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Frequency patterns of semantic change: Corpus-based evidence of a near-critical dynamics in language change

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It is generally believed that, when a linguistic item acquires a new meaning, its overall frequency of use in the language rises with time with an S-shaped growth curve. Yet, this claim has only been supported by a limited number of case studies. In this paper, we provide the first corpus-based quantitative confirmation of the genericity of the S-curve in language change. Moreover, we uncover another generic pattern, a latency phase of variable duration preceding the S-growth, during which the frequency of use of the semantically expanding word remains low and more or less constant. We also propose a usage-based model of language change supported by cognitive considerations, which predicts that both phases, the latency and the fast S-growth, take place. The driving mechanism is a stochastic dynamics, a random walk in the space of frequency of use. The underlying deterministic dynamics highlights the role of a control parameter, the strength of the cognitive impetus governing the onset of change, which tunes the system at the vicinity of a saddle-node bifurcation. In the neighborhood of the critical point, the latency phase corresponds to the diffusion time over the critical region, and the S-growth to the fast convergence that follows. The duration of the two phases is computed as specific first passage times of the random walk process, leading to distributions that fit well the ones extracted from our dataset. We argue that our results are not specific to the studied corpus, but apply to semantic change in general.

Language can be approached through three different, complementary perspectives. Ultimately, it exists in the mind of language users, so that it is a cognitive entity, rooted in a neuro-psychological basis. But language exists only because people interact with each other: It emerges as a convention among a community of speakers, and answers to their communicative needs. Thirdly, language can be seen as something in itself: An autonomous, emergent entity, obeying its own inner logic. If it was not for this third *Dasein* of language, it would be less obvious to speak of language change as such.

The social and cognitive nature of language informs and constrains this inner consistency. Zipf's law, for instance, may be seen as resulting from a trade-off between the ease of producing the utterance, and the ease of processing it [1]. It relies thus both on the cognitive grounding of the language, and on its communicative nature. Those two external facets of language, cognitive and sociological, are similarly expected to channel the regularities of linguistic change. Modeling attempts (see [2] for an overview) have explored both how socio-linguistic factors can shape the process of this change [3, 4] and how this change arises through language learning by new generations of users [5, 6]. Some models also consider mutations of language itself, without providing further details on the social or cognitive mechanisms of change [7]. In this paper, we propose to view language change as initiated by language use, which is the repeated call to one's linguistic resources in order to express oneself or to make sense of linguistic productions of others.

This approach is in line with exemplar models [8] and related works, such as the Utterance Selection Model [9] or the model proposed by Victorri [10], which describes an out-of-equilibrium shaping of semantic structure through repeated events of communication.

Leaving aside socio-linguistic factors, we focus on a cognitive approach of linguistic change, more precisely of semantic expansion. Semantic expansion occurs when a new meaning is gained by a word or a construction (we will henceforth refer more vaguely to a linguistic 'form', so as to remain as general as possible). For instance, *way*, in the construction *way too*, has come to serve as an intensifier (e.g. 'The only other newspaper in the history of Neopia is the Uggia Ugg Times, which, of course, is way too prehistoric to read.' [11]). The fact that polysemy is pervasive in any language [12] suggests that semantic expansion is a common process of language change and happens constantly throughout the history of a language. Grammaticalization [13] – a process by which forms acquire a (more) grammatical status, like the example of *way too* above – and other interesting phenomena of language change [14, 15], fall within the scope of semantic expansion.

Semantic change is known to be associated with an increase of frequency of the form whose meaning expands. This increase is expected indeed: As the form comes to carry more meanings, it is used in a broader number of contexts, hence more often. This implies that any instance of semantic change should have its empirical counterpart in the frequency rise of the use of the form. This

rise is furthermore believed to follow an S-curve [16, 17], yet such claim, to our knowledge, has not been quantitatively grounded on more than a few chosen examples. Besides, it is not easily accounted through theoretical modeling: In a sociolinguistic framework for instance, it requires either a very specific social structure, or the assumption that the new use is favored intrinsically [18]. Such a framework also suffers from what is known as the Threshold Problem, the fact that a novelty will fail to take over an entire community of speakers, because of the isolated status of an exceptional deviation [19].

In this paper, we provide a broad corpus-based investigation of the frequency patterns associated with a few hundred semantic expansions. It turns out that the S-curve pattern is corroborated, but must be completed by a preceding latency part, in which the frequency of the form does not significantly increase, even if the new meaning is already present in the language. To explain this surprising behavior, which seems to have escaped notice so far, we propose a usage-based model of the process of semantic expansion, implementing basic cognitive hypotheses regarding language use. By means of our model, we relate the micro-process of language use at the individual scale, to the observed macro-phenomenon of a recurring frequency pattern occurring in semantic expansion.

I. QUANTIFICATION OF CHANGES IN A LARGE CORPUS

We worked on the French corpus *Frantext* [20], to our knowledge the only textual database allowing for a reliable study covering several centuries (see Material and Methods and Appendix A). We studied changes in frequency of use for 400 forms which have undergone one or several semantic expansions, on a time range going from 1321 up to nowadays. We choose forms so as to focus on semantic expansions leading to a functional meaning — such as discursive, prepositional, or procedural meanings. Semantic expansions whose outcome remains in the lexical realm (as the one undergone by *sentence*, whose meaning evolved from ‘verdict, judgment’ to ‘meaningful string of words’) have been left out. Functional meanings indeed present several advantages: They are often accompanied by a change of syntagmatic context, allowing to track the semantic expansion more accurately (e.g. *way* in *way too* + adj.); they are also less sensitive to socio-cultural and historical influences; finally they are less dependent on the specific content of a text, be it literary or academic.

The profiles of frequency of use extracted from the database are illustrated on Figure 1 for nine forms. We find that 286 cases display at least one sigmoidal increase of frequency in the course of their evolution, which makes up more than 70% of the total. We provide a small selection of the observed frequency patterns (Fig. 2a), whose associated logit transforms (Fig. 2b) follows a linear be-

havior, indicative of the sigmoidal nature of the growth (see Material and Methods). We thus find a robust statistical validation of the sigmoidal pattern, confirming the general claim made in the literature.

Furthermore, we find two major phenomena besides this sigmoidal pattern. The first one is that, in most cases, the final plateau towards which the frequency is expected to stabilize after its sigmoidal rise is not to be found: The frequency immediately starts to decrease after having reached a maximum (Fig. 1). However, such a decrease process is not symmetrical with the increase, in contrast with other cases of fashion-driven evolution in language, e.g. first names distribution [21]. Though this decrease may be, in a few handful of cases, imputable to the disappearance of a form (ex: *après ce*, replaced in Modern French by *après quoi*), in most cases it is more likely to be the sign of a narrowing of its uses.

The second feature is that the fast growth is very often preceded by a long latency up to several centuries, during which the new form is used, but with a comparatively low and rather stable frequency (Fig. 2a). One should note that the latency times may be underestimated: If the average frequency is very low during the latency part, the word may not show up at all in the corpus, especially in decades for which the available texts are sparse. The pattern of frequency increase is thus better conceived of as a latency followed by a growth, as exemplified by *de toute façon* (Fig. 3) — best translated by *anyway* in English, since the present meanings of these two terms are very close, and remarkably, despite quite different origins, the two have followed parallel paths of change.

To our knowledge, these two features, latency and absence of a stable plateau, have not been documented before, even though a number of specific cases of latency have been observed. For instance, it has been remarked in the case of *just because* that the fast increase is only one stage in the evolution [22]). In the following, we propose a model describing both the latency and the S-growth periods. We leave for future work the study of the decrease of frequency following the S-growth.

II. A COGNITIVE SCENARIO

To account for the specific frequency pattern evidenced by our data analysis, we propose a scenario focusing on cognitive aspects of language use, leaving all sociolinguistic effects back-grounded by making use of a representative agent, mean-field type, approach. We limit ourselves to the case of a competition between two linguistic variants, given that most cases of semantic expansion can be understood as such, even if the two competing variants cannot always be explicitly identified. Initially, in some concept or context of use C_1 , one of the two variants, henceforth noted Y , is systematically chosen, so that it conventionally expresses this concept. The question we address is thus how a new variant, say X , can be used in this context and eventually evict the old variant Y ?

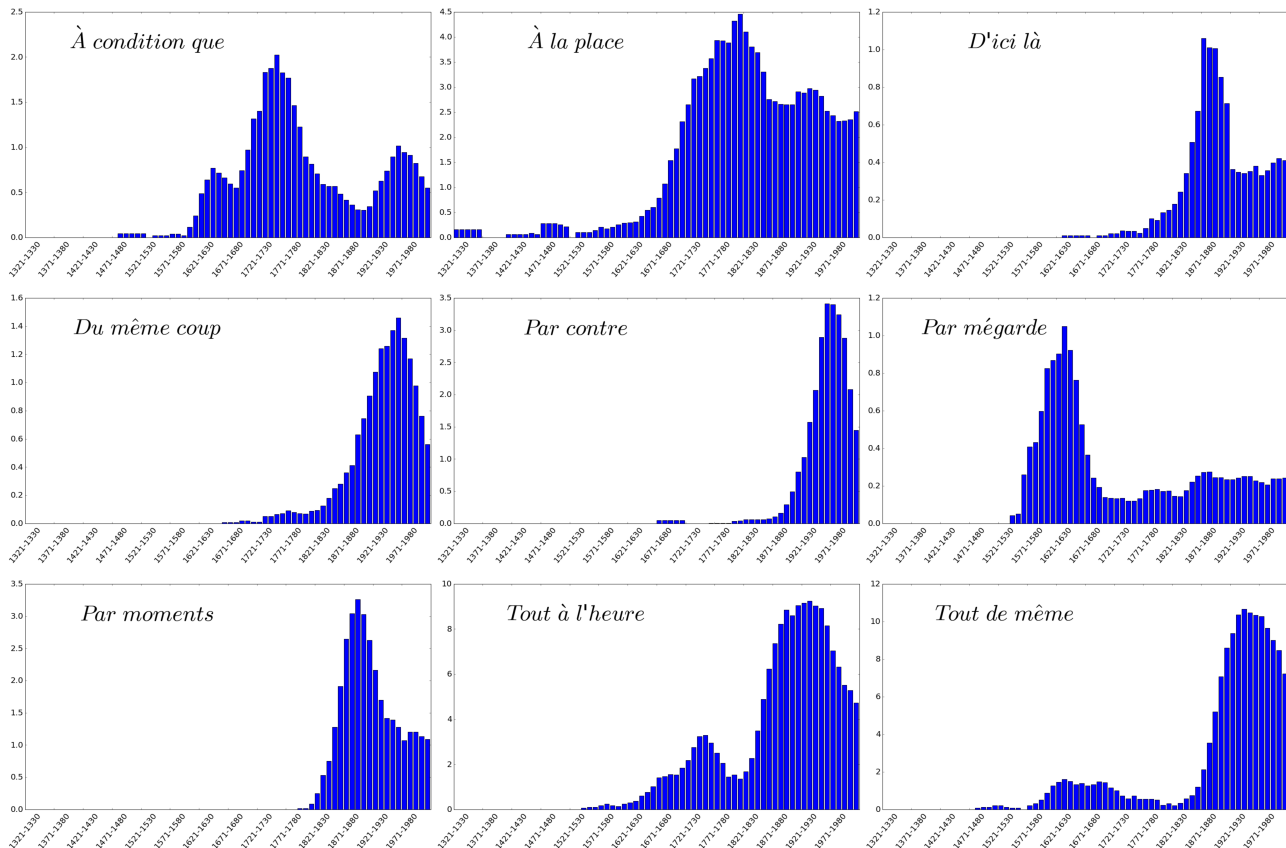


FIG. 1. Frequency evolution on the whole time range (1321-2020) of nine different forms. Each blue bar shows the frequency associated to a decade. Frequency has been multiplied by a 10^5 factor for an easier reading.

A. Hypotheses

The main hypothesis we propose is that the new variant almost never is a brand new merging of phonemes whose meaning would pop out of nowhere. As Haspelmath highlights [23], a new variant is almost always a periphrastic construction, i.e., actual parts of language, put together in a new, meaningful way. Furthermore, such a construction, though it may be exapted to a new use, may have showed up from time to time in the time course of the language history, in an entirely compositional way; this is the case for *par ailleurs*, which incidentally appears as early as the XIVth in our corpus, but arises as a construction in its own right during the first part of the XIXth century only. In other words, the use of a linguistic form X in a context C_1 may be entirely new, but the form X was most probably already there in another context of use C_0 , or equivalently, with another meaning.

We make use of the well-grounded idea [24] that there exists links between concepts due to the intrinsic polysemy of language: There are no isolated meanings, as each concept is interwoven with many others, in a complicated tapestry. These links between concepts are asymmetrical, and they can express both universal mappings

between concepts [25, 26] and cultural ones (e.g. entrenched metaphors [27]). As the conceptual texture of language is a complex network of living relations rather than a collection of isolated and self-sufficient monads, semantic change is expected to happen as the natural course of language evolution and to occur repetitively throughout its history, so that at any point of time, there are always several parts of language which are undergoing changes. The simplest layout accounting for this network structure in a competitive situation consists then in two sites, such that one is influencing the other through a cognitive connexion of some sort.

B. Model formalism

We now provide details on the modeling of a competition between two variants X and Y for a given context of use, or concept, C_1 , also considering the effect exerted by the related context or concept C_0 on this evolution.

- Each concept $C_i, i = 0, 1$, is represented by a set of exemplars of the different linguistic forms. We note $N_\mu^i(t)$ the number at time t of encoded exemplars (or occurrences) of form $\mu \in \{X, Y\}$, in context C_i , in the memory, of the representative agent.

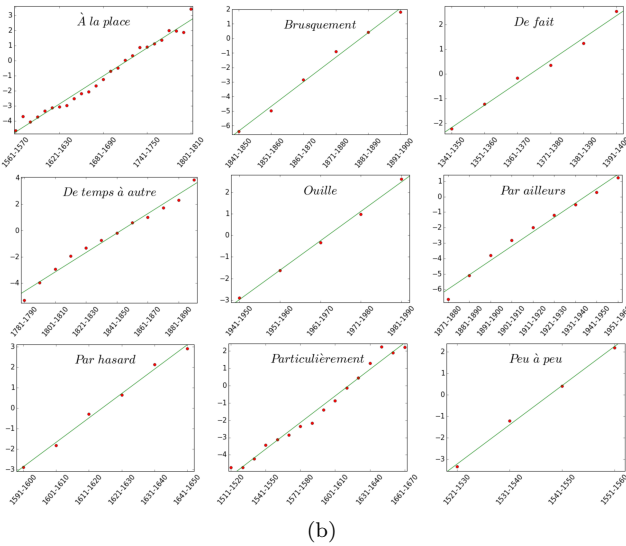
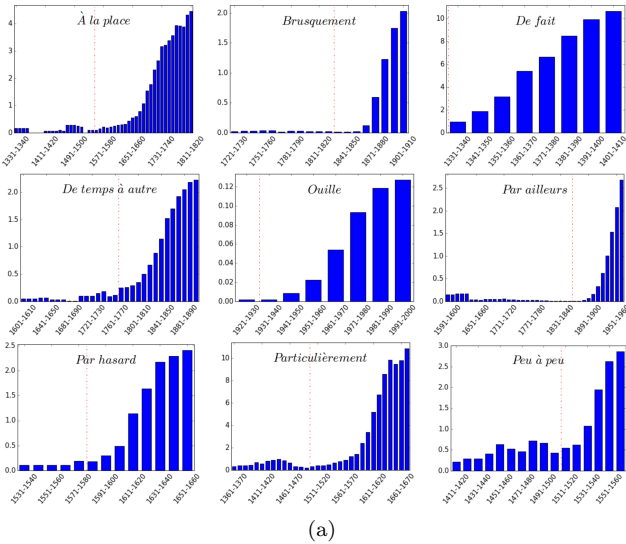


FIG. 2. (a) A selection of frequency evolutions showing the latency period and the S-growth, separated by a red vertical line. (b) Logit transforms of the S-growth part of the preceding curves. Red dots correspond to data points and the green line to the linear fit of this set of points.

- The memory capacity of an individual being finite, the population of exemplars attached to each concept C_i has a finite size M_i . For simplicity we assume that all memory sizes are equal ($M_0 = M_1 = M$). As we consider only two forms X and Y , for each i the relation $N_X^i(t) + N_Y^i(t) = M$ always hold: We can focus on one of the two forms, here X , and drop out the form subscript, granted that all quantities refer to X .

- The absolute frequency x_t^i of form X at time t in context C_i — the fraction of ‘balls’ of type X in the bag attached to C_i — is thus given by the ratio $N^i(t)/M$. In the initial situation, X and Y are assumed to be established convention for respectively expressing C_0 and C_1 , so that we start with $N^0(t=0) = M$ and $N^1(t=0) = 0$.

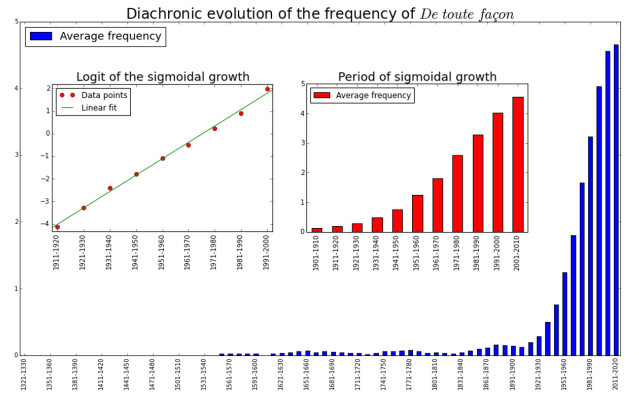


FIG. 3. Overall evolution of the frequency of use of *de toute façon* (main panel), with focus on the S-shape increase (right inner panel), whose logit transformation follows a linear fit (left inner panel). Preceding the S-growth, one observes a long period of very low frequency (up to 34 decades).

- Finally, C_0 exerts an influence on context C_1 , but this influence is assumed to be unilateral. Consequently, the content of C_0 will not change in the course of the evolution and we can focus on C_1 . An absence of explicit indication of context is thus to be understood as referring to C_1 .

C. Dynamics

The dynamics of the system runs as follow. At each time t , one of the two linguistic forms is chosen to express concept C_1 . The form X is uttered with some probability $P(t)$, to be specified below, and Y with probability $1 - P(t)$. In order to keep constant the memory size of the population of occurrences in C_1 , a past occurrence is randomly chosen (with a uniform distribution) and the new occurrence takes its place. This dynamics is then repeated a large number of times. Note that this model focuses on a speaker perspective (for alternative variants, see Appendix B).

We want to explicit the way $P(t)$ depends on $x(t)$, the absolute frequency of X in this context at time t . The simplest choice would be $P(t) = x(t)$. However, we want to take into account several facts, as explained below.

- As context C_0 exerts an influence on context C_1 , denoting by γ the strength of this influence, we assume the probability P to rather depend on an effective frequency $f(t)$ (Fig. 4a),

$$f(t) = \frac{N^1(t) + \gamma N^0(t)}{M + \gamma M} = \frac{x(t) + \gamma}{1 + \gamma}. \quad (1)$$

- We now specify the probability $P(f)$ to select X at time t as a function of $f = f(t)$. First, $P(f)$ must be nonlinear. Otherwise, the change occurs with certainty as soon as the effective frequency f of the novelty is non-zero, that is, insofar two meanings are related, the form expressing the former will also be recruited to express the

latter. This change would also start in too abrupt a way, while sudden, instantaneous takeovers are not known to happen in language change.

Second, one should preserve the symmetry between the two forms, that is, $P(f) = 1 - P(1 - f)$, as well as verify $P(0) = 0$ and $P(1) = 1$. Note that this symmetry is stated in terms of the effective frequency f instead of the actual frequency x , as production in one context always accounts for the contents of neighboring ones.

For the numerical simulations, we made the following specific choice which satisfies these constraints:

$$P(f) = \frac{1}{2} \left\{ 1 + \tanh \left(\beta \frac{f - (1 - f)}{\sqrt{f(1 - f)}} \right) \right\}, \quad (2)$$

where β is a parameter governing the non-linearity of the curve. Replacing f in terms of x , the probability to choose X is thus a function $P_\gamma(x)$ of the current absolute frequency x :

$$P_\gamma(x) = \frac{1}{2} \left\{ 1 + \tanh \left(\beta \frac{2x - 1 + \gamma}{\sqrt{(x + \gamma)(1 - x)}} \right) \right\} \quad (3)$$

D. Analysis: Bifurcation and latency time

The dynamics outlined above (Fig. 4b) is equivalent to a random walk on the segment $[0; 1]$ with a reflecting boundary at 0 and an absorbing one at 1, and with steps of size $1/M$. The probability of going forward at site x is equal to $(1 - x)P_\gamma(x)$, and the probability of going backward to $x(1 - P_\gamma(x))$.

For large M , a continuous, deterministic approximation of this random walk leads, after a rescaling of the time $Mt \rightarrow t$, to the first order differential equation for $x(t)$:

$$\dot{x} = P_\gamma(x) - x. \quad (4)$$

This dynamics admits either one or three fixed points (Fig. 5a), $x = 1$ always being one. Below a threshold value γ_c , which depends on the non-linearity parameter β , a saddle-node bifurcation occurs and two other fixed points appear. The system, starting from $x = 0$, is stuck at the smallest stable fixed point. The transmission time, i.e. the time required for the system to go from 0 to 1, is therefore infinite (Fig. 5b). Above the threshold value γ_c , only the fixed point $x = 1$ remains, so that the new variant eventually takes over the context for which it is competing. Our model thus describes how the strengthening of a cognitive link can trigger a semantic expansion process.

Slightly above the transition, a stranglehold region appears where the speed almost vanishes. Accordingly, the time spent in this region diverges. The frequency of the new variant will stick to low values for a long time, in a way similar to the latent behavior evidenced by our dataset. This latency time in the process of change can

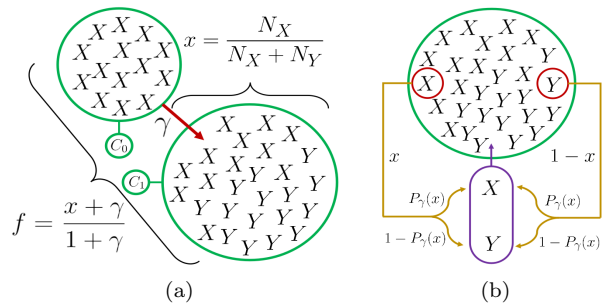


FIG. 4. (a) Difference between absolute frequency x and relative frequency f in context C_1 . Absolute frequency x is given by the ratio of X occurrences encoded in C_1 . Effective frequency f also takes into account the M occurrences contained in the influential context C_0 , with a weight γ standing for the strength of this influence. (b) Schematic view of the process. At each iteration, either X or Y is chosen to be produced and thus encoded in memory, with respective probability $P_\gamma(x)$ and $1 - P_\gamma(x)$; the produced occurrence is here represented in the purple capsule. Another occurrence, already encoded in the memory, is uniformly chosen to be erased (red circle) so as to keep the population size constant. Hence the number of X occurrences, N_X , either increases by 1 if X is produced and Y erased, decreases by 1 if Y is produced and X erased, or remains constant if the erased occurrence is the same as the one produced.

thus be understood as a near-critical slowing down of the underlying dynamics.

Past this deterministic approximation, there is no more clear-cut transition (Fig. 5b) and the above explanation needs to be refined. The deterministic speed can be understood as a drift velocity of the Brownian motion on the $[0; 1]$ segment, so that in the region where the speed vanishes, the system does not move in average. In this region of vanishing drift, the frequency fluctuates over a small set of values and does not evolve significantly over time. Once it escapes this region, the drift velocity drives the process again, and the replacement process takes off. Latency time can thus be understood as a first-passage time out of a trapping region.

III. NUMERICAL RESULTS

A. Model simulations

We ran numerical simulations of the process described above (Fig. 4b), with the following choice of parameters: $\beta = 0.808$, $\delta = 0.0$ and $M = 5000$, where $\delta = (\gamma - \gamma_c)/\gamma_c$ is the distance to the threshold. The specific value of β corresponds to a maximization of x_c , the frequency value at which the system gets stuck. It reflects the assumption that the linguistic system should allow for synonymic variation in the situation where no replacement takes place. We chose $\delta = 0.0$ in order for the system to be purely diffusive in the vicinity of x_c . The choice of M

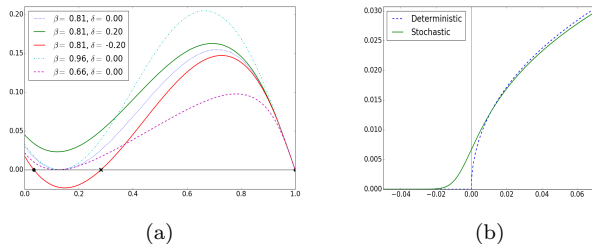


FIG. 5. (a) Speed \dot{x} of the deterministic process for each of the sites, for different values of β and $\delta = (\gamma - \gamma_c)/\gamma_c$, the distance to threshold. Depending on the sign of δ , there is either one or three fixed points. (b) Inverse transmission time (time required for the system to go from 0 to 1), for the deterministic process (blue dotted line), and for the averaged stochastic process (green line), as a function of the control parameter δ . Deterministic transmission time diverges at the transition while averaged stochastic transmission time remains finite.

is arbitrary.

From the model simulations, data is extracted and analyzed in two parallel ways. On one side, simulations provide surrogate data: We can mimic the corpus data analysis and count how many tokens of the new variant are produced in a given timespan (set equal to M), to be compared with the total number of tokens produced in this timespan. We then extract ‘empirical’ latency and growing times (Fig. 6a), applying the same procedure as for the corpus data.

On the other side, for each run we track down the position of the walker, which is the frequency $x(t)$ achieved by the new variant at time t . This allows to compute first passage times. We then alternatively compute analytical latency and growth times (‘analytical’ to distinguish them from the former ‘empirical’ times) as follows. Latency time is here defined as the difference between the first-passage times at the exit and the entrance of a ‘trap’ region (see Appendix C for additional details). Analytical growth time is defined as the remaining time of the process once this exit has been reached. Their distribution over 10,000 runs of the process are fitted with Inverse Gaussian distribution, which would be the expected distributions if the jump probabilities were homogeneous over the corresponding regions (an approximation then better suited for latency time than for growth time). Figure 6d shows the remarkable agreement between the ‘empirical’ and ‘analytical’ approaches, together with the quality of the fits with the Inverse Gaussian distribution.

Crucially, those two macroscopic phenomena, latency and growth, are thus to be understood as of the same nature, which explains why their statistical distribution must be of the same kind. Furthermore, the boundaries of the trap region leading to the best correspondence between first passage times and empirically determined latency and growth times are meaningful, as they correspond to the region where the uncertainty on the transmission time significantly decreases (Fig. 6b).

B. Confrontation with corpus data

Our model predicts that both latency and growth times should be governed by the same kind of statistics, Inverse Gaussian being a suited approximation of those. Inverse Gaussian distribution is governed by two parameters, its mean μ and a parameter λ given by the ratio μ^3/σ^2 , σ^2 being the variance. We fit the empirical histograms with an Inverse Gaussian distribution whose parameters are given by the empirical mean and variance of the relevant quantities. We find a good agreement for both the latency and the growth times (Fig. 7).

Although there are short growth times in the frequency patterns of the forms we studied, below six decades they are not described by enough data points to assess reliably the specificity of the sigmoid fit. On the histogram there is therefore no data for these growth times. This issue is further discussed in Appendix D. However, the distribution must decrease when growth time approaches 0 (notably an exponential fit is to be ruled out); otherwise, instantaneous changes would be far too numerous, so that language would be completely unstable. The decrease predicted by the Inverse Gaussian is realistic in this aspect.

The main quantitative features extracted from the dataset are thus correctly mirrored by the behavior of our model. We confronted the model with the data on other quantities, such as the correlation between growth time and latency time. There again, the model proves to match appropriately quantitative aspects of semantic expansion processes Appendix E.

IV. DISCUSSION

Based on a corpus-based analysis of frequency of use, we have uncovered two robust stylized facts of semantic change: an S-curve of frequency growth, preceded by a latency period where the semantic change has already taken place while the frequency remains low. We have proposed a model predicting that these two features, albeit qualitatively quite different, are two aspects of one and the same phenomenon.

The hypotheses on which this model lies are well-grounded on claims from Cognitive Linguistics: Language is resilient to change (non-linearity of the P function); language users have cognitive limitations; the semantic territory is organized as a network whose neighboring sites are asymmetrically influencing each other. The overall agreement with empirical data tends to suggest that language change may indeed be cognitively driven by semantic bridges of different kinds between the concepts of the mind, and constrained by the mnemonic limitations of this very same mind. We note that our model may however be given a different, purely socio-linguistic, interpretation: this, together with the limits of such a view point, is discussed in Appendix B 5.

According to our model, the onset of change depends

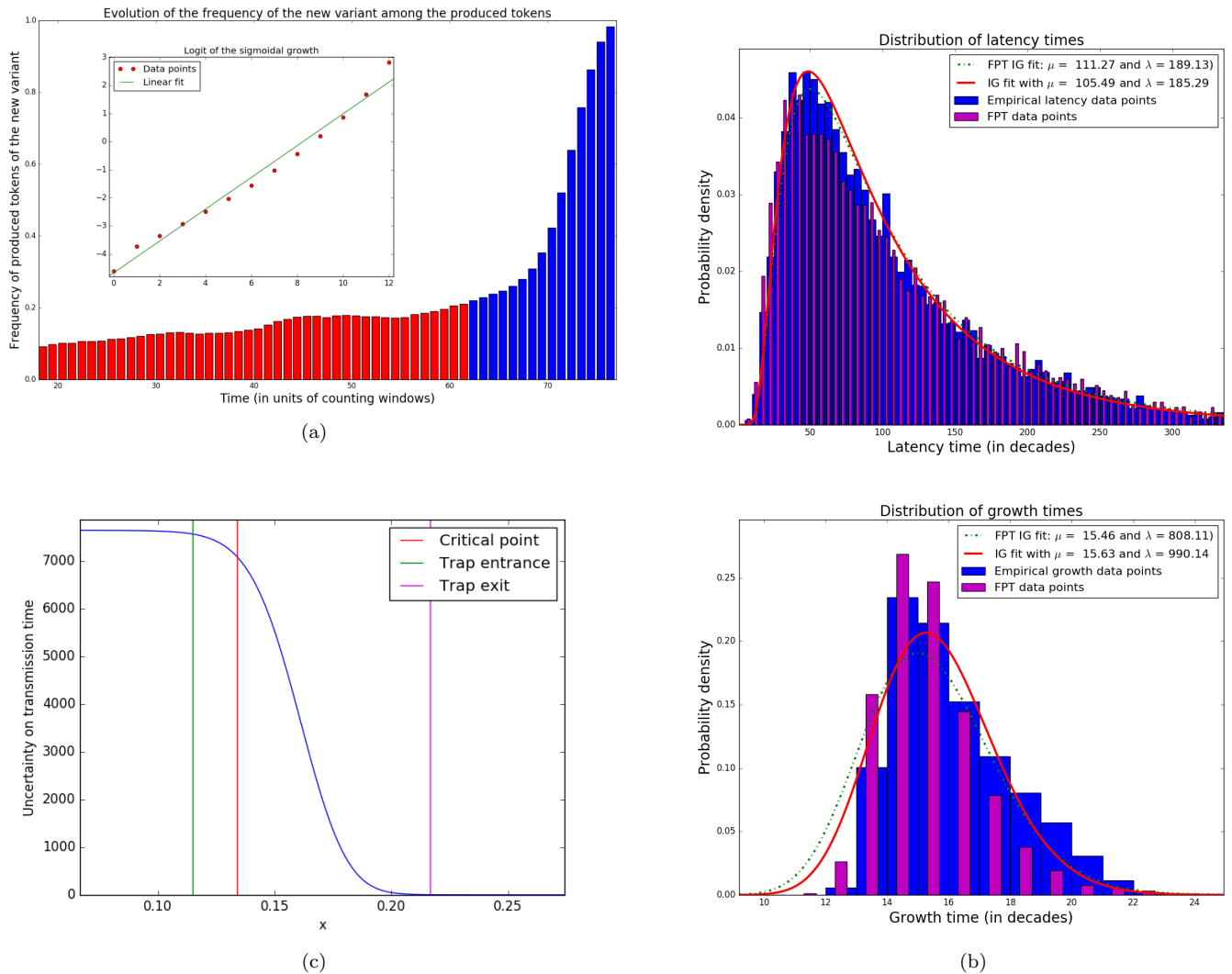


FIG. 6. (a) Time evolution of the frequency of produced occurrences (output of a single run). Growth part and latency part are shown respectively in blue and red. The logit transform (with linear fit) of the growth is shown in the inset. (b) Distribution of latency time (top) and growth time (bottom) over $10k$ processes, extracted from an empirical approach (blue wide histogram) and a first-passage time one (magenta thin histogram), with their respective Inverse Gaussian fits (in red: Empirical approach; in green: First-passage time approach). (c) Uncertainty on the transmission time given the position of the walker. The entrance and the exit of the trap are shown, respectively, by green and magenta line. The trap corresponds to the region where the uncertainty drops from a high value to a low value.

on the strength of the conceptual link between the source context and the target context: If the link is strong enough, that is, above a given threshold, it serves as a channel so that a form can ‘invade’ the target context and then oust the previously established form. In a sense, the sole existence of this cognitive mapping is already a semantic expansion of some sort, yet not necessarily translated into linguistic use. Latency is specifically understood as resulting from a near-critical behavior: If the link is barely strong enough for the change to take off, then the channel becomes extremely tight and the invasion process slows down drastically. These narrow channels are likely to be found between lexical and grammatical meanings [28, 29]. This would explain why

the latency-growth pattern is much more prominent in the processes of grammaticalization, posing latency as a phenomenological hint of this latter category.

Finally, we argue that our results, though grounded on instances of semantic expansion in French, apply to semantic expansion in general. The time period covered is long enough (700 years) to exclude the possibility that our results be ascribable to a specific historical, sociological, or cultural context. The French language itself has evolved, so that Middle French and contemporary French could be considered as two different languages, yet our analysis apply to both indistinctly. Besides, the latency-growth pattern is to be found in other languages; for instance, Google Ngram queries for constructions such

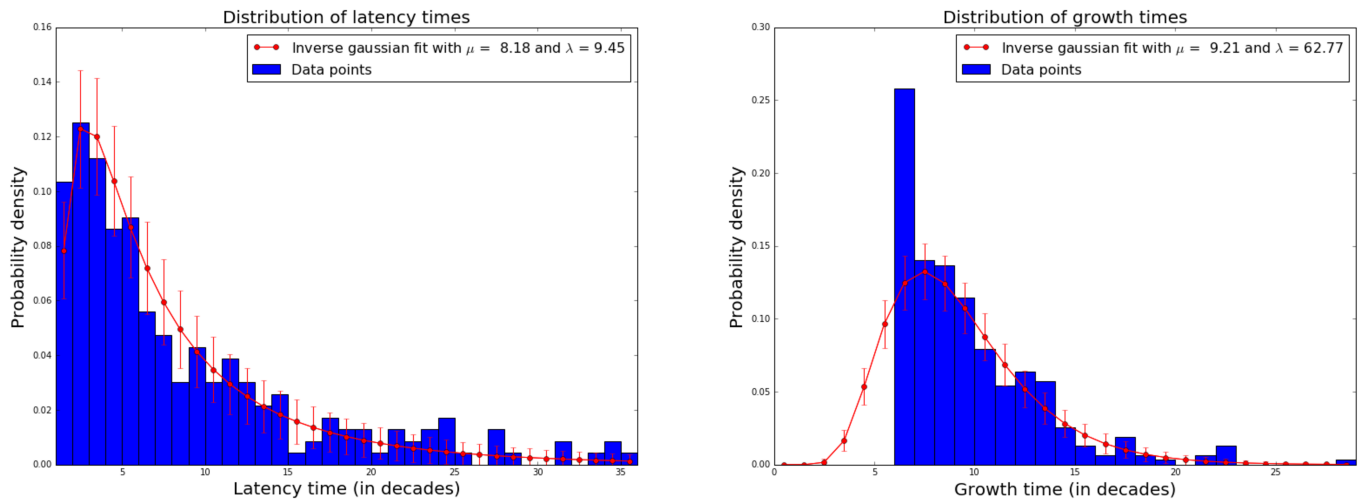


FIG. 7. Inversian Gaussian fit of the latency times (left) and the growth times (right) extracted from corpus data. Parameters are computed from the mean and the variance of the data. Data points are shown by a blue histogram, the Inverse Gaussian fit being represented as red dots. The discrepancy observed for six decades is discussed in Appendix D.

as *way too, save for, no matter what*, yield qualitative frequency profiles consistent with our claims. Our model also tends to confirm the genericity of this pattern, as it relies on cognitive mechanisms whose universality has been well evidenced [30].

V. MATERIALS AND METHODS

We worked on the *Frantext* corpus [20], which in 2016 contained for the chosen time range 4674 texts and 232 millions of words. More details are given in Appendix A. It would have been tempting to make use of the large database Google Ngram, yet it was not deemed appropriate for our study, as we explain in Appendix F.

We studied changes in frequency of use for nearly 400 instances of semantic expansion processes in French, on a time range going from 1321 up to nowadays. See Appendix G for a complete list of the studied forms.

A. Extracting patterns from corpus data

a. Measuring frequencies. We divided our corpus into 70 decades. Then, for each form, we recorded the number of occurrences per decade, dividing this number by the total number of occurrences in the database for that decade. The output number is called here the *frequency* of the occurrence for the decade, and is noted x_i for decade i . In order to smooth the obtained data, we replaced x_i by a moving average, that is, for $i \geq i_0 + 4$, i_0 being the first decade of our corpus: $x_i \leftarrow \frac{1}{5} \sum_{k=i-4}^i x_k$.

b. Sigmoids. We looked for major increases of frequency. When such a major shift is encountered, we automatically (see below) identify frequencies x_{min} and x_{max} , respectively at the beginning and the end of the

increasing period. If we respectively note i_{start} and i_{end} the decades for which x_{min} and x_{max} are reached, then we define the duration w of the increasing period as $w = i_{end} - i_{start} + 1$. To quantify the sigmoidal nature of this growth pattern, we apply the logit transformation to the frequency between x_{min} and x_{max} :

$$y_i = \log \left(\frac{x_i - x_{min}}{x_{max} - x_i} \right). \quad (5)$$

If the process follows a sigmoid \tilde{x}_i of equation:

$$\tilde{x}_i = x_{min} + \frac{x_{max}}{1 + e^{-hi-b}}, \quad (6)$$

then the logit transform of this sigmoid satisfies: $\tilde{y}_i = hi + b$. We thus fit the y_i 's given by (5) with a linear function, which gives the slope h associated with it, the residual r^2 quantifying the quality of the fit. The boundaries i_{start} and i_{end} have been chosen so as to maximize w , with the constraint that the r^2 of the linear fit should be at least equal to a value depending on the number of the data points.

c. Latency period. In most cases (74% of sigmoidal growths), one observes that the fast increasing part is preceded by a phase during which the frequency remains constant or nearly constant. The duration of this part, denoted by T_1 in this paper, is identified automatically as follows. Starting from the decade i_{start} , previous decades j are included in the latency period as long as they verify $|x_j - x_{min}| < 0.15 * (x_{max} - x_{min})$ and $x_j > 0$, and cease to be included either as soon as the first condition is not verified, or if the second condition does not hold for a period longer than 5 decades. Then the start i_{lat} of the latency point is defined as the lowest j verifying both conditions, so that T_1 is given by $T_1 = i_{start} - i_{lat}$.

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Appendix A: Textual data base Frantext

The data we collected for the present study comes from the *Frantext* database [20], one of the most extensive databases available in French, to which one has access under subscription by the ATILF-CNRS laboratory. Frantext is an ever-expanding gathering of 4,746 texts to this day (8th december 2016), updated every year. This corpus presents various literary genres (epistolary, drama, poetry, essays, scientific books), but mainly novels, almost exclusively from French literature (with a few translated works). The publication year of the texts range from 950 to 2013. The allotment of the texts between the different time periods is however far from being homogeneous, and most of them belong to the twentieth century: Indeed, the number of texts by decade roughly follows an exponential increase (Fig. 8).

Frantext, while being much smaller than Google Ngram, provides much cleaner and more controlled results (see E). We decided to start from the decade 1321-1330, as from this date all decades are associated with at least seven texts. In our corpus, we retained most of the texts, with a few exceptions, e.g. when the date provided by Frantext was unsatisfying (for instance, the text referred to as 6205, *Le Canarien, pièces justificatives* is dated ‘between 1327 and 1470’), or when we knew that the text has been written over too long a time period, as is the case for the text *Chartes et documents de l’abbaye de Saint-Magloire* (ref 8203), whose publication year (1330) is far from covering the time span during which the document was compiled. Most interestingly, Frantext also provides the surrounding text on which a token is to be found, so that it is possible to check if the different occurrences make sense and truly correspond to the request.

Frantext is not flawless. Some parts of the scanned texts have been appended through posterior editing. This is clearly the case for the text A017, *Chroniques de Morée*, where some page notes from a contemporaneous edition of this medieval chronicle have been included, so that the request for ‘dans’ may return an occurrence such as ‘Erreur dans la numérotation de l’édition’ (‘error in the edition numbering’). Some decades are also strongly unbalanced in the available texts. For instance, among the 2.7 million words of decade 1551-1560, more than one third of them comes from the works of a single author, Jean Calvin (references E198, B022, R849 to R852). Another bias comes from the fact that drama pieces, up to the end of the Modern Era, were making use of represented orality [31] much more than literary texts, so that many new constructions appear in them before spreading among the other texts. This would not be a problem if the proportion of dramas were more or less constant across the decades, which is not the case. This problem vanishes in more recent times, when represented orality appears also frequently in novels, while drama becomes itself more sophisticated and shifts further away from daily language.

Frantext is not only a database. It comes also with built-in text-mining algorithms which allow to submit very refined queries to the database. Such queries can make use of booleans and a given number of blank words. For instance, the query (à|a) &q(1,2) (insçu|insu|insceu) (&q(1,2) is a blank slot for any one or two words) will retrieve occurrences such as *à l’insu*, *à leur insu*, but also *à son propre insu*. This kind of flexible requests are especially relevant when one is looking for specific constructions with a filling slot, as the corresponding possibilities cannot be exhaustively predicted. We studied for instance the construction *d’une voix* + ADJ. If we cannot list all adjectives, we can rule out all the parasite occurrences with an elaborated request such as \sim (tous|reces) d’une voix \sim (que|qui|qu’|et|ensemble|trestous|de|d’|vous|le|la|les|par|pour|dont|-|.|;|,|:), where \sim and | respectively stands for the booleans ‘not’ and ‘or’. Such a request makes it possible to capture unexpected adjectival constructs such as *toute changée*, *si peu effroyée* or *extraordinairement rauque et rouillée*, while discarding all spurious occurrences. Frantext also allows for special requests, for instance if one wishes to encompass several orthographic variations in a single query, for instance **souventes?f*** captures all possible variants of *souventesfois*, such as *souventeffoiz*, *souvente fois*, *souventez fois*, *souventefoys*, etc. This kind of elaborations prove to be all the more useful in the first stages of the evolution, where a functional construction has not yet become entrenched into an idiomatic form and can still be found in a high diversity of variants.

Once a request is submitted to the database, Frantext returns a datafile whose contents may vary according to the needs of the user. Depending on the options one chooses, the file displays, for each text, the text reference, the publication year, and the total number of occurrences of the query in that text. Next to this automatized procedure, we can also look across all individual occurrences in their context, as a sanity check. This was used frequently to help refining our queries. Unfortunately, it was impossible to ask Frantext for a file providing the statistics of the corpus itself, listing the number of occurrences per text reference. We extracted this information from an HTML page which does display this information (Corpus de travail > Visualiser). The data file provided by Frantext was then directly treated by our own algorithm to compute average frequencies for each decade.

A note on French

We acknowledge that we restricted ourselves to instances of semantic expansions in French, a choice which may appear to restrict the scope of our findings. As we argue in the main text, we believe this is not the case. In the following, we stress, 1 - the necessity to conduct the analysis on a long timescale (i.e. long enough so that we can consider the language to have changed dur-

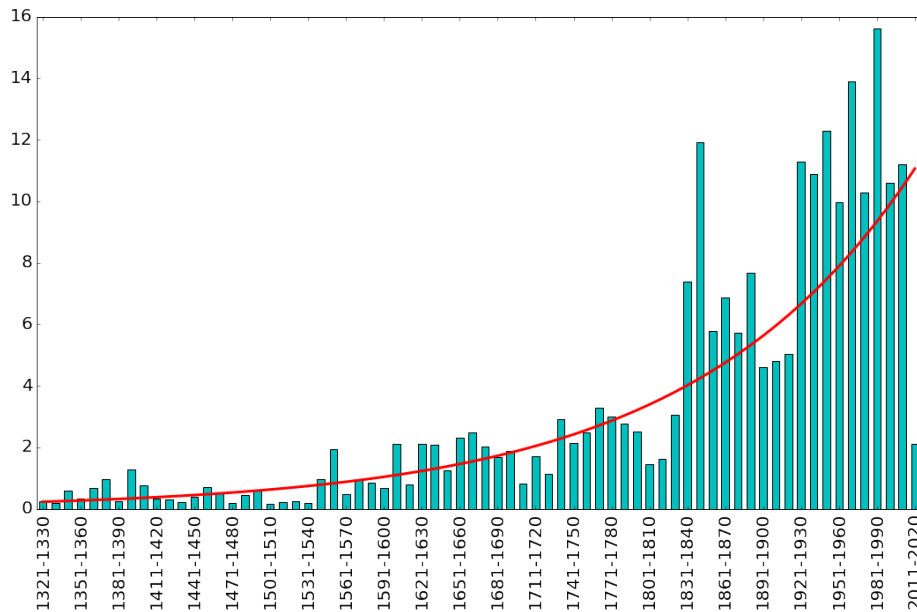


FIG. 8. Number of millions of occurrences per decade in the Frantext database. Exponential fit is shown by a red line.

ing that period, just as contemporary French has drifted sufficiently away from Middle French (XIVth century) so that, without specific training, the latter is only partially intelligible to speakers of the former), 2 - that few corpora are as efficient as Frantext to achieve such a goal.

Given the issues addressed in this paper, it appears important to consider instances taken from a large time period (seven centuries in our case). Indeed, a frequently asked question is whether or not recent technological advances (radio, TV, the Internet) have had an influence on the way language changes. Sociologically, this influence is obvious: Languages tend to homogenize over greater geographical areas and dialects have constantly declined throughout the twentieth century. Yet, the pattern of change of an established language is something entirely different. Our statistical survey shows that the pattern of change is the same, no matter in which century it may happen. It is furthermore consistent with recent findings establishing that the rate of change did not increase in the most recent decades [32]. It also goes along our claim that the pattern we exhibit is cognitively driven by memory retrieval and conceptual organization, two cognitive mechanisms that the most recent technological evolutions could not have significantly altered.

Alas, finding appropriate corpora covering a long time period in a given language is not obvious. As discussed in this SI, section S5, Google Ngram cannot be used for texts earlier than the nineteenth centuries, since the scanning procedure does not lead to reliable digital data. For the English language, the reputed British National Corpus restricts itself to the twentieth century. The Helsinki Corpus spans a time period suited for our purposes, but the texts are too sparse (450 in total) for the corpus to be fitted for a statistical survey. The CORDE

corpus, in Spanish, spans several centuries (XIIIth to XXth), and gathers an impressive amount of data as well (250 M words), but it covers different variants of Spanish (Argentinian, Colombian, Castilian, etc.) which cannot be blended together when it comes to investigate semantic expansions (note that CORDE dutifully offers to treat them apart, but then the database is not extensive enough for each of the variant separately). The querying system also suffers from serious limitations, and it is not possible to submit complex queries as is the case with Frantext. This latter database is therefore truly remarkable in many aspects and has to be considered an exception. We thus leave to further studies the case of other languages.

A last remark is in order: We deliberately do not provide any translation of the studied forms (SI, Table S1), however obscure they may appear to the reader. Indeed, these forms have all undergone a semantic expansion, so that a translation would be most mistaking as it would concern only one among several meanings adopted by the form. The only satisfying way of glossing the items we studied would have been to find forms which not only have the same meaning, but have also undergone (at least roughly) the same meaning shifts, as in the case of *anyway* and *de toute façon* for the later stages of their respective semantic evolutions. Obviously, this would have been possible only for a handful of cases, and we chose to leave the items without translation.

Appendix B: Model variants

The model we propose in the main body of the paper describes a mechanism associated with language produc-

tion: It is solely based on a speaker perspective. Yet, language change may not come only from innovation in producing language, but also in understanding it. Actually, these two aspects cannot be separated: If an innovation is possible in a speaker perspective, it must also be accessible from a hearer perspective. Be it a speaker or a hearer, a language user relies on the same cognitive entity. It seems thus necessary to consider model variants where the novelty can come from this complementary perspective, as well as from a combination of the two.

1. Hearer variant

Let us consider the same situation as for the listener model: There are two meanings, C_0 and C_1 , to which are attached a pool of memories of linguistic tokens. Initially, C_0 is populated by X tokens only, while C_1 is populated by Y tokens only. Just as context C_1 is fed by the memory of C_0 when it came to express C_1 , if a linguistic occurrence yields meaning C_0 , it can elicit meaning C_1 as well. Occurrences of X thus have a chance to populate context C_1 , so that we will note x the proportion of X tokens in C_1 , just as we did in the speaker-based model. If we ascribe to the inference $C_0 \Rightarrow C_1$ a probability equal to γ , then we can describe the dynamics as follows:

1. Either C_0 or C_1 are chosen to be expressed, with equal probabilities.
2. If C_0 has been chosen, X is produced. If C_1 has been chosen, X is produced with probability $P_0(x)$, otherwise Y is produced. $P_0(x)$ is the same function as $P_\gamma(x)$, except that γ is now set to 0 (there is no such thing as an effective frequency in this framework).
3. The produced occurrence is recorded in the chosen context. If C_0 has been chosen, an additional occurrence of the same kind as the previous one is recorded in C_1 with probability γ (C_0 has elicited the meaning C_1).
4. A past occurrence is deleted whenever needed, so as to keep both memory sizes constant.

These dynamics correspond once more to a random walk where the jump probabilities, forward and backward, respectively $R^H(x)$ and $L^H(x)$ (where H stand for 'hearer'), are given by:

$$\begin{cases} R^H(x) &= \frac{1}{2} [\gamma + P_0(x)] (1 - x) \\ L^H(x) &= \frac{1}{2} (1 - P_0(x)) x \end{cases}, \quad (\text{B1})$$

to be compared with the jump probabilities in the speaker perspective (respectively $L^S(x)$ and $R^S(x)$ for

the forward and backward jump probabilities):

$$\begin{cases} R^S(x) &= P_\gamma(x)(1 - x) \\ L^S(x) &= (1 - P_\gamma(x))x \end{cases}. \quad (\text{B2})$$

These modified jump probabilities lead to a new expression for the drift velocity:

$$\dot{x} = \frac{1}{2} [P_0(x) - x + \gamma(1 - x)]. \quad (\text{B3})$$

A change of variable $y = (1 + \gamma)x - \gamma$ leads to the same equation as equation 5 of the main paper, with a slightly different timescale accounting for the fact that two contexts are now being called:

$$\frac{2}{1 + \gamma} \dot{y} = \left[P_0 \left(\frac{y + \gamma}{1 + \gamma} \right) - y \right]. \quad (\text{B4})$$

Indeed, $P_0 \left(\frac{y + \gamma}{1 + \gamma} \right)$ is exactly $P_\gamma(y)$, so that the fixed point in the hearer perspective x_c^H will be given, as a function of the fixed point x_c^S of the speaker perspective, as:

$$x_c^H = \frac{x_c^S + \gamma}{1 + \gamma}, \quad (\text{B5})$$

which is higher than x_c^S . This means that, in the hearer perspective, the latency frequency will also be higher. However, it does not entail that the change will be more or less likely to happen, since what triggers the change is the fact that γ is equal to γ_c or higher, and this parameter γ_c remains the same throughout the perspective shift.

2. Combined model

We can now combine the Listener and Hearer perspectives, by taking into account the effective frequency f instead of the actual frequency x in step 2 of the dynamics outlined in the previous subsection. Then, in the above formulae, all $P_0(x)$ become $P_\gamma(x)$ (or equivalently, $P_0(f)$). The velocity is now set to:

$$\dot{x} = \frac{1}{2} [P_\gamma(x) - x + \gamma(1 - x)]. \quad (\text{B6})$$

Setting $X = (x + \gamma)/(1 + \gamma)$, we get:

$$2(1 + \gamma)\dot{x} = P_0(X) - X + (1 - X)\gamma(2 + \gamma). \quad (\text{B7})$$

We can now define a renormalized parameter $\tilde{\gamma} = \gamma(2 + \gamma)$ to make this velocity similar to the one given by (B3). Setting $Y = (1 + \tilde{\gamma})X - \tilde{\gamma}$, we finally get:

$$2 \frac{1 + \tilde{\gamma}}{1 + \tilde{\gamma}} \dot{Y} = P_{\tilde{\gamma}}(Y) - Y. \quad (\text{B8})$$

This implies that $(Y_C, \tilde{\gamma}_c) = (x_c^S, \gamma_c^S)$, so that the critical point (x_c^T, γ_c^T) in this combined perspective is equal to:

$$(x_c^T, \gamma_c^T) = \left(\frac{x_c^S + \gamma_c^S}{1 + \gamma_c^S}, \sqrt{1 + \gamma_c^S} - 1 \right). \quad (\text{B9})$$

In this case γ_c^T is lower than its hearer and speaker perspectives counterparts. It entails that the change would happen more easily. x_c^T is somewhere in between x_c^S and x_c^H .

3. Summary

All three variants of the model give rise to the same picture of sigmoidal growth preceded by a period of latency. The data does not allow to discriminate between either one of these three possibilities. Yet, the hypothesis that the change is driven by both hearer and speaker mechanisms is the most probable, as all language users adopt the role of hearer and speaker alternatively. An enthralling perspective of research would be to devise a quantitative criterion so as to see which of the three mechanisms best account for real language data. One could also investigate which features of language change speaker and hearer perspectives are respectively able to account for independently, and if some features need the conjunction of both to appear. Obviously, all those questions hinge upon available data and the finding of relevant observable quantities to look at.

4. Interpretations of the cognitive strength γ

In the proposed model, we make the assumption that all memory sizes are equal in the speaker perspective, and that all meanings C_i are expressed with equal probability in the hearer perspective. Here we consider the alternative that the links in the network are not weighted: They are either 1 or 0. The asymmetric structure between the two contexts C_0 and C_1 is however maintained.

a. Heterogeneous memory sizes

Now let us assume different memory sizes for the two concepts, denoting by m and M the memory sizes of C_0 and C_1 , respectively. Then the effective frequency of X in C_1 is given by:

$$f = \frac{N + m}{M + m} = \frac{x + m/M}{1 + m/M} \quad (\text{B10})$$

By defining γ as the ratio of memories m/M , we recover the same effective frequency as before.

This means that the strength γ of the cognitive link can be interpreted as a ratio between memory sizes. If all sites were connected to each other, the occurrences

expressing the contexts whose associated memory is the greatest would spread all over the network. However, not all sites lead to all others: There are pathways in the conceptual organization, which constrain possible semantic changes and allow for low-memory contexts to invade higher-memory ones.

The main difference brought forth by this interpretation is that it allows for γ 's greater than one. In general, there would be no critical behavior and thus no latency, except if the conquering occurrence type comes from a very low memory context. This would suggest that, as grammaticalizations are well-characterized by the latency-growth pattern with sigmoidal increase, lexical meanings are allocated a much smaller memory than grammatical ones. However, it would also be the case within the lexicon, when a word goes from a concrete meaning to an abstract one.

It is not clear why functional and abstract meanings should be allocated a greater memory than concrete meanings. There could be for instance some advantage in making the more abstract and structural part of the conceptual realm more stable in their linguistic expression than other parts of speech, especially because they serve to constrain the processing of utterances and provide structure to the flow of speech. Were it the case, then we could understand the strong asymmetry evidenced by grammaticalization — the fact that lexical forms are recruited to express grammatical meanings overwhelmingly more frequently than the reverse. Indeed, if the links were from the stable (i.e. supported by a large memory size) to the unstable parts of the language, then all those links would be associated to a very high γ parameter, so that all parts of language would soon come to be expressed by the grammatical forms. This would right away lead to a complete communicative failure. There would thus be an obvious advantage in preventing the links from grammatical concepts to lexical ones, hence in the unidirectionality exhibited by grammaticalization.

b. Different probabilities of use

We now introduce different calling probabilities for C_0 and C_1 in the hearer perspective. Let's say that the probability to call C_0 is α . Here again γ is set to 1 (i.e. C_0 automatically entails C_1). The jump probabilities becomes thus:

$$R^H(x) = [\alpha + (1 - \alpha)P_0(x)](1 - x) \quad (\text{B11})$$

and:

$$L^H(x) = (1 - \alpha)(1 - P_0(x))x. \quad (\text{B12})$$

We can factorize $R^H(x)$ by $1 - \alpha$. Then we recover the same computation as before, with the ratio of calling probabilities $\alpha/(1 - \alpha)$ playing the role of γ . Furthermore, if we set the call probability to be proportional to memory size, then we recover the same γ as in the preceding subsection. This assumption seems natural, since

greater memory sizes would help stabilizing the linguistic expressions of widely used meanings.

In such case, the near-criticality associated to the latency-growth pattern is recovered only if the links in the conceptual network are from the seldom called contexts to the often called contexts (so as to insure low enough values of γ). This seems a natural assumption for grammaticalization phenomena, since functional meanings are much more frequently called than lexical ones. Such assumption remains of course to be carefully investigated.

These two interpretations of the cognitive link point in the same direction: In short, the links of the conceptual network would be distributed so as to prevent highly frequent forms from invading the less frequent ones, i.e., to ensure linguistic diversity. The asymmetry evidenced by grammaticalization would thus be a consequence of the fact that the highly pervasive functional forms must be kept away from the lexical, referential, more context-specific forms. This puzzling unidirectionality could thus have been selected as a cognitive structure able to guarantee a wide spectrum of possibilities in linguistic expression.

5. Sociolinguistic interpretation

We can give our model a completely different interpretation, taking a sociolinguistic view point. Instead of sites C_0 and C_1 , one considers two separate communities of speakers, C_0 and C_1 . Different tokens represent now different individuals, who make binary choices between either variant X or variant Y . The different community sizes, m and M , are then the analogous of the different memory sizes. The fact that C_0 influences unilaterally C_1 may be understood as the fact that community C_0 has some prestige compared to C_1 , so that C_1 members listen to C_0 members while the reverse does not hold. Similarly, different call frequencies may represent different representations in society — people from prestige communities being given media visibility to the exclusion of

the other communities. With this purely sociolinguistic interpretation, the model formalism thus remains exactly the same. Note that this point of view is akin to the one defended in [18].

In this interpretation, however, the model does not explain why the prestige community C_0 adopted X in the first place; nor does it explain the regularities in semantic change. Another point in which this interpretation weakens is the timescale. Linguistic change can be very slow, taking up to several centuries, as shown in our corpus study. Is it reasonable to presume that the social structure holds and remains the same throughout centuries? On the contrary, some aspects of conceptual structure happen to be extremely stable, as they are both deeply constitutive of a culture, e.g. through entrenched metaphors [27], and due to the generic cognitive features of the mind (expressing time relations through spatial ones [25], for instance). As it happens, metaphors prove to be very stable, even if the reasons for this stability are still unclear. The astonishing persistence of myths schemata through the ages [33] is another hint of the remarkable resilience of human cultural features.

Appendix C: Boundaries of the trap region

The analytical definitions, used to compute the latency and growth times in the model, are based on first passage times. In this section we outline the procedure to compute these times

1. Analytical computation of mean first passage times

Let us note $T_{n \rightarrow m}$ the first passage time at site m , starting at site n , $0 \leq n$, $m \leq M$. This is a random variable for which one can write down a recursion equation for its generatrix function:

$$\langle e^{\lambda T_{n \rightarrow m}} \rangle = R_n \langle e^{\lambda(T_{n+1 \rightarrow m+1})} \rangle + L_n \langle e^{\lambda(T_{n-1 \rightarrow m+1})} \rangle + (1 - L_n - R_n) \langle e^{\lambda(T_{n \rightarrow m+1})} \rangle, \quad (C1)$$

where R_n and L_n are, respectively, the forward and backward jump probabilities, and $\langle \cdot \rangle$ denotes the average. We recall that $n = 0$ is a reflecting boundary ($L_0 = 0, R_0 > 0$), and $n = M$ an absorbing boundary ($R_M = L_M = 0$). We have $T_{n,n} = 0$, and for the left boundary condition, that is for $n = 0$:

$$\langle e^{\lambda T_{0 \rightarrow m}} \rangle = R_0 \langle e^{\lambda(T_{1 \rightarrow m+1})} \rangle + (1 - R_0) \langle e^{\lambda(T_{0 \rightarrow m+1})} \rangle. \quad (C2)$$

The first and second derivatives of this equation (C1) with respect to λ , at $\lambda = 0$, leads to recurrence relations

for the first and second moment of $T_{n \rightarrow m}$, respectively. More specifically, we can compute the first two moments of the first passage time between one site and its immediate successor, $T_{i \rightarrow i+1}$:

$$\langle T_{i \rightarrow i+1} \rangle = t_i \quad (C3)$$

And:

$$\langle T_{i \rightarrow i+1}^2 \rangle = u_i, \quad (C4)$$

Where the t_i 's and u_i 's are iteratively computed from:

$$\begin{cases} t_0 = \frac{1}{R_0} \\ u_0 = \frac{2t_0 - 1}{R_0} \end{cases} \quad (\text{C5})$$

And:

$$\begin{cases} t_i = \frac{1}{R_i} + \frac{L_i}{R_i} t_{i-1} \\ u_i = 2t_i^2 + \frac{L_i}{R_i} u_{i-1} \end{cases} \quad (\text{C6})$$

From this, we can easily compute the first two moments for any $T_{n \rightarrow m}$:

$$\mu(T_{n \rightarrow m}) = \sum_{k=n}^{m-1} t_k \quad (\text{C7})$$

And:

$$\sigma^2(T_{n \rightarrow m}) = \sum_{k=n}^{m-1} (u_k - t_k^2) \quad (\text{C8})$$

2. Trap boundaries

In the main text, we explain latency time and growth time as first passage times. However, these two quantities are both empirically extracted from the macroscopic pattern obtained at the end of a run, in a procedure exactly transposed from the corpus data treatment. The question is then: Which trap boundaries n_{in} and n_{out} should we set in order for the properly defined time $T_{n_{in} \rightarrow n_{out}}$ correspond statistically to the empirically defined latency time?

Besides, growth time can be seen as well as a first passage time between two sites. Though the exit site should be M , it is more appropriate to define a cut-off n_{last} . Indeed, there is a discrepancy between the fact that, close to the absorbing point, the walk gets slowed down again, and that, in this region, the new variant is almost always produced anyway. In other terms, growth time, as extracted from the time evolution of the ratio of produced new variant occurrences, is not sensitive whether the end of the walk is reached or not.

Let us note μ_g and σ_g^2 , and μ_{lat} and σ_{lat}^2 , respectively the mean and the variance of the growth and latency times (obtained from the distributions of those empirically extracted quantities from ten thousand runs). Then, over a reasonable range of n , we look for m so that $\mu(T_{n \rightarrow m})$ is as close as possible to μ_g ; we then choose the pair $(n; m)$ such that $\sigma^2(T_{n \rightarrow m})$ is as close as possible to σ_g^2 . This pair defines thus the region of growth, $(n_{out}; n_{last})$. We then choose n_{in} so as to fit the mode of the empirical latency distribution, assuming that first passage time is distributed according to an Inverse Gaussian (and is thus a function of μ and σ^2).

Appendix D: Growth times distribution

In the main text, Figure 7, Right panel, shows the fit of the corpus data growth times distribution by an Inverse Gaussian distribution. Here we discuss the disagreement observed for short growth times.

Because of the necessity to define the extreme values of the sigmoid, x_{min} and x_{max} , a growth times of d decades will be described by a number $N = d - 2$ of points. The problem is, a scarce number of points is more easily compatible with any pattern than a high number of points. A linear fit of eight points is for instance more statistically significant than a linear fit of three points. For this reason, we did not consider any growth time lower than 6 decades, as stated in the main text. We kept the 6 decades growths, even though the bias is still important, as the corresponding growth time is associated with a very few number of points (4). We observe that this particular value appears over-represented compared to the Inverse Gaussian fit.

We detail below two ways by which low growth times could be over-represented in the growth times distribution. The first one is the existence of false positives. The second one accounts for the easier rejection of false negatives for higher number of points. The combination of both effects explains the spurious over-representation of six-decades growth times in our dataset. Note, however, that keeping this point allows for a better estimate of the mean growth time, which is used for the fit.

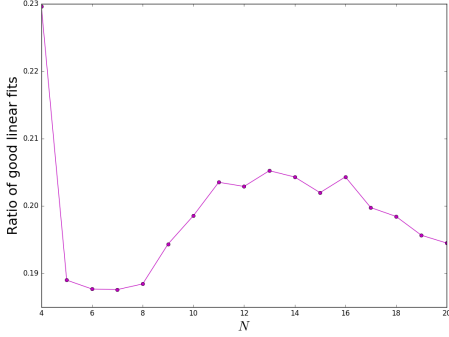
This technical issue does not affect sensitively the analysis of the simulated data, for the timescale there is such that there is no growth time associated to fewer than 8 data points.

a. False positives To give an estimate of the probability to accept false positives, we generate 100,000 samples each built through the following steps: We produce a given number N of random points between 0 and 1 (the domain on which is properly scaled sigmoid takes its values), order them, apply the logit transform, and compute the r^2 parameter of the linear fit of this latter transform. We then approximate the probability of a false positive by the ratio of samples whose associated r^2 is greater than 0.98. The probability of a false positive is significantly higher for samples of 4 points (Fig. 9). This effect is higher still if one accounts for the fact that the probability for four points to be ordered is much higher than it is for more.

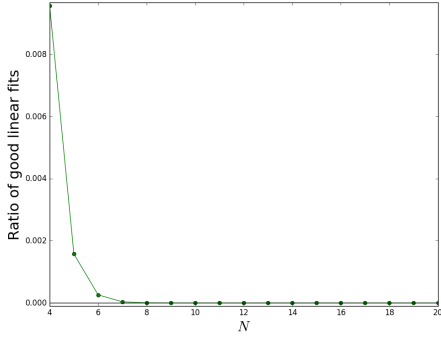
b. False negatives Provided a sigmoidal pattern, what is the probability for the pattern to remain robust in presence of a Gaussian white noise? To address this question, for a given number N of points, we generate a discretized sigmoid as:

$$y_i = \frac{1}{1 + e^{-\alpha(N)(x - N/2)}}, \text{ for } 0 \leq i \leq N - 1. \quad (\text{D1})$$

To provide an estimate of $\alpha(N)$, the slope of a N -points sigmoid, we make use of a relation exhibited by the data itself (Fig. 10), according to which $\alpha(N) =$



(a)



(b)

FIG. 9. (a) Ratio of good linear fits (i.e. such that $r^2 > 0.98$) of logit transforms of 100,000 samples of N randomly generated ordered points, for different values of N . (b) Same ratios, divided by a factor $N!$ to account for the ordering of the points.

$e^{3.58} (N + 2)^{-1.47}$. Then we produce a noisy version of the sigmoid such that, for each i , $\tilde{y}_i = y_i + \eta_i$, with η_i a white Gaussian noise of standard deviation σ . Producing 10,000 of such samples, we compute the ratio of samples such that the linear fit of their logit transforms display an r^2 greater than 0.98. Comparing these ratios for different numbers of points lead to a bias from the uniform distribution (Fig. 11). This bias depend on the level of noise; however it is clear that when the noise is high enough, short growth times are likely to be over-represented.

Appendix E: Further comparisons with data

In our paper, we show that an Inverse Gaussian distribution is adequate to capture both latency time and growth time distributions, indicating that these two quantities are of the same nature, and result from the same mechanism of change. However, the agreement between our model and the corpus data goes much further, as we show in this section.

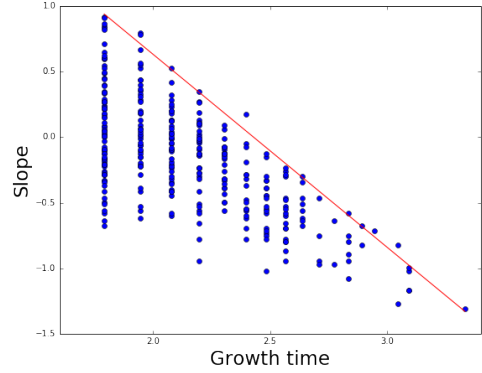


FIG. 10. Log-log graph of the slope of the linear transform vs the growth time. The red line is given by the linear fit of the maximum slopes for each growth time (slope: -1.47; intercept: 3.58)

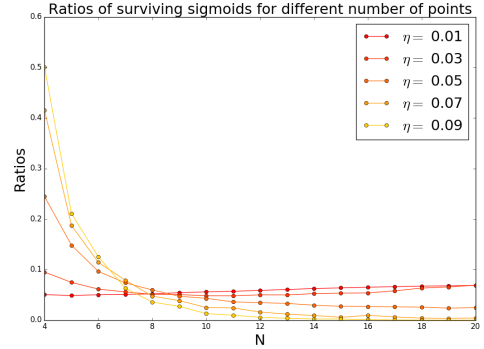


FIG. 11. Distribution over N of resisting samples in presence of a Gaussian white noise of amplitude η . In absence of noise, the distribution is a uniform one.

1. Péclet number

The parameters μ and λ of the Inverse Gaussian distribution scale with time length in the same way, so that is relevant to consider their ratio, which is called the Péclet number [34]. Note that, because the relation $\lambda = \mu^3/\sigma^2$ holds, the Péclet number is but the ratio between the squared mean and the variance.

The Péclet number for latency times from corpus data is equal to 1.1 while the model gives back a Péclet number of 1.4, so they both are of the same order of magnitude. However, for growth times, we get 6.8 for corpus data, while the model gives 63, which means that the growth time varies much less in the model than it should.

Actually, this discrepancy is rather expected. Given the definition of the Péclet number, it means that the variance of the growth time is comparatively greater in the data than it is in our model. Yet, this can be understood in terms of the latter: Indeed, it has been stressed that the conceptual network of language is organized as a small-world network [35], and we have proposed that major semantic change, characterized by the latency-growth

pattern, would correspond to a leap from a cluster to another. It means that latency involves only one bridge, so that the set-up we explored should be enough to cover it. Growth, on the other hand, depends on the cluster size, and on the inner organization of the cluster. It thus involves a varying number of contexts, which explains why the variance of the growth would be greater in actual data, leading to a smaller Péclet number.

Concerning the scale of the process, it could be tempting to compare mean latency between model and data to find the value of M (size of the memory) which would correspond to the data. However, the scale entangles both M and the size of the counting window. It also depends on the total number of involved contexts. There is thus no obvious way to compare the scales involved in the model and in the data.

2. Statistical distribution of the slopes

From the empirical procedure, we can extract, for both corpus and numerical datasets, the statistical distributions of the slopes of the logit transform of the sigmoidal part. Inverse Gaussian distribution fits very well both numerical and corpus data (Fig. 12). Gaussian distribution fits numerical data as well, but does not capture the behavior of corpus data. This is not surprising, as an Inverse Gaussian distribution tends to a Gaussian one with parameter λ going to infinity. The fact that λ is much bigger compared to μ in numerical data than in corpus data is in agreement with the discrepancy between the Péclet numbers for the growth time distributions: There are more sources of variation for the growth part of the process than what we considered in the model. However, we still have no definitive explanation to provide concerning the fact that slopes should follow an Inverse Gaussian distribution as well.

3. Latency-Growth correlation

It may be intuitively expected for latency and growth to be correlated: The longer the wait, the more momentum is gained. Yet, according to our model, there is no such correlation: Latency and growth times, as seen as first passage times in different parts of a Markov chain, are strictly independent quantities. However, in the empirical procedure, these two parameters become correlated, for the latency is defined as the time spent in a region comprised between $x_{t_{out}} \pm a * (1 - x_{t_{out}})$, where $x_{t_{out}}$ is the frequency attained at the beginning of the growth process and a is set to 0.17. Thus, the higher $x_{t_{out}}$, the smaller the margin, so that a short growth (high $x_{t_{out}}$) will be correlated with a short latency. These two quantities are thus weakly positively correlated, with a Pearson coefficient of 0.20 (Fig. 13b).

If we now turn to corpus data, we find a Pearson coefficient of 0.24 (Fig.13a). The correlation between latency

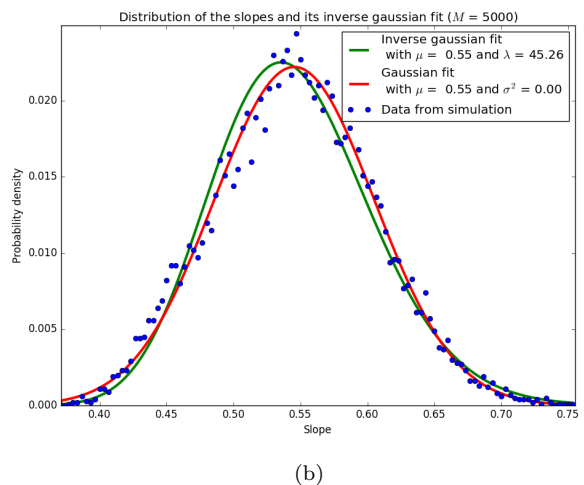
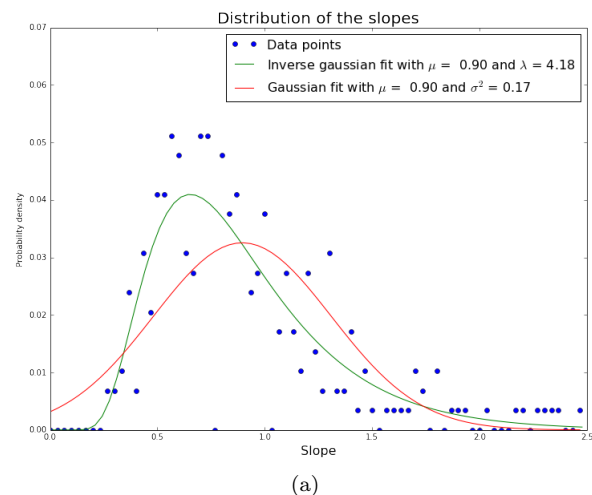
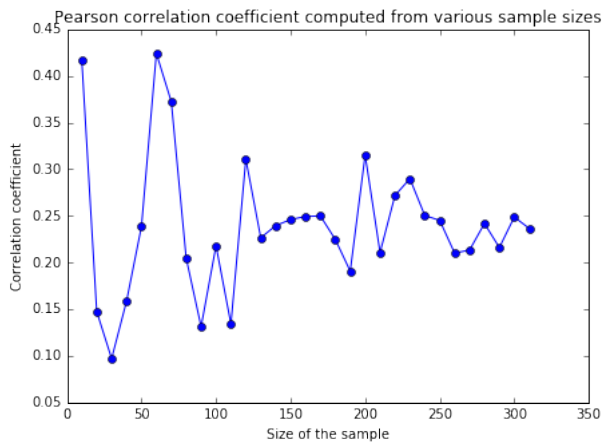


FIG. 12. Statistical distribution of the slopes of the logit transform of the sigmoidal growth, for both corpus data (a) and numerical data (b). An Inverse Gaussian distribution fits both.

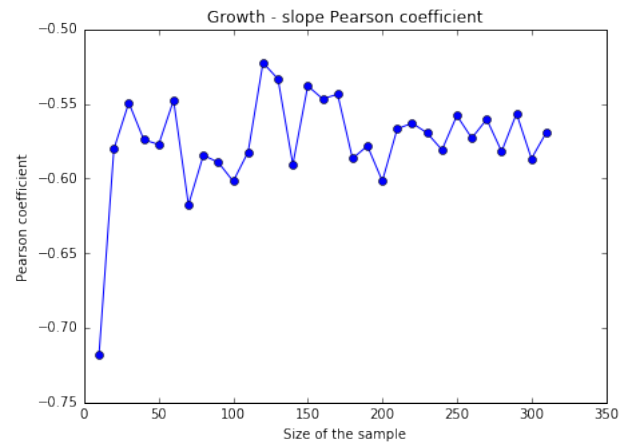
and growth is weak, and can be entirely imputed to the details of the empirical procedure, as we have just seen for the numerical data. It thus means that growth time and latency time are two independent quantities, so that positing a Markovian nature of language change is in line with findings from corpus data.

4. Growth-Slope correlation

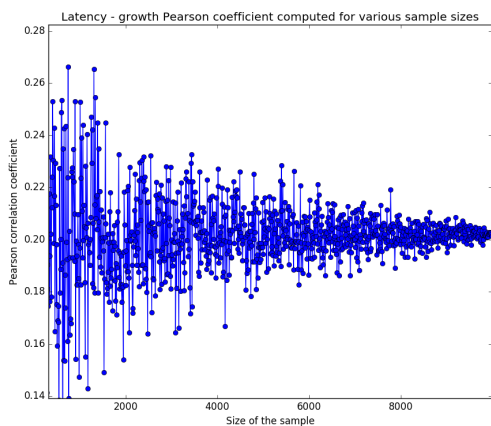
Growth and slope are expected to be correlated. One may even expect to find a scaling law between the two, in line with what has been evidenced for other socio-cultural changes [36]. We did not find any striking scaling law, yet the two quantities are convincingly negatively correlated, both in our model (Pearson coefficient of -0.69 , Fig.14b) and in corpus data (Pearson coefficient of -0.57 , Fig.14a).



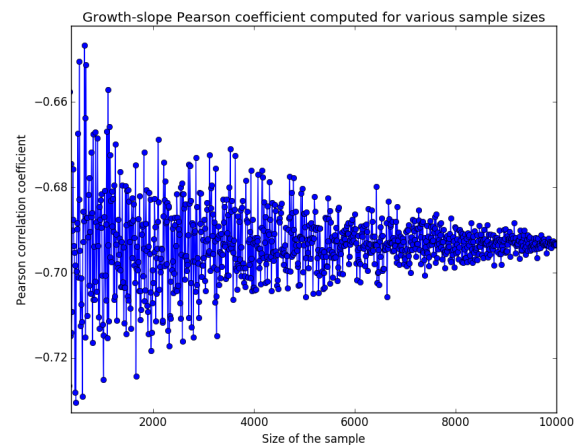
(a)



(a)



(b)



(b)

FIG. 13. Pearson coefficient for the correlation between growth time and latency time obtained from (a) corpus data and (b) numerical simulations

FIG. 14. Pearson coefficient for the correlation between growth time and slope obtained from (a) corpus data and (b) numerical simulations

Appendix F: Why not using Google Ngram?

Google Ngram (<https://books.google.com/ngrams>) gathers an impressive quantity of digitalized books from about the sixteenth century. It hosts about 800,000 texts in French (about twenty times more than Frantext). Nevertheless, it presents some major limitations which make this database inappropriate for the present study, as we discuss at length in this section.

Some limits of the Google Ngram database have already been stressed in the recent past [37]. However, these concerns are specifically relevant for lexical changes, most subject to socio-historical contingencies, and they do not straightforwardly apply to our aims. Functional words, unlike proper names like ‘Frodo’ or items like ‘computer’, are not that sensitive to cultural shifts. This is why we point out other serious limits inherent to Google Ngram. In the following, we use Google Books as a probe to the contents of Google Ngram,

though the two algorithms are different (e.g. the former does not recognize punctuation while the latter does), and the exact overlapping between the contents of the two databases is unknown.

The first concern about Google Ngram regards quality of digitalization. Texts older than the nineteenth century have been printed in fonts for which the character recognition algorithm has clearly not been optimized. For instance, the following sentence from *The royal dictionary abridged, in two parts*, by Abel Boyer, 1715: ‘Parler avantageusement de quelqu’un, to speak well of one, to speak much to his advantage, to give a good character of him, to speak honourably of him.’ has been transcribed as: ‘Parler avantageusement e quelqu’un, 1° speak well of one, te steak much to his advant 1ge, to ive a gead characier of him, to steak h2nourably of him.’ Some words, such as ‘steak’ and ‘rince’, consequently appear much more frequently than they should, as they are mistaken for ‘speak’ and ‘Prince’. Another example of this poor scan-

ning quality can be seen in the comparison between: ‘I found that the New-modelling of this Story, would force me sometimes on the difficult Task of making the chiefest Persons speak something like their Characters, on Matter whereof I had no Ground in my Author.’ and ‘I faura that the Ne: -we kling of this Story, troi’i fr e ve { ctives on the di ili 7 k of making ti e li fist Perffns steak { like their Carefiers, en -i/attro sviereof. I had no Gréard in , Author.’, to be found in *The History of King Lear, A Tragedy. Acted as the King’s-Theatre.* by Nahum Tate, 1736. The original text is admittedly hard to decipher, yet any posterior check on the scan would immediately detect such nonsensical concatenations of characters. By comparison, every text in the Frantext database has been digitalized with great care and such blatant errors are not to be found.

The second point on which Frantext deserves to be favored is the kind of available data. Google Ngram provides statistics on n-grams, which are strings of n successive items (the so-called ‘grams’), with n ranging from 1 to 5. For each n-gram, it is provided, per year, the number of times it appears and in how many texts. Thus one cannot identify in which texts it appears most; nor can one have access to its context of use. The only way to probe the contents of Google Ngram is through Google Books (which we used here for all the discussed examples), yet it seems impossible to know the exact overlap between the two databases. This data structure based on n-grams is furthermore limiting when it comes to slot constructions. For instance, the French construction ‘à X reprises’, with X being a quantity, can hardly be tracked using Google Ngram, as it corresponds to far too many n-grams, which would need to be listed one by one: ‘à deux reprises’, ‘à deux ou trois reprises’, ‘à plusieurs reprises’, ‘à de nombreuses reprises’, etc. This search is made all the more difficult by the fact that ‘à’ did not always take an accent in older texts. In Frantext, as we have seen in Appendix A, we can work out an elaborate request using booleans and blank words to capture the diverse uses of this construction and overcome the orthographic difficulties.

The third and final point we want to stress here is the choice of texts and their dating. In Frantext, a text may appear in several editions, as is the case for *Le Cid*, by Pierre Corneille, which appear thrice in the database, associated to the years 1637, 1637 and 1682. These dates usually correspond to the first edition of a book, rather than to the edition which is actually digitalized (such information being also provided). Google Ngram displays about thirty versions of *Le Cid*, with publication ranging from 1775 to 2013, some of them being ascribed to Jean Racine (as they are found in several editions of a book called *Oeuvres de J. Racine et de P. et T. Corneille*). The case of *Le Cid* is, in Frantext, quite an exception; while in Google Ngram, most famous classical novels from past centuries are found in a dozen versions at least.

The contents of the database is problematic as well. As highlighted in [37], Google Ngram over-represent aca-

demical literature. This also tends to bias the data; for instance, among the fourteen results of the request ‘par ma barbe’ on the French Google Books subdatabase, for the years 1950-2000, only three of them are relevant, two being modern translations of older texts (Don Quixote and an nineteenth century German play by Töpffer). The third one comes from an anthology of French folktales. All other occurrences are academic quotes and glosses of past works, or reprints of such works. In such a case, it means than only one fifth of the occurrences would be reliable as a reflect of language use in this time period (two of them being borderline cases). Frantext, on the other hand, has two occurrences of ‘par ma barbe’, one of them from the song lyrics of singer Georges Brassens, the other from a 1988 translation of a Shakespeare play (and so more debatable). There is thus almost as many relevant occurrences in Frantext and Google Ngram (two versus three), while none in Frantext are completely irrelevant.

This being said, Google Ngram is a formidable tool, which can lead to interesting insights and be of great use. It is not, however, fitted for the work that we performed, where we need an accuracy and a reliability that this database is unable to provide.

Appendix G: Studied forms

The corpus data through which we evidence the latency-growth pattern has been extracted from the study of about 400 hundred semantic expansions in the functional realm (with the exception of *liberté*, which we have shown to suggest the further generality of the pattern), with the help of the Frantext database and retrieving tools. We selected these forms according to several criteria: They must have undergone at least one semantic expansion towards a functional use during the time period under consideration; they must be easily distinguished (e.g. *entre deux*, in the meaning of ‘in between’, can be confused with occurrences of literal meaning ‘between two’). The set of chosen forms is far from exhausting the pool of possible examples.

On table I, we provide the full list of studied forms. For each of those, we display the length (in decades) of the latency part, of the growth part, the slope of the logit transform of the growth part, the r^2 parameter associated to the linear fit of this logit transform, the standard deviation between the data and the inferred sigmoidal pattern, and the total number of occurrences of the form in our corpus. A standard deviation less than 0.03 corresponds to an especially good sigmoidal fit of the data. Some forms are listed several times; it corresponds to the case where a form underwent several semantic expansion processes, each associated with the latency-growth pattern. ‘BUG’ corresponds to a flaw of the Frantext search and retrieve algorithm, sometimes unable to build up the output file of the query. This bug cannot be override through a manual manoeuvre, for it is caused by a faulty

encoding of some parts of the texts. The data thus exist, but could not be retrieved.

An upper-case ‘NO’ indicates that no such pattern has been found in the time-evolution of the frequency of that form. The fact that a form does not follow a S-curve during its semantic expansion may spread doubt on the genericity of this pattern. In many cases however, we found such a pattern and rejected it because the data was too spurious. It should also be stressed that the criterion we applied (the r^2 residual of the linear fit of the logit transform must be greater than 0.98, see Materials and Methods) is a really strong one and can easily lead to rejection.

It is nonetheless interesting to note that the robustness of the pattern does not depend excessively on the scarcity of data. Indeed, instances associated to a very low number of occurrences can lead to a very clean pattern (e.g. *à plus d’un titre*, whose growth lasts for 8 decades in total, scores as low as 59 occurrences, and still brings out

a remarkable r^2 of 0.995). What seems to be crucial is thus not the question of how much data we can get, but of whether or not the change is isolated. Indeed, some changes are not independent from one another. Many constructions beginning with the preposition *par*, for instance, follow their own course of evolution, while the meaning of *par* itself also expands. Several constructions can also compete for the same paradigm (e.g. *il me semble, je pense, je suppose*). Their individual frequency pattern not following an S-curve of growth may thus be seen as resulting from interferences between the different semantic expansion processes. In these cases, only the refinement of linguistic queries can lead to better results. It thus confirms, once again, the necessity to rely on a clean and easily manipulable database rather than on giant databases where the sheer amount of data is of no help.

TABLE I: List of studied forms

Researched form	Latency	Growth	Slope	r^2	Deviation	# of occ.
à base de	9	8	1.02	0.983	0.043	607
à bien des égards (i)	0	8	0.79	0.983	0.049	147
à bien des égards (ii)	2	6	1.57	0.984	0.041	147
à bord de	NON	NON	NON	NON	NON	1728
acabit	0	7	1.20	0.992	0.031	148
à cause de	NON	NON	NON	NON	NON	24840
à cause que	2	6	0.61	0.997	0.105	2516
à ce moment	14	13	0.46	0.990	0.080	8861
à ce propos (i)	2	7	2.22	0.988	0.011	1711
à ce propos (ii)	13	7	0.81	0.991	0.048	1711
à ce sujet	10	7	1.95	0.988	0.037	4001
à cet égard	0	6	0.85	0.993	0.087	4974
à cet instant	2	13	0.55	0.993	0.034	1198
à condition de	5	9	0.79	0.991	0.035	1151
à condition que (i)	11	6	1.19	0.997	0.031	1653
à condition que (ii)	4	6	0.83	0.981	0.068	1653
à contre-courant	3	11	0.75	0.995	0.021	171
à côté de	23	13	0.52	0.990	0.034	18065
à coup sûr	7	7	1.70	0.996	0.012	2546
à court terme	13	7	2.19	0.997	0.019	751
à couvert	NON	NON	NON	NON	NON	1144
actuellement	10	11	0.46	0.989	0.048	6618
à découvert	1	7	1.33	0.981	0.035	930
à défaut de	NON	NON	NON	NON	NON	1725
afin de	4	6	0.81	0.995	0.073	21833
afin que	BUG	BUG	BUG	BUG	BUG	19850
à fond de	8	6	0.91	0.987	0.059	486
à fond de train	BUG	BUG	BUG	BUG	BUG	180
à force	NON	NON	NON	NON	NON	294
à force de	NON	NON	NON	NON	NON	8178
à grand renfort de	NON	NON	NON	NON	NON	230
ainsi donc	NON	NON	NON	NON	NON	1247
à la base	NON	NON	NON	NON	NON	574
à l’accoutumée	0	8	0.99	0.988	0.027	196
à l’aide de	NON	NON	NON	NON	NON	5247
à la limite	7	11	0.73	0.983	0.076	603
à la lisière de	6	12	0.56	0.985	0.036	527
à la longue	9	7	0.57	0.987	0.115	1245

Researched form	Latency	Growth	Slope	r ²	Deviation	# of occ.
à la lumière de	0	7	1.10	0.987	0.031	1141
à la mesure de	24	9	1.14	0.988	0.056	820
à la place	22	22	0.31	0.983	0.029	5638
à la rigueur	9	8	1.14	0.983	0.049	1717
à l'écart	NON	NON	NON	NON	NON	2517
à l'écart de	6	12	0.58	0.992	0.030	854
à l'égard de	7	11	1.19	0.992	0.038	13396
à l'encontre de	9	17	0.45	0.986	0.026	1272
à l'envi	0	9	0.88	0.991	0.025	817
à l'exception de	1	8	0.81	0.995	0.080	1883
à l'heure actuelle	0	11	0.95	0.981	0.045	858
à l'heure dite	NON	NON	NON	NON	NON	234
à l'heure où	2	9	0.79	0.982	0.043	1779
à l'improviste	NON	NON	NON	NON	NON	1024
à l'instant	0	6	1.02	0.993	0.047	1550
à l'instar de (i)	4	10	0.61	0.981	0.044	663
à l'instar de (ii)	1	7	0.99	0.988	0.035	663
à l'insu	0	22	0.36	0.982	0.045	2776
à l'inverse	8	10	1.06	0.988	0.021	764
à l'occasion de	6	8	1.52	0.983	0.042	2032
à l'orée de	5	6	1.00	0.996	0.047	311
alors que (i)	3	7	1.01	0.983	0.044	28016
alors que (ii)	4	13	0.50	0.983	0.031	28016
à mesure de	4	8	0.71	0.990	0.087	774
à mesure que	12	7	1.74	0.993	0.017	10183
à moins que	2	8	0.90	0.981	0.059	5924
à mon avis	NON	NON	NON	NON	NON	1989
à nouveau	7	13	0.59	0.987	0.031	6039
à outrance	1	6	0.53	0.996	0.132	552
à part	0	28	0.27	0.986	0.037	12506
à part entière	0	8	1.33	0.983	0.034	180
à partir de	0	9	0.76	0.986	0.038	10996
à peine (i)	0	6	1.73	0.994	0.023	40230
à peine (ii)	0	6	1.70	0.986	0.026	40230
à peu de chose près	0	7	0.94	0.987	0.039	320
à plus d'un titre	1	7	1.02	0.995	0.031	59
à plusieurs reprises	9	7	1.22	0.994	0.023	3873
après ce	NON	NON	NON	NON	NON	101
après que	6	6	2.34	0.997	0.022	8487
après quoi	10	16	0.53	0.982	0.048	3468
après tout	NON	NON	NON	NON	NON	7741
a priori	3	9	1.21	0.985	0.046	1565
à propos	NON	NON	NON	NON	NON	1255
à propos de	0	12	0.50	0.980	0.056	9414
à proprement parler	NON	NON	NON	NON	NON	1204
à rebours (i)	2	6	1.09	0.994	0.070	640
à rebours (ii)	2	6	0.85	0.997	0.068	640
à qui mieux mieux	NON	NON	NON	NON	NON	247
à sa guise	0	6	1.40	0.992	0.028	1079
à son terme	1	11	0.75	0.991	0.032	359
à tel point que (i)	0	7	0.75	0.996	0.054	555
à tel point que (ii)	0	6	1.69	0.991	0.028	555
à terme	12	6	0.56	0.997	0.117	470
à titre de	5	13	0.63	0.990	0.026	1481
à tous égards	0	6	1.91	0.998	0.013	556
à tout à l'heure	0	10	0.93	0.983	0.037	280
à tout instant	NON	NON	NON	NON	NON	903
à tout moment	5	6	1.49	0.988	0.032	2262
à tout prendre	NON	NON	NON	NON	NON	480

Researched form	Latency	Growth	Slope	r ²	Deviation	# of occ.
au bord de	NON	NON	NON	NON	NON	11850
au bout de	NON	NON	NON	NON	NON	23173
au bout du compte	NON	NON	NON	NON	NON	469
au contraire	5	8	1.13	0.990	0.027	29571
au contraire de	1	8	1.14	0.989	0.028	1429
aucunefois	BUG	BUG	BUG	BUG	BUG	1248
au demeurant	0	12	0.68	0.983	0.039	1344
au dépourvu	NON	NON	NON	NON	NON	402
au détrimment de	5	6	1.03	0.981	0.050	798
au dernier moment	NON	NON	NON	NON	NON	1370
au final	NON	NON	NON	NON	NON	38
au fur et à mesure	6	12	0.72	0.987	0.027	1908
au jour d'aujourd'hui	NON	NON	NON	NON	NON	87
au même moment	2	6	0.75	0.992	0.081	1437
au moment où	6	19	0.49	0.984	0.024	12729
à un moment donné	1	12	0.48	0.980	0.043	659
au passage	0	7	1.43	0.990	0.034	1754
au pire	0	6	1.63	0.994	0.026	401
au reste	0	7	1.39	0.987	0.036	4375
au sujet de	4	9	0.87	0.986	0.035	4945
au terme de	3	6	0.66	0.991	0.102	1492
aux trouses	NON	NON	NON	NON	NON	419
avant tout	27	10	0.91	0.986	0.029	5342
avec force	NON	NON	NON	NON	NON	324
bah	9	9	1.31	0.992	0.021	2681
bien entendu	33	18	0.44	0.984	0.042	4476
bien sûr	5	9	0.74	0.994	0.029	7997
bref	12	7	1.07	0.993	0.033	5536
brusquement	11	8	1.69	0.993	0.029	1783
carrément (i)	1	8	1.22	0.982	0.044	1207
carrément (ii)	1	7	1.55	0.982	0.042	1207
ce faisant (i)	0	6	1.88	0.992	0.027	781
ce faisant (ii)	19	8	0.64	0.994	0.059	781
ce par quoi	0	10	0.61	0.984	0.040	163
c'est alors que	6	10	0.85	0.982	0.026	3223
c'est pour le coup que	0	6	0.77	0.990	0.079	64
c'est pourquoi (i)	0	13	0.56	0.984	0.053	10994
c'est pourquoi (ii)	0	8	0.95	0.986	0.040	10994
chemin faisant	NON	NON	NON	NON	NON	641
complètement	NON	NON	NON	NON	NON	11560
compte tenu de	0	8	1.26	0.985	0.038	928
concernant	9	10	1.10	0.984	0.047	3477
considérant que	NON	NON	NON	NON	NON	191
contre mon attente	NON	NON	NON	NON	NON	102
contre toute attente	0	6	0.84	0.991	0.080	167
d'abord et avant tout (i)	0	6	0.80	0.982	0.073	62
d'abord et avant tout (ii)	1	6	1.24	0.982	0.039	62
dans ce cas	NON	NON	NON	NON	NON	4289
dans la mesure de	NON	NON	NON	NON	NON	480
dans la mesure du possible	0	11	0.62	0.988	0.050	188
dans la mesure où	NON	NON	NON	NON	NON	2753
dans le cadre de	11	6	1.27	0.988	0.069	1145
dans le même temps (i)	0	9	1.02	0.986	0.029	1217
dans le même temps (ii)	3	7	0.90	0.983	0.046	1217
dans l'ensemble (i)	0	8	0.99	0.986	0.045	1809
dans l'ensemble (ii)	10	7	0.82	0.981	0.068	1809
dans l'immédiat	10	9	1.10	0.984	0.033	329
dans quelque temps (i)	0	6	0.81	0.987	0.081	234
dans quelque temps (ii)	0	6	0.76	0.991	0.077	234

Researched form	Latency	Growth	Slope	r ²	Deviation	# of occ.
dans son ensemble	1	8	0.67	0.990	0.063	835
dans un autre temps	NON	NON	NON	NON	NON	143
dans un cas comme dans l'autre	1	8	1.04	0.983	0.042	111
dans une large mesure	5	8	0.66	0.994	0.062	381
dans un instant	2	10	0.87	0.981	0.035	661
dans un moment	0	15	0.47	0.984	0.037	1473
dans un premier temps	NON	NON	NON	NON	NON	229
dans tous les cas	NON	NON	NON	NON	NON	1609
d'autant plus	0	9	0.52	0.987	0.061	11584
d'autant plus que	NON	NON	NON	NON	NON	3339
d'autre part	24	12	0.64	0.982	0.045	11012
décidément	2	13	0.50	0.984	0.048	4795
de ce fait	2	8	0.66	0.993	0.105	628
de façon que	NON	NON	NON	NON	NON	1473
de fait	0	8	0.91	0.989	0.034	5018
d'année en année	NON	NON	NON	NON	NON	505
de ce côté	NON	NON	NON	NON	NON	3665
de jour en jour	NON	NON	NON	NON	NON	2217
de la part de	NON	NON	NON	NON	NON	16400
de la sorte	11	8	0.77	0.982	0.046	3752
de l'aveu de	0	17	0.34	0.986	0.054	196
de l'avis de	0	6	1.17	0.987	0.039	146
de loin	16	10	0.73	0.994	0.031	1262
de loin en loin	0	17	0.41	0.984	0.042	1348
de long en large	3	9	0.76	0.983	0.054	734
de main en main	NON	NON	NON	NON	NON	464
d'emblée	3	10	0.72	0.986	0.034	1451
de mèche	0	6	0.72	0.987	0.087	98
de mieux en mieux	0	6	1.32	0.996	0.028	445
de moins en moins	6	21	0.28	0.980	0.038	1536
de mon côté	0	14	0.71	0.981	0.043	8788
de mon fait	NON	NON	NON	NON	NON	467
de nulle part	24	12	0.36	0.993	0.063	289
de pair	12	7	1.04	0.983	0.050	578
de place en place	13	7	0.86	0.988	0.058	376
de point en point	0	6	0.75	0.988	0.079	247
de part en part (i)	0	7	1.49	0.995	0.019	498
de part en part (ii)	7	6	1.42	0.989	0.027	498
de part et d'autre	NON	NON	NON	NON	NON	2505
de plus en plus	0	6	1.08	0.999	0.038	18226
de près ou de loin	NON	NON	NON	NON	NON	221
de proche en proche	3	9	1.00	0.987	0.024	702
de quelque part	NON	NON	NON	NON	NON	166
des fois	5	10	0.89	0.982	0.032	1423
des fois que	2	6	0.90	0.988	0.063	182
dès l'instant	1	8	0.96	0.988	0.030	769
dès lors que	21	7	0.59	0.983	0.126	994
de sorte que	6	6	0.85	0.997	0.063	11320
de surcrot	38	9	0.91	0.988	0.032	720
de temps à autre	17	14	0.74	0.983	0.028	3547
de temps en temps	2	13	0.45	0.981	0.047	8916
de toute façon	35	7	0.94	0.996	0.066	3595
de toute manière	NON	NON	NON	NON	NON	727
de toutes façons (i)	4	6	2.04	0.989	0.039	715
de toutes façons (ii)	1	6	1.56	0.986	0.038	715
de toutes parts	0	8	1.38	0.992	0.035	4792
d'heure en heure	NON	NON	NON	NON	NON	573
d'ici là	16	9	0.60	0.985	0.096	904
dorénavant	NON	NON	NON	NON	NON	256

Researched form	Latency	Growth	Slope	r ²	Deviation	# of occ.
d'outre en outre	NON	NON	NON	NON	NON	47
du fait de	24	8	0.73	0.986	0.055	1423
du même coup	14	17	0.47	0.991	0.026	1502
du moment que	3	6	1.64	0.999	0.015	1765
d'une manière ou d'une autre	NON	NON	NON	NON	NON	320
d'une part (i)	0	8	1.13	0.985	0.038	5671
d'une part (ii)	3	7	0.80	0.982	0.061	5671
d'une voix claire	6	10	0.68	0.993	0.030	13511
du pareil au même	NON	NON	NON	NON	NON	92
du point de vue de	7	8	0.80	0.995	0.039	899
du reste	1	6	1.82	0.994	0.027	5510
en attendant	NON	NON	NON	NON	NON	3351
en attendant de	0	6	1.41	0.983	0.038	510
en attendant que	NON	NON	NON	NON	NON	2270
en bordure de	0	11	0.83	0.983	0.030	434
en bref	1	6	1.06	0.996	0.041	339
en ce moment (i)	5	8	1.09	0.985	0.038	12751
en ce moment (ii)	2	9	0.79	0.983	0.038	12751
en ce que	0	7	1.55	0.990	0.036	3971
en ce qui concerne	34	8	0.70	0.981	0.057	3950
en ce qui me concerne	NON	NON	NON	NON	NON	682
en considération de	NON	NON	NON	NON	NON	409
en cours de	0	14	0.54	0.984	0.074	1110
en cours de route	0	8	0.91	0.986	0.036	301
en d'autres termes (i)	0	6	0.63	0.980	0.102	1228
en d'autres termes (ii)	0	9	0.66	0.987	0.058	1228
en définitive	NON	NON	NON	NON	NON	1538
en dépit de	NON	NON	NON	NON	NON	4016
en face de	18	17	0.39	0.982	0.058	10956
en façon que	NON	NON	NON	NON	NON	48
en fait	19	11	0.57	0.985	0.047	8871
en fin de compte	27	13	0.42	0.980	0.054	1417
en gros	18	7	1.06	0.984	0.044	320
en guise de	7	10	0.93	0.982	0.035	1598
en instance de	NON	NON	NON	NON	NON	77
en l'occurrence	0	11	0.58	0.993	0.038	525
en long et en large	NON	NON	NON	NON	NON	108
en même temps	3	10	0.88	0.996	0.023	18370
en même temps que	NON	NON	NON	NON	NON	8241
en mesure de	NON	NON	NON	NON	NON	1470
en particulier (i)	2	6	1.26	0.993	0.050	8949
en particulier (ii)	17	15	0.39	0.984	0.057	8949
en particulier (iii)	4	7	0.80	0.987	0.072	8949
en partie	NON	NON	NON	NON	NON	5645
en passe de	NON	NON	NON	NON	NON	46
en plein	7	6	0.51	0.997	0.135	183
en plein qqch	31	10	0.86	0.982	0.035	15939
en quelque sorte	NON	NON	NON	NON	NON	6422
en sorte que	3	6	0.97	0.982	0.056	4786
en suspens	BUG	BUG	BUG	BUG	BUG	961
en tant que tel	8	6	0.91	0.997	0.065	314
entre autres	NON	NON	NON	NON	NON	4402
en vérité (i)	0	6	0.93	0.988	0.060	8194
en vérité (ii)	1	6	0.75	0.981	0.080	8194
en voie de (i)	2	6	0.57	0.996	0.200	1027
en voie de (ii)	21	22	0.31	0.980	0.052	1027
en vue de	5	6	1.31	0.995	0.026	3625
époque	7	14	0.75	0.993	0.037	32290
essentiellement	NON	NON	NON	NON	NON	5471

Researched form	Latency	Growth	Slope	r ²	Deviation	# of occ.
étant donné que	2	13	0.62	0.984	0.036	341
et après	NON	NON	NON	NON	NON	7562
excepté	5	7	0.66	0.990	0.076	5042
faute de (i)	5	7	1.76	0.990	0.024	6725
faute de (ii)	4	11	0.58	0.983	0.054	6725
faute de quoi	NON	NON	NON	NON	NON	262
force est de	NON	NON	NON	NON	NON	84
fors	BUG	BUG	BUG	BUG	BUG	4451
graduellement	3	9	1.42	0.983	0.061	827
hormis	5	6	1.01	0.987	0.070	1464
il me semble	NON	NON	NON	NON	NON	1822
il s'agit de	3	11	0.50	0.983	0.044	11558
il y a moyen	4	6	1.34	0.994	0.088	1295
j'ai l'impression	0	9	0.57	0.983	0.052	74
ja soit ce que	NON	NON	NON	NON	NON	268
je pense	5	6	1.48	0.989	0.029	4033
je suppose	0	8	1.00	0.995	0.025	1110
j'imagine	11	9	0.39	0.989	0.107	824
jusque là	0	6	0.81	0.980	0.075	6908
juste un	14	8	0.83	0.984	0.063	1366
l'autre jour	NON	NON	NON	NON	NON	4438
lendemain	NON	NON	NON	NON	NON	28780
le temps de	20	11	0.54	0.987	0.035	1195
liberté	2	9	0.87	0.990	0.031	46705
l'un dans l'autre	NON	NON	NON	NON	NON	69
l'un après l'autre	NON	NON	NON	NON	NON	2010
m'est avis	NON	NON	NON	NON	NON	797
nettement	0	7	0.68	0.982	0.070	6109
nommément	1	6	1.20	0.981	0.044	453
non pas tant	3	6	1.25	1.000	0.029	855
non seulement	NON	NON	NON	NON	NON	22599
non pas seulement	6	6	0.88	0.988	0.062	1605
notamment	10	8	0.55	0.991	0.091	7508
nulle part	5	12	0.57	0.980	0.045	5006
or donc	4	6	2.50	0.988	0.028	237
ouille	1	7	1.36	0.997	0.015	106
outré mesure	3	7	0.86	0.997	0.054	664
par à-coups	0	11	0.55	0.985	0.042	212
par ailleurs	27	11	0.93	0.983	0.035	2676
par avance	2	12	0.64	0.980	0.048	1265
par ce fait	0	9	1.05	0.990	0.028	101
par conséquent	6	6	1.30	0.998	0.026	12234
par contre	18	12	0.72	0.989	0.044	3014
par degrés	NON	NON	NON	NON	NON	1447
par dessus tout (i)	3	6	0.91	0.988	0.075	1433
par dessus tout (ii)	2	10	0.73	0.991	0.028	1433
pareil à	14	10	0.68	0.983	0.041	6787
par excellence	NON	NON	NON	NON	NON	1749
par faute de	4	7	0.91	0.983	0.107	353
parfois	12	17	0.56	0.983	0.030	39445
par hasard	5	8	1.20	0.994	0.023	7071
par instants	0	9	0.73	0.993	0.041	1357
par mégarde	NON	NON	NON	NON	NON	578
parmi d'autres	9	12	0.86	0.991	0.030	620
par moments	0	12	0.88	0.984	0.031	2774
par rapport à (i)	0	9	0.91	0.985	0.043	5290
par rapport à (ii)	3	8	0.74	0.993	0.044	5290
par surcrot	19	12	0.59	0.982	0.034	498
particulièrement	14	18	0.51	0.982	0.038	12784

Researched form	Latency	Growth	Slope	r ²	Deviation	# of occ.
par voie de	NON	NON	NON	NON	NON	976
par voie de conséquence	0	9	0.56	0.983	0.058	130
petit à petit	3	10	0.77	0.985	0.030	1547
peu à peu (i)	10	6	1.83	0.997	0.014	16450
peu à peu (ii)	1	9	0.96	0.981	0.049	16450
peu s'en faut	0	9	0.92	0.982	0.030	221
pour ainsi dire	1	13	0.77	0.982	0.038	7704
pour autant	0	13	0.79	0.994	0.015	457
pour finir	23	15	0.63	0.982	0.039	838
pour le coup	14	6	0.72	0.986	0.123	464
pour l'essentiel	0	9	0.97	0.985	0.030	284
pour le moment	1	21	0.44	0.981	0.034	2986
pour l'heure	NON	NON	NON	NON	NON	546
pour l'instant	11	14	0.63	0.988	0.027	1859
pour ma part	5	6	1.12	0.997	0.097	2744
pour peu que	0	9	0.98	0.990	0.026	2479
pour surcrot de	NON	NON	NON	NON	NON	90
pourtant que (i)	0	6	1.05	0.989	0.054	4220
pourtant que (ii)	0	6	1.70	0.989	0.024	4220
pour tout dire	2	7	1.14	0.986	0.040	655
pour un temps	NON	NON	NON	NON	NON	1333
présentement	11	6	0.88	0.981	0.070	2683
probablement (i)	2	8	1.22	0.981	0.054	8497
probablement (ii)	2	10	0.70	0.981	0.033	8497
proprement	4	6	1.05	0.989	0.044	9817
principalement	17	7	1.31	0.993	0.029	6695
progressivement	NON	NON	NON	NON	NON	2235
quand même	3	14	0.57	0.993	0.019	12171
quant à	4	11	0.61	0.989	0.036	20878
quant à cela	NON	NON	NON	NON	NON	91
quant à moi	4	6	0.71	0.989	0.093	4875
que dalle	NON	NON	NON	NON	NON	163
quelquefois	13	7	1.44	0.982	0.033	34408
quelque part	NON	NON	NON	NON	NON	6454
relatif à	12	10	0.57	0.980	0.081	2850
relativement à	15	7	0.54	0.992	0.119	1469
rien de plus	NON	NON	NON	NON	NON	1537
sans ambages	NON	NON	NON	NON	NON	130
sans commune mesure	2	9	1.12	0.986	0.032	112
sans crier gare	0	11	0.69	0.989	0.026	211
sans détour	9	12	0.47	0.988	0.037	467
sans façon	NON	NON	NON	NON	NON	650
sans tenir compte de	5	8	0.85	0.983	0.037	143
sauf	4	8	1.03	0.983	0.038	11138
sauf si	3	12	0.74	0.994	0.027	247
sauf que	0	13	0.58	0.985	0.026	910
selon moi	1	13	0.39	0.982	0.066	1055
si besoin est (i)	5	6	2.30	0.992	0.035	106
si besoin est (ii)	3	6	2.27	0.995	0.021	106
si bien que	4	9	0.59	0.981	0.048	4831
si ça se trouve	0	7	1.21	0.986	0.029	144
s'il en est	NON	NON	NON	NON	NON	88
si possible	22	10	0.88	0.983	0.033	760
soit dit en passant	NON	NON	NON	NON	NON	276
soudain	28	12	0.63	0.989	0.031	3498
soudainement	0	6	2.38	0.980	0.044	94
sous peu	0	6	1.83	0.993	0.028	291
sous prétexte de	NON	NON	NON	NON	NON	2341
sous prétexte que	6	6	0.69	0.997	0.112	1364

Researched form	Latency	Growth	Slope	r^2	Deviation	# of occ.
sous réserve que	NON	NON	NON	NON	NON	89
souventes fois	NON	NON	NON	NON	NON	530
spécialement	NON	NON	NON	NON	NON	3764
sur ce thème	NON	NON	NON	NON	NON	130
sur le champ	NON	NON	NON	NON	NON	5152
sur le moment	8	16	0.38	0.992	0.033	715
sur le sujet de	NON	NON	NON	NON	NON	292
sur le point de	2	8	0.92	0.984	0.031	3321
sur l'heure	NON	NON	NON	NON	NON	720
sur l'instant	9	14	0.53	0.987	0.044	162
un de ces jours	5	6	1.31	0.996	0.026	983
une sorte de	1	6	1.82	0.985	0.034	31306
une sorte de	2	8	1.29	0.991	0.032	31306
tandis que	BUG	BUG	BUG	BUG	BUG	39303
tant et plus	NON	NON	NON	NON	NON	155
tel quel	4	8	1.07	0.983	0.036	985
tour à tour	11	22	0.37	0.982	0.043	4480
tout à coup	3	9	1.11	0.983	0.046	20468
tout à fait	25	12	0.46	0.981	0.047	25611
tout à l'heure (i)	7	9	0.99	0.985	0.040	12853
tout à l'heure (ii)	3	9	0.88	0.995	0.022	12853
tout au long de	13	12	0.68	0.980	0.035	1363
tout au plus	11	10	0.65	0.990	0.060	2954
tout bien considéré	2	6	1.16	0.994	0.038	152
tout bien réfléchi	NON	NON	NON	NON	NON	17
tout compte fait	7	6	0.86	0.995	0.068	390
tout court	0	6	2.49	0.985	0.046	1149
tout de même	34	13	0.74	0.991	0.017	13315
tout du long	NON	NON	NON	NON	NON	302
toutefois	NON	NON	NON	NON	NON	20576
tout juste	17	13	0.45	0.982	0.038	2055
tout juste de	4	6	0.60	0.982	0.107	197
tout plein de	NON	NON	NON	NON	NON	1014
tout sauf	12	9	0.46	0.995	0.075	158
tout spécialement	4	7	0.96	0.997	0.031	164
tout un chacun	NON	NON	NON	NON	NON	260
très très	3	14	0.51	0.991	0.081	356
une espèce de	8	6	1.87	0.981	0.046	12365
un lendemain	8	8	0.56	0.993	0.072	505
un petit peu	8	14	0.60	0.983	0.048	692
un surcroît de	NON	NON	NON	NON	NON	454
un tas de	23	9	1.30	0.990	0.023	4352
venir de	21	15	0.38	0.984	0.056	35884
vis à vis de	2	12	0.49	0.982	0.052	3384
voilà	3	13	0.75	0.984	0.033	90090
vu que	0	10	0.93	0.981	0.027	1230
zut	0	10	0.99	0.987	0.037	525