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ORIGINAL PAPER

The complexity of knowledge sharing in multilingual corporations: evidence from agent-based simulations

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Abstract

This article discusses the possibility of adopting a complexity theory approach to the study of language policy and planning (LPP). Besides, it argues that agent-based modelling provides a significant support in this sense. Indeed, while agent-based modelling has become a major ally of researchers in the social sciences, it remains largely unexploited in the study of language-related issues in society. As a central tool of complexity theory, agent-based models (ABMs) lend themselves particularly well to the study of all sorts of complex systems. To provide justification for the use of ABMs in LPP, I show how language issues display the typical traits of complex systems and how ABMs can easily translate ideas and notions from the literature into computer-simulated processes. To support my argument, I discuss communication within multinational corporations as an example of a highly complex language matter. In particular, I focus on how language skills impact the process of knowledge creation and knowledge sharing among employees. By means of a model based on a number of straightforward rules, I show how poor language skills (or an utter lack thereof) risks creating an unbalanced distribution of knowledge (and, consequently, of power) across language groups and how this unbalanced distribution is very sensitive to initial conditions. On the contrary, average language skills seem to support communication well enough to avoid skews that favour even slightly more numerous language groups.

Keywords Language · Multilingualism · Knowledge · Communication · Complexity · Agent-based

JEL Classification C63 · D83 · F23 · Z13

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1 Introduction

In the past few decades, scholars of all sciences have been paying increasing attention to aspects of complexity that characterize both natural and social issues, which gave an interdisciplinary spin to much research effort. 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," James 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 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. Dynamics inside and outside complex systems can (and often do) have unexpected repercussions in terms of "what is reacting to what" and "with what intensity." Scholars in the management and economic sciences have been exploring the issue of complexity since the early 1990s.

In what follows I will argue that complexity theory and agent-based modelling can provide a great support to the research on language issues. 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, with a view to detecting 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 will focus on the unbalanced accumulation of knowledge across different language groups within corporations as a function of language skills. I shall point out that the objective of this article 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 were only very seldom applied to language issues, and virtually never to issues of language policy. My objectives are therefore to develop an AMB of communication in a multilingual context and to show that AMBs lend themselves very well to the analysis of language matters. Besides, I will discuss the limitations of such model and how they could be addressed in the future. In general, this article wishes to contribute to the fields of language policy and language economics by expanding its research methodologies.

[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.

Although this is mostly a theoretical article, 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.

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 base 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 (2003b) 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, also the global economy has 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 focussed 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 et al. 1999). Piekkari et al. (2014) add to this the fact that language has often been subsumed

[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.

under the larger umbrella of culture without acknowledging their peculiarities. As noted by Iannàccaro et al. (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 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 discuss later in this article, language problems have a cross-disciplinary nature that makes it hard to come up with a shared set of concepts and definitions. I shall 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 make a trade-off between prioritizing the use of a single corporate language and constantly adapting to the local context and its linguistic landscape. On the one hand, unrestricted multilingualism can cause severe inefficiencies in terms of cross-border collaboration. On the other hand, a common language can come at a high cost, such as shadowing talented workers who are not proficient in the selected common language and, quite paradoxically, generate miscomprehensions as a consequence of a non-proficient use of foreign languages (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 (2003a: 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]

[3] For an in-depth review of the characteristics of complex systems, see Mitchell (2009).

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). The non-negligible impact of language policies on people called for deep 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 (of any nature) with "no language policy"—as a matter of fact, the simple fact of declining to take decisions concerning language issues is a language policy (which is being, anyway, communicated in a certain language). Nevertheless, scholars in this domain have not yet agreed on a comprehensive theory of language policy. 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 (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 take on a complexity theory approach. A notable exception is represented by a position paper by Beckner et al. (2009), in which the authors discuss at length 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, an articulated 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 interlocutor 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.

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,

[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,

widening the free exchange area comes with an exponential growth of diversity both in cultural and linguistic terms (28 member states, 24 official languages plus several regional and minority languages, as of February 2019), as opposed to less linguistically heterogeneous areas, such as Mercosur in the South-American sub-continent, with four full members, five associated countries, one suspended member and two observers, but only three official languages.[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 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), *global* (where the competitiveness of a firm is interconnected with and highly affected by firms in other countries) or any nuance between these two extrema. 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 Perlmutter's (1969) typology of multinational corporations (ethnocentric, polycentric and geocentric) in terms of their identification, information flow and complexity, 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, whether it means proficiency in the corporate language or multilingual skills in general. Indeed, the fact that employees are proficient in the corporate language does not imply that their customer base is too. 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.

Footnote 4 (continued)
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 English, French, Dutch, and, to a lesser extent, Guarani. 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.

Yanaprasart (2016) notes that the approach to language management also varies along a spectrum that stretches from monolingualism to multilingualism. Focussing on 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. She notes that every strategy comes with its advantages and drawbacks. 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 versus 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 disadvantage of those who have limited proficiency in the *lingua franca*.[6] 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.[7] In any case, regardless of the approach chosen and its pros and cons, language-related issues must be addressed, in a way or another. Appointing a language officer to manage the language strategy is therefore a necessary measure in multilingual realities (Piekkari et al. 2014). Such officer, or "language champion", as Piekkari et al. (2014) label her, would be in charge of the articulation and implementation of the language strategy and would be

[6] 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 Sect. 6.

[7] 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 articulated then 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. We 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. 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. This discussion, however, is left for future research.

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, better, 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).[8] 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): "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 discuss more in depth in the rest of this article, 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 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 on, among other things, education, increasing the importance of language skills in school curricula and the demand for language courses. Therefore multinational corporations exist in a complex environment.

[8] For more on the classification of language policies, see Grin and Civico (2018).

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[9] 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.[10] 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. 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.[11] 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 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:

[9] 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."

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

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

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 article, we can take parts 1 and 3 of the definition for granted, i.e. we 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 "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 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 our purposes, 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 discuss 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 requisite for this process to take place. Indeed, Lønsmann (2017) observes that failing to consider language competence issues can seriously hinder communication and knowledge transfer.

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. Several 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 of 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 complicated. On the contrary, ordinary differential equations cannot do that, while systems of stochastic differential equations can only do that with 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 causation links and clarify relationships among variables.

Concerning specifically the model presented in this paper, 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 discuss their main limitations. Although an in-depth discussion of the epistemological limitations of computer-based approaches is far beyond the scope of this article, a few words on this matter are necessary in order for the reader to have a better understanding of this type of modelling strategies. Ever since the introduction of computational models, scholars have asked themselves to what extent we 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 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 together to replicate it. As much as I recognize the limitations of computational modelling, the model presented in this paper does not attempt to explain the cognitive processes underlying multilingual knowledge exchange. Rather, it takes the exchange of information as 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 will become clearer in the following pages, my objective here is not to give a full explanation of the process of multilingual knowledge transfer, but only to contribute to a general discussion, which is clearly much more articulated.

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 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 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:
    a. 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;
    b. 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;
    c. if a random strategy is adopted, the new employee is hired at random.

I will spend a few words to comment 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 […]."[12]
> "The Confederation ensures that linguistic communities are equally represented within the federal authorities […]."[13]

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 […]:

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

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 […]."[14]

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 *aggregate* knowledge. Rather, the model looks at employees with individual knowledge greater than the overall mean 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 practice. Specifically, they mention (1) the case of the South Korean and Japanese subsidiaries of an MNC having trouble to find highly proficient English speakers due to a shortage in 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.

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

5.2 Interactions

When the simulation is started, the following happens:

1. at every time step, individuals move towards a randomly assigned group to work together—the amount 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[15];
2. when all the groups are reunited, 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—in the (admittedly rare) 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:

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

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 level of knowledge where an individual reaches maturity (the same for everyone). This formula 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.[16] In a group of m individuals, total shared knowledge T will be equal to:

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

[15] 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.

[16] As has been stressed, the goal of this article 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.

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

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

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 1.

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 nor b, a will only be able to give r_a of knowledge and b will get r_b of it (that is, $r_a * r_b$).[17] 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.

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

[17] This 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.

linguistic unease when speaking a different language that might affect the quality of one's speech.[18] 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 et al. (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.

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 the code and the expected result. Therefore, I will 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 Fig. 1).

When all groups are reunited (as in the bottom-right quadrant of Fig. 1), 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 will keep the layoff rate at zero and will not put any limit to working age. Consequently, we are not interested in selecting different hiring strategies. The reason why I do this is that I want to look

[18] On this topic, it is worth mentioning Iannàccaro et al. (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. 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.

Table 1 Knowledge sharing between two individuals

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

at the process of short-term knowledge accumulation for each language group. We present different simulations in Fig. 2.

Each line of plots represents 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,[19] while the third one reports the average level of knowledge across language groups. We immediately notice 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 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 et al. 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 Fig. 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 Fig. 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

[19] With 240 employees and an arbitrary maximum value of knowledge maturity of 100, the maximum total knowledge that can be possibly achieved is 24,000.

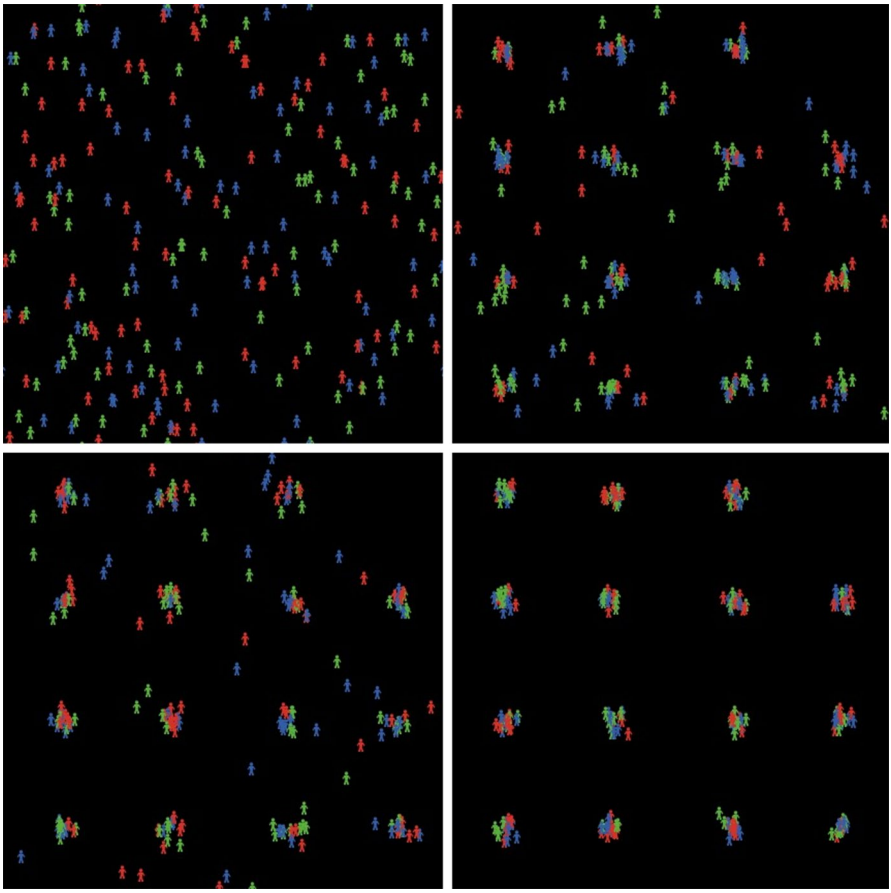

Fig. 1 Grouping motion of individuals

of language training among employees). I shall also note that, when one language group is larger than the others, knowledge accumulation seems to run faster (as in the first line of plots). 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 still "diversity-saving" and the layoff rate is still set at 0. In Fig. 5, we compare (from top to bottom) the monolingual scenario and plurilingual scenarios with levels of average language skills equal to 0.3 and 0.6.[20]

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

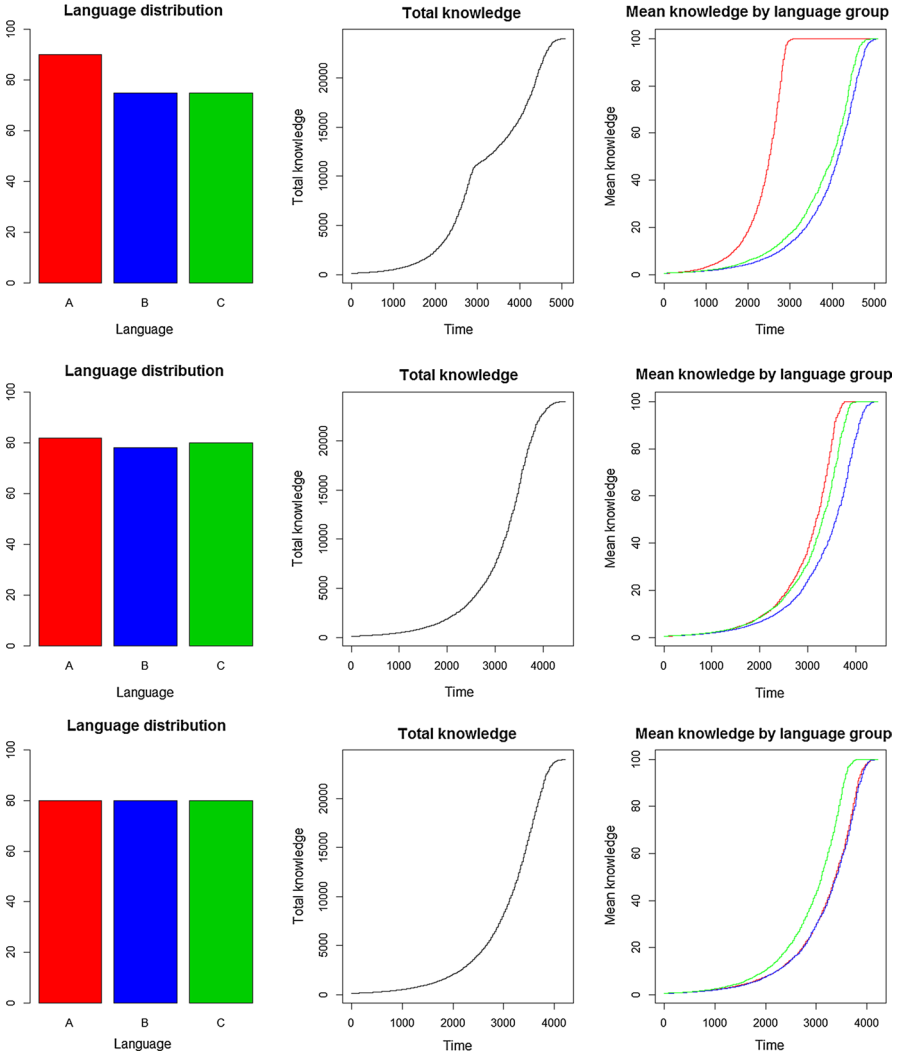

Fig. 2 Monolingual employees, different simulations of short-term knowledge accumulation

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 that 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. 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

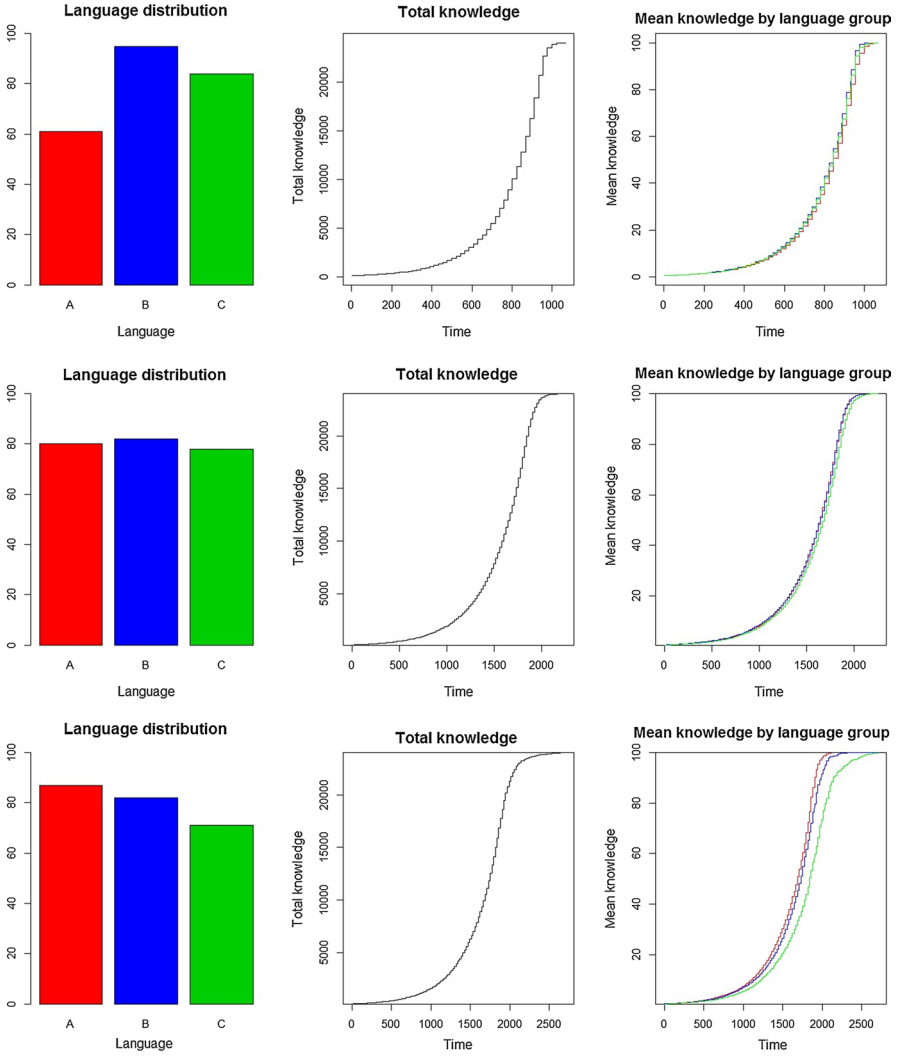

Fig. 3 Plurilingual employees with low skills, different simulations of short-term knowledge accumulation

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 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 10. 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.

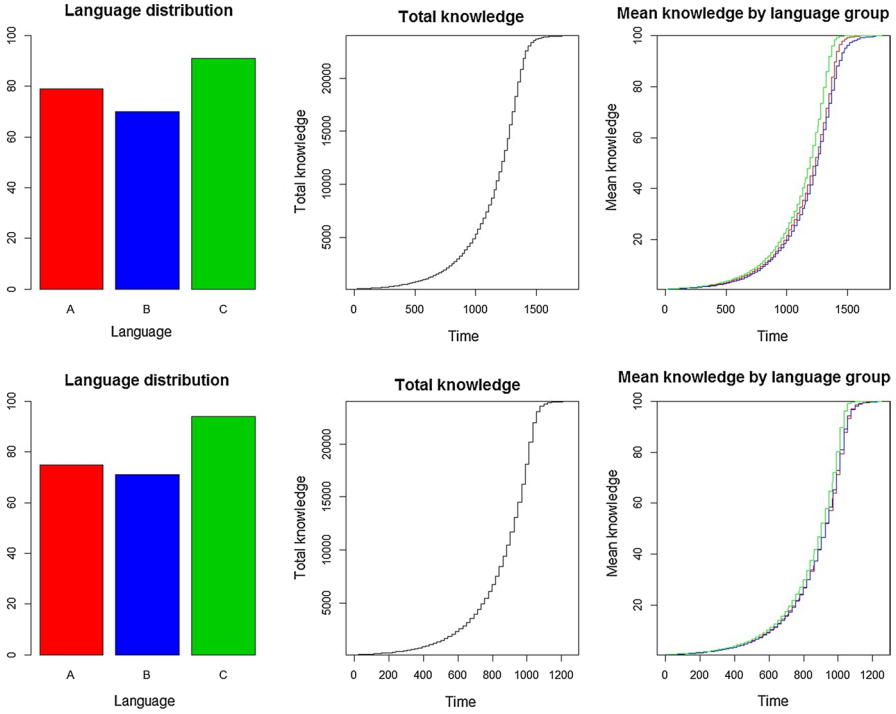

Fig. 4 Plurilingual employees with average skills, different simulations of short-term knowledge accumulation

Let us now look at the consequences of adopting a "knowledge-maximizing" hiring strategy on the company's linguistic landscape. Figure 6 shows a comparison between four scenarios. It shows the trend of the Greenberg index.[21] In the first scenario (top-left) agents are monolingual, while in the other agents are plurilingual

[21] 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 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:

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

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

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

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 goes 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 approximately equal to 0.67, 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 21,000 time-steps, more than eight 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 distribution of language groups.

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 paper 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 inbuilt 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 the hiring practices in the Swiss public administration and the language-based networks resulting from the Merida-Nordbanken merger. 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. 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

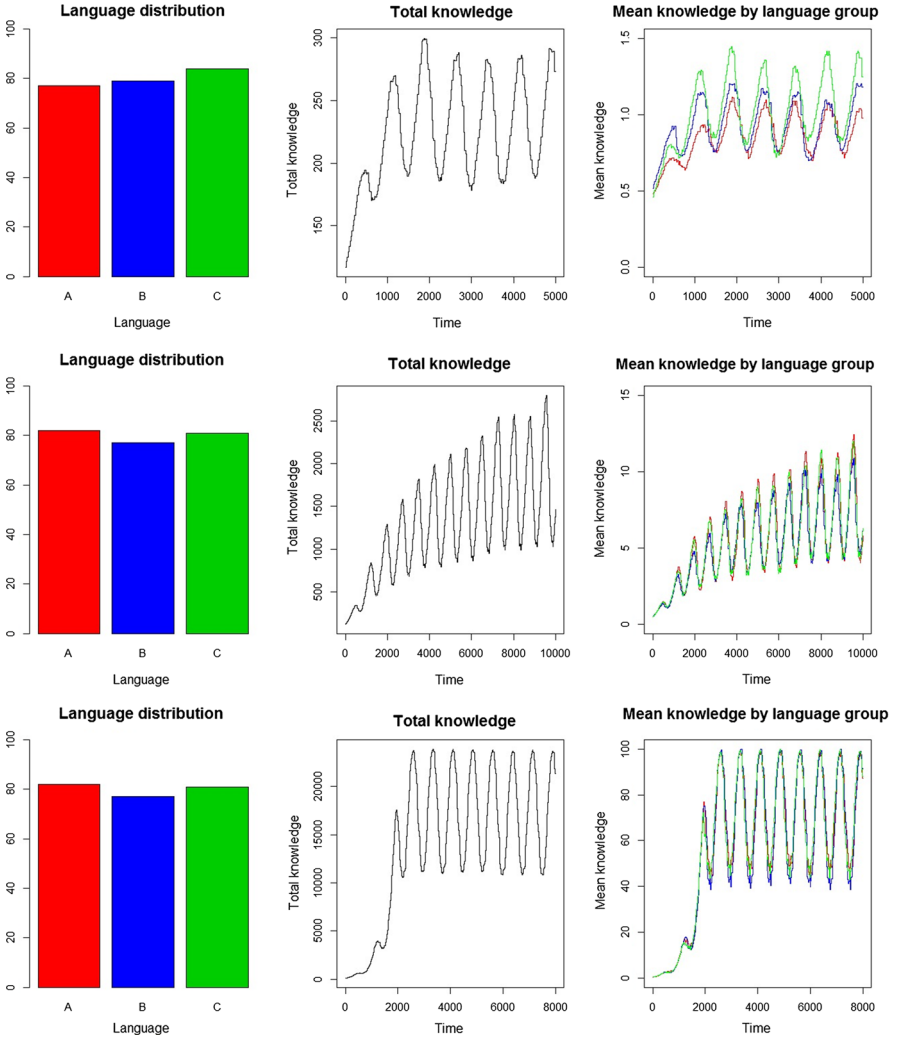

Fig. 5 Trends of long-term knowledge accumulation, monolingual (first line) and plurilingual employees with different levels of average language skills (second and third line)

a qualitative study, go in the same directions 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 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.

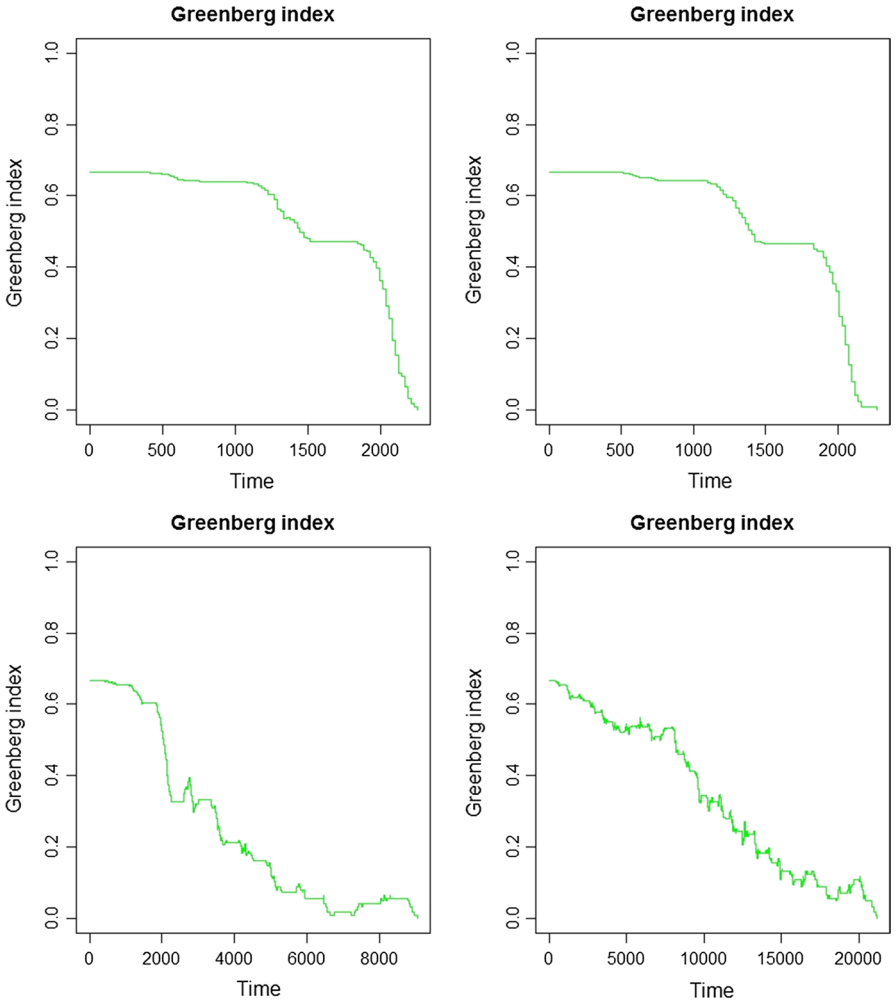

Fig. 6 Greenberg index, monolingual case (top left); Greenberg index, average skills 0.2 (top right); Greenberg index, average skills 0.5 (bottom left); and Greenberg index, average skills 0.8 (bottom right)

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 article. 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.[22] In our simulation, such 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 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 et al. 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 was driven by the fact that we were 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 rises. 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.

[22] 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 (2008).

Also, it could be interesting to integrate results from qualitative studies of knowledge creation dynamics with a view to refining 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), 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 article, 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 qualitative reasoning, help researchers by providing order to the overall discussion around languages and favour qualitative reasoning in a virtuous circle.

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