Language-competition models

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Abstract

The modeling of the long-run dynamics of language competition as well as of the survival of (minority) languages is reviewed. One can thereby distinguish three basic types of models in the literature.

In macro models the transmission of the involved languages by the family and public institutions from one generation to the next is in the center of the analysis. This transmission is generally determined by the aggregate number of speakers of the different languages as well as by status and acquisition planning. The implicit or explicit parental choice of the language(s) in which their children are socialized involves a trade-off between emotional attachment to a language and its practical usefulness. This trade-off is influenced by the relative status of the idioms, which in turn is a result of language policy. We present a meta model of this approach.

In micro models the chief driving force behind language choice and change is imitation during random encounters of single individuals. This approach allows the analysis of the spatial distribution of language use and the changes thereof. This approach can also be used to analyze changes in corpus and structure of the language as a system.

The third approach consists of various hybrids of the other two.

Keywords: language dynamics, language death, status planning, acquisition planning, inter-generational transmission, language change

JEL classification:

1 INTRODUCTION

In today's world some 7000 languages are spoken.[1] Many of these languages are in competition with one another, and in 100 years as many as half of the languages might be extinct.[2] The

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[1] See LEWIS, SIMONS, and FENNIG (2014). Due to the inclusion of some mutually comprehensive varieties of some languages, the relevant number might be around 6000, see HAMMARSTRÖM (2015).

[2] See, for instance, CRYSTAL (2000) for an overview.

language competition is the object of study in many disciplines, not only in (socio-)linguistics, but also in biology, physics, economics, etc. Many standard models in these fields can easily be modified to model language competition.

Economists can contribute substantially to this literature, since language choice is often an individual decision made under restrictions. In order to understand how linguistic choices are made and how the linguistic repertoire of different individuals is formed, it is important to analyze how people react to incentives. Often, this is reduced to simple cost-benefit considerations. These considerations can be applied in a statistic analysis based on average behavior – we talk about macro models – or to imitation behavior in individual encounters – micro models. In micro models one can analyze both the choice between different well-defined languages – language choice and shift – and the internal change in a variety – language evolution or change. In the encounters an individual can chose to imitate the other individual in shifting to his or her language totally or in taking over certain features of the language usage of the interlocutor. If the effects of individual incentives on language use or change can be identified, language policy affecting these incentives can be discussed, This is a central point in this essay.

We first discuss the macro models, introducing some key concepts in a few early models in section 2.1 and in a general meta-structure in section 2.2. This general framework makes the often implicit behavioral assumptions explicit and comparable. The framework is applied to three specific models in section 3, and in section 4 further similar models are briefly reviewed. Applications to language policy are discussed in section 5. The relatively new trend of micro models with imitation behavior is briefly discussed in section 6, and we give some suggestions for further reading in section 7.

2 KEY ISSUES, CONCEPTS, AND DEFINITIONS

The key issue, the importance of the language choice of individuals under different incentives for the survival of minority languages is modeled in some detail in a few articles inspired by economics in section 2.1. However, the intricacies of the long-run dynamics is, if not neglected, at most treated *en passant* in these models. The integration of behavior and long run dynamics in a general framework is discussed in section 2.2.

2.1 MODELS WITH THE ORIGIN IN ECONOMIC ANALYSIS

GRIN (1992) considers a context with two languages where bilinguals gain utility from various activities in one of two languages. The utility of using the minority language depends on its linguistic vitality, which is determined by the number of speakers and use of the language throughout society. The author presents a dynamic model for vitality, use, and number of speakers of a minority language and concludes that given a minimal amount of speakers and a positive attitude towards using the language, the minority language can survive in a steady state. JOHN and YI (2001) analyze a situation with two languages and bilinguals living in two regions. The individuals, who live trough three generations, can every period either learn the other language or engage in production. Between the periods, they may move to the other region and engage in production there. The authors assume network externalities with one individual's decision affecting the well-being of others. This is specified in assuming that the *per capita* production of an individual (weakly) increases with the number of individuals speaking the same language. It is shown that with migration bilingual steady states are possible. KENNEDY and KING (2005) also construct a three-generation model with overlapping generations, where (young and old) adults vote for public language policies. Children learn the language of their parents in the family and the other language used in society at school. Also here network externalities are present. In the production, adults profit from others speaking their language and are, hence, interested in educational policies with the goal of teaching their language to all children. At the same time education is costly, such that the adults in their voting decisions have to weight the education costs against the benefits of spreading their language. It is demonstrated that in a median-voter equilibrium under certain conditions there will be a number of bilinguals in society.

2.2 A general framework – the trade-off between communication and identity

Many macro models in the literature have a similar structure and can be brought together in a meta model. We focus on the behavioral assumptions of the modeling which is captured in how families are formed and how they decide on the language(s) in which the offspring is raised. Social policy, in general, and language policy, especially, can influence the behavior of the individuals.[3]

A society characterized by a peaceful intercourse between ethnic groups can be expected to have a higher rate of intermarriage over ethnic groups than a society where suspicion or outright animosity between ethnic groups prevails. We can, hence, assume that the family formation is strongly influenced by the social capital which in turn can be influenced by the general (social) policy of the government. The decision in the family, which language(s) to transmit to the offspring is motivated by two types of arguments, *communication possibilities* and *emotional attachment* to the language as carrier of traditions and culture. The communication possibilities are largely dependent on the linguistic landscape, that is which languages are generally used and understood in society. This can be influenced by planning. The emotional value is a subjective variable that can depend on the pride in the culture which in turn can be at least partially determined by the status of the language in society. This status is highly dependent on language policy. All types of language policy, status, corpus, and acquisition planning, can contribute to the general status of the language and consequently to its transmission to the next generation.

Two forces will then confront one another:[4] The desire to communicate with a large number of individuals will favor big languages.[5] Countering this force is the desire of individuals to preserve their language for future generations.[6] In this section we try to abstract from the many details and characterize two processes that capture these two forces.

[3] This discussion closely follows Wickström (2014).

[4] For two detailed classic studies of language shift in reality, see Gal (1979) or Dorian (1981).

[5] As a matter of fact, in considering only the communicative function of a language, due to the so called network externality there are good arguments for accelerating the demise of the smaller language, see, for instance, Church and King (1993).

[6] Also here we can talk about an externality. The language choice of one generation determines the social benefits of choosing languages in the following generation etc. For a detailed discussion, see Wickström (2013).

2.2.1 Notation and definitions

We distinguish between two well-defined languages, A and B and three types of individuals, monolinguals, type A or B, as well as bilinguals, type C.[7] The number of individuals of type L in the society is then Np_L with N is the total number of individuals and p_L the fraction of individuals of type L. That is, we define the distribution of linguistic types in society as a vector $p := \{p_A, p_B.p_C\}$, $p_A + p_B + p_C = 1$. For simplicity, we assume that language is transmitted in families consisting of two parents and, on the average, two children.[8] That is, the size of the total population remains constant over time. Ignoring the fact that there are (at least) two genders, we can define six different family types, $F = \{AA, AB, AC, BB, BC, CC\}$. The frequency distribution of the family types is written as $\mu = \{\mu_{AA}, \mu_{AB}, \mu_{AC}, \mu_{BB}, \mu_{BC}, \mu_{CC}\}$, $\mu_{AA} + \mu_{AB} + \mu_{AC} + \mu_{BB} + \mu_{BC} + \mu_{CC} = 1$, and the frequency distribution of the types of children emerging from families of type F is written as $\alpha(F) = \{\alpha_A(F), \alpha_B(F), \alpha_C(F)\}$, $\alpha_A(F) + \alpha_B(F) + \alpha_C(F) = 1$. Let p^t be the distribution of language groups in generation t and p^{t+1} in the next generation. Formally, we can describe the dynamics as:

$$p^t \xrightarrow{\mu} F \xrightarrow{\alpha} p^{t+1}$$

The dynamics of this simple model is easily characterized:

$$Np_L^{t+1} = \sum_F \mu_F \frac{N}{2} 2\alpha_L(F)$$

or:

$$\dot{p_L} := p_L^{t+1} - p_L^t = \sum_F \mu_F \alpha_L(F) - p_L^t \tag{2.1}$$

2.2.2 Behavioral assumptions

Behavior as a response to different incentives is at the core of any economic analysis. In our simple model, both variables, μ and α, are to a certain extent determined by behavioral processes that in turn are influenced by the linguistic landscape.[9]

The family formation is modeled as a stochastic process. Assuming that people meet at random, the probability that a given individual meets an individual of type L is equal to p_L. The probability that such an encounter leads to a family is given by θ_F. In table 2.1 it is assumed that $\theta_F = 1$ for all F and in table 2.2, $\theta_{AB} = 0$ and all other $\theta_F = 1$.[10]

The most crucial behavioral variables are the $\alpha_L(F)$. As discussed above, we can distinguish two important motivations for learning a language, the practical benefit of the language as a

[7] For our purposes, the assumption that languages are well-defined and distinct is justified, since the models analyze competition between mutually unintelligible variants, like Castillian and Basque or English and French. The competition between close varieties is analyzed in some contribution i section 4.1, and their development is touched upon in section 6.2.

[8] In some studies, for instance TEMPLIN (2019a) and TEMPLIN (2019b), adult learning and migration is also considered. This can easily be accommodated in the general framework.

[9] MUFWENE (2001) and other (socio-)linguists talk about the linguistic ecology.

[10] For a derivation of the frequencies, the reader is referred to WICKSTRÖM (2005).

F	AA	AB	AC	BB	BC	CC
μ_F	p_A^2	$2p_Ap_B$	$2p_Ap_C$	p_B^2	$2p_Bp_C$	p_C^2

Table 2.1 Family types if all $\theta_L = 1$

means of communication and its subjective value to the speakers as a carrier of identity and culture. The first aspect is determined by the number of speakers of the language in question; the higher the number of speakers, the higher the practical value of the language as a means of communication *ceteris paribus*.[11] That is, the practical benefit of becoming an A-type depends on $N(p_A + p_C)$, the number of individuals who can communicate in language A. Similarly the benefit of becoming a B-type or C-type depends on $N(p_B + p_C)$ and N, respectively. Against this practical benefit, we have to weigh the emotional value of the languages in the family. We assume this to depend on the types of the parents and on the (relative) status of the languages, $S = \{S_A, S_B\}$. This latter variable is influenced by the language policy of the government. We write the α as $\alpha_L(F, p, S)$. The dynamic structure of the model is schematically illustrated in figure 2.1. On the objective side, we have the observable variables of the linguistic landscape reduced to the distribution of linguistic types in the population.[12] On the subjective side, we find some social norms (θ) influencing the frequency of the various family types, as well as the "status of the languages" (S). Both these variables are influenced by public policy.

F	AA	AB	AC	BB	BC	CC
μ_F	$p_A^2 + p_Ap_B$	0	$2p_Ap_C$	$p_B^2 + p_Ap_B$	$2p_Bp_C$	p_C^2

Table 2.2 Family types if $\theta_{AB} = 0$ and all other $\theta_L = 1$

[11] Of course, a number of other factors are also important. On a global basis, English, for instance, is (still) generally more useful than Putonghua with many more speakers, since English is spread all over the globe, whereas Putonghua is generally limited to certain parts of Asia. Similar arguments also have some validity in multilingual countries if we consider the spatial distribution of the speakers, see section 4.2.

[12] In a more realistic model, various publicly regulated language rights would also form a part of the linguistic landscape, for instance the use of a minority language on street signs.

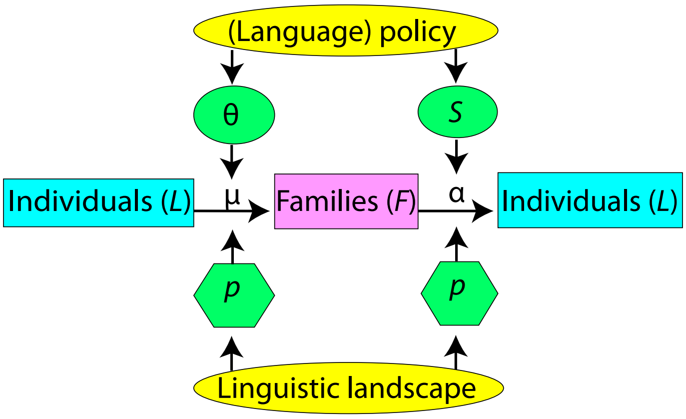


FIGURE 2.1 Dynamic structure

3 EARLY DEVELOPMENT – THREE SPECIFIC MODELS IN SOME DETAIL

We will in some detail discuss three of the macro models in the general framework and thereby see how important the behavioral assumptions are for the survival of (societal) bilingualism and bilinguality (individual bilingualism).[13] Many of the other models can also be seen as special cases of the general framework and will be briefly discussed without going into the technical details.

3.1 LANGUAGE DEATH AND THE MODEL OF ABRAMS and STROGATZ (2003)

The simplest model, by far is ABRAMS and STROGATZ (2003). The authors apply the model to Gaelic in Cataibh (English: Sutherland), Scotland, to Quechua in Wanuku suyu (Spanish: Huánuco), Peru, to Welsh in Sir Fynwy (Englisch: Monmouthshire), Wales, and to Welsh in in all of Wales and manage to calibrate the parameters of the model to get a rather good fit for the decline of those languages in those areas, predicting their death. Adapting the model to our framework, the two functions μ and α are easily found. There are only two types of individuals, A or B, and $\theta_{AA} = \theta_{BB} = 1$. All other θ are equal to zero (table 3.1). The family behavior is also as simple as possible:

$$\alpha_B(AA; S, p) = kS_B p_B^r \quad \alpha_A(AA; S, p) = 1 - \alpha_B(AA; S, p)$$
$$\alpha_A(BB; S, p) = kS_A p_A^r \quad \alpha_B(BB; S.p) = 1 - \alpha_A(BB; S, p)$$

F	AA	AB	AC	BB	BC	CC
μ_F	p_A	0	0	p_B	0	0

TABLE 3.1 Family types in ABRAMS and STROGATZ (2003)

[13] Some authors distinguish between bilinguality and bilingualism, reserving the latter term for a society with two languages in use; see, for instance, HAMERS and BLANC (2000).

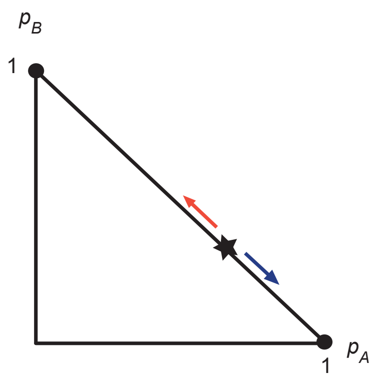


FIGURE 3.1 Phase diagram for the model in ABRAMS and STROGATZ (2003)

The status variable is normalized, $S_A + S_B = 1$; k and r are two positive constants. There is a "leakage" from the two family types to the other language that depends on the status and size of that language. The dynamics permit three possible stationary states, $p^{SS} = (p_A^{SS}, p_B^{SS})$:

$$p^{SS} = \begin{cases} (1,0) \\ \left(\frac{\sigma_B}{\sigma_A+\sigma_B}, \frac{\sigma_A}{\sigma_A+\sigma_B}\right), \quad \sigma_L := (S_L)^{\frac{1}{r-1}} \\ (0,1) \end{cases} \tag{3.1}$$

The dynamics can be pictured in a simple phase diagram, figure 3.1. It turns out that only the corner steady states (marked by a bullet) are stable. The location of the unstable steady state (marked by a star) is determined by the relative status of the two languages. The higher the status of language A is in comparison to language B, the further up in the diagram will be the unstable steady state and language A will prevail also from a low initial fraction. Independently of the initial distribution of the two types, the model implies the demise of one of the competing languages.

3.2 ADDING BILINGUALITY IN MINETT and WANG (2008)

MINETT and WANG (2008) modify the model of ABRAMS and STROGATZ (2003) by introducing bilinguals. There are no mixed families, however, and language shift only occurs via bilinguals. The family frequencies are given in table 3.2 and the α are:

F	AA	AB	AC	BB	BC	CC
μ_F	p_A	0	0	p_B	0	p_C

TABLE 3.2 Family types in MINETT and WANG (2008)

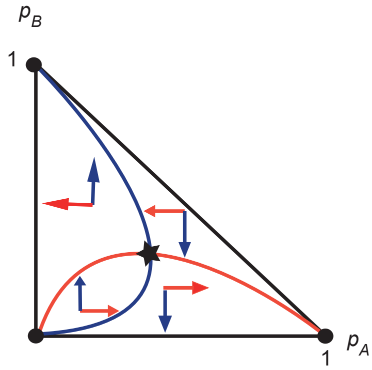


FIGURE 3.2 Phase diagram for MINETT and WANG (2008)

$$\alpha_C(AA;S,p)=k_1 S_B p_B^r \quad \alpha_A(AA;S,p)=1-\alpha_C(AA;S,p) \quad \alpha_B(AA;S,p)=0$$
$$\alpha_C(BB;S,p)=k_1 S_A p_A^r \quad \alpha_B(BB;S,p)=1-\alpha_C(BB;S,p) \quad \alpha_A(BB;S,p)=0$$
$$\begin{array}{l}\alpha_A(CC;S,p)=k_2 S_A p_A^r\\ \alpha_B(CC;S,p)=k_2 S_B p_B^r\end{array} \quad \alpha_C(CC;S,p)=1-\alpha_A(CC;S,p)-\alpha_B(CC;S,p)$$

We find the phase diagram in figure 3.2. There are three possible steady states $p^{SS} = (p_A^{SS}, p_B^{SS}, p_C^{SS})$:

$$p^{SS}=\begin{cases}(1,0,0)\\(a,b,c), & 0<a,b,c<1\\(0,1,0)\end{cases}$$

Only the corner steady states are stable. There can be no bilingualism in the long run; see, however, the introduction of policy in section 5.

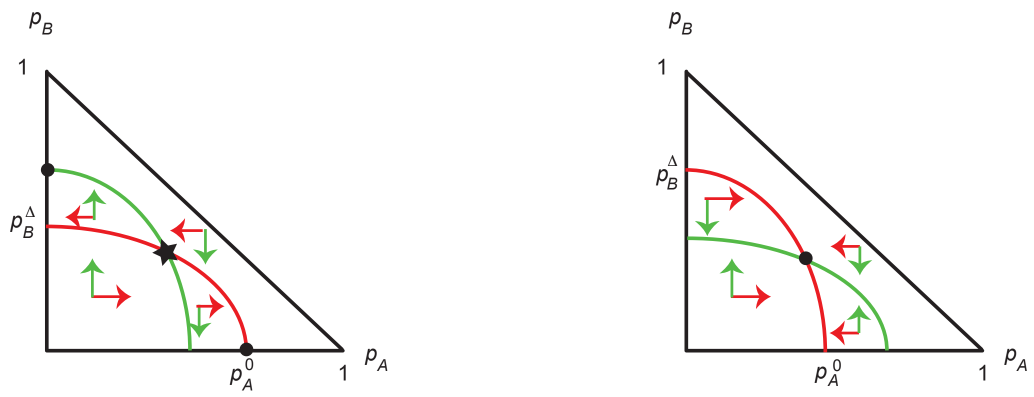
3.3 THE SURVIVAL OF MINORITY LANGUAGES AND THE MODEL OF WICKSTRÖM (2005)

This model permits all family types based on random matching. All θ but θ_{AB} are equal to one and $0 \leq \theta_{AB} \leq 1$. The frequency distribution is given in table 3.3 with $\lambda := 2\theta_{AB}/(1+\theta_{AB})$. The family behavior is very general with the only restriction:

$$1 \geq \alpha_A(AA;\cdot) \geq \alpha_A(AC;\cdot) \geq \left\{\begin{array}{c}\alpha_A(CC;\cdot)\\ \alpha_A(AB;\cdot)\end{array}\right\} \geq \alpha_A(BC;\cdot) \geq \alpha_A(BB;\cdot) \geq 0$$

F	AA	AB	AC	BB	BC	CC
μ_F	$p_A^2+p_Ap_B(1-\lambda)$	$2p_Ap_B\lambda$	$2p_Ap_C$	$p_B^2+p_Ap_B(1-\lambda)$	$2p_Bp_C$	p_C^2

TABLE 3.3 Family types in WICKSTRÖM (2005)



(a) *AC and BC steady states* (b) *ABC steady state*

FIGURE 3.3 Phase diagrams for the model in WICKSTRÖM (2005) with different values of the status variable and of the relative importance of language as means of communication in comparison to as carrier of identity

That is, the frequency of type A children emerging from a family is the higher, the stronger is the language A in the parent generation. Further, α_A is non-decreasing in S_A and non-increasing in p_B. *Mutatis mutandis* the same holds for B type children and α_B.

Again, stationary states can be characterized and pictured in phase diagrams. Figure 3.3a depicts the case when in a stable stationary state all individuals speaking the minority language are bilingual, whereas in figure 3.3b all types of individuals can coexist in a stationary state. Of course, also mono-lingual stationary states are possible. Which situation obtains depends, on the one hand, on the relative status of the two languages and, on the other hand, on the relative weight the families attach to the practical utility of the languages as means of communication compared to the emotional value attached to the languages. One important result is that the minority language, B say, can survive if at least 50% of the children from a AC-family grow up bilingual as C-types ($\alpha_C(AC; \cdot) \geq 0.5$).[14] See also the extension of the model to include optimal language policy in section 5.

4 REFINED THEORIES AND METHODS

With minor modifications, a number of other models display a similar structure and could be analyzed in the general framework. The modifications are mainly the addition of mobility (migration into or out of the area) and language learning (change of type during the life cycle), as well as modifyinf the dynamics and making the models spatial.

4.1 OTHER MODALS WITH A VERY SIMILAR STRUCTURE

A number of contributions take their point of departure in the model of MIRA and PAREDES (2005) which applies ABRAMS and STROGATZ (2003) to the competition between two similar languages, Galician and Castillian in nothern Spain. Due to the similarity of the languages,

[14] The number 50 depends on the assumption that the size of the total population is constant. If the population increases or decreases, the number will be different. Fix is that the families of type AC are decisive, though.

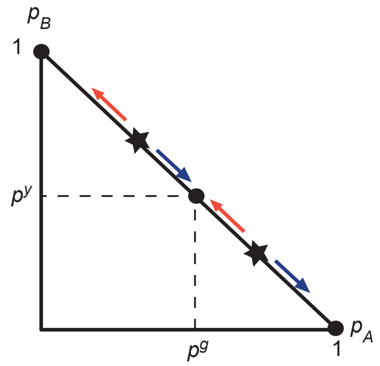


FIGURE 4.1 Phase diagram for the models in PATRIARCA and LEPPÄNEN (2004) as well as PATRIARCA and HEINSALU (2009)

bilingual steady states are possible. MIRA, SEOANE, and NIETO (2011) make a mainly numerical stability analysis, OTERO-ESPINAR, SEOANE, NIETO, and MIRA (2013), as well as COLUCCI, MIRA, NIETO, and OTERO-ESPINAR (2016) perform analytic studies of the model, its stationary states, and their stability. The model in HEINSALU, PATRIARCA, and LÉONARD (2014) can be seen as an extension of MINETT and WANG (2008). Here the decision to learn the other language is a function of all speakers of this language (mono- and bilingual), while in the original paper it is only a function of monolinguals. Bilingualism is possible and the authors also model a simple language policy, see section 5. TEMPLIN (2019a) introduces migration and adult language learning into the framework, but without the status variable, which is included in TEMPLIN (2019b).

A number of very similar papers, BAGGS and FREEDMAN (1990). BAGGS and FREEDMAN (1993), EL-OWAIDY and ISMAIL (2002), and V. S. H. RAO and P. R. S. RAO (2008), model the development of language use in settings with two, three, or many competing. languages. The offsprings of monolingual parents are monolingual in the parents' language and those of bi- or multilingual parents are monolingual in one of the family languages. A second or third language is acquired later in life with the transition probabilities dependent on the prestige and presence of the other language in society. The population dynamics is modeled in a slightly different manner (similar to Lotka-Volterra type models, see section 4.3 below) from other modals in this section. Behavior is not explicitly modeled and the existence of different multilingual equilibria and their stability are analyzed in dependence of the model parameters.

4.2 SPATIAL MODELS

The model of ABRAMS and STROGATZ (2003) has two stable monolingual steady states. If there are two different separate territories, one steady state can obtain in one territory and the other one in the other territory. If the territories are joined and communication flows freely between the two parts of the joined territory one of the languages will win at the end. This is the result of the model. However, this is not necessarily the case if the populations in the two parts are different in the sense that they evaluate the relative status of the two languages differently or if the diffusion of information is sufficiently restricted between the two parts. This is the driving force behind two models of PATRIARCA and LEPPÄNEN (2004) as well as PATRIARCA and HEINSALU (2009).

In PATRIARCA and LEPPÄNEN (2004) part of the population, the greens, say, give a very high relative status to language A as compared to language B, whereas the other part of the population, the yellows, say, give a high status to language B. If there is no intermarriage between the greens and the yellows in the society and both fractions are sufficiently large, there will exist a stable steady state in our general framework with $p_A^{SS} = p^g$, the fraction of the greens, and $p_B^{SS} = p^y$, the fraction of the yellows. The natural interpretation is that the greens live in one part of the country and the yellows in another part. Each part can then have its own language in a stable situation. The model, however, also fit a situation with two homogeneous ethnic groups with different view on the relative status of the two languages living on the same territory. In PATRIARCA and HEINSALU (2009) there are also two distinctive groups and the amount of communication between the groups is smaller than within each group. Formally, the same kind of dynamics will occur and a stable steady state with $p_A^{SS} = p^g$ and $p_B^{SS} = p^y$ exists. Again, the natural interpretation is that the two distinct groups occupy different pets of the territory. However, any situation with two distinct homogeneous ethnic groups with more interaction within each group than between the groups, fits the model. The dynamics of both models can be illustrated in the same phase diagram with five steady states whereof two are unstable and three are stable. See figure 4.1. The stable steady states $p^{SS*} = (p_A^{SS*}, p_B^{SS*})$ are:

$$p^{SS*} = \begin{cases} (1,0) \\ (p^g, p^y) \\ (0,1) \end{cases}$$

4.3 LOTKA-VOLTERRA TYPE MODELS

When analyzing language competition one might not only want to know what the steady states of the systems are, but also how much time it takes until the system is approaching them. The speed at which the system changes strongly depends on general population dynamics: How frequently are children born and how many deaths occur in a given time frame. If both numbers are high, the system changes faster compared to a situation where both are rather low. Moreover, if both numbers differ from one another, or if the numbers are not the same for speakers of A and B, then population dynamics will also affect the systems steady states.

A straight-forward way to add population dynamics to the general framework is to include (language group specific) birth and death rates. Another way to model population dynamics was first presented in PINASCO and ROMANELLI (2006). The authors propose a version of ABRAMS and STROGATZ (2003) with logistic population dynamics. The basic assumption is that resources are limited and hence that population growth is limited. Over time, the population size approaches a steady state which depends on the available resources. PINASCO and ROMANELLI (2006) show that with logistic population growth the minority language can survive in a stable equilibrium, even in the absence of bilinguals. KANDLER and STEELE (2008) and KANDLER, UNGER, and STEELE (2010) adapted the logistic population dynamics and combined it with the spatial model of PATRIARCA and LEPPÄNEN (2004) discussed in section 4.2. They can show that, depending on the situation at hand, coexistence as well as extinction of the minority language can yield stable steady states. HEINSALU, PATRIARCA, and LÉONARD (2014) show that in the steady state, population dynamics is not relevant anymore. Therefore, the general approach can be seen a model for the population steady state. Finalöly, we like to mentioned ZHANG and

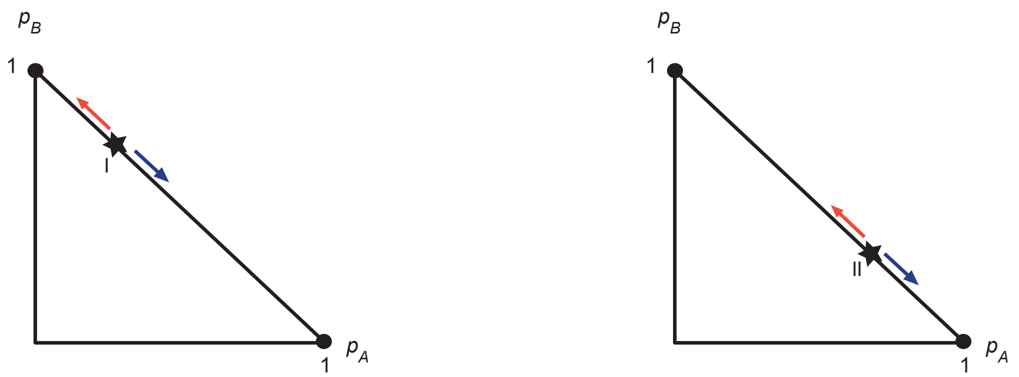
GONG (2013) who combine logistic population growth with a language diffusion model inspired by Fourier's law of heat conduction.

5 APPLICATIONS TO LANGUAGE POLICY

In almost all models discussed so far, a status variable play an important rôle. In figure 5.1, two versions of a phase diagram are presented, one with a high relative status of language A and one with a high relative status of language B. Assume that the policy maker can change the status of the languages at will through language policy and assume that he or she increases the relative status of language A if its fraction of the population falls below a certain value p_A^C and increases the relative status of language B if the fraction of A speakers becomes bigger than p_A^C. Then the phase diagram in figure 5.1a will describe the language dynamics if p_A is below p_A^C and the diagram in figure 5.1b if p_A is above p_A^C. This is illustrated in figure 5.2. There is a stable steady state in point III.

MINETT and WANG (2008) observed this phenomenon and introduced language policy into their model in this way. A change in the status variable is illustrated in figure 5.3a, where the relative status of language A is lower by the broken than by the solid lines. The phase diagram resulting from the introduction of language policy is illustrated in figure 5.3b. Like in the simple case above, the phase diagram with a high relative status for language A is relevant for p_A below p_A^C and the phase diagram with a low relative status for language A is the relevant one if p_A is above p_A^C. There is now a set of stable steady states with p_A equal to p_A^C. As noted above in section 4.1, the model in HEINSALU, PATRIARCA, and LÉONARD (2014) can be seen as an extension of MINETT and WANG (2008) with a simple language policy altering the effect of bilinguals on the language decision. The model in BERNARD and MARTIN (2012) is a bilingual model similar to ABRAMS and STROGATZ (2003) where status can be influenced by language policy. Here, however, the rate of change in the status is what can be controlled within certain limits. That is, a certain time is necessary in order to change the status from one level to another in contrast to the models above with an instantaneous change in the status variable. The authors investigate policies that maintain given levels of monolinguals in both languages.

FERNANDO, VALIJÄRVI, and GOLDSTEIN (2010) analyze language use in two domains, public



(a) *High relativ status of language A* (b) *High relativ status of language B*

FIGURE 5.1 Phase diagram for the model in ABRAMS and STROGATZ (2003) with different values of the status variable

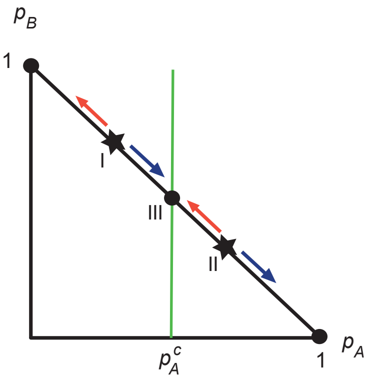
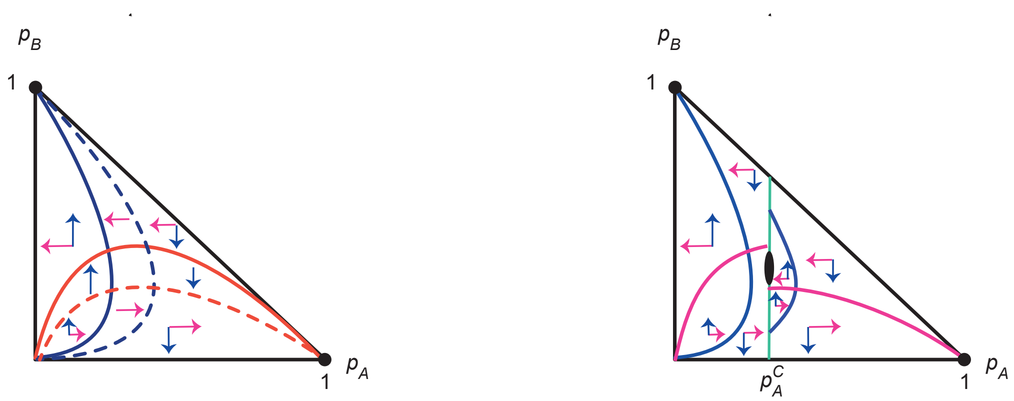


Figure 5.2 Phase diagram for the model in Abrams and Strogatz (2003) with policy

and private, and allow diglossia. In the model, which is similar to Wickström (2005), they show how education of the majority in the minority language as well as status planning making the minority language more visible in the public space can guarantee the survival of the minority language.[15] Deka and Sinha (2016) is a version of Fernando, Valijärvi, and Goldstein (2010) which uses Markov chains to analyze the effects of different status parameters. Templin, Seidl, Wickström, and Feichtinger (2016) introduces an optimal policy into Wickström (2005). The goal of the policy maker is to maximize the number of (bilingual) speakers of the minority language. This goal is approached through a language policy that determines the rate of change in the status parameter.



(a) *Different relative status of the languages* (b) *Language policy*

Figure 5.3 Phase diagrams for Minett and Wang (2008) with language policy

[15] The visibility in the public space is also discussed in Grin (1992), see section 2.1 below.

6 NEW PERSPECTIVES – MICRO MODELS OF LANGUAGE USE

In contrast to the macro models discussed so far, where each individual is influenced by the behavior of all other individuals, in the micro-models, individuals are only influenced by a limited number of other individuals in a social network. In the macro models, for instance, the fraction of individuals using a certain language is important for all individuals in society and influence the behavior of each individual and the average behavior matters. In the micro models each individual encounters a limited number of other individuals in a network and his or her language use is influenced only by the language behavior of the individuals in the network. By each new encounter, there is a certain probability that the individual changes his or her behavior, imitating the interlocutor. Our functions $\alpha_L(F;S,p)$ have to be reinterpreted as individual transition probabilities with p the language use in the network. The macro-models can be seen as a limiting case when the network consists of the entire society,

Since the networks in the models, as a rule, are spatial, local language use and the change in local language use is modeled. Computer simulations can then show the (stochastic) development of language use in space and time. This approach is also very useful in modeling the development of language varieties. Innovations in vocabulary, phonetics, grammar, etc. spread through contact and imitation and different local varieties can develop. In the latter case, the transitions are marginal, changing some small element of the language thereby causing a continuous change in a variety of the language, whereas in the former case the transitions are discrete with a person changing from one distinct language to another.

6.1 Language choice

Oliveira, Gomes, and Tsang (2006) use this approach to model the number and distribution of languages on the entire earth. Mutations are due to colonization and the interaction between colonizers and colonized as well as to diffusion. The important parameters are the density of languages in a geographic area and the number of languages of a certain size. It is shown that linguistic diversity is a plausible outcome of the model.

In Castelló, Loureiro-Porto, Eguíluz, and San Miguel (2007), the assumptions of the model of Minett and Wang (2008) with equal status of the two languages form the basis. Each person has a local network of four persons and the transition probabilities are the α of Minett and Wang (2008). Simulations show that in general a number of "language islands" using one language develop in a sea of users of the other language. Bilingualism and bilinguality will only be a temporary phenomenon occurring on the "shores" of the islands. With time, the islands will disappear and monolingualism will prevail. Caridi, Nemiña, Pinasco, and Schiaffino (2013) extend the structure by combining the language-shift structure with a Shelling migration model.[16] Agents may change place of residence or language when surrounded by many agents speaking the other language. The model can have different stable situations: extinction of one language, ghetto formation, segregated coexistence, and diluted coexistence.

Stauffer, Castelló, Eguíluz, and San Miguel (2007) as well as Vazquez, Castelló, and San Miguel (2010) compare the simple monolingual macro model of Abrams and Strogatz (2003) as well as a bilingual version with network simulations, especially for the case with equal status of the two languages. They find that both coexistence and dominance are possible

[16] See Schelling (1969) and Schelling (1971).

depending on the type of network. Steady states and stability are also analyzed.

6.2 MICRO MODELS OF INTERNAL LANGUAGE CHANGE

Language evolution and change can be modeled in a way similar to the diffusion of innovations or vira.[17] The general structure is that a certain fraction of the population, p_I, has adopted a linguistic innovation, a sound change, say, and the rest of the population, a fraction $(1 - p_I)$, use the old manner of expressing themselves. By random encounters, the probability that two individuals of different types meet is $2p_I(1 - p_I)$. If the the first person continues using the innovation and the second person adopts it, mutates, with a certain probability, the rate of diffusion of the innovation can be described by the equation:

$$\dot{p}_I = kp_I(1 - p_I) \tag{6.1}$$

where k is a constant related to the mutation probability. For small values of p_I, p_I will be growing exponentially and for value close to one, $(1 - p_I)$ will decrease exponentially. The graph of p_I as a function of time will be the typical S-shaped curve describing diffusion of innovations.[18] Various modifications of the process modeled by equation 6.1 (moving us away from the virus interpretation) like a positive probability for the first person stopping using the innovation after an encounter, refines the model, but do not change the big picture. Since we are here dealing with a phenomenon that is on the margin of language competition we will not attempt anything near a complete overview of the literature, but will limit ourselves to discussing but a few pioneering models fitting this general picture and one model with distinct policy implications. For other work in this direction, the reader is referred the overview articles listed in section 7.

In a pioneering studies, SHEN (1997) studied phonetic changes in some Chinese dialects and managed to show that the diffusion of the sound changes fit this framework very well. WANG, KE, and MINETT (2004) extend the model, introducing two processes of imitation. On the one hand, there is the imitation of the usage of individuals and on the other hand, the diffusion is stronger the more systematic is the innovation. That is, if a sound shift occurs in many words of a similar type in some linguistic sense. They call the reinforcement a "snow-ball" effect. KE, GONG, and WANG (2008) discuss different network structures and introduce various asymmetries, such as different age groups with different imitation behavior and assume that linguistic innovations improve the functioning of the language as a system.

In WICKSTRÖM (2011) and WICKSTRÖM (2012) the focus is on the stability of linguistic structures in the face of linguistic innovations, for instance changes in the vocabulary or in grammatical structures with the origin outside the language. An innovation is first seen as a foreign element in the language system that needs some time to be nostrified, that is become a natural part of the language. Two processes operate at the same time: innovations are spread in the language and are adapted to the language system. The structure is the more unstable, the higher is the fraction of non-nostrified innovations at any time. The author speculates that the diffusion rate and the absorption rate depend both on the status of the language and on its typology. Based on that, some recommendations for language-policy measures are derived.

[17] A standard text on modeling social phenomena over networks and through imitation and diffusion is CAVALLI-SFORZA and FELDMAN (1981).

[18] See ROGERS (2003).

7 FURTHER READING

A number of contributions reviews different types of models of language competition and language evolution. Patriarca, Castelló, Uriarte, Eguíluz, and San Miguel (2012) discuss various modeling approaches to the competition between two languages. Wang and Minett (2005) give an overview of some early models of language competition, but also discuss models of language evolution. In Schulze, Stauffer, and Wichmann (2008) language competition and language evolution are combined in attempts to explain the total number of languages on earth and their geographical distribution. Depending on parameter constellation, results of the reviewed models range from Babel like situations (many different languages) to situations with one dominant language. Lately, a great number of papers discussing computer simulations of micro models of language evolution have emerged. These models are mostly linguistically relevant and do not model (the possibility of) language policy. A representative selection of reviews of such models are Baker (2008), Vogt (2009), Loreto, Baronchelli, Mukherjee, Puglisi, and Tria (2011), as well as Gong, Shuai, and Zhang (2014).

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