trying to answer here is: "How are the odds of surviving beyond 500 time steps affected by our predictors?"

The logistic regression model looks as follows:

$$ln\left(\frac{p(y)}{1-p(y)}\right) = \beta_0 + \beta_1 exogamy.rate + \beta_2 reveal.strategy + \beta_3 education + \\ + \beta_4 minority.threshold \tag{3.16}$$

As can be seen, this is again a linear model. However, the predictors are in a linear relationship with the logarithm of the odds of a certain event (in our case, the minority-language community surviving beyond 500 time steps).[23] From equation 3.16, we can compute the odds as follows:

$$\frac{p(y)}{1-p(y)} = \exp(\beta_0 + \beta_1 exogamy.rate + \beta_2 reveal.strategy + \beta_3 education + \\ + \beta_4 minority.threshold) \tag{3.17}$$

[23] The odds of an event y are defined as $\frac{p(y)}{1-p(y)}$ where $p(y)$ is the probability of said event. For example, the probability of rolling a (fair) die and getting a 4 is 1/6, while the odds of the same event is 1 to 5, that is, if we roll a die many times, we would expect to get a 4 every 5 times the roll gives any other outcome. Indeed, $\frac{1/6}{5/6} = \frac{1}{5}$.

	Estimate	Exp(coef)	Exp(coef)-1	Std. Error	z-value	Pr(>|z|)	Sig.
(Intercept)	-3.09506	0.04527222	-0.9547278	0.062164	-49.79	<2e-16	***
Exogamy rate	-0.20383	0.81560056	-0.1843994	0.002298	-88.72	<2e-16	***
Reveal strategy	0.017651	1.01780779	0.01780779	0.000595	29.66	<2e-16	***
Education	0.04314	1.04408437	0.04408437	0.000708	60.95	<2e-16	***
Minority threshold	0.077953	1.08107185	0.08107185	0.001299	60.02	<2e-16	***

TABLE (3.4) Results of logistic regression analysis (dependent variable: status of minority-language community after 500 time steps - 0 = dead, 1 = alive)

The advantage of reporting the odds rather than the probability is that the variation in the odds is constant for all values of the predictors. It only depends on the magnitude of the variation. Indeed, assuming the case of two independent variables x_1 and x_2 and a variation Δk in x_1, we can compute the odds ratio:

$$\frac{\frac{p(y|x_1=k+\Delta k)}{1-p(y|x_1=k+\Delta k)}}{\frac{p(y|x_1=k)}{1-p(y|x_1=k)}} = \frac{exp(\beta_0+\beta_1(k+\Delta k)+\beta_2 x_2)}{exp(\beta_0+\beta_1 k+\beta_2 x_2)} = exp(\beta_1 \Delta k) \tag{3.18}$$

Therefore, if we assume unitary increases, the variation in the odds is constant and equal to e^{β_1}. Although it is customary to assign a value of 0 to a negative event (or an event that did not happen) and a value of 1 to a positive event (or an event that did happen), I preferred to assign 0 to the cases in which the minority-language community "died" within 500 time steps and 1 to those where the community did not die, regardless of the final proportion with respect to the majority-language community.[24] This does not imply any technical difference in the procedure of coefficient estimation. However, this way the signs of the estimated coefficients are consistent with the results of the previous analysis and easier to interpret.

The results of the logistic regression are reported in Table 3.4. The results of the logistic regression analysis seem to confirm the finding of the previous analysis. We can concentrate on column 2 ("Exp(coef)") and 3 ("Exp(coef)-1"). Following the terminological convention adopted in survival analysis, I refer to predictors with negative values in the third column as "risk" factors, while I refer to those with positive values as "protective" factors. Exogamy rate is once again the strongest predictor. A unitary increase in the rate of exogamy multiplies the odds of surviving beyond 500 time steps by a factor of about 0.82 (column 2), reducing them. In other words, it causes a variation in the odds of about -0.18 (column 3). The second strongest predictor is,

[24] The words "positive" and "negative" are clearly not meant as synonymous with, respectively, "desirable" and "undesirable".

once again, minority threshold, followed by education and reveal strategy. While the latter predictor has only a slight impact on the odds of survival, the combined effect of the two education-related variables is substantial. A unitary increase in both variables multiplies the odds of surviving beyond 500 time steps by a factor of about 1.13.[25]

Let us explore further the weight of the exogamy rate variable. Figure 3.6 shows a heat map plotting the proportion of minority language speakers to the total populations at time steps 0 through 500 (recorded every 50 time steps) for exogamy rates 0% through 50%. The initial proportion of minority language speakers for these simulations was 40%. Reveal-strategy was arbitrarily set at 60%, minority-threshold at 100%, and education at 20%. This corresponds to a fictitious scenario in which 1 in 5 students is involved in education plans (which are always active, regardless of the proportion of minority-language speakers) and a bit more than 1 in 2 minority-language speakers is willing to converse in the minority language from the outset. These variables were kept at constant values, as having them vary and then averaging them over all simulations would have confounded the effect of the variables under study and made the heat maps all but non-informative. The blue lines at every time step represent the proportion of the minority community for the exogamy rates indicated. Obviously, at time 0, it's almost a line, in that they all start at 0.40 (the little wiggles are due to the in-built stochasticity of NetLogo). As we move from left to right we observe two things. First, shades go from darker (more minority speakers) to lighter (less minority speakers) at increasing speeds for increasing exogamy rates. Second, the line is less and less regular: it stays high at 0% exogamy rate, but it becomes lower and lower over time and it does so at increasing speed for higher exogamy rates.

Figure 3.7 shows a heat map exploring the interaction between reveal strategy and education to see to what extent education needs to be supported by an inclination to speak the minority language. In these simulations I assumed that the exogamy rate is 0%, which, as explained above, can be interpreted to mean either that there are no mixed households or that the minority language is always passed on to the next generation in mixed households.

[25] The combined impact of the variation in two factors is computed by multiplying the two exponentiated coefficients. Indeed,

$$\frac{exp(\beta_0 + \beta_1(x_1 + 1) + \beta_2(x_2 + 1))}{exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2)} = e^{\beta_1 + \beta_2} = e^{\beta_1} e^{\beta_2} \tag{3.19}$$

In this case, we have that $e^{0.044} e^{0.081} \approx 1.13$.

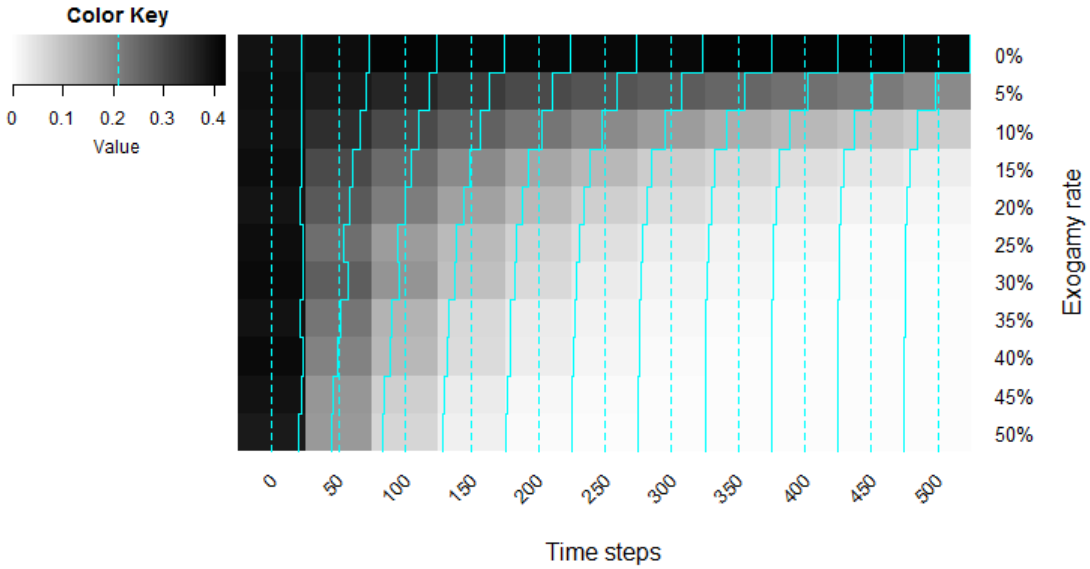


FIGURE (3.6) Minority proportion at various times for different levels of exogamy rate

Besides, minority-threshold was again at 100%, so that the education variable is always active. As above, these variables were kept constant. Darker shades represent higher proportion of the minority language community after 500 time steps. The heat map shows that education policy is effective only if it is backed up by a willingness of the people to speak the minority language as a first-choice strategy. Indeed, a good deal of the upper-left corner of the map has clearly lighter shades of grey, indicating that even having education policies that involve 50% of the minority-language community can have disappointing results if fewer than 40% of minority-language speakers are reveal-type individuals.

In the second analysis I used linear regression analysis to study the factors affecting the impact of the same variables on the fluency of minority-language speakers in the medium term. Therefore, a time limit of 100 steps was set. However, as said, I do not devote too much time discussing these results, in that the ABM was only validated for the proportion of minority speakers, as accurate statistics on people's language skills are hard to obtain and less reliable as often based on self-assessment. The model has the mean level of fluency of minority language speakers as a dependent variable. The independent variables are the same as above, i.e. minority-threshold, exogamy-rate, reveal-strategy, and education. This time, all of them were allowed to vary between 0% and 100% in steps of 10%. Each scenario was simulated five times. The number of scenarios simulated was 14,641, while the total number of simulations was 73,205. Of all these simulations, I only

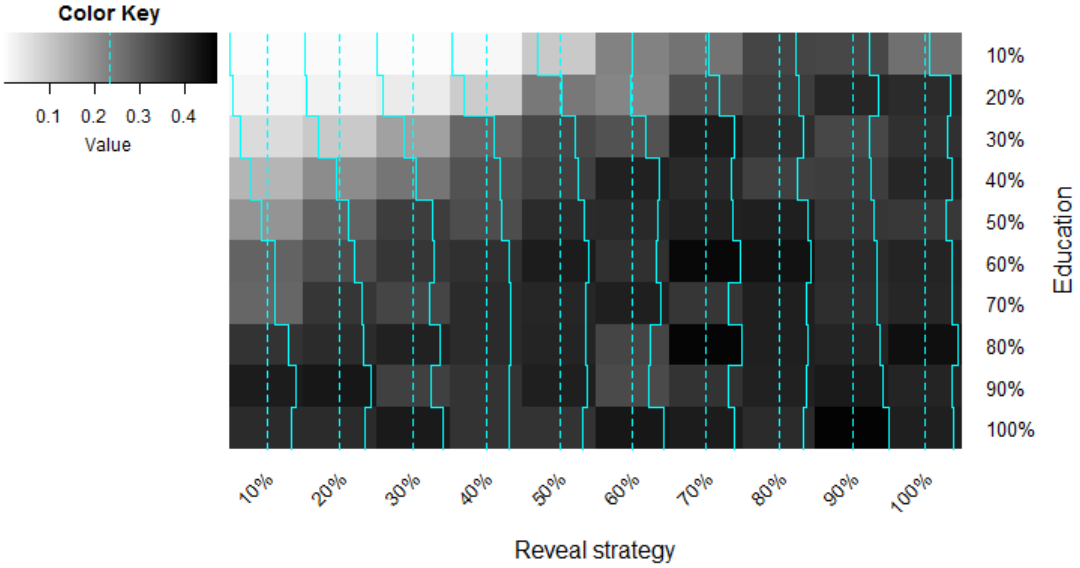


FIGURE (3.7) Interaction between education and reveal strategy

	Estimate	Std. Error	t value	Pr(>|t|)	Sig.
(Intercept)	32.803818	0.155221	211.3	<2e-16	***
Exogamy rate	-0.253376	0.001644	-154.1	<2e-16	***
Reveal strategy	0.236482	0.001484	159.4	<2e-16	***
Education	0.298659	0.001484	201.3	<2e-16	***
Minority threshold	0.195549	0.001484	131.8	<2e-16	***

TABLE (3.5) Results of regression analysis (dependent variable: mean level of fluency of minority-language speakers)

included in the analysis those that did not result in complete assimilation within 100 time steps, which were 65,985, i.e. roughly 90.1%. Obviously, if the minority community is completely absorbed into the majority, the level of fluency is zero. The direct consequence of this choice is that the coefficient of the exogamy rate variable might be underestimated, in that, as we have seen, it has the strongest impact on the survival of minority language communities. Therefore, the observations excluded are more often those with very high level of exogamy. Nevertheless, as the objective of this second analysis is to provide an estimate of the relative impact of all variables in minority language communities that still exist in the medium term, I found it appropriate to exclude cases of full assimilation. Results are reported in Table 3.5. All regressors have a statistically significant impact on the level of fluency of minority-language speakers.[26] Clearly, they all have a positive impact, except for exogamy rate. Unlike the previous analysis, the relative impact

[26] As was the case for the previous analysis, the extremely low p-values are most likely a consequence of the very high amount of data.

does not vary substantially across regressors, and education seems to have the biggest effect. The model has an (adjusted) R^2 of 0.618, meaning that almost 62% of variation in the response variable is explained by the regressors, while the rest is due to stochasticity.

I conclude by quickly presenting some results concerning the relationship between the vitality and the long-term survival of minority languages, which was quickly mentioned in Chapter 1 (Subsection 1.6.3). The third analysis puts the initial proportion of bilingual speakers (varying between 10% and 90% in steps of 5%) in relation with the number of time steps until language disappearance. All other variables were kept constant at some arbitrary values. There were 17 different scenarios, and each one was run 20 times, making a total of 340 simulations. Giles, Bourhis, and Taylor (1977) suggest that language vitality feeds on itself. In other words, more used languages tend to have higher chances to survive in the long term. Grin (1992), through formal economic modelling, argues that this is not necessarily the case, i.e. vitality is not always associated with higher survival likelihood. As noted by Grin (1992), the view on vitality and long-term survival provided by Giles, Bourhis, and Taylor (1977) is somewhat circular, in that survival is simultaneously described as an indicator of vitality and a consequence thereof. Therefore, it is not actually possible to conclude that vitality feeds on itself. The computational simulation presented here contributes to the qualitative discussion of Giles, Bourhis, and Taylor (1977) and the economic modelling of Grin (1992). My analysis seems to support the idea that language vitality per se can hardly be considered a major driver of minority-language survival. Indeed, the results suggest that there is only a weak positive correlation between the initial proportion of bilingual speakers and time to extinction. Besides, this correlation tends to wither and almost disappear for initial proportions higher than 40% (this trend is presented in Figure 3.8). In other words, a small group of minority-language speakers can survive for a very long time, while a high initial proportion is in no way guarantee of long-term survival. This allows us to confirm further the results of the two previous analyses, i.e. that long-term survival of minority-language communities is highly dependent on other factors, such as the ones identified in this chapter.

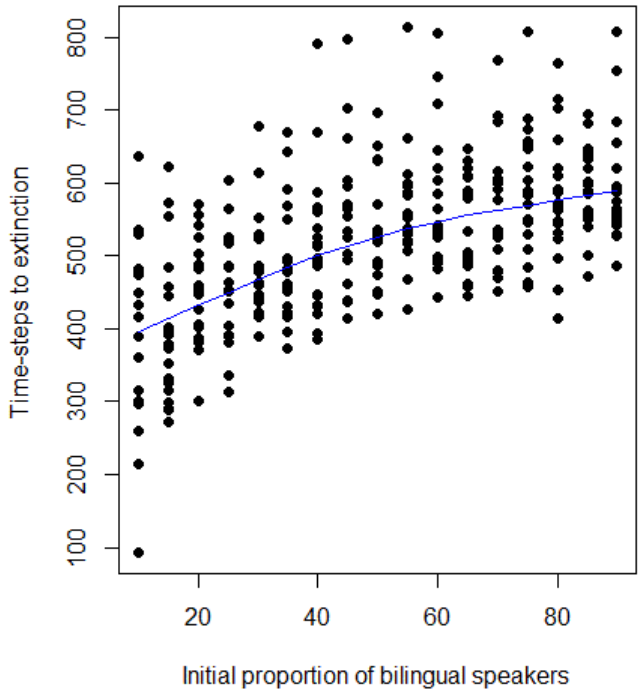


FIGURE (3.8) Scatterplot of time steps until extinction for various levels of initial proportion of bilingual speakers

3.6 Discussion

On the basis of the analysis of the simulations performed, a number of conclusions can be drawn. I try to back them up by referring to cases actually observed. It is probably worth starting our discussion with the impact of the exogamy rate of minority-language speakers, i.e. the frequency with which minority people tend to pair and build a family with a non-minority individual. According to the observed results, exogamous pairing, with the implications in terms of language transmission presented earlier, seems to have a major negative impact on the long-term chances of survival of the minority language. Indeed, numerous authors have observed a substantial negative correlation between the rate of exogamy and the level of minority language intergenerational transmission. For example, Harrison (1999), discussing the case of German immigrants to Canada, observes that a considerable amount of exogamy contributes to a lower level of language maintenance across generations. He compares this with the case of Punjabi-, Chinese- and Spanish-speaking immigrants to Canada, who were characterized by substantially lower rates of exogamy and a higher tendency to pass their language on to the next generation. These trends are confirmed by Frideres (2014), who studied the patterns of intergenerational language transmission among Aboriginal communities in Australia. He observes that within communities with

a high a level of exogamy there is a considerably lower use of Aboriginal languages and, consequently, diminished language continuity across generations. Referring to a previous study by Stevens and Schoen (1988), he associated linguistic intermarriage with an instance of group disaffiliation, whose direct effect on the next generation is complete language loss. Finally, Jan, Kuan, and Lomeli (2016) provide further support for this claim by studying the case of Hakka speakers in Taiwan. These findings fit particularly well in our discussion in that, as the authors argue, Hakka minority people are not physically distinguishable from majority people. The distinct Hakka language, along with Hakka traditions and cultures, is the main feature of the Hakka identity. The authors find that linguistic intermarriage has a significant negative impact on the likelihood of retention of the Hakka language across generations. In particular, they find that exogamy is the single strongest predictor of language loss and that for Hakka people born in mixed (Hakka-Han) families, the likelihood of speaking Hakka decreases by 87% with respect to those who have two Hakka parents.

Moving on to the relationship between education and survival of the minority-language community, we could notice that teaching the minority language has a positive impact on the chances of long-term survival and on the level of fluency of speakers. This is especially true if these programs are put in place before the size of the minority community declines too much. The analysis shows that both variables concerning education programs ("education" and "minority threshold") have a positive impact on the chances of long-term survival of the minority language. However, the impact is not enough to compensate the decline due to higher rates of exogamy. Indeed, they only seem to slow down the decline of the minority language, rather than stop it, let alone reverse it. Sadly, tales of unsuccessful language education programs are quite frequent in the relevant literature, the case of Irish being one of the most famous. To make a list of all the issues that caused Irish revival to be by and large a failure goes well beyond the scope of this chapter. Numerous authors have already discussed the matter in great detail, such as Ó Giollagáin et al. (2007) and Ó Giollagáin and Charlton (2015). Here I only discuss how language education plans can end up being a failure if they are not backed up by the right attitude among the very addressees of the plan. Even if we assume that schooling does make students fluent in the minority language, continuous exposure to majority language and the fact that the majority language might be the first option for many minority-language speakers (i.e., a scenario with a low level of speakers who play the "reveal"

strategy), not to mention a low level of mixed households where the minority language is passed on to the next generation, are largely enough to eliminate the benefits of schooling. Already in the nineties, Carnie (1996) mentioned an emblematic issue related to the Irish language revival program, which he labelled a "spectacular failure". Each year, thousands of English-speaking students with only limited knowledge of Irish participate in language immersion programs at "Gaelic colleges" in the Gaeltacht (the collection of primarily Irish-speaking regions of the Republic of Ireland). However, the massive infusion of English speakers who are reluctant to speak Irish causes the Irish-speaking students to be dramatically outnumbered. As a consequence, English quickly becomes the language of first choice for everyone. This program, rather than pushing English speakers to speak Irish, pushes Irish speakers to speak English.

3.7 Conclusions and potential developments

The model presented here provides some useful insights into the complex dynamics of language contact and its implications for the decline of minority languages. In particular, it does so by building on a number of relatively simple intuitions on individual language strategies. It considers multiple aspects, which can be combined to create different scenarios. Such scenarios can inform on the variations of the current conditions in the long term and/or on the potential long-term impact of different policies. Consequently, it can be used to serve policy-making purposes. It should be noted, however, that I developed and used the model with the final objective of testing the impact of different variables. The idea of creating an *in silico*[27] version of a multilingual community and study it derives from the fact that, in real life, it is not possible to observe enough different scenarios with a view to studying the relative impact of each variable. For a practical use, the model would have to be calibrated to reflect the actual case scenario under study and only then it would be able to provide some insights to inform, along with other qualitative and quantitative observations, the process of policy making. Therefore, this model should be seen as a first step towards the higher-level objective of getting language disciplines, social sciences and computational simulation closer together.

[27] *In silico* is a Latin expression coined on the model of *in vitro* and *in vivo* that is used to refer to experiments performed via computer simulations. It alludes to the silicon used to produce computer chips.

As it works through simulations rather than actually observed data, the model can be used to estimate the impact of different variables over very long periods of times, which would be otherwise unobservable. Besides, it can be amended or further developed to accommodate all sorts of different settings. For example, should a policy maker want to simulate a specific environment in which behavioural rules are known to work in a different way, she could simply go into the code and modify it accordingly. Alternatively, the model could be extended to abstract and parameterize more behavioural rules, so that they could be switched on and off according to need. One possible variation could be to change the assumptions concerning education. As said, it is assumed that students involved in language education programs become fluent by the end of schooling. If policy makers have precise data on the average level of fluency reached by students, it could be interesting to modify the model accordingly and look at long-term implications. Clearly, the direct consequences of any lower-than-proficient level at the end of school would result in a reduced effect of education policies. Another extension could be to compare scenarios with different types of reveal-strategy players, to reflect contexts with higher or lower power distance. For example, we may develop a scenario in which the decision to reveal or hide their background is not fixed but conditional on the power distance between them and their interlocutor.

On the basis of the previous discussion we can say that the ABM presented in this chapter provides a reasonably accurate representation of the actual trends of minority language decline resulting from language contact. Indeed, it provided realistic estimates of the trends in the proportions of Romansh speakers with respect to German speakers in the Canton of Grisons. Besides, several studies confirmed the relative weight of each individual factor included in the model as identified by our analysis. This suggests that the simple behavioural rules that I used to describe individual linguistic strategies of communication and intergenerational transmission are able to capture the essence of people's actual behaviour. In short, the model found that linguistic intermarriage and the implications assumed by the model in terms of language transmission seem to be the strongest factors affecting the likelihood of long-term survival of minority languages, while factors such as language education and the willingness to speak the minority language seem to have only a marginal impact. Higher levels of exogamy are associated with quicker rates of decline of the minority language. On the contrary, all the variables included in the model seem to have a non-negligible impact on the

level of fluency of minority-language speakers.

Needless to say, promoting endogenous marrying is not an advisable solution, nor is forcing people to speak the minority language. Rather, an answer to the decline of minority languages could lie in the social perception of these languages. The strong impact of the exogamy rate variable is mostly due to the assumed consequences of exogamy, i.e. that children born to mixed couples *do not* learn the minority language. The ABM presented in this chapter reveals the importance of language choice in exogamic couples. As I explained, the simulations assume that in bilingual households, the home language will be the majority one. This can be amended to reflect other possibilities, in which, for example, mixed families are actually encouraged to pass both languages on to the next generation. Or else, it could be assumed that majority-language speakers learn the minority language if their partner speaks it. This might easily hedge the decline of the minority-language community, if not reverse it.

A more positive social attitude towards minority languages, which may result from measures such as granting the status of official language or supporting cultural activities, could improve the chances of long-term survival. Indeed, it could:

1. influence communication dynamics in mixed families, pushing the monolingual parent to learn the minority language, raise the children bilingually and make sure that they become fluent in the minority language;

2. increase the likelihood that a minority-language speaker reveals that she speaks the minority language.

These two effects combined could have a significant impact on the long-term survival of minority languages. Indeed, attitude and social perception seem to play an important role in the dynamics of minority languages and that any measure in support of these languages risks being a failure if it is not welcomed by individuals with a positive attitude. As a matter of fact, success stories of this kind already exist. For example, ever since the end of Francoism, many institutional campaigns have been launched to support the revitalization of the Catalan language in Catalan-speaking regions of Spain. For example, the Government of Catalonia started many initiatives that explicitly addressed the issue of people feeling ashamed to speak Catalan. One of them was the "Dóna corda al català" ("Unleash the Catalan language") campaign, which was articulated in three themes: "Parla sense vergonya", "Parla amb llibertat" and "Per començar, parla en català", which roughly translate

to "Don't feel ashamed to speak", "Speak freely" and "Speak Catalan from the outset", respectively.[28] These campaigns were further supported by the introduction of Catalan as a preferential language for education and by the creation of Catalan-speaking media.

We can also expand our discussion to speculate on the implications of opening up to migration dynamics. In particular, we could consider the case of immigration flows and the issue of language choice for immigrants. As Chiswick and Miller (1994) note, the choice is straightforward for individuals migrating to monolingual countries. However, a number of variables come into play when the destination country is multilingual. These variables include proximity to the immigrant's native language, the predominant language in the specific region where they settle and its relative weight on the labour market. Considering these variables, it is easy to see that significant migration flows can have an impact on the size of minority-language communities, either positive or negative. For example, it is no secret that, among other things, massive immigration of French-speakers and other immigrants who preferred French over Dutch, combined with the perception of French as an elite language, is one of the factors that turned Brussels, a historically Dutch-speaking area, into a French-majority city (Leclerc, 2008).

It should be noted that education programs, as conceived in our ABM, were only addressing individuals in school age. They are then left to normal communication dynamics for the rest of their life, with the implications in terms of fluency in the minority language explained above. One way to increase the impact of education could be to introduce lifelong learning programs, so that the level of fluency of minority-language speakers could be sustained also after school age in spite of continuous exposition to the majority language. Besides, one could also think of extending minority-language education programs to majority-language speakers, whether they have a majority-majority or a mixed majority-minority background. This would easily amplify the impact of the two education-related variables.

Finally, concerning the relationship between vitality, defined as the proportion of people able to speak the minority language, and the long-term survival of the minority language, we saw that the initial proportion of bilingual speakers is only weakly correlated with long-term survival, and that this correlation is virtually non-existent for initial proportions greater than

[28] Examples can be found at the following addresses: https://www.youtube.com/watch?v=XlH4ZLSi3YM, https://www.youtube.com/watch?v=rtjniMmgY5A, https://www.youtube.com/watch?v=2wBmCrvj7Iw.

40%. This finding is somehow comforting, in that it implies that the long-term survival of the minority-language community is highly dependent on other factors. This means that it is possible to improve the vitality of minority languages through "policy-actionable" variables, almost regardless of the current proportion of minority-language speakers.

Chapter 4

Language Knowledge across the EU: Language Regimes, Language Learning and Consequences for Linguistic Disenfranchisement

4.1 Introduction

The objective of this chapter is to develop a model able to test different language education orientations and their consequences in terms of linguistic disenfranchisement. In particular, I will focus on the impact of linguistic distance and language learning. Ideally, this model would be a tool to help EU policy makers make informed decisions about language regimes and education policies, taking into account their consequences in terms of diversity and linguistic disenfranchisement. The model can be thought of as a "playground" where the player can force agents to make certain choices in terms of language skills acquisition. The player can then go on to compare different scenarios in which language skills are acquired according to different rationales. Differently from Chapters 2 and 3, the aim of this chapter is to show how a simulation model can be used practically in a policy-making context to compare different scenarios and get a grasp of the consequences of different policy measures. Therefore, the scope of this chapter is less theoretical and more practice-oriented.

Though to a lesser extent than other parts of the world, such as Africa, Europe is traditionally a very culturally and linguistically diverse continent. Throughout the history of Europe, diversity has often represented a major obstacle to peaceful cohabitation. Multilingualism is but one of the numerous aspects of European diversity. Therefore, it is not striking that more than

half a century since the beginning of the big European integration project known today as the European Union, linguistic diversity is still a hotly debated issue. Discussions on EU multilingualism revolve around some recurring macro-issues, such as integration, education, and trade. Many of these discussions have important ideological connotations, which often boil down to one simple question: should EU multilingualism be supported, neglected or even discouraged by the institutions?

As was briefly seen in Chapter 1, multilingualism is also a hot topic when it comes to discussions on the administration and functioning of the Union. As a consequence of the enlargement of the EU since the early 2000s, the number of languages has increased dramatically. It is not unusual to read in the general press complaints about a presumed perception among EU citizens of the EU language services (generally divided between translation and interpreting) as a costly and cumbersome apparatus. However, to the best of my knowledge, an actual survey asking citizens about their opinion on the EU language services was never conducted. The most common reply to this comment is that giving up language services would put at risk the capability of every EU citizen to fully understand what is going on in the EU. Democratic participation is an imperative that the EU cannot neglect. Besides, one should keep in mind that the cost of language services is small compared to other possibilities, such as making every EU citizen fluent in at least one *lingua franca* (often assumed to be English) to the point of being able to participate fully in the political life, should they wish to. This argument is further reinforced by the fact that this would not only represent an increase in the overall expense for multilingualism, but also a transfer of the financial burden from the EU institutions to the individual member states or even to individual citizens. Besides, multilingual skills are not evenly distributed across demographic groups. Therefore, giving up language services would unfairly put some specific categories at a disadvantage (for example, elderly people, people with low income and, clearly, non-native speakers of the chosen *lingua franca*) (Gazzola, 2014). In sum, a few simple considerations on the different strategies to deal with multilingualism in the EU are already enough to highlight several critical issues.

A language regime is roughly defined as the set of rules and measures concerning the language(s) to be used by the institution(s) in various situations. As of today, all EU institutions adopt a full language regime where the official languages of the member states are also official languages of the EU, at least when it comes to communication between the institutions and

the outside.[1] The right of every EU citizen to write to the institutions in her native language (or any other EU language of her choice) and receive an answer in the same language is indeed at the core of democratic participation and equal treatment. Some institutions, though, may have a different arrangement for inter- and intra-institutional communication. Employees of EU institutions are often expected to be able to master at least a couple of EU languages, with some languages being more frequently requested than others. Everything considered, the intricacies of multilingual communication practices seem to reflect the complexity of the EU linguistic landscape. Among all EU institutions, the European Parliament seems to be the one that accommodates language diversity the most. Indeed, no specific foreign language skills can and should be expected from elected members of the Parliament, and all EU citizens should be able to participate, actively or passively, in the parliamentary debate, regardless of their linguistic profile. Restricting communication to one or a few selected languages might push some people further away from the institutions, working against the ultimate goal of an integrated Europe.

Many scholars have discussed the consequences of different strategies of approaching multilingualism in the EU. In particular, some have brought forward the idea of "linguistic disenfranchisement", which is roughly defined as the condition of citizens who would lose their ability to understand EU documents and parliamentary discussions, should the full multilingualism regime be abandoned by the institutions. In this chapter, I develop a tool to sketch and project the linguistic landscape of the EU by means of computational simulations. In particular, I test how different strategies in terms of languages to learn lead to different outcomes in terms of overall disenfranchisement of EU citizens. The tool is developed as an agent-based model (ABM) that depicts the distribution of languages across the EU by number of speakers and project the evolution of this distribution based on different language learning strategies. On the basis of these projections, the model shall:

1. evaluate the evolution of language skills among EU citizens, based on different approaches to the choice of the language(s) to learn;

[1] It should be noted, however, that this is certainly true in theory, but not always in practice. For example, it was noted that the communications drafted by the EU to address the Covid-19 pandemics emergency were only available in English, which, at the time when these documents were published, was the native language of only 2 percent of the EU population. For more on this, see https://www.corriere.it/opinioni/20_febbraio_26/anche-emergenze-a993f9c2-58c6-11ea-8e3a-a0c8564bd6c7.shtml.

2. estimate the level of linguistic disenfranchisement based on different options of language regime for the EU; and

3. as a further development of point 2, estimate the relative impact of disenfranchisement across different social groups (e.g. what socio-economic or demographic classes are more affected).

The rest of the chapter is structured as follows. In Sections 4.2 and 4.3, I discuss multilingualism in Europe and in the European Union, along with its historical evolution. In particular, I explore in more depth the notion of language regime, its legal bases and practical implications within various EU institutions. In Section 4.4, I discuss language skills among EU citizens. I present the methodology adopted in this chapter to study linguistic diversity and linguistic disenfranchisement. Therefore, I discuss the development of the ABM and the data used. Finally, in Sections 4.5 and 4.6 I present the main results of the model and conclude by addressing its main limitations.

4.2 Language diversity in Europe

In this section, I discuss language diversity in Europe, focusing in particular on the territory of the European Union. This section is not an in-depth analysis of the linguistic landscape of Europe, which would be largely beyond the scope of this chapter. Rather, it is intended as a brief overview that shall help the reader familiarize herself with linguistic diversity in Europe and to show why it cannot be neglected by the institutions.

As mentioned in the introduction, Europe has a long tradition of linguistic diversity, as well as other forms of diversity. Most languages spoken across Europe belong to the Indo-European language family, with some notable exceptions, such as Finnish, Hungarian, Estonian (Uralic languages), Maltese (Semitic) and Basque (a language isolate). Within the Indo-European language family, Romance, Germanic and Slavic languages are by far the most commonly spoken. Smaller sub-families include Hellenic, Celtic and Baltic languages. If we also take non-indigenous languages into consideration, a number of African and Asian languages are added to the picture, such as Arabic, Turkish and Chinese. According to Ethnologue,[2] a total of 288 languages are currently spoken by about 741 million people throughout Europe (including the whole Russian Federation and not counting Turkey). The overwhelming majority of these languages are spoken by minorities. It has

[2]See https://www.ethnologue.com/region/Europe.

been observed that linguistic diversity (understood as the collection of living languages) is on a decreasing trend in Europe. Indeed, more than 40% of these 288 languages are classified as either "in trouble" or "dying" according to the EGIDS (Expanded Graded Intergenerational Disruption Scale, a scale that classifies languages based on their level vitality),[3] meaning that these languages are threatened with extinction within a few generations.

The only Europe-wide treaty on the protection and promotion of regional and minority languages is the European Charter for Regional or Minority Languages (ECRML), adopted by the Council of Europe in 1992 and ratified by a majority of its member states (with the notable exceptions of, among others, France and Italy, which signed the Treaty but have yet to ratify it). The ECRML applies to all languages that are

1. traditionally used within a given territory of a State by nationals of that State who form a group numerically smaller than the rest of the State's population, and

2. different from the official language(s) of that State,

thereby excluding recent immigrant languages. Generally speaking, languages listed in the Treaty are granted different levels of support, ranging from the mere recognition of such languages as an expression of cultural wealth to the implementation of *ad hoc* education plans.[4]

Migration flows also play a major role in shaping and reshaping Europe's linguistic landscape. Language and migration are linked by a double thread. On the one hand, people who migrate to Europe bring their language(s) along with them, which then end up being used within communities of migrants with the same linguistic background. On the other hand, a common language (as well as other forms of cultural proximity) can act as a driver for migration. Beine, Docquier, and Rapoport (2007) and Grogger and Hanson (2011) find that sharing a common language increases migration flows. Belot and Ederveen (2012) find that migration flows are positively correlated with the linguistic proximity[5] between the language of the origin and that of the destination. Interestingly, they find that the impact of linguistic proximity on migration flow is twice as strong as that of per capita GDP of the destination country.

[3] For more on the EGIDS, see https://www.ethnologue.com/language-development.

[4] For the complete text of the Treaty, see https://www.coe.int/en/web/conventions/full-list/-/conventions/rms/0900001680695175.

[5] The authors define linguistic proximity as a value from 1 to 5 calculated from the number of common nodes in a linguistic classification tree between the closest official languages of pairs of countries.

On top of all this, the acquisition of skills in languages other than one's own is highly encouraged within the European Union with a view of strengthening intercultural comprehension across a highly diverse territory. In a sense, one could argue that this is a way of "acquiring" diversity, especially if one assumes that learning a foreign language does not only mean acquiring language skills, but also being exposed to the culture and traditions that come with it. The EU is officially committed to fostering multilingualism among its citizens, by working together with Member States to reach ambitious objectives, such as "teaching at least two languages in addition to the main language(s) of instruction from an early age and by exploring the potential of innovative approaches to the development of language competences" (Council of the European Union, 2014). The EU recognizes that "[i]ncreasing and improving language learning and teaching could strengthen the European dimension in education and training [and] foster the development of a European identity in all its diversity [...]. Multilingual competence provides a better understanding of other cultures, thus contributing to the development of citizenship and democratic competences" (Council of the European Union, 2019).

All in all, one could argue that languages are simultaneously a manifestation and a driver of diversity. As I discuss in the next section, the European Union acknowledges the importance of diversity and eventually gave it legal recognition through Article 22 of the Charter of Fundamental Rights of 2000, which states that "the Union shall respect cultural, religious and *linguistic* diversity" (emphasis added) (European Convention, 2000, art. 22, p. 13).

4.3 EU language regimes and linguistic disenfranchisement

In this section I discuss the notion of language regime, its application in the context of the European Union and its implications in terms of linguistic disenfranchisement. Concerning the latter point, I present a number of different language regimes that shall serve as a basis for the simulation model. Besides, I review a few previous studies on this topic.

4.3.1 Language regimes in the EU

The earliest steps towards European integration date back to 1951, when six European countries (Belgium, France, Italy, Luxembourg, the Netherlands

and (West) Germany) signed the Treaty of Paris and established the European Coal and Steel Community (ECSC) as a means of preventing arms race in the aftermath of the Second World War. The Treaty was drafted in French and contains no reference to languages. Article 100 states that the Treaty is drafted in a single authentic copy and that certified copies will be delivered to each member states.[6] Although there was a general perception that French had a privileged status as the only official language of the ECSC (Hnízdo, 2005), the language issue was officially addressed one year later by the committee of the foreign ministers during a meeting held in Paris in July 1952 (European Commission, 2009). The committee established a full multilingualism regime based on four official and working languages (Dutch, French, German and Italian).[7] The debate mainly revolved around two ideas. On the one side, the French delegation supported the idea that having every document drafted in one language was the only way to grant legal consistency with the Treaty. On the other side, the German delegation insisted that priority should be given to respecting the rights of the recipients of the law and that this would only be possible if the legal texts were equally binding in all official languages. The latter view eventually prevailed and, in a protocol issued on July 24, 1952, the committee of foreign ministers established the principles at the basis of the language regime of the ECSC (and, as a matter of fact, of the institutions in which it evolved):

1. decisions, recommendations and individual opinions of the Community must be drafted in the language of the recipients;

2. correspondence with the Community institutions takes place in one of the four official languages and replies must be written in the language of the sender;

3. the Assembly may determine autonomously the practices of language use for the purposes of its own functioning;

[6] Article 100 of the Treaty establishes that "[l]e présent Traité, rédigé en un seul exemplaire, sera déposé dans les archives du gouvernement de la République française qui en remettra une copie certifiée conforme à chacun des gouvernements des autres États signataires." (Official English translation: "This Treaty, drawn up in a single original, shall be deposited in the archives of the Government of the French Republic, which shall transmit a certified copy thereof to each of the Governments of the other signatory States.") (Traité instituant la Communauté Européenne du Charbon et de l'Acier, 1951).

[7] The distinction between "official" and "working" languages echoes practices adopted by other international organizations. The International Criminal Court, for example, has six official languages (Arabic, Chinese, English, French, Russian and Spanish), of which only English and French are also working languages for everyday activities (see https://www.icc-cpi.int/about). In the case of the ECSC this distinction becomes meaningless, as its language regime puts all official languages on the same level.

4. legislative acts must be published in all four official languages;

5. the Court of Justice can define its own regime and determines autonomously the language of the draft judgement;

6. member states with more than one official language can request that the rules provided for by their legislation be applied (European Commission, 2009).

This view quickly became a standard approach to the language issue. Indeed, both Treaties of Rome of 1957 (establishing the European Economic Community and the European Atomic Energy Community) read (in the French version):

> "Le présent Traité, rédigé en un exemplaire unique, en langue allemande, en langue française, en langue italienne et en langue néerlandaise, *les quatre textes faisant également foi*, sera déposé dans les archives du Gouvernement de la République Italienne qui remettra une copie certifiée conforme à chacun des gouvernements des autres États signataires" (emphasis added)[8] (Traité instituant la Communauté Économique Européenne, 1957; Traité instituant la Communauté Européenne de l'Énergie Atomique, 1957)

This represents a clear change of direction with respect to the Treaty of Paris, as the equal treatment of languages had eventually received legal recognition.

The legal basis of the current multilingual regime of the EU is Regulation No. 1 adopted by the Council on 15 April 1958. The Regulation lists rules identical to those applied by the ECSC. In its original version, it officially provides that "[t]he official languages and the working languages of the institutions of the Community shall be Dutch, French, German and Italian" (Council of the European Economic Community, 1958) and it has been amended with every enlargement to include new languages. From a legal standpoint, this means that all texts are drafted in all official languages, they are not mere translations of an original version and are all equally binding.[9]

[8] "The present Treaty, drawn up in a single original in the German, French, Italian and Netherlands languages, all four texts being equally authentic, shall be deposited in the archives of the Government of the Italian Republic which shall transmit a certified copy to each of the Governments of the other signatory States."

[9] In this regard, it is worth noting that Articles 3 and 4 of the Regulation distinguish between documents to be sent to a specific member state or individual falling under the jurisdiction of a member state, which shall be drafted in the official language of the member state, and documents of general application, which shall be drafted in all official languages.

It is worth noting here that there exists a difference between the *external* and the *internal* language regime. Most of the preceding considerations apply to the external language regime, which covers all exchanges between the institutions and the outside. On the contrary, the internal language regime governs the exchanges within and between the institutions of the Community. Regulation 1/1958 allows for a great deal of flexibility within institutions by providing that "[t]he institutions of the Community may stipulate in their rules of procedure which of the languages are to be used in specific cases" (Council of the European Economic Community, 1958, art. 6). It was observed that French, German and, starting from the 80s, English quickly became the languages of everyday use within the institutions (European Commission, 2009). Some even go as far as to argue that French was the only official language of the European Economic Community up until 1973, when the UK and the Republic of Ireland joined the Community (Šlosarčík, 2002; Hnízdo, 2005). The European Commission explicitly lists English, French and German as its "procedural" languages for internal business.[10]

At the time that I started developing the model, the European Union had 28 member states and 24 official and working languages (OWLs).[11] However, for a more complete representation of the linguistic landscape of the European Union, a number of regional and minority languages and dialects would need to be mentioned in addition to the list of official languages. For example, although Scottish Gaelic enjoys equal status (or, in the words of the Gaelic Language Act, equal *respect*) as the English language in Scotland,[12] it is not one of the official languages of the EU. Although by "regional and minority languages" one usually refers to languages traditionally spoken on the European territory, we should not disregard the weight of non-autochthonous language communities that resulted from migration flows. Some of these languages even have local recognition in some member states. It is the case, for example, of Vietnamese, which is an officially recognized minority language in the Czech Republic. Other immigrant languages do not have official recognition in any EU member states but are still spoken by a sizeable share of people as a native language, such as (different varieties of) Arabic in France (Talon, 2012).

[10] See http://europa.eu/rapid/press-release_MEMO-13-825_en.htm.

[11] Since February 1st, the number of member states went down to 27, but the number of official languages is still 24. For the purposes of the model presented here, the United Kingdom is still taken into consideration.

[12] For the full text of the Gaelic Language (Scotland) Act 2005, see http://www.legislation.gov.uk/asp/2005/7.

4.3.2 Types of language regimes

Various authors have discussed different types of language regimes. Often, language regimes vary simply in the number of languages they include, although other variables can come into play. Referring to Pool (1991b) and Gazzola (2006a), Grin (2008b) provides a detailed classification of the different types of language regimes for multilingual international organizations that have been discussed over time. He lists seven types of language regimes:

1. the "monarchic" regime, in which there is only one official and working language (often English, in the case of the European Union), implying that everybody needs to be able to speak the chosen language and that there is no need for language services;

2. the "synarchic" regime, which works in the same way as the monarchic one, with the only difference that the chosen language is not native to the citizens of any member state (such as Esperanto);

3. the "oligarchic" regime, in which there are more than one official and working language (for example three or six), implying a need for translation and interpretation services from and into these languages and that everybody is fluent in at least one of them;

4. the "panarchic" regime, in which all languages are official and working language of the institution (which is currently the case of the European Parliament), implying a need for translation and interpretation services between all these languages, but no need for foreign language skills;

5. the "hegemonic" regime, which works like the panarchic regime, with the only difference that translation and interpretation does not happen directly between all languages, but through a "pivot" language, such as English;

6. the "technocratic" regime, which is the same as the hegemonic one, with the difference that the pivot language is no one's native language, such as Esperanto;

7. finally, the "multiple symmetrical relay", which works like the hegemonic regime, but relying on n pivot languages instead of one (often with $n = 3$, in which case we speak specifically of "triple symmetrical relay").

Regime	Number of OWLs	Nature of OWLs	T&I directions	Foreign language learning needs
Monarchic	1	English	0	English by all non-Anglophones
Synarchic	1	Esperanto	0	Esperanto by all
Oligarchic	1<n<24	English, French, German	6	English, French or German by non-native speakers
Panarchic	24	All 24	n(n-1)=552	None
Hegemonic	24	All 24	2(n-1)=46, via English	None
Technocratic	24	All 24 + Esperanto	2n=48, via Esperanto	None
Triple symmetrical relay	24	All 24	r(2n-r-1)=132, where r=3	None

TABLE (4.1) Language regimes for multilingual international organizations (adapted from Grin, 2008)

Table 4.1, adapted from Grin (2008b), summarizes the seven language regimes, assuming that the language chosen for the monarchic and hegemonic regimes is English, the one for the synarchic and technocratic ones is Esperanto, and the ones for the oligarchic one are English, French and German.[13]

4.3.3 Linguistic disenfranchisement

Linguistic disenfranchisement, first introduced by Ginsburgh and Weber (2005), is a direct consequence of different language regimes. The rate of linguistic disenfranchisement measures the share of a population that is excluded from the group of beneficiaries of a given language policy (Burckhardt, 2018). In the specific context of the European Union, the linguistic disenfranchisement rate is generally defined as the percentage of citizens who do not master any official language. These people would be unable to understand EU documents and participate in the EU political discussion, either actively or passively, following a reduction of the number of working languages of EU institutions. Ginsburgh and Weber (2005) further distinguish *dichotomous* and *distance-adjusted* (or *continuous*) disenfranchisement rates. The dichotomy of the first dimension refers to the fact that an individual either speaks or does not speak a given language, regardless of anything else. The second dimension adds linguistic distance to the picture. Linguistic distance can be

[13]The numbers are updated to account for the addition of Croatian in the set of OWLs.

	Disenfranchised if...	
	Dichotomous	**Distance-adjusted**
Native	...unable to speak any OWLs natively	...unable to speak any OWLs natively according to distance from mother tongue
All languages	...unable to speak any OWLs natively or as a second language	...unable to speak any OWLs natively or as a second language, according to distance from mother tongue or any other known language

TABLE (4.2) Types of disenfranchisement (adapted from Burckhardt, 2018)

roughly defined as an index (between 0 and 1) that captures the (mostly lexical) similarity between two languages, higher values indicating greater similarity.[14] An individual is considered disenfranchised if she does not speak any OWL, but the level of disenfranchisement that she experiences is a function of the linguistic distance between her language(s) and the OWL(s). For example, if we imagine a language regime that only has Spanish as an OWL, an individual speaking Italian would be "less disenfranchised" than an individual speaking German, due to Spanish being closer to Italian than it is to German.

Regardless of whether one takes a dichotomous or a distance-adjusted approach, when deciding whether an individual is disenfranchised, one can take into consideration either an individual's native language only, or all the languages in which she is proficient. The first case only looks at native vs non-native speakers. Therefore, one is considered disenfranchised simply if one's *native* language is not included in the list of OWLs, regardless of one's skills in other languages. In the second case, one is counted as disenfranchised if one does not speak any OWL, considering one's native language and any other language one is able to speak. The four indices can therefore be arranged in a two-by-two matrix in which the two dimensions are "dichotomous vs distance-adjusted" and "native vs all languages", as represented in Table 4.2. When looking at second languages, one might also want to take into consideration the level of proficiency in said second languages. One might indeed consider as disenfranchised all those who have a less-than-proficient knowledge of a (working) language. This is equivalent to expanding the "native vs all languages" dimension to include any nuance of knowledge between basic and native-like. This distinction is also discussed by Gazzola (2016), who speaks of *absolute* disenfranchisement, which considers as disenfranchised all individuals having absolutely no knowledge of the

[14] For an in-depth discussion of linguistic distance and how it can be computed, see Dyen, Kruskal, and Black (1992).

official language(s), and *relative* disenfranchised, which considers as disenfranchised also individuals who have less-than-proficient knowledge of the official language(s).

4.4 A model of language acquisition

In this section I present in detail the ABM developed for the purposes of this chapter.[15] The model is developed using the Python programming language, as opposed to the models presented in Chapters 2 and 3, which were developed in the NetLogo environment. The environment simulated is a collection of agents that represent roughly the linguistic and socio-economic profile of the European Union. As said in the introduction, this model can be used to test different language learning strategies among agents. This can be thought of as the consequence of education policies. For example, one might wonder what the consequences would be if EU member states favoured (e.g. through education policy) the acquisition of skills in one of the most spoken languages or in languages more closely related to people's native language.

In order to replicate the environment of the European Union, the agents are provided with a set of characteristics collected from actual databases. In the following subsections I explain how the database that feeds the model is constructed. The final database draws from two different databases, the Special Eurobarometer 386 and the linguistic distance database compiled by Dyen, Kruskal, and Black (1992).

4.4.1 The Special Eurobarometer 386 survey

A number of properties are assigned to agents using data from the "Special Eurobarometer 386: Europeans and their Languages" (European Commission, 2012). The Eurobarometer surveys are conducted periodically on behalf of the European Commission and investigate many issues throughout its member states. They focus particularly on the citizens' perception and expectations towards the intervention of the European Union and the challenges that it faces. The topics covered by the survey are numerous, ranging from air quality, gender equality and democracy to sports, trade and climate change.[16] In particular, the Special Eurobarometer 386, carried out in 2012, is the latest survey concerning languages (similar surveys were carried out

[15] The complete code of the model is available in appendix D.

[16] For a list of the topics covered by the Eurobarometer surveys, see https://ec.europa.eu/COMMFrontOffice/publicopinion/index.cfm

in 2001, 2005 and 2006) and provides information about language skills and the attitude of EU citizens towards multilingualism and language services. It covers the then 27 member states (the 28th member state, Croatia, joined the EU in 2013). The survey includes information collected from 26,751 EU citizens from different social and demographic groups, aged 15 or older and residing in a EU member state, with a view to making the results of the survey as representative of the whole EU population as possible. In addition to information about languages, the database includes general demographic information, such as age, sex, profession and education. The survey collects data from roughly 1000 respondents per member state, except Cyprus, Luxembourg and Malta, with only about 500 respondents each. In the interviews, respondents were asked about the languages they speak, their motivation to learn foreign languages, the difficulties they encountered, the situations in which they resort to foreign languages, the impact of translation in their life, and so on.

For the purposes of the model presented here, I use a section of this database. For the practical reasons explained in Subsection 4.4.2, four countries had to be excluded from the analysis, namely Finland, Hungary, Estonia and Malta. In the model, each agent reproduces the linguistic, social and demographic profile of an actual respondent from the survey. In particular, agents have the following properties:

1. country of residence;
2. nationality(ies);
3. age;
4. age when they finished education (which can be considered a proxy for the level of education);
5. mother tongue(s);
6. profession (one of eight categories);
7. living condition (countryside, small city or big city);
8. first, second and third foreign language (if any) and related level of fluency (from 1, basic, to 3, very good).

As the focus is on the impact of language acquisition on linguistic disenfranchisement given the language regime, I look exclusively at the competences

of citizens in the official languages of the EU countries considered, disregarding all other languages they might now. As a consequence, agents that spoke none of these languages were also excluded, leaving a database of 21,890 observations.

4.4.2 The linguistic proximity matrix

In addition to the ones mentioned above, agents have an additional property, whose value depends on their mother tongue(s). Based on their native language, each agent takes on a vector of values that defines the linguistic proximity between their native language and all official languages of the environment simulated. The notion of linguistic proximity (or, equivalently, that of linguistic distance) is very interesting, but it poses many issues, in that it is highly dependent on the method used to compute it. For the purposes of the model developed here, I use the concept of linguistic proximity in order to have a proxy of the subjective perception of each individual when it comes to picking a language that is closer to her native language and that she could learn relatively faster.

The information about linguistic distances comes from a different database, adapted from Dyen, Kruskal, and Black (1992). The linguistic distance between languages is estimated using the lexicostatistical method, first introduced by Swadesh (1952). The method works by and large as follows:

- in the first phase, one prepares a list of basic terms that exist in all the languages that one wants to compare and collects the related terms;
- in the second phase, one looks at the terms for the same meaning across languages and establishes whether they are *cognates*, i.e. they descend from the same root;[17]
- in the third phase, one goes on to compute the percentage of cognate words within the list considered across pairs of languages.

It is often more intuitive to speak of *linguistic proximity* rather than linguistic distance. The value of the linguistic proximity index goes from 0 (no cognate words in the list considered) to 1 (all words considered are cognate). Intuitively, the higher the value of the index, the closer the languages under

[17] It should be noted that two terms in two different languages are considered cognates if and only if they are descended from the same ancestors, and not if a language simply borrowed the term from the other.

	Irish	Romanian	Italian	French	Spanish	Portuguese	German	Dutch	Swedish	Danish
Irish	1	0,163	0,2	0,188	0,195	0,183	0,194	0,18	0,186	0,183
Romanian	0,163	1	0,66	0,579	0,594	0,629	0,249	0,254	0,239	0,237
Italian	0,2	0,66	1	0,803	0,788	0,773	0,265	0,26	0,259	0,263
French	0,188	0,579	0,803	1	0,734	0,709	0,244	0,244	0,244	0,241
Spanish	0,195	0,594	0,788	0,734	1	0,874	0,253	0,258	0,253	0,25
Portuguese	0,183	0,629	0,773	0,709	0,874	1	0,247	0,253	0,258	0,25
German	0,194	0,249	0,265	0,244	0,253	0,247	1	0,838	0,695	0,707
Dutch	0,18	0,254	0,26	0,244	0,258	0,253	0,838	1	0,692	0,663
Swedish	0,186	0,239	0,259	0,244	0,253	0,258	0,695	0,692	1	0,874
Danish	0,183	0,237	0,263	0,241	0,25	0,25	0,707	0,663	0,874	1
English	0,183	0,227	0,247	0,236	0,24	0,24	0,578	0,608	0,589	0,593
Lithuanian	0,196	0,203	0,242	0,221	0,23	0,215	0,224	0,214	0,218	0,222
Latvian	0,176	0,179	0,218	0,207	0,206	0,196	0,2	0,195	0,209	0,203
Slovenian	0,191	0,21	0,24	0,218	0,228	0,219	0,267	0,246	0,253	0,267
Czech	0,212	0,223	0,247	0,231	0,24	0,236	0,259	0,244	0,25	0,254
Slovakian	0,205	0,227	0,251	0,235	0,244	0,24	0,258	0,247	0,259	0,268
Polish	0,2	0,216	0,236	0,219	0,228	0,224	0,246	0,231	0,237	0,251
Bulgarian	0,182	0,202	0,231	0,209	0,218	0,219	0,231	0,221	0,236	0,24
Croatian	0,204	0,222	0,245	0,228	0,232	0,234	0,236	0,221	0,237	0,251
Greek	0,141	0,157	0,178	0,157	0,167	0,167	0,188	0,188	0,184	0,183

study. For example, Swadesh (1952) finds that English and German are connected by 57.8% of the 200 words that he considered (or, equivalently, have a proximity index of 0.578), while French and English are connected by 23.6% of the words (or have a proximity index of 0.236).

For the purposes of the model, it was necessary to create a 20 by 20 matrix that would include the pairwise linguistic proximity indexes for the Indo-European EU official languages. This choice stems from the fact that the original database by Dyen, Kruskal, and Black (1992) only includes Indo-European languages. Therefore, the linguistic proximity index for some EU official languages, namely, Hungarian, Finnish, Estonian and Maltese, was not available. Therefore, these languages were excluded from the model. As a consequence, in order not to skew the results, Hungary, Finland, Estonia and Malta were also excluded from the database. The linguistic proximity indexes are reported in Table 4.3.

4.4.3 Simulating language learning

In the setup phase of the simulation, agents are created and residence is assigned proportionally to the actual distribution throughout the EU. As residence is more or less uniformly distributed in the original database (roughly 1000 observations per country), the model samples randomly out of it, in order to replicate the actual distribution of residents by country.[18] All other

[18] In the simulation performed, I sample 50000 agents (allowing for repetitions in the sampling process) with the following distribution: Austria, 915; Belgium, 1177; Bulgaria, 707; Cyprus, 123; Czech Republic, 1088; Denmark, 589; France, 6633; Germany, 8513; Greece, 1059; Ireland, 502; Italy, 6144; Latvia, 191; Lithuania, 276; Luxembourg, 64; Netherlands, 1741; Poland, 3846; Portugal, 1037; Romania, 1955; Slovakia, 554; Slovenia, 211; Spain, 4751; Sweden, 1026; United Kingdom, 6898.

	English	Lithuanian	Latvian	Slovenian	Czech	Slovakian	Polish	Bulgarian	Croatian	Greek
Irish	0,183	0,196	0,176	0,191	0,212	0,205	0,2	0,182	0,204	0,141
Romanian	0,227	0,203	0,179	0,21	0,223	0,227	0,216	0,202	0,222	0,157
Italian	0,247	0,242	0,218	0,24	0,247	0,251	0,236	0,231	0,245	0,178
French	0,236	0,221	0,207	0,218	0,231	0,235	0,219	0,209	0,228	0,157
Spanish	0,24	0,23	0,206	0,228	0,24	0,244	0,228	0,218	0,232	0,167
Portuguese	0,24	0,215	0,196	0,219	0,236	0,24	0,224	0,219	0,234	0,167
German	0,578	0,224	0,2	0,267	0,259	0,258	0,246	0,231	0,236	0,188
Dutch	0,608	0,214	0,195	0,246	0,244	0,247	0,231	0,221	0,221	0,188
Swedish	0,589	0,218	0,209	0,253	0,25	0,259	0,237	0,236	0,237	0,184
Danish	0,593	0,222	0,203	0,267	0,254	0,268	0,251	0,24	0,251	0,183
English	1	0,216	0,197	0,249	0,241	0,25	0,239	0,228	0,234	0,162
Lithuanian	0,216	1	0,613	0,338	0,376	0,395	0,361	0,342	0,357	0,172
Latvian	0,197	0,613	1	0,323	0,333	0,357	0,332	0,306	0,337	0,152
Slovenian	0,249	0,338	0,323	1	0,663	0,694	0,633	0,615	0,684	0,179
Czech	0,241	0,376	0,333	0,663	1	0,914	0,766	0,689	0,719	0,164
Slovakian	0,25	0,395	0,357	0,694	0,914	1	0,778	0,685	0,732	0,168
Polish	0,239	0,361	0,332	0,633	0,766	0,778	1	0,631	0,68	0,163
Bulgarian	0,228	0,342	0,306	0,615	0,689	0,685	0,631	1	0,709	0,189
Croatian	0,234	0,357	0,337	0,684	0,719	0,732	0,68	0,709	1	0,179
Greek	0,162	0,172	0,152	0,179	0,164	0,168	0,163	0,189	0,179	1

TABLE (4.3) Language proximity indexes (Dyen, Kruskal, and Black (1992)

properties are assigned by randomly selecting a respondent from the database and assigning her properties to an agent with the same residence, allowing for repetitions. When the simulation is launched, agents are asked to make a decision about learning a language. In the simplest case, an agent does not speak any EU language (other than her own). The agent is then asked, with a certain probability, to start learning a new EU language (I will discuss later how the agent selects the language to learn). In case the agent already knows one or more foreign languages, she is asked to look at her level of fluency in them (which, as said, goes from 1 to 3). If she speaks a foreign language at a level of fluency lower than 3, she is asked, with a certain probability, to go on learning it until she is proficient in it (i.e. she reaches level 3).[19] If the agent's foreign languages are all at level 3, she picks a new one with a certain probability, based on the rules explained below. This process goes on as a long as an agent knows fewer than three foreign languages at level 3.[20]

A property that does not belong to any agent but to the environment is the language regime. I consider three types of scenarios, that is, monolingual (monarchic), trilingual and hexalingual (oligarchic with, respectively,

[19] In case the agent speaks more than one foreign language at the same level of fluency, she picks one of them based on the rules explained below.

[20] I am aware that this is a relatively extreme choice, given that not everyone is willing (or simply has the chance) to learn three foreign languages. However, I can justify this choice in two ways. First, this number is certainly a limit, but only a very small minority of agents get to learn three foreign languages in the time allowed for the simulation. Therefore, it should rather be seen as a possibility to learn more languages, should an agent be able to do so. Second, having a high cap to the number of languages can be interpreted as a context in which the acquisition of language skills is highly encouraged, which is the scenario that I am interested in exploring.

n=3 and n=6).[21]

At the beginning, no agent is learning a foreign language. The corresponding status is "not learning". After the first iteration, agents start learning a language with a certain probability p and switch their status from "not learning" to "learning". At every time step, an agent learns the language she has picked, that is, her level of fluency in that language increases. The speed at which she acquires skills in that language (that is, the speed at which her level in that language increases from 0 to 3) depends directly on the proximity between the language that she is trying to learn and the closest language among her native language(s) and the foreign language(s) in which she is fully proficient. The shorter the distance between the two languages, the fewer the time steps required by the agent to reach proficiency in the new language. When the agent has reached proficiency, she switches her status back to "not learning" and the process starts again (i.e. the same agent can go on to learn an additional language). Every agent is programmed to be able to learn up to three foreign languages in total, including the ones that she already knows from the start. The languages are learned in succession and not in parallel. This is due to two reasons: first, I find that it is more reasonable for an individual to focus on the acquisition of one language at a time; second, as agents can base the choice of the language(s) to learn on their skills in all the languages in which they are proficient (native or non-native), becoming proficient in a foreign language can influence the pattern of future choices.

As has been explained before, if an agent already knows one or more foreign languages at a less-than-proficient level, it is assumed that she is currently learning it and will keep doing so, starting from the one that is closer to proficiency. When asked to pick a new language to learn, agents can then use one of three strategies, which is selected before the simulation is launched and applies to all agents:

1. they can pick the language that has the highest number of native (L1) and non-native (L2) speakers;

2. they can pick the language that is closest to (one of) their native language(s) or any other language in which they are fluent, that is, the language they will learn in the shortest amount of time;

[21] In the simulated database, the six most spoken languages as native or foreign language (at a proficient level) are, in descending order, English, German, French, Italian, Spanish and Polish. These are the languages taken into consideration for the three language regimes.

3. a combination of strategies 1 and 2, that is, they can pick a language close to their own and having a relatively high number of L1 and L2 speakers.

During the simulation, the model updates and keeps track of a number of values. It keeps track of the total number of L1 and L2 speakers of every language. This information is crucial and affects the model in two ways. At the micro level, it affects individual agents' decision about the language they should learn, if they are using strategies 1 or 3 in the list above. At the macro level, this information is necessary for the system to establish the OWLs of the language regimes. Indeed, the three regimes consider, respectively, the one, three or six most spoken languages. After the simulation, I use the data generated to calculate the level of disenfranchisement, which is a direct consequence of the language regime. Finally, given that the model keeps the original information regarding the individual properties of the agents, it is possible to identify the socio-demographic categories most likely to be disenfranchised.

4.5 Results and discussion

The model generates a massive amount of data. As a consequence, it is possible to simulate many different scenarios and to analyse the results from different perspectives. In this chapter, I focus on the consequences of various approaches to language learning in terms of linguistic disenfranchisement. This can be interpreted as a harmonized education policy across EU member states to encourage citizens to acquire language skills on the basis of different rationales. I discuss two aspects of the results. First, I look at the changes in disenfranchisement rates across three different language regimes in three scenarios, one for each of the learning rules described in Subsection 4.4.3. Then, I try to identify to categories more at risk of being disenfranchised, in terms of some of the properties mentioned in Subsection 4.4.1.

In the simulations presented here, I assumed a probability of starting to learn a language equal to 1, in order to analyze the effect of the three different strategies under the general assumption that all actors are willing to learn. Indeed, a varying probability, although useful to simulate a scenarios in which not everybody decides to learn a language, would have mitigated the impact of the strategies. The initial population was randomly sampled from the database, as explained above, and then I ran three simulations, one for each strategy. Agents are allowed to learn during an arbitrary period

	Initial situation	Outcome after six iterations		
		Scenario 1	Scenario 2	Scenario 3
Monolingual	78.15%	47.21%	56.09%	48.42%
Trilingual	46.96%	32.09%	24.76%	24.28%
Hexalingual	19.04%	9.60%	6.09%	3.03%

TABLE (4.4) Disenfranchisement rates of different regimes across various scenarios.

of six iterations (which can be thought of as six years),[22] during which the proficiency level in the language(s) that they learn increases according to the proximity between the language studied and the closest of the languages they speak fluently.

First, we can look at the numbers reported in Table 4.4, which displays the disenfranchisement rates associated with the three regimes across the various scenarios. The first column, "Initial situation", reports the initial situation of disenfranchisement, before starting any learning process. As expected, the highest disenfranchisement rate is associated with the monolingual (English-only) regime, with almost 80% of the agents unable to speak English at a high level, either as a native or as a foreign language. The values associated with the two oligarchic regimes are clearly much lower, indicating that less people are left out when one of these regimes is adopted. Scenarios 1, 2 and 3 can be seen as three different directions in which the same initial situation evolves following the implementation of three different orientations in language education (i.e. the three different learning strategies explained earlier). Unsurprisingly, the disenfranchisement rates associated with the monolingual regime are still relatively high across all scenarios. However, although the differences are not particularly big, it is interesting to note that the monolingual regime is optimized under the first learning strategy, that is, learn the language with the highest number of fully proficient speakers (as L1 or L2), which is English.[23] This is probably due to the fact that many agents already had a basic level of English and managed to reach proficiency during the simulation. For many other agents English was probably close enough to allow them to become fluent in it within the time allowed. However, there

[22] These simulations are remarkably shorter than the ones discussed in Chapter 3, which developed over hundreds of iterations. However, it should be noted that the focus of the two models is very different. The model presented in Chapter 3 focuses on the long-term dynamics of language competition. Therefore, it was necessary to let the simulations run for a very high number of iterations to observe the trends over various generations. Conversely, the model presented in this chapter focuses on the acquisition of language skills by individuals. As a consequence, a much shorter time-span was necessary.

[23] Obviously, if an agent is already fluent in English, she will start learning the second or third most spoken language.

is still a sizeable number of people who did not manage to become fluent in English in the time allowed for the simulation. This is mostly due to two facts. First, for many agents English is a distant language. Therefore, six iterations were not enough to allow them to reach fluency. Second there were people who were already learning languages other than English, who might have managed to become fluent in those other languages. This last remark can be confirmed by the fact that the two oligarchic regimes under this same scenario are associated with much lower disenfranchisement rates.

The trilingual regime is almost equally optimized under scenarios 2 and 3, where people are allowed to learn the genetically closer languages to any of the languages in which they are fluent (any language in scenario 2, one of the six most spoken languages in scenario 3). This strategy ensures that agents could learn new languages at a much faster pace, as they systematically pick the languages that would optimize their learning process. As could be expected, these two scenarios also grant a more uniform distribution of L2 skills, as opposed to scenario 1, in which L2 skills are more concentrated in the top three most spoken languages, as shown in Figure 4.1. The same arguments apply to the hexalingual regime, with the only difference that it is significantly better-performing under the conditions of scenario 3 in terms of disenfranchisement rate. This is most likely due to the fact that, under the conditions of scenario 2, agents too often pick languages to learn that would leave them disenfranchised. For example, a Bulgarian speaker would not pick Polish as her first choice, since there are other Slavic languages which are closer. However, Polish is the only Slavic language that is included in the hexalingual regime. Therefore, speakers of a Slavic languages are less likely to be disenfranchised if they pick a more widely spoken Slavic language, instead of simply the closest one.

I now move on to the second part of the analysis. One might argue that, if the strategies are adopted in the same way by all agents, the impact should be uniformly distributed among them. However, the interest of looking at the categories that are more susceptible of being disenfranchised stems from the fact that the language skills in the database used to create the simulated population are not evenly distributed. Therefore, the uneven distribution of language skills might reverberate even after the implementation of the language learning policies, especially because it is assumed that agents can rely on their previously acquired language skills to learn new languages. For example, a French speaker would learn German at a relatively slow pace, because French and German are not very close. However, if this agent is fully

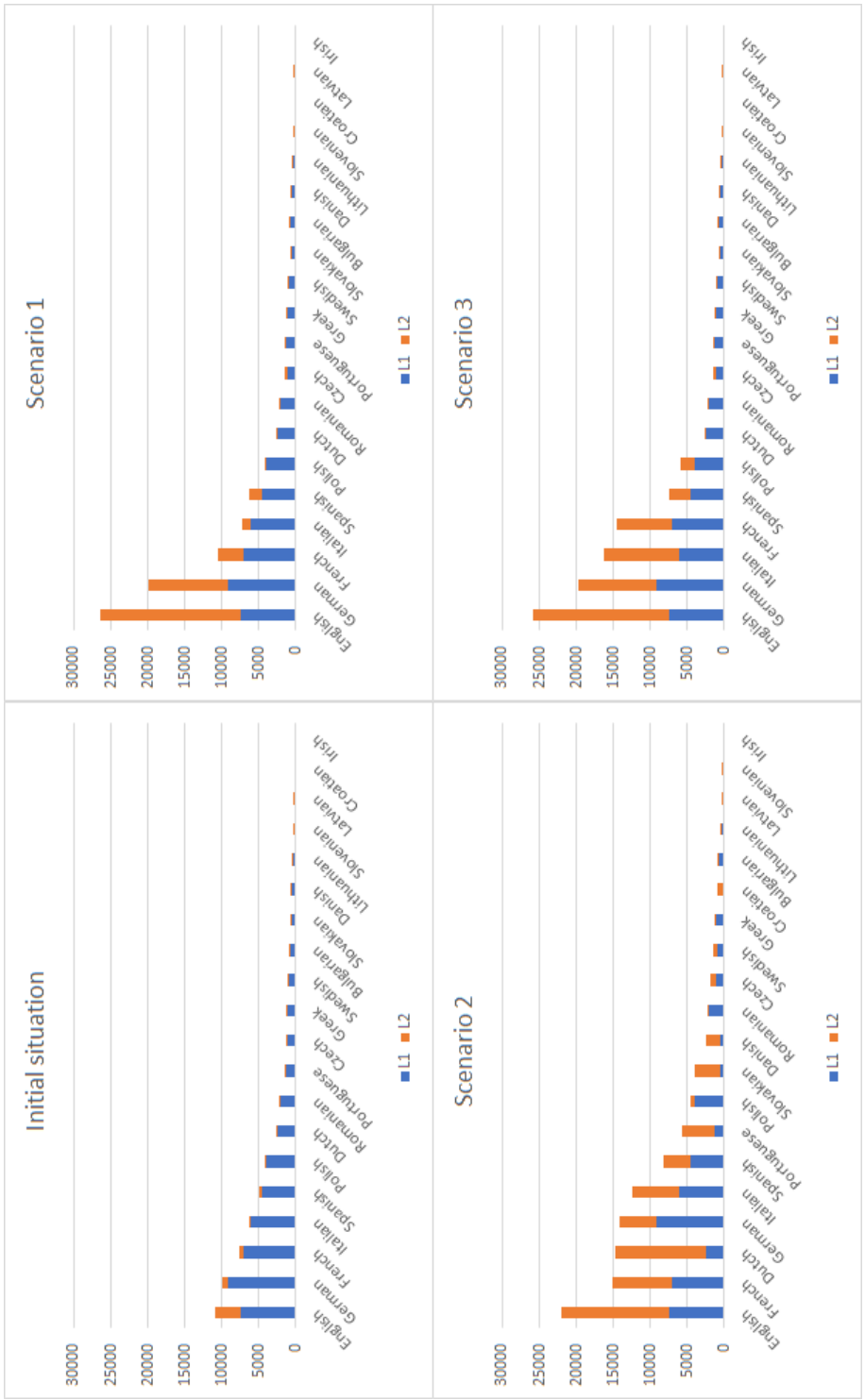


FIGURE (4.1) Distribution of L1 and L2 across the different scenarios.

Country	% of disenfranchised people by country	
	Scenario 2	Scenario 3
Belgium	2,07%	3,96%
Bulgaria	16,98%	3,30%
Cyprus	1,38%	2,77%
Czechia	21,29%	3,69%
Denmark	2,50%	0,13%
Germany	0,07%	0,13%
Greece	21,19%	42,15%
Ireland	0,07%	0,13%
Latvia	4,73%	9,50%
Lithuania	5,19%	10,36%
Netherlands	0,16%	0,33%
Poland	0,72%	0,73%
Portugal	3,65%	6,99%
Romania	5,26%	10,49%
Slovakia	7,10%	1,72%
Slovenia	2,83%	2,90%
Spain	0,43%	-
Sweden	3,98%	0,26%
UK	0,43%	0,46%
TOTAL	100,00%	100,00%

TABLE (4.5) Distribution of disenfranchised people across countries.

proficient in English, she will be able to learn German at a faster pace, since she will be able to rely on her knowledge of English, which is closer to German. Besides, the languages most spoken across the countries considered are not equally close to all other languages. As a consequence, native speakers of certain languages could potentially learn them faster than others.

Several categories could be looked at. In this chapter, I focus on a comparison of the hexalingual regime in scenarios 2 and 3 in terms of distribution of disenfranchised people across countries. I pointed out earlier that the hexalingual regime performs better in scenario 3, where agents learn the closest of the top six most spoken languages. However, if we look at the distribution of disenfranchised people (reported in Table 4.5), we can notice that, although the number of disenfranchised agents is lower in scenario 3, they tend to be much more concentrated in certain countries. Also under the conditions of scenario 2 some countries have more disenfranchised people than other, but the distribution is somewhat more even. This seems to suggest that, in terms of fair and equal treatment of all citizens, scenario 2 performs better than scenario 3.

4.6 Conclusions and future research

I conclude this chapter by addressing some of the limitations of the study and possibilities for future research. Furthermore, I propose some considerations about the usefulness of such an approach for policy-making purposes.

One of the most important things to point out about the model presented in this chapter is that it is strictly focused on understanding one aspect of language acquisition, that is, the consequences of linguistic distance and language learning in terms of linguistic disenfranchisement. Obviously, there are many other factors that come into play in the process of language acquisition, such as daily exposition to a given language in one's daily life. An interesting development of the model presented in this chapter could be represented by the inclusion of these other factors, with a view to studying their interaction. For example, one might be interested in seeing whether and to what extent exposition to a certain language through the media can compensate for the distance between languages.

For practical reasons, I have only taken a selection of EU official languages into consideration to calculate disenfranchisement indexes. However, the linguistic landscape of the EU has significantly changed over the past few years as a consequence of migration from the outside, and it is likely to keep on changing in the coming years. Migration can change the relative proportions of language speakers by either reinforcing one particular language group (say, Spanish speakers from South America) or creating allophone communities, i.e. groups of people speaking a non-EU language (for example, Chinese migrants). This picture becomes all the more intricate if we add to the equation all the regional and minority languages spoken throughout the EU. Besides, many people are able to speak more than one language in addition to their own, at different levels of proficiency. All in all, it can be challenging to sketch the linguistic landscape of the EU, let alone to predict its evolution. However, if EU institutions are to take linguistic disenfranchisement into consideration when drafting language policies, keeping track of changes in the linguistic landscape becomes crucial. With this objective, agent-based modelling, as well as computational methods in general, are a good resource to have in the policy-maker's toolbox. For a more complete view of the EU linguistic landscape, an interesting extension to this model would be the inclusion of the remaining EU official languages and other non-EU languages. However, a non-trivial difficulty that would need to be tackled would be the modelling of linguistic distance encompassing also non-Indo-European

languages among all of the language considered. If possible, it would be advisable to rely on more sophisticated metrics of language distance, in that, as said, the linguistic distance index has its flaws.

Finally, this study was started when the UK was still part of the European Union. As of today, it is still not clear what the future of English within the EU institutions will be. The relative weight of English in terms of native speakers was drastically reduced after Brexit, and this could have repercussions not only on the communication practices among EU employees, but also on education policies across various member states. Therefore, it would be interesting to repeat this study in a few years, leaving some time for the linguistic repercussions of Brexit to manifest.[24]

Before concluding, I also want to point out that I limited myself to making objective and technical observations about the results generated by the model, avoiding policy recommendations. This choice derives from the fact that policy making is an eminently political process. Starting a discussion on whether a specific regime should be preferred or whether a fair and equal treatment of citizens should be prioritized is well beyond the scope of this chapter and left for future research.

[24]For an interesting discussion on this matter, as well as on the dominant position of English in the EU, see https://www.publico.pt/2016/07/01/mundo/opiniao/as-linguas-na-europa-o-que-mudara-com-o-brexit-1736870.

Chapter 5

Concluding Remarks: Complexity and Language Matters

5.1 Overview

In this dissertation I tried to explore in depth the many ways in which complexity manifests itself. Although my research work focused mainly on language matters, I referred to numerous examples from the social and natural sciences, in order to provide as comprehensive an overview of complexity as possible and to gently usher the readers into the more specific applications on language-related issues. Obviously, this required not only a review of complexity theory, but also a reinterpretation of language policy from a complexity theory perspective. This is what Chapter 1 was devoted to. In Chapters 2 through 4 I presented some applications of agent-based modelling, one of the major analytical tools of complexity theory, to three traditional language policy issues, namely, multilingual communication, language dynamics, and linguistic disenfranchisement. In so doing, my goal was to explore and explain the potential contribution of complexity theory to language policy making. Although they are clearly three separate applications that share the same methodology, they all contribute to showing the usefulness of agent-based modelling in language policy. Chapter 2 focuses in particular on how micro-level qualitative observations can be extended and generalized through agent-based modelling in order to observe their impact on the macro-level. Building on this, Chapter 3 adds social theories to the picture, showing how theory-based observations can inform agent behaviour even in the absence of direct observation. Finally, Chapter 4 develops a very practical application for policy making and complements the discussion of the preceding chapters by moving the attention from theory to practice. By highlighting different virtues of agent-based modelling, Chapters 2 through

4 allow me to make a strong point in favour of the adoption of agent-based modelling in policy making.

Admittedly, the approach adopted to develop the cases presented in this dissertation diverges slightly from more orthodox approaches, that would prescribe that various modelling options are considered before selecting the most appropriate. However, as I said in many occasions, the same issues discussed in this dissertation have been already studied by means of other methodologies. My objective was not to find out which methodologies is best for each case. Rather, I aimed at showing that different research methods should not be seen as alternative but as complementary and that agent-based modelling, a methodology still to a certain extent disregarded by sociolinguists and language policy makers, can complement significantly other methodologies and result in improved research and policy making.

In this final chapter I wrap up the main findings of this dissertation, acknowledge critical aspects and potential limitations, and discuss opportunities for future research. I also mention briefly some other promising techniques of computational social science that can contribute to language policy research and other research methods that can be integrated with agent-based modelling in order to create ever more realistic and accurate simulations.

5.2 The role of simulation in social science research

The first and probably most important objective of this dissertation was to show that language-related matters are intrinsically complex and that, consequently, they should be addressed from a suitably complex perspective. I hope to have shown convincingly that this is the case. In general, many scholars have observed that complexity recurs in many aspects of natural and social phenomena. In Chapter 1 complex systems were defined as "system[s] in which large networks of components with no central control give rise to (i) non-trivial emergent behaviour at different levels of aggregation, (ii) sophisticated information processing, (iii) non-linear and/or unexpected effects, (iv) processes of self-regulation, and (v) adaptation via learning and evolution". In other words, a complex system is often better understood by looking at its constituent parts and their interactions, rather than looking at the overall system itself. The single most important element of this definition is probably *emergence*. With this word, complexity scientists refer to the fact that complex systems have properties that do not belong to any of their individual components. Emergence stems directly from the non-additivity

property of the system, meaning that the system and its dynamics are more than the sum of the components and their behaviour. This characteristic of complex systems makes it crucial for researchers to break them down and study them at different scales, from the micro to the macro level. As a matter of fact, one could say that complexity science is all about trying to study the micro-level properties of systems with a view to reconnecting the patterns observed at a macro-level with the local behaviour of agents.

To address the difficulties posed by complex systems, researchers often resort to large-scale controlled studies for the purpose of spelling out individual causal links. When it comes to the study of social phenomena, however, such investigations are often not possible, for a number of practical and ethical reasons. Besides, "controlling" a group of people in their social interactions is not the same as controlling, for example, the way they are treated with a specific drug, not to mention controlling the behaviour of particles or molecules. Humans and their behavioural patterns can vary in virtually countless ways and very similar conditions can sometimes lead to radically different results, as was observed several times in the previous chapters. It is very hard to isolate social systems from the influence of the greater network in which they exist. For example, it is not sufficient to study the behaviour of the students of a given school without considering the city in which the school is located. This makes it virtually impossible to rule out the impact of external causes on the dynamics under examination. Besides, this becomes all the more critical as global interconnectedness and interdependence increase. In short, a purely *in vitro* study is usually not possible in social science research. Sometimes, researchers get around this problem by resorting to theoretical modelling, which is highly mathematics-based and, thanks to its inherent formality, helps spelling out causal links with a high degree of conceptual consistency. Theoretical modelling is, in a certain sense, a way of "controlling" the experiment, in that the modeller can make assumptions about properties and behaviours. However, this still does not solve the problem of mutual influence with other systems, nor does it account for the fact that individual human beings are extremely heterogeneous in their properties. Analytical models often need to put aside such heterogeneity for the sake of mathematical tractability. This is where computational social science, the field of social science that resorts to computational methods, comes into play. Among computational methods, agent-based modelling, a type of computer simulation method, is a particularly important ally of social scientists.

The general idea behind computer simulations for the social sciences is relatively straightforward. Given that it is often impractical to realize large-scale controlled studies, social scientists can resort to computer simulations to recreate an *in silico* version of the context of interest and simulate the dynamics considered. The environments and the agents are usually informed through real-life observation, so as to make the model representative of reality. If the model is conceptually coherent and its behaviour is validated by actually observed trends, one usually goes on to study the dynamics of the system under different conditions. In so doing, one can evaluating how and to what extent different variables impact the overall system.

Applications of agent-based modelling have been increasing at an accelerating pace and concern a wide range of fields. Simply looking at a few recent publications in which agent-based modelling was the main methodology, we find applications as varied as:

- a simulation of firms' decision making processes with a view to detecting the relation between the heterogeneity of firm sizes and innovation stemming from collaborative behaviour (Hwang, 2020);
- a simulation model investigating how different policy interventions contribute to the use of electric vehicles and the use of renewable energy sources to recharge them (van der Kam et al., 2019);
- a simulation of people's meat consumption in Britain and the different impacts of price changes, animal welfare campaigns and health campaigns on people's propensity to consume meat (Scalco et al., 2019).

It should be clear, then, that computation-based methods are an important ally for social scientists. Obviously, they are not meant to replace other methods, such as equation-based and statistical models, but rather to complement them, in order to put the massive progress in information technology at the service of research. As a matter of fact, simulation models rely heavily on other methodologies both in the development part and in the analysis of the results. As an example of such practice, Carrella, Bailey, and Madsen (2020) discuss the application of linear regularized regression to find the optimal calibration of the model parameters to match the data. Starting from the fact the regression is a well-understood and commonly-used method, the authors leverage this knowledge and apply it to the delicate task of parameter estimation. In short, they propose following these four steps:

1. repeatedly run the model with a random vector of K parameters at every simulation;

2. collect M summary statistics for each simulation;

3. train K different regressions using each parameter as a dependent variable and the collected summary statistics as independent variables;

4. finally input the actually observed statistics in the K regressions in order to find the "real" parameters that generated them.

For another example, ten Broeke, van Voorn, and Ligtenberg (2016) review in great detail the pros and cons of various methodologies to perform sensitivity analysis on agent-based models in terms of different aims. The three methodologies analyzed are:

1. regression-based methods, which decompose the variance of the ABM outcomes by regressing them against the input parameters;

2. the OFAT (one-factor-at-a-time) sensitivity analysis, which looks at the variation in the output when one parameter changes, while all other parameters are kept fixed;

3. the so-called Sobol method, which decomposes the overall variation in the model by attributing fractions of it to individual parameters.

The aims taken into consideration by the authors are the following:

1. to find how patterns and emergent properties are generated within the model;

2. to examine the robustness of emergent properties;

3. to quantify the variability in the outcomes resulting from model parameters.

It is clear, then, that agent-based models, as well as simulation models in general, do not represent an alternative to other more traditional research methods. Quite to the contrary, their potential is fully exploited when they are used in combination with other methods.

5.2.1 The role of simulation in language policy

In light of the considerations discussed in Chapters 2, 3 and 4, it should be clear that language-related phenomena unfold in a complex environment. Indeed, as was seen, language issues are never *just* language issues, which is why they should always be studied from an interdisciplinary perspective.

All the cases studied in this dissertation display many of the traits of complexity discussed in Chapter 1. They all involve numerous agents with heterogeneous properties, whose interactions are non-trivial and able to affect the overall system in a non-linear way. There are feedback loops by which micro-level agents influence the macro-level system and whose behaviour is, at the very same time, affected by changes in the system.

Besides, it is enough to look at some recent publications in the field of language policy and language economics to realize how language matters are strictly connected to numerous seemingly unrelated areas.[1] For example:

1. Golesorkhi et al. (2019) examine the relationship between language use and the financial performance of microfinance banks;

2. Civico (2019) discusses the use of language policy to serve socio-political objectives throughout the 20th and 21st centuries in China;

3. Kang (2020) analyzes the changes in North Korea's language policy and attitudes towards the English language following the rise to power of Kim Jong-un.

To give an idea of the numerous ways in which language matters, and in particular the multilingual challenge, can be articulated, Grin et al. (2018) address 72 questions concerning languages organized in six different sections. The topics included range from language policy analysis to linguistic diversity and language education. The collection of questions was addressed by teams of people having different disciplinary backgrounds, ranging from economics, mathematics and philosophy, to education, sociolinguistics and law. This comprehensive approach stems from the realization that language issues are all interrelated and exist in a greater system. Issues such as language teaching, the provision of language services, the protection of minority languages and the official adoption of a language all influence and are influenced by each other. In light of all this, a complex perspective on language matters becomes crucial if one hopes to gain more complete and deeper insights. Ideally, this would be achieved by setting up large-scale studies involving numerous people with different disciplinary backgrounds. However, this is not always possible, in that it calls not only for a conjoint and coordinated effort, but also for substantial financial support. This is where

[1] Incidentally, it is worth noting that many of these publications appear in scientific journals other than those strictly mentioning language policy or sociolinguistics in the list of topics addressed. For example, Karhunen et al. (2018) review a long list of articles on language-related issues that were published in management journals.

computational modelling comes in particularly handy. Thanks to their flexibility and capacity to integrate knowledge from various fields, simulation models allow us to gain insights into dynamics that would otherwise be unobservable. The model presented in Chapter 2, for example, drew from a great amount of qualitative studies on multilingual communication at the workplace. The information gained was then used to validate the macro-level dynamics of knowledge transfer generated by the model. These dynamics can hardly be observed from a top-down perspective. They can only be deduced by looking at the micro level and trying to guess their impact on the system. Agent-based modelling helps us perform exactly this task. With simulation model, we could give greater analytical soundness to qualitative guesses stemming from micro-level observations. Besides, we could observe these dynamics over long periods of time. The model presented in Chapter 3 allowed us to test various scenarios with different combinations of parameters that are not necessarily available for observation in the real world. This eventually led to the estimation of the relative impact of each of the variables considered. Therefore, agent-based modelling provided a way to make sensible use of qualitative findings in the study of the whole system. Finally, the model presented in Chapter 4 allowed us to get an idea of the potential impact in terms of linguistic disenfranchisement following different orientations in language education across the EU.

In light of the converging evidence about the complexity of language matters adduced throughout this dissertation, it seems reasonable to conclude that, as is the case for many other fields, language policy can benefit from the application of a complex approach. An optimal implementation and evaluation of language policies (as well as policies in general) requires a large amount of data and, ideally, direct observation of the impact. However, this is not often possible, and in many cases it is not advisable to implement a measure just for the sake of observing its effect. Agent-based modelling offers a natural solution to such problems. It can help language policy makers in at least three different ways:

1. by simulating existing phenomena to gain insights about the matter under study (such as the development of different communication strategies);

2. by providing an assessment of the potential impact of different measures (for example, investigating how an increase in the average level

of fluency in a minority language affects the number of speakers over time);

3. by simulating the changes in the system caused by exogenous shocks (such as the impact of a sudden wave of immigration on the linguistic landscape).

All these objectives can be achieved by policy makers by drawing from, and building on the already vast amount of qualitative research on language matters. Indeed, agent-based modelling is a natural extension of qualitative studies. Besides, as I will discuss in Section 5.4, ABMs do not need to rely exclusively on social theories to provide agents with realistic behavioural rules. Agent-based modelling is very flexible and can be easily combined with other more qualitative-oriented methodologies.

5.2.2 Agent-based modelling beyond research

Throughout this dissertation I have stressed in multiple occasions the value of agent-based modelling for research purposes and theory development. However, I also mentioned several times how policy makers can benefit from such an approach. Among the virtues of agent-based modelling, I highlighted aspects such as flexibility, adaptability, effective visualization, ease of programming and immediate usability by both experts and non-experts. However, I would like to mention another strength of ABMs, one that may speak especially to policy makers, i.e. their ability to capture potential unintended consequences of policy measures. Unexpected or unintended effects of policies are rather common and discussed at length in the relevant literature. For example, Bernauer and Knill (2012) investigate the case of a German packaging waste policy that turned out to be ineffective soon after its implementation and that proved very hard to dismantle. Unintended consequences usually result from a combination of complexity and lack of information that limits policy makers' understanding of the policy (Lindkvist et al., 2020). They can be frustrating, confusing and time-wasting. Most importantly, unintended consequences can be costly.

The issue of unintended consequences is crucial for policy makers, who are often reluctant to put in place costly large-scale policy measures on the basis of theory-based models that can only be verified after implementation. However, ABMs can provide a risk-free environment in which policy makers can experiment with different measures. Indeed, if developed with sufficient attention to social and behavioural mechanisms, an ABM can highlight some

unexpected or unintended dynamics thanks to its integrated multi-scale environment. In practice, this would amount to saving a non-negligible amount of money that would have otherwise been invested either in testing practically the theory-based policies or in developing and implementing measures aimed at fixing or even reverting the unintended effects of the policy. Therefore, the integration of agent-based modelling in the current policy making process can result in non-negligible savings, better resource allocation and generally improved governance.

5.3 Limitations of agent-based modelling

Throughout this dissertation I have discussed in depth the numerous qualities of agent-based modelling, focusing in particular on its value for social scientists. However, for a conscious use of agent-based modelling, it is also important to acknowledge its limitations, so as to be able to tell when it represents the best (or at least a viable) option or not. In the previous chapters I addressed the limitations and critical aspects of each one of the models presented. In this section, I discuss the major limitations of agent-based modelling in general, with no reference to any specific application.

One of the most criticized aspects of agent-based modelling is the difficulty of finding the optimal number of parameters, agents' properties and behavioural rules to include in the model. Indeed, ABMs are often accused of being either *too trivial* or *too complex* (Waldherr and Wijermans, 2013). Eberlen, Scholz, and Gagliolo (2013) mention two main problems deriving from this aspect. The first one is the increased difficulty in the programming process, that is, the actual creation of the model in terms of code. As parameters and properties need to be integrated in a meaningful way, every additional variable increasingly complicates the coding process. The second problem is that, assuming that one manages to write a logically consistent and well-functioning code, a model with too many parameters could be hard to interpret, making the model basically useless. Besides, one has to pay attention to the so-called "curse of dimensionality". By increasing the number of parameters, one ends up with fewer observations per combination of parameters. This forces the modeller to increase significantly the number of runs.

This leads us to a second critical aspect of agent-based modelling, that is, the high computational cost that it implies with respect to other methods. To give an idea of the magnitude of this issue, a model that only features

two variables taking on only three values has 3^2 possible combinations to be tested. In general, a model with n parameters that can take on m different values has m^n different combinations. Besides, it is advisable to have several runs for the same parameter configurations to account for stochasticity. Therefore, every additional variable implies that the number of configurations increases by a factor m, which must then be multiplied by the number of runs planned for each configuration. This cost increases very quickly, with every new variable implying a huge increase in the computational power (and therefore physical time and energy) required to perform the simulations. Besides, the massive amount of data generated by each simulation means a big rise in data storage cost.

These two critical aspects imply that a researcher wishing to resort to agent-based modelling should never start by trying to develop a model that accurately represents the idea that she has in mind, in that it could be unnecessarily computationally expensive. A researcher should always start with a very simple model and then make it increasingly complex to match the level of refinement envisaged, but not any more complex.

Another critical aspect of agent-based modelling is that, by its very nature, it requires the researcher to be knowledgeable about individual-level behaviour (Wilensky and Rand, 2015). If the researcher cannot confidently rely on theories or empirical observations to ground individual agents' behavioural rules, developing an agent-based model would be simply pointless. One might even go as far as to develop a model that effectively reproduces the macro-level dynamics expected by forcing it out of the agents. This means that one can fictitiously program agents to behave in such a way as to produce the macro-level results that one expects or wishes to observe. However, this result would be completely arbitrary, in that it is not grounded in any solid theoretical basis, not to mention the intellectual dishonesty that such behaviour would entail. Therefore, when previous knowledge about individual-level behaviour is not available, other research methods should be adopted, such as social experiments or psychometric tests. Once the researcher has collected enough knowledge about the individuals' behavioural patterns, she can go on to develop an ABM in order to extend the micro-level observations to a higher scale and gain further insights about the system.

5.4 Research perspectives

In this very last section I will discuss a number of future potential research perspectives. It should in no way be considered a comprehensive list of topics. Rather, the objective of this section is to provide the reader with an idea of other applications in which agent-based modelling, as well as computational methods in general, can be a valuable asset. At the same time, this section will further show how flexible ABMs can be and how easily they can be integrated with other research tools. First, I will discuss how agent-based modelling can be used in combination with natural language processing (NLP) and how the latter can also benefit language policy making in its own way. Then, I will discuss how agent-based modelling can benefit from the integration of other research tools, namely fuzzy logic and ethnographic studies. The focus will remain on language-related matters, but it can be easily extended to include applications in many other fields of the social sciences.

5.4.1 Natural language processing and machine translation

As was said many times, agent-based models are highly dependent on reliable and accurate decision rules for agents. Grounding these rules in qualitative and empirical studies has often proved a successful though labor-intensive practice, because it is based on the direct observation of human behaviour. Recently, an increasing number of authors have suggested leveraging the vast amount of text data available today to model human cognition.

An interesting application of this idea is the use of NLP to model the role of associations in judgment and decision making, which represents a major challenge in the creation of realistic agents. Bhatia (2017) notes that, through associations, individuals are able to process co-occurrences and statistical regularities on the basis of their past experiences in a relatively fast and effortless way. Such evaluations, whether correct or not, play a central role in the individual decision of the behavioural response to a stimulus. He proposes using word embeddings (vector-based representations of words) to generate realistic agents. Word embeddings map words drawn from a corpus to a vector space, while conserving semantic similarity through basic operations. This property allows word embeddings to capture well human associative reasoning (a well-known example is the relation "king" - "man" + "woman" = "queen"). He discusses how often people fall in the so-called "conjunction fallacy", a common cognitive fallacy occurring when the joint probability of a set of conditions is erroneously believed to be higher than

the probability of a single general one. This fallacy, first discussed by Tversky and Kahneman (1983), is due to the fact that a more detailed description of an event (for example, an individual having a certain profile) can deceptively seem more "representative" of the population from which it is drawn and hence more likely.[2] Bhatia (2017) argues that an idea or a situation (such as a stimulus) can be represented as a vector of the words that make up its description in terms of a given number of dimensions. The same can be done to represent possible reactions (such as the potential behavioural responses to a stimulus). One can then calculate the distance between these vector space representations (usually as the cosine of the angle for each pair of vectors) to determine the most likely reaction to an input.

Following this line of reasoning, Runck et al. (2019) argue that word embeddings are able to capture people's cognitive biases and therefore reproduce more realistic behaviours. Therefore, the authors point to the fact that informing agents in this way may help overcome the too often fallacious assumption that agents behave rationally. As an example, they reproduce Axelrod's famous model of cultural diffusion, where interactions and cultural convergence depend on the level of similarity between agents (Axelrod, 1997). While Axelrod's original model only defined individual agent's culture as a vector of integers, in their modified version, the authors use word

[2] Tversky and Kahneman (1983) exemplify this issue by resorting to the well-known "Linda problem", which reads: "Linda is 31 years old, single, outspoken, and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations. What is more probable?

1. Linda is a bank teller;
2. Linda is a bank teller and is active in the feminist movement."

Falling victim to the "conjunction fallacy", the majority of those asked chose option 2, though option 2 is clearly less likely than option 1. Indeed, the basic axioms of probability theory tell us that the probability of two independent events happening simultaneously is equal to the product of their respective probabilities. Formally:

$$P(A \wedge B) = P(A)P(B) \tag{5.1}$$

with $P(A)$ being the probability of Linda being a bank teller and $P(B)$ the probability of Linda being active in the feminist movement. Given that probabilities of events can only take on values included between 0 and 1, it follows that

$$P(A \wedge B) \leq P(A) \tag{5.2}$$

and

$$P(A \wedge B) \leq P(B) \tag{5.3}$$

the equality in 5.2 and 5.3 being satisfied only for an event with probability equal to zero.

embeddings to define agents' perceived similarity between them. Their findings match previous theoretical results, suggesting that natural language processing does indeed help generating agents that behave more realistically.

The use of natural language processing is very promising in the context of policy making. Many applications of NLP to policy issues were proposed in the past few years, such as:

1. analyzing political speeches over two centuries in Latin American countries to detect volatility in the significance of various topics with a view to determining its impact on long-term economic growth (Calvo-González, Eizmendi, and Reyes, 2018);

2. the use of sentiment analysis techniques (NLP-based methods aiming at extracting people's opinion on a given matter from textual data) as a means of obtaining a deeper understanding of the needs and problems of the citizens along with their perceptions and feelings, and to formulating more effective public policies (Charalabidis, Maragoudakis, and Loukis, 2015);

3. using machine translation and fixed-phrase translators in emergency settings to enable communication between medical staff and refugee patients when they cannot communicate in a common language (Spechbach et al., 2019).

Specifically concerning language policies, many examples could be discussed. For example, one could wonder about the role of language-related computer-based methods, such as machine translation, in the provision of multilingual services. One might hastily conclude that, in an ideal future, a sufficiently advanced machine translation system might be the key to a world free of language barriers. In the context of minority language protection, being able to provide accurate translation across various languages could be seen as a measure in support of the diffusion of less spoken languages. Besides, in this ideal context, there would be no particular pressure to acquire skills in a more spoken language, in that one could simply rely on machine translation. One might even go as far as to say that reliable machine translation would make language rights (a form of human rights specifically concerning languages and their use) obsolete. Indeed, in an ideal (admittedly, sci-fi) scenario in which one could, say, wear a device that provides highly accurate translation of spoken and written language on the spot, one

could easily live one's life in one's own native language.[3] However, the discussion would not be so simple. One could even argue that machine translation might actually work against minority languages. As a matter of fact, artificial intelligence (and, consequently, all machine-mediated services) improves significantly when it is trained with an increasing amount of information. Given that, as of today, the availability of corpora to train machine translation systems is strongly skewed towards a very limited number of languages, extremely accurate machine-based translations are very unlikely to exist for all language pairs. As a consequence, translation between some specific pairs of languages would be much more accurate than other combinations. Eventually, machine translation would simply incorporate and transpose to a virtual context the already existing bias that favours widely spoken languages. Once again, we find ourselves in an apparently paradoxical situation, in which policy makers face a trade-off between two objectives pulling in seemingly opposite directions, as discussed at length in Chapter 1. Besides, one should really ask oneself to what extent and in which cases machine translation can be useful for minority languages. In a context such as the one discussed in Chapter 3, where every minority language speaker is fluent in the majority language, machine translation would play no vital role. Indeed, minority language speakers might prefer and understand better a text in the majority language than a potentially inaccurate and sloppy translation in the minority language.[4] These as well as other considerations are challenges that will have to be faced by policy makers willing to exploit the potential of computer-based methods.

5.4.2 Agent-based modelling and fuzzy logic

In an attempt to increase the level of realism of simulation models, some authors have suggested combining agent-based modelling with fuzzy logic as a further extension to the use of natural language data to inform agents. Fuzzy sets are sets in which elements have a "certain degree" of membership. Differently from Boolean logic, in which membership may only take one of two values, i.e. 0 (not a member) or 1 (member), in a fuzzy framework, an

[3] This is in no way a new idea in the sci-fi literature. In his renown "The Hitchhiker's Guide to the Galaxy" sci-fi series, British writer Douglas Adams created the "Babel fish", a small yellow fish, which can be placed in one's ear in order for one to hear any language translated immediately into one's own native language.

[4] However, I shall note that such preferences might themselves be the consequence of a set of sub-optimal language policies, or even of a generalized oppressive attitude towards the minority language(s).

element can belong to a set with a varying degree of intensity. In short, each member of the set takes on a "grade of membership" that ranges from 0 (not a member) to 1 (full member). All members taking on values in between are "partial" members. Fuzzy logic is able to capture the vagueness and uncertainty which often guide human behaviour. In the perspective of using textual data to define the behaviour of artificial agents, being able to discern the intensity of people's attitude with respect to specific facts can be crucial. Besides, also the extrapolation of agents' properties from text data can greatly benefit from the use of an approach that can deal with uncertainty. After all, humans constantly function with a certain degree of uncertainty. Izquierdo et al. (2015) propose the following example. Consider the sentence "a tall, blonde, middle-aged guy with long hair and casually dressed is waiting for you at *(sic)* the lobby". While a human can more or less easily figure out who the concerned person is in a group of people (or at least narrow down the selection to a number of elements), implementing an equally effective artificial agent can be extremely challenging. The reason is that concepts such as "tall" or "middle-aged" are not clear-cut, but fuzzy. Indeed, it would be ridiculous to impose a threshold above which a person is "tall" and one who is a few millimeters shorter is not.

In this context, fuzzy logic tries to cope with the fact that computers cannot match the natural ability of humans to deal well with imprecise information. Fuzzy logic represents a step further in the treatment of a concept that was stressed many times throughout this research work, i.e. the heterogeneity of agents. As said, the agents in a system might belong to the same class but they might differ slightly or significantly in their characteristics. This includes the subjective way agents might perceive and respond to certain properties of the system. Consider the following example, partially inspired by Izquierdo et al. (2015). Let us imagine a system of reading recommendations for language learners. The objective of the system is to recommend to individual language learners a set of readings whose difficulty matches their level of fluency. This could be achieved by asking readers to rate the readings in terms of difficulty (for example on a scale from 1 to 10, where 1 is "extremely easy" and 10 is "extremely difficult"), along with their self-assessed level of fluency (say, from basic to advanced). Ideally, this system would be recommending readings that are accessible to readers of the same level. However, such a system (or at least, a system of this sort that is accurate and consistent) is very hard to implement. One of the reasons is that

users are faced with a number of fuzzy concepts at various levels. For example, users usually have different understandings of the words "easy" and "difficult". Words like "extremely" might be interpreted as carrying different amounts of intensity. When asked to self-assess their level of fluency, users might have radically different understandings of what it means to have basic knowledge of a language or being fluent in it.[5] Consequently, one might consider implementing a framework of shared definitions to correctly assess users' evaluations. Such a framework might have varying degrees of precision. On the one side, very general definitions are quick and easy to handle for users, but might not lead to any significant improvement. On the other, a long list of very detailed descriptions could be cumbersome and discourage users. In order to find the appropriate level of detail, one might consider simulating the recommendation system in a computer environment. The model would reproduce individual users, each with their own (randomly assigned) level of fluency and understanding of the various concepts mentioned above.[6] The agents would then be presented with readings (whose difficulty is exogenously determined) and asked to rate them selecting from a list of descriptive words, according to their interpretation of these words. The implementation of a framework of shared definitions would be represented by a lower or greater variation of these understandings among users. The objective of the model would be to determine to what extent leaving room for the concepts mentioned above to be fuzzy causes a mismatch in the recommendations and the actual level of users. This way it is possible to determine how precise the framework of shared definitions should be, in order to find an optimal compromise between a superficial set of indications and a cumbersome and tedious list of descriptions.

5.4.3 Agent-based modelling and ethnography

As discussed at length throughout this research work, particularly in Chapter 3, researchers often rely on social theories to define agents' behavioural rules. However, some authors suggested that ethnography also represents a valuable tool in this task (Bharwani, 2004; Ghorbani, Dijkema, and Schrauwen, 2015). Ethnography can be defined as a set of research methodologies rooted

[5] The Common European Framework of Reference for Languages (CEFRL) tries to address specifically this issue by accurately breaking down each level of fluency in terms of skills expected from language learners.

[6] I will not present here the technical details of how fuzzy logic is implemented in agent-based modelling, as they can be somewhat cumbersome. For a technical explanation, see Izquierdo et al. (2015).

in anthropology that aim at examining the behaviour of the participants in a certain social situation through direct observation, along with providing an interpretation thereof (Dewan, 2018). Ethnography is also an important tool in much research on language-related matters. For example, Duff (2008) notes that language learning is often described as a highly social and cultural process and that culture itself is reflected in many linguistic interactions. This idea implies that individuals acquire a culture's core values, beliefs and dispositions in the process of learning the language, whether as L1 or L2. Education ethnographers are chiefly interested in the identification of aspects of education practices that are hard to see in quantitative descriptions of learning activities (Toohey, 2008). In this sense, ethnographic studies offer the possibility of gaining insights very close to the source. However, these results should be handled with caution. Indeed, ethnographic studies have often been the object of much criticism. Many authors have questioned the methodological rigour of ethnographic studies. Aunger (1995), for example, notes that ethnographers tend to extrapolate and generalize on the basis of very few direct observations. Often the interpretation provided is strongly subjective and biased towards the researcher's personal perspective. Eventually, a researcher's observation is nothing more than her simple point of view on some social matter. Nevertheless, this does not mean that ethnographic studies can in no way provide significant insights about humans and their behaviour. Indeed, Aunger (1995) goes on arguing that ethnographic studies do have the ability of producing interesting and useful results, provided that procedures and methods of data collection are duly described and that the data are analyzed through the right set of statistical methodologies.

In the specific case of agent-based social simulations, observations from ethnographic studies can contribute to the definition of agents' behavioural rules. Data collected through ethnographic methods usually consist of interviews, notes and recordings. Consequently, it is often hard to restructure them to be immediately available for a quantitative analysis. Luckily, specific programs exist that address this issue. For example, Ghorbani, Dijkema, and Schrauwen (2015) discuss how to build an ABM using an ethnographic approach through a conceptualization framework first presented in Ghorbani et al. (2013) and specifically developed for agent-based social simulation. In short, the framework provides a set of guidelines designed to reach a comprehensive overview of a social system, in order to collect all the necessary elements to build a simulation model. In this sense, this framework also helps provide a structure to the data collection methods, especially interviews. The

guidelines guide the researcher in the collection of information about the actors involved in the system considered, their role within the system, and the environment in which they interact. This information is collected by asking questions directly to the agents involved in the real system, in order to gain a qualitative understanding of the dynamics. Other sources, such as legal documents, can be used to complement the information collected with data about the institutional agents (e.g. government agencies) involved in the system.

Applying ethnography to agent-based modelling can be seen as an alternative to the use of social theories to inform agents' behaviour. This method seems particularly promising to model those contexts to which no previously established social theory applies. Certain social contexts might be one of a kind and the researcher might be interested in studying them as separate from other analogous cases. Therefore, the researcher might be unwilling to use previously observed behaviours, build a model and plug in the data from the context under examination. Rather, she might want to try and build a model relying on observations from interviews with the agents involved. In this way, even though no suitable social theory applies, it is still possible to build a simulation model to recreate macro-level dynamics and project long-term trends.

5.5 Closing remarks

In general, if one were to choose one major takeaway from this research work, I believe that it would be that computational methods can play an important role in the field of language policy. This role has been largely overlooked until recently. This does not only concern simulation-based methods, but computational methods in general, such as natural language processing and other machine learning-based methods. This is largely justified by the fact that, as I have discussed at length throughout this dissertation, language matters display many traits commonly associated with complex systems. As a matter of fact, numerous scholars have observed over the past few years that language-related issues are extremely multi-faceted and that a single disciplinary perspective can only shed light on one side at a time. Only genuinely interdisciplinary approaches can hope to capture more complexity. Nevertheless, while such approaches are strongly supported by numerous scholars in the scientific community, they still represent the exception rather than the

rule. Drawing from many disciplinary backgrounds, a complexity theory approach represents a step in the direction of spelling out with greater accuracy all the causal links involved in language issues.

I would like to stress once more the great potential of simulation models, as well as computational models in general, for the purposes of policy making in all its phases, from development to evaluation. The possibility to experiment in a virtual world that is fully controlled by the policy maker represents a major advantage over randomized controlled trials involving actual people. Once the policy model is developed, various scenarios can be simulated under different conditions at virtually no cost. Conversely, setting up multiple controlled trials can be very costly, not to mention the fact that it might have important ethical implications. Moreover, controlling for the impact of external variables can be really challenging in real life, while it is an almost trivial task in a simulated environment. Furthermore, even when there is little data for calibration and validation, a simulation model can be very useful in providing an overall idea of the type of impact that one should expect from a given policy. To conclude, I shall say that the culture of computational modelling will need to spread in the policy making environment for the full potential of simulation models to be exploited.

Appendix A

Proof of the logistic equation

The logistic equation describes the change of a certain population V (in our case, the amount words known by an individual) over time as a function of a growth rate r and a value N to which the growth tends and that can be thought of as the total amount of words in a given language or, rather, the maximum amount of words that an individual can possibly learn, also known as *carrying capacity*. Having a derivative among its variables, it is a differential equation and is described by the following formula:

$$\frac{dV}{dt} = rV\left(1 - \frac{V}{N}\right) \tag{A.1}$$

where dV and dt mean infinitely small changes in, respectively, V and t. To find the solution of this equation we need to find a general form that describes the value of V at every time t as a function of its initial value V_0 and of the other two parameters, r and N. The logistic equation can be solved analytically by resorting to separation of variables.

We note immediately that the equation has two trivial solutions. If we set the right-hand side of the equation equal to zero (that is, the value of V does not change), we find $V = 0$ and $V = N$ as constant solutions. The first solution does not have an interpretation for our purposes, and it fits better the case of biological populations, where it indicates that the population will never grow when there are no organisms present. The second solution indicates that when the population is already at the carrying capacity, it will not change. That is, if one already knows all the words of a language or is already at one's cognitive limit, one will not learn any new word.

To find a general solution to equation A.1, we start by isolating the r term and bringing all other terms to the left-hand side of the equation. Therefore,

we multiply both sides by $\frac{1}{V(1-\frac{V}{N})}$ and obtain:

$$\frac{1}{V(1-\frac{V}{N})}\frac{dV}{dt} = r \tag{A.2}$$

As we will need to find the anti-derivative of equation A.2, we can try and find a more tractable form for the left-hand side. We can separate the $\frac{1}{V(1-\frac{V}{N})}$ term by partial fraction decomposition. That is, we need to find two terms a and b that satisfy this equation:

$$\frac{a}{V} + \frac{b}{1-\frac{V}{N}} = \frac{1}{V(1-\frac{V}{N})} \tag{A.3}$$

Through some manipulation, we can rewrite equation A.3 as follows:

$$\frac{a - \frac{a}{N}V + bV}{V(1-\frac{V}{N})} = \frac{1}{V(1-\frac{V}{N})} \tag{A.4}$$

which implies that

$$a - \frac{a}{N}V + bV = 1 \tag{A.5}$$

Equation A.5 can be rewritten as follows:

$$a + V\left(b - \frac{a}{N}\right) = 1 \tag{A.6}$$

As there are no V terms on the right-hand side of equation A.6, we can conveniently assume that $b - \frac{a}{N} = 0$, which implies that $a = 1$ and $b = \frac{1}{N}$. Now we can rewrite equation A.2 as follows:

$$\left(\frac{1}{V} + \frac{\frac{1}{N}}{1-\frac{V}{N}}\right)\frac{dV}{dt} = r \tag{A.7}$$

For simplicity, we rewrite equation A.7 as

$$\left(\frac{1}{V} + \frac{1}{N-V}\right)dV = rdt \tag{A.8}$$

We can now find the anti-derivative of equation A.8 by integrating both sides. Keeping in my mind that $\int \frac{1}{x} = \ln|x| + c$, we can write:

$$\int\left(\frac{1}{V} + \frac{1}{N-V}\right)dV = \int rdt \tag{A.9}$$

$$\ln|V| + c_1 - \ln|N-V| + c_2 = rt + c_3 \tag{A.10}$$

We can relabel $c_3 - c_1 - c_2$ as C and multiply both sides by -1 to obtain:

$$-\ln|V| + \ln|N - V| = -rt - C \tag{A.11}$$

$$\ln\left|\frac{N-V}{V}\right| = -rt - C \tag{A.12}$$

Keeping in mind that $e^{\ln x} = x$, we can exponentiate both sides and obtain:

$$\left|\frac{N-V}{V}\right| = e^{-rt-C} \tag{A.13}$$

As the exponential function is strictly positive, we can remove the absolute values. Besides, the exponential on the right-hand side can be split in two parts, as follows:

$$\frac{N-V}{V} = e^{-rt}e^{-C} \tag{A.14}$$

$$\frac{N}{V} - 1 = e^{-rt}e^{-C} \tag{A.15}$$

Let $A = e^{-C}$ and add 1 to both sides:

$$\frac{N}{V} = Ae^{-rt} + 1 \tag{A.16}$$

We now isolate V and write it as function of t:

$$V(t) = \frac{N}{1 + Ae^{-rt}} \tag{A.17}$$

which is the same as equation 1.10 in Chapter 1.

To find $V(t)$ as a function of the initial vocabulary (or population) V_0, we let $t = 0$ to find $V(0)$ by plugging it into equation A.16:

$$\frac{N}{V_0} = Ae^0 + 1 \tag{A.18}$$

$$\frac{N - V_0}{V_0} = A \tag{A.19}$$

We can now replace the value of A in equation A.17 and obtain:

$$\frac{N}{1 + \frac{N-V_0}{V_0}e^{-rt}} \tag{A.20}$$

$$\frac{N}{\frac{V_0 + Ne^{-rt} - V_0e^{-rt}}{V_0}} \tag{A.21}$$

$$\frac{NV_0}{V_0(1-e^{-rt})+Ne^{-rt}} \tag{A.22}$$

Noting that $e^{-x}e^{x}=1$, we can multiply the numerator and the denominator by e^{rt} and obtain:

$$\frac{NV_0e^{rt}}{V_0e^{rt}-V_0+N} \tag{A.23}$$

$$\frac{NV_0e^{rt}}{N+V_0(e^{rt}-1)} \tag{A.24}$$

which is the same as equation 1.11 in Chapter 1.

Appendix B

Code of the model presented in Chapter 2

```
globals [ colors ]

turtles-own [ knowledge ;; how much knowledge does an agent have?
  language-spoken ;; what is the agent's native language?
  my-group ;; to what working group was the agent assigned?
  my-group-majority-language ;; what is the most represented language
      in the agent's group in terms of native language speakers?
  understanding-other-languages ;; how well do I understand other the
      other languages spoken in the company?
  age ;; what is the age of the agent?
    ]

to setup ;; generate the environment for the simulation
  clear-all
  set colors [ orange red blue green yellow brown ]
  make-workers
  select-grouping-strategy
  reset-ticks
end

to make-workers ;; create agents
  create-turtles total-population [
    setxy random-xcor random-ycor ;; place agents in random position
    set shape "person"
    set understanding-other-languages median (list 0 (random-normal av-
        LK 0.2) 1) ;; provide agents with an understanding of languages
        other than their own according to a double truncated normal
        distribution
```

```
    set my-group -1
    set language-spoken random number-of-languages + 1
    set color (item (language-spoken) colors)
    set my-group-majority-language 0
    set age round median (list 0 (random-normal 10 5) 20)
    set knowledge random-float 1
      ]
end

to select-grouping-strategy ;; select one of the two grouping
    strategies, that is, by size of each group or by number of total
    groups.
  if grouping-strategy = "assign-by-size" [ assign-by-size ]
  if grouping-strategy = "assign-by-number" [ assign-by-number ]
end

to assign-by-size
  ask turtles [ set my-group -1 ]
  let unassigned turtles
  let current 0
  while [any? unassigned]
  [
    ask n-of (min (list group-size (count unassigned))) unassigned
      [ set my-group current ]
    set current current + 1
    set unassigned unassigned with [my-group = -1]
  ]
end

to assign-by-number
  let tmp-group-size ceiling (count turtles / number-of-groups)
  ask turtles [ set my-group -1 ]
  let unassigned turtles
  let current 0
  while [any? unassigned]
  [ ask n-of tmp-group-size unassigned
      [ set my-group current ]
    set current current + 1
    if current = ((count turtles) mod number-of-groups)
      [ set tmp-group-size tmp-group-size - 1 ]
    set unassigned unassigned with [my-group = -1]
```

```
  ]
end

to go
  ask turtles [ define-majority-language ] ;; agents look at their
      group and decide which is the most spoken language
  ask turtles with [ count turtles in-radius 1 != group-size ]
  [ group-up ]
    if all? turtles [ distance max-one-of other turtles with [ my-group
        = [ my-group ] of myself ] [ distance myself ] < 2 ] [ ask
       turtles [ converse ]]
    if all? turtles [ distance max-one-of other turtles with [ my-group
        = [ my-group ] of myself ] [ distance myself ] < 2]
  [ if retire? [ get-old-and-retire ]
    reassign-position ]
  tick
end

to get-old-and-retire ;; agents increase the number of years spent
    working in the company and leave the environment when their working
     age is equal to 35. At the same time, a new agent is created,
    whose properties depend on the hiring strategy adopted.
  ask turtles [
    set age age + 1
    if (random 100 < layoff-rate and knowledge < mean [ knowledge ] of
       turtles with [ age = [ age ] of myself ]) or age >= 35 [
      if Strategy = "Diversity-saving"
      [ hatch 1 [
        set age 0
        set knowledge random-float 1
        set understanding-other-languages median (list 0 (random-normal
           av-LK 0.2) 1)
        set language-spoken [ language-spoken ] of myself
        set color (item (language-spoken) colors) ]
        die ]
      if Strategy = "Knowledge-maximizing"
      [ hatch 1 [
        set age 0
        set knowledge random-float 1
        set understanding-other-languages median (list 0 (random-normal
           av-LK 0.2) 1)
```

```
       set language-spoken [ language-spoken ] of one-of turtles with [
            knowledge > mean [ knowledge ] of turtles ]
       set color (item (language-spoken) colors) ]
       die ]
     if Strategy = "Random"
     [ hatch 1 [
       set age 0
       set knowledge random-float 1
       set understanding-other-languages median (list 0 (random-normal
           av-LK 0.2) 1)
       set language-spoken random number-of-languages + 1
       set color (item (language-spoken) colors) ]
       die ] ] ]
end

to define-majority-language
if my-group-majority-language = 0
    [ let my-mates turtles with [ my-group = [ my-group ] of myself ]
      set my-group-majority-language one-of modes [ language-spoken ] of
          my-mates
      ask my-mates [ set my-group-majority-language [ my-group-majority-
          language ] of myself ]
    ]
end

to reassign-position ;; agents are assignet a new position in the
    environment
  ask turtles [ setxy random-xcor random-ycor set my-group-majority-
      language 0 ]
  if grouping-strategy = "assign-by-size" [ assign-by-size ]
  if grouping-strategy = "assign-by-number" [ assign-by-number ]
end

to group-up
     if my-group != -1
     [ face get-home ]
    lt random 5
    rt random 5
    fd 1
end
```

```
to converse ;; agents change their individual level of knowledge
    according to various strategies
  if communication-strategy = "monolingual" [
    if my-group-majority-language = language-spoken
      [ set knowledge min list knowledge-maturity (knowledge + sum [
          knowledge / knowledge-maturity ] of other turtles with [ my-
          group = [ my-group ] of myself and my-group-majority-language
          = language-spoken ]) ]
    ]
  if communication-strategy = "multilingual" [
    ifelse my-group-majority-language = language-spoken
      [ set knowledge min list knowledge-maturity (knowledge + sum [
          knowledge / knowledge-maturity ] of other turtles with [ my-
          group = [ my-group ] of myself and my-group-majority-language
          = language-spoken ]
    + sum [ knowledge / knowledge-maturity * understanding-other-
        languages ] of other turtles with [ my-group = [ my-group ] of
        myself and my-group-majority-language != language-spoken ]) ]
      [ set knowledge min list knowledge-maturity (knowledge + (
          understanding-other-languages * ( sum [ knowledge / knowledge-
          maturity ] of other turtles with [ my-group = [ my-group ] of
          myself and my-group-majority-language = language-spoken ]
    + sum [ knowledge / knowledge-maturity * understanding-other-
        languages ] of other turtles with [ my-group = [ my-group ] of
        myself and my-group-majority-language != language-spoken ] ) ) )
         ]
    ]
  if communication-strategy = "intercomprehension" [
     set knowledge min list knowledge-maturity ( knowledge + sum [
         knowledge / knowledge-maturity ] of other turtles with [ my-
         group = [ my-group ] of myself ] )
    ]
end

to-report get-home
  let side ceiling (sqrt (max [my-group] of turtles + 1))

  report patch
           (round ((world-width / side) * (my-group mod side)
            + min-pxcor + int (world-width / (side * 2))))
          (round ((world-height / side) * int (my-group / side)
```

```
            + min-pycor + int (world-height / (side * 2))))
end

to-report upper-quartile [ xs ]
  let med median xs
  let upper filter [ x -> x > med ] xs
  report ifelse-value (empty? upper) [ med ] [ median upper ]
end

to-report lower-quartile [ xs ]
  let med median xs
  let lower filter [ x -> x < med ] xs
  report ifelse-value (empty? lower) [ med ] [ median lower ]
end
```

Appendix C

Code of the model presented in Chapter 3

```
turtles-own [
  minority? ;; does the person belong to the minority group?
  fluency ;; what is the level of fluency of the minority speaker in
      the minority language?
  nearest-neighbor ;; who's your physically closest agent?
  age
  sex
  reveal? ;; do you always try to speak the minority language or not?
  educated? ;; are you currently involved in an education plan in the
      minority language?
]

to setup
  clear-all
  set-default-shape turtles "person"
  make-turtles
  generate-minority
  reset-ticks
end

to make-turtles ;; the initial population is created and randomly
    scattered around the area. Everybody is given the same attributes.
  create-turtles total-population [
    set minority? false
    set color blue
    setxy random-xcor random-ycor
    set age median (list 0 (random-normal 40 10) 80)
    set sex one-of [ "male" "female" ]
```

```
    set educated? false
  ]
end

to generate-minority ;; minority language speakers are given their
    specific attributes.
  ask turtles [
    if (random 100) < minority-group ;; a part of the population is
        given minority status, colored red and given a level of fluency
        in the minority language
    [ set minority? true
      set color red
      set fluency median (list 1 (random-normal average-initial-lv 10)
          100) ]
    ask turtles with [ minority? = true ] [
      ifelse (random 100) < reveal-strategy ;; minority language
          speakers are split in two types of personality, reveals vs
          hide
      [ set reveal? true ] [ set reveal? false ]
      ifelse (random 100) < education ;; should education plan be
          implemented by the government, a part of the population is
          being involved in them
      [ set educated? true ] [ set educated? false ]
  ] ]
end

to go
  ask turtles [
    get-old ;; agents age 1 year.
    check-death ;; check if they reached age 80 - if so, the agent
        leaves the simulation.
    wiggle   ] ;; if the agent is alive, it moves one step in a random
        direction.
  ask turtles with [ color = red and age >= 6 ] [
    converse ;; minority agents who are at least 6, interact with their
         closest agent who is also at least 6.
    change-color ;; if a minority speakers reaches fluency 0, it turns
        blue, i.e. become a majority speaker only.
    activate-policy ;; (see below)
  ]
  reproduce ;; female agents might give birth to a new agent.
```

```
  if grim-reaper? [ grim-reaper ] ;; randomnly kills agent if the total
       population grows above a certain number - only to try simulations
       on laptot (simulations with two many agents would be too slow).
  tick
  if all? turtles [ color = blue ] [ stop ] ;; stops the simulation if
      there's no more diversity
  if all? turtles [ color = red ] [ stop ]
end

to grim-reaper
 let num-turtles count turtles
  if num-turtles <= carrying-capacity
    [ stop ]
  let chance-to-die (num-turtles - carrying-capacity) / num-turtles
  ask turtles
  [
    if random-float 1.0 < chance-to-die
      [ die ]
  ]
end

to wiggle ;; move 1 step in a random direction.
  rt random 90
  lt random 90
  forward 1
end

to converse ;; interact with closest agent aged at least 6.
  set nearest-neighbor min-one-of (other turtles with [ age >= 6 ]) [
      distance myself ]
  ifelse reveal? = true [ ;; if you are a reveal type agent...
    ifelse [ color ] of nearest-neighbor = blue ;; ...and your closest
        agent is NOT a minority language speaker...
    [ set fluency fluency - 1 ] ;; ...your fluency in the minority
        language goes down by 1.
    [ ifelse (fluency < 99) ;; if you are a reveal type agent and your
        closest neighbor is also a minority language speaker...
      [ set fluency fluency + 1 ] ;; ...your fluency goes up by 1 if
          your fluency is currently less than 100...
      [ set fluency 100 ] ] ] ;; ...and stays at 100 if you're already
          proficient.
```

```
  [ ifelse [ reveal? ] of nearest-neighbor = true ;; if you're a hide-
      personality minority agent, but your closest neighbor is a
      minority language speaker of reveal type personality...
    [ ifelse (fluency < 99)
      [ set fluency fluency + 1 ] ;; ...your fluency goes up by 1, if
          your fluency is currently less than 100...
      [ set fluency 100 ] ] ;; ...and stays at 100 if you're already
          proficient.
    [ set fluency fluency - 1 ] ] ;; if you're a hide-personality
        minority agent, and so is your closest neighbor, your fluency
        goes down by 1.
end

to change-color
  if fluency <= 0 ;; if your fluency in the minority language reaches
      zero, you change to a majority agent.
    [ set color blue
 set minority? false set reveal? false set educated? false ]
end

to get-old
  set age age + 1
end

to check-death
    if age >= life-expectancy [ die ] ;; if the attribute age reaches
        the value set for life expectancy, the agent dies (i.e. leaves
        the simulation).
end

to reproduce
  ask turtles with [ color = red and sex = "female" and age >= 14 and
      age <= 50 ] [ ;; if you're a minority female agent aged between 14
       and 50...
    if random 100 < (count turtles with [ color = red ] / count turtles
        with [ color = red and sex = "female" and age >= 14 and age <=
        50 ]) * minority-growth-rate ;; ...with a probability X... [ N.B
        .: if we have a population of N and a portion m < N is fertile
        women, in order to have a growth equal to g (where g is the
        growth rate * 100), the percentage (* 100) X of women giving
        birth is equal to (N/m)*g ]
```

```
      [ hatch 1 [ set age 0 ;; ...give birth to a new majority agent
         with age 0.
        set sex one-of [ "male" "female" ]
        ifelse (random 100) < reveal-strategy
          [ set reveal? true ] [ set reveal? false ]
        ifelse (random 100) < education
          [ set educated? true ] [ set educated? false ]
        ifelse (random 100) < exogamy-rate ;; With a probability Z, the
           baby will be a majority speaker only (e.g. if exogamy is 10,
            10 babies out of 100 born to a minority mother will be
           assumed to have a majority father).
          [ set color blue set minority? false set reveal? false ] [ set
              color red ]
    ]
  ] ]
  ask turtles with [ color = blue and sex = "female" and age >= 14 and
      age <= 50 ] [ ;; if you're a majority female agent aged between 14
       and 50...
    if random 100 < (count turtles with [ color = blue ] / count
        turtles with [ color = blue and sex = "female" and age >= 14 and
         age <= 50 ]) * majority-growth-rate ;; ...with a probability Y
        ...
    [ hatch 1 [ set age 0 ;; ...give birth to a new majority agent with
        age 0.
     set sex one-of [ "male" "female" ]
     set minority? false
     set educated? false
     set reveal? false ]
    ]
  ]
end

to activate-policy
    if policy and (count turtles with [ color = red ] / count turtles <
        minority-threshold / 100) [ ;; if education policies are active
        and the proportion of the minority drops below a given
       threshold...
    if (age <= 18) and educated? = true [ ;; and you're aged between 6
       and 18...
      ifelse fluency < 90
```

```
      [ set fluency fluency + ed-intensity ] [ set fluency 100 ] ;;...
         increase your fluency by an amount equal to the variable "ed-
         intensity" if its below 90, or set it to 100 if it's already
         at least 90.
    ] ]
end

to-report year-report
 if (ticks = 25) or (ticks = 50) or (ticks = 100)
    [report count turtles with [ color = red ] / count turtles ]
  end
```

Appendix D

Code of the model presented in Chapter 4

```
# -*- coding: utf-8 -*-

import pandas as pd
import numpy as np
from collections import Counter
import random
import time

# -- Parameters --
p_learning = 0 # probability of not starting to learn - value between 0
     a 1 - if it's 0, everyone decides to learn a language, if it's 1,
    nobody does
learning_rate = 1 # factor that defines the speed of learning, which is
     also dependent on the proximity language matrix
np.random.seed(24)
random.seed(24)

# ---------- Data ----------
# Read agent_data
filepath=r"..." # replace dots with path to the excel file
print('Importing agent data...')
agent_data = pd.read_excel(filepath, sheet_name="Database") # reading
    the excel file to import the relevant data

agent_data['lvl1'] = agent_data['lvl1'].astype('int32')
agent_data['lvl2'] = agent_data['lvl2'].astype('int32')
agent_data['lvl3'] = agent_data['lvl3'].astype('int32')
```

```
# Ratios
print('Importing population ratios...')
ratios = pd.read_excel(filepath, sheet_name="Agents") # importing the
    ratios of the populations of the various countries from the excel
    file
ratios_dict = pd.Series(ratios["No croatia.2"].values, index=ratios["
    Country"]).to_dict()

# Language PROXIMITY matrix.
matrix_data = pd.read_excel(filepath, sheet_name="Dyen") # importing
    the language proximity matrix from the excel file
SimMat = matrix_data.to_numpy()[:,1:] # list of proximity values
simMatLanguages = matrix_data.columns[1:] # list of languages

# Hash tables (for accessing SimMat elements)
langIdx = {} # number: language
idxLang = {} # language: number
for idx, lang in enumerate(simMatLanguages):
    langIdx[lang] = idx
    idxLang[idx] = lang

# ------- Print formatting -------
pd.set_option('display.max_rows', 500)
pd.set_option('display.max_columns', 500)
pd.set_option('display.width', 1000)
# --------------------------------

class Agent: # assign agents properties from the excel file
    def __init__(self, data):
        self.residence = data[0]
        self.ol1 = data[1] # official language of the country in which
            the agent lives
        self.ol2 = data[2]
        self.ol3 = data[3]
        self.nationality1 = data[4]
        self.nationality2 = data[5]
        self.nationality3 = data[6]

        self.mt1 = data[7] # mother tongue
        self.mt2 = data[8]
        self.mt3 = data[9]
```

```
        self.mt4 = data[10]

        self.fl1 = data[11] # foreing language
        self.lvl1 = data[12] # level of fluency in the foreign language
            (1=basic, 2=good, 3=very good)

        self.fl2 = data[13]
        self.lvl2 = data[14]

        self.fl3 = data[15]
        self.lvl3 = data[16]

        self.attitude = data[17]
        self.edu = data[18]
        self.edugroup = data[19]
        self.sex = data[20]
        self.age = data[21]
        self.agegroup1 = data[22]
        self.agegroup2 = data[23]
        self.profession = data[24]
        self.living = data[25]

        # -------- for each agent, make a list of native and foreign
            languages, along with their associated levels of fluency
            --------
        self.all_mts = [lang for lang in [self.mt1, self.mt2, self.mt3,
            self.mt4] if lang != 'NN']
        self.all_fls = [lang for lang in [data[11], data[13], data[15]]
            if lang != 'NN']
        self.all_fl_lvls_list = [lang for lang in [data[12], data[14],
            data[16]] if lang != 0]
        self.fl_lvl_dict = dict(zip(self.all_fls, self.all_fl_lvls_list)
            )
        self.currently_learning = 0
        self.mts_and_flAtLvl3 = self.all_mts + [lang for lang in self.
            all_fls if self.fl_lvl_dict[lang] == 3]

    def fl_closest_to_lvl3(self): # this function returns the foreign
        language that is closer to proficiency (level 3) among the ones
        spoken by the agent
```

```
        all_fl_lvls = np.array([lang for lang in self.all_fl_lvls_list],
             dtype=np.float)
        all_below_lvl3 = np.where(all_fl_lvls < 3)[0]
        closest_to_lvl3 = all_below_lvl3[all_fl_lvls[all_below_lvl3].
            argmax()]
        return closest_to_lvl3

    def reset_lang_learning_method(self):
        self.language_learning_method_selected = 0

    def fl_at_lvl3(self): # this function returns a list of foreign
        languages spoken at level 3
        fl_at_lvl3_list = []
        for fl in self.fl_lvl_dict.keys():
            if self.fl_lvl_dict[fl] == 3:
                fl_at_lvl3_list.append(fl)
        return fl_at_lvl3_list

    def check_all_fl_lvl3(self): # this function checks whether all
        foreign languages spoken are at level 3 (up to 3 different
        languages)
        if (len(self.all_fl_lvls_list) == 3) and (all(i==3 for i in self
            .all_fl_lvls_list)):
            return int(1)
        else:
            return int(0)

    def has_fl(self):
        return any(i<3 for i in self.all_fl_lvls_list)

    def highest_fl_lvl(self):
        all_fls_and_lvls = list(zip(self.all_fls, self.all_fl_lvls_list)
            )
        highest_fl = max(all_fls_and_lvls, key=lambda x: x[1])
        return highest_fl

    def empty_fl_slot(self):
        for idx, lang in enumerate(self.all_fls, 1):
            if self.fl_lvl_dict[lang] == None:
                return idx
            else:
```

```
                continue

    def at_least_1FL_below3(self):
        return any(i<3 for i in self.all_fl_lvls_list)

class Agent_repository:
    def __init__(self):
        self.all_agents = []

    def populate_repository(self):
        global agent_data, ratios_dict

        # random sampling based on population ratios
        for country in ratios_dict.keys():
            agent_data_temp = agent_data[agent_data['residence'] ==
                country]
            agent_data_temp.reset_index(drop=True, inplace=True)
            for i in range(ratios_dict[country]):
                random_agent_index = np.random.choice(np.arange(len(
                    agent_data_temp)), 1)[0]
                agent = Agent(agent_data_temp.iloc[[random_agent_index]].
                    values.tolist()[0])
                self.all_agents.append(agent)

    def continue_or_coinFlip(self): # this function lets agent decide
        whether they start learning or not
        global p_learning
        for idx, agent in enumerate(self.all_agents):

            if agent.check_all_fl_lvl3 == int(1):
                agent.currently_learning = 0
                continue
            else:
                if agent.at_least_1FL_below3() is True:
                    agent.currently_learning = 1
                else:
                    coin_flip = np.random.uniform(0, 1, 1)[0]
                    if coin_flip > p_learning:
                        agent.currently_learning = 1
                    else:
                        continue
```

```
def update_agents(self, pick_lang_rule): # this function updates
    the agent's fluency in the language they are currently learning
    global learning_rate
    all_agents_len = len(self.all_agents)

    most_freq_languages = [i[0] for i in self.max_count_lang(top_n
        =6)]
    for idx, agent in enumerate(self.all_agents):
        if agent.check_all_fl_lvl3 == 1:
            agent.currently_learning = 0
            continue
        else:
            if agent.currently_learning == 1:

                if agent.at_least_1FL_below3() == True:
                    closest_to_lvl3_idx = agent.fl_closest_to_lvl3()
                    actual_lang = agent.all_fls[closest_to_lvl3_idx]
                    max_sim = [SimMat[langIdx[lang], langIdx[
                        actual_lang]] for lang in agent.
                        mts_and_flAtLvl3]
                    max_sim = max(max_sim)
                    updated_language_score = min(agent.
                        all_fl_lvls_list[closest_to_lvl3_idx] + float(
                        max_sim) * learning_rate, 3)
                    agent.all_fl_lvls_list[closest_to_lvl3_idx] =
                        updated_language_score
                    if  updated_language_score == 3:
                      agent.mts_and_flAtLvl3.append(actual_lang)
                else:
                    if pick_lang_rule == 1:
                        self.pick_language_rule_1(agent,
                            frequency_list=most_freq_languages)
                    elif pick_lang_rule == 2:
                        self.pick_language_rule_2(agent)
                    elif pick_lang_rule == 3:
                        self.pick_language_rule_3(agent,
                            frequency_list=most_freq_languages)
```

```
    def max_count_lang(self, top_n=6): # this function defines the top
        n languages by number of speakers (useful for learning rule 3)
        all_relevent_langs = []
        for agent in self.all_agents:
            all_relevent_langs += agent.all_mts
            for fl in agent.fl_at_lvl3():
                all_relevent_langs.append(fl)
        most_common = [i for i in Counter(all_relevent_langs).
            most_common(n=top_n)] # list of tuples
        return most_common

#---------- the following functions define the three learning
    strategies -----------

    def pick_language_rule_1(self, agent, frequency_list):
        global SimMat, langIdx
        agent_langs = agent.all_mts + agent.all_fls
        selected_most_freq_lang = 0
        most_freq_languages = frequency_list
        for most_freq_lang in most_freq_languages:
            if most_freq_lang not in agent_langs:
                selected_most_freq_lang = most_freq_lang
                break
            else:
                continue

        max_sim = [SimMat[langIdx[lang], langIdx[selected_most_freq_lang
            ]] for lang in agent.mts_and_flAtLvl3] # index 24 is out of
            bounds for axis zero for size 24
        max_sim = max(max_sim)

        agent.all_fl_lvls_list.append(min(max_sim * learning_rate, 3))
        agent.all_fls.append(selected_most_freq_lang)

    def pick_language_rule_2(self, agent):
        global SimMat, langIdx, idxLang, simMatLanguages
        similar_langs = []
        for lang in agent.mts_and_flAtLvl3:
            for sim_lang in simMatLanguages:
                if sim_lang not in agent.mts_and_flAtLvl3:
                    similarity = SimMat[langIdx[lang], langIdx[sim_lang]]
```

```
                similar_langs.append((sim_lang, similarity))
        similar_langs = sorted(similar_langs, key=lambda x: x[1])[::-1]
        most_similar_lang = similar_langs[0][0]
        most_similar_lang_sim = similar_langs[0][1]
        agent.all_fls.append(most_similar_lang)
        agent.all_fl_lvls_list.append(min(most_similar_lang_sim *
            learning_rate, 3))

    def pick_language_rule_3(self, agent, frequency_list):
        global SimMat, langIdx, idxLang, simMatLanguages
        most_freq_langs = frequency_list
        #print(most_freq_langs)
        #time.sleep(100)
        similar_langs = []
        for lang in agent.mts_and_flAtLvl3:
            for sim_lang in simMatLanguages:
                if (sim_lang not in agent.mts_and_flAtLvl3) and (sim_lang
                     in most_freq_langs):
                    similarity = SimMat[langIdx[lang], langIdx[sim_lang]]
                    similar_langs.append((sim_lang, similarity))
        similar_langs = sorted(similar_langs, key=lambda x: x[1])[::-1]
        most_similar_lang = similar_langs[0][0]
        most_similar_lang_sim = similar_langs[0][1]
        agent.all_fls.append(most_similar_lang)
        agent.all_fl_lvls_list.append(min(most_similar_lang_sim *
            learning_rate, 3))

print('Build agent repository')
Agent_repo = Agent_repository()

print('Populate the repository.')
Agent_repo.populate_repository()

for iteration in range(6): # here we can set the number of iterations
    before the output excel files are generated
    print(iteration)
    start_time = time.time()
    print('Continue learning or flip coin.')
    Agent_repo.continue_or_coinFlip()
    print('Update agents...')
    Agent_repo.update_agents(pick_lang_rule=3)
```

```
    print('Elapsed time: {} sec'.format(time.time() - start_time))

final_data = []
final_data_fl_lvls = []
for agent in Agent_repo.all_agents:
    temp_agent_results = [agent.residence,
                          agent.ol1,
                          agent.ol2,
                          agent.ol3,
                          agent.nationality1,
                          agent.nationality2,
                          agent.nationality3,
                          agent.attitude,
                          agent.edu,
                          agent.edugroup,
                          agent.sex,
                          agent.age,
                          agent.agegroup1,
                          agent.agegroup2,
                          agent.profession,
                          agent.living,
                          agent.mt1,
                          agent.mt2,
                          agent.mt3,
                          agent.mt4]

    for fl in agent.all_fls:
        temp_agent_results.append(fl)

    final_data_fl_lvls.append(agent.all_fl_lvls_list)

    final_data.append(temp_agent_results)

results = pd.DataFrame.from_records(final_data)
results_lvls = pd.DataFrame.from_records(final_data_fl_lvls)
results.to_excel(r'.../xxx.xlsx') # replace dots and xxx with path and
    name of the output file (properties)
results_lvls.to_excel(r'.../xxx.xlsx') # replace dots and xxx with path
     and name of the output file (language levels)
print('Exported')
```

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