Sophocles's Play: Greek Theater and Psychological Game Theory

Laurent Gauthier

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Abstract

The application of economic approaches, in particular game theory, to literature (Brams 2011) or to historical narratives (Mongin 2018) has seen some development over time but has generally remained an off-the-run endeavour, one important issue being that they may reflect the authors' interpretation more than the underlying texts. A loosely related body of research, focused on quantitative approaches to character relations in literature, has shown their complexity but not provided any theoretical framework (Kenna, MacCarron, and MacCarron 2017; Labatut and Bost 2019). We aim to bridge this gap by focusing on decision in drama as devices for writers to produce works of optimal interest to their audience. We use the apparatus of psychological game theory (Gilboa and Schmeidler 1988; Battigalli and Dufwenberg 2020) in order to represent the tension between surprise and convention in literary work, and obtain certain theoretical optimal patterns. We test this model on the earliest plays available, from the Greek theater of the 5th century BC, which were produced in a highly competitive environment. We show that the frequency of refusals and of important decisions, the unpredictability of these important decisions, the distribution of decisions among characters, and of the timing between actions, all behave in a manner consistent with the model.

Keywords: Ancient Greek theater, psychological game theory, games and literature

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There are certain fields in economics where it is difficult to associate a theoretical model with data. This is particularly true in cliometrics, because the desired data is often not available, and above all in the cliometrics of ancient history, for data is so sparse. One example of such difficulty, albeit not strictly related to ancient history, is that of literature: economic analysis may help put ancient or medieval texts into a new perspective, but how exactly can one relate the models and the data? There have been in fact quite a few attempts at directly modeling particular texts, as Brams (2011) shows in his book. The models attempt to represent the decisions of characters, and more specifically their strategic interactions. However, since every such model is built in an adhoc fashion for every situation, one cannot really test anything: there are, in essence, as many models as there are datapoints. In contrast, there has also been a substantial volume of research on the empirical patterns of characters interactions in literary texts. In their book, Kenna, MacCarron, and MacCarron (2017) review some of this work, and they apply the tools of network analysis to various mythological texts; Labatut and Bost (2019) offer a survey of character network research. In general, these empirical approaches rely on complex systems analysis and, while they can look at the data in all its granularity, they do not offer any theoretical model for the patterns that emerge. We hence have models on one side, data with patterns on the other, and nothing in-between.

In this article, we will try and combine both perspectives, economic and data-driven. We will focus on the decision structure in the oldest theater texts available to us, those of ancient Greek tragedy. We are not interested, however, in the characters' decisions for their own sake, but instea in how the playwright constructed the play in order to please the audience. Theater, at the time, was a highly competitive affair: plays were written to win the audience and judge's votes, in a unique representation during a religious festival. Considering these ancient Greek texts, we follow a cliometrics & complexity approach, by developing a microeconomic model accounting for the optimal selection of the importance, form and timing of decisions, and examining the data with complex systems tools. In order to account for the strategic choices made by the author, we rely on psychological game theory, which has recently been reviewed by Battigalli and Dufwenberg (2020). Research in cliometrics & complexity has mostly been concerned with economic questions (Bastidon et al. 2019, 2020; Bastidon and Parent 2022; Abry et al. 2022), but it has also addressed historical strategic behavior with the tools of complexity sciences (Gonzales-Feliu and Parent 2016). Our approach to the data, relying on network construction and the identification of the generating mechanisms for particular distributions, follows the same principles.

In the first section, we review existing research on the economic analysis of literature, focusing on the applications of game theory to literature, on the empirical study of character networks and on the few works that have addressed author-audience games. The second section concentrates on ancient Greek tragedy and shows why it is particularly suited for our empirical analysis. We discuss how one may define decisions in a manner consistent with ancient and current philosophy. Then, we build general models for the playwright's choices, based on psychological game theory, concerning the structure of the play, in particular the selection of alternatives, the semantic importance of events, and their timing. Finally, we drill down into the data: we discuss the identification of decisions from the Greek text, and tests several aspects of the economic model. We focus on character interactions, the timing of events, and the predictability of their decisions as a function of social standing.

1 The Economic Analysis of Literature

How does economics help in the understanding of literature? We first address the links that have been drawn between game theory and literature. Then, we look into the modeling of character networks, and finally consider the game between author and reader.

1.1 Literature and Game Theory

The application of game theory to literature has been explored by economists as much as literature specialists. The Romanian school of mathematical poetry, mainly focused on the combinatoric and probabilistic modeling of literature, tackled some texts with a game-related perspective (Davey 1984). Later, de Ley (1988) using a less general and more standard perspective, looks into several examples of associating simple games to particular junctures in a story, in particular in texts from French author Maupassant. Brams (1994) gives a survey of the work that had been done to that point, which was mostly not quantified, but made use of the general ideas of game theory in order to illustrate various ideas in the study of literature. Holler (2007) considers Machiavelli's writings under the light of game theory, without building actual games however. Pillet (2007) constructs a few simple games based on some of Sartre's plays. Reeb (2009) analyzes the *Adventures of Huckleberry Finn* with various games, essentially in order to lay out the consequences of the characters' choices. In his book, Brams (2011) looks at a broad range of applications of game theory in the Humanities, and gives many examples of the application of simple quantified games to literature, ranging from the Bible to Renaissance drame. Brams also proposes a systematic classification of 2x2 games, the most common in applications to literature, depending on the shape of the payoffs. Chwe (2014) proposed in his book a systematic analysis of Jane Austen's works, applying game theory to study the optimality of the main characters' decisions. Wainwright (2016) in his extensive study shows how the whole gammut of standard games, such as the game of Chicken or the Prisonner's Dilemma, can be found in post-war American literature.

The field of *Analytic Narratives* (Bates et al. 1998; Levi 2004; Mongin 2016) can be included as part of the relationship between game theory and literature, because it operates in very much the same way. Historical situations are analyzed in the light of game theory, so when these situations are known from texts, it comes down to analyzing literature. This is a different situation from the economic analysis of historical contracts or of institutions, for example, which may resort to game theory, but does not involve the translation of a unique strategic situation read from a text into a game (Pénard 2008). The analysis of the battle of Waterloo (Mongin 2018), or of Caesar's decision to walk into the Roman Senate on the day of his death (Crettez and Deloche 2018), for example, can be considered as applications of game theory to literature.

There are two fundamental issues with these applications of game theory to literature. First, there is no methodology that specifies how, given a text, one should extract games worth of interest. In fact, the mapping from text to game is entirely arbitrary; one cannot exactly say which part of the text corresponds to which aspect of the resultiing game, unlike in the case of a historical contract that would be formalized, for instance. This layer of interpretation implies that it is fundamentally not the text that is analyzed, but rather what the economists have read into it. This is probably one of the reasons why literature researchers and historians have not paid much attention to these endeavours. Second, whatever theoretical perspective may be represented by these games, it cannot be tested and confronted to empirical results, because there are at most a handful of data points in each case. While they are engaging illustrations of game-theoretical approaches, these results do not help much in understanding the workings of literature.

1.2 Analysis of Character Networks

Literary texts have also been extensively scrutinized with the tools of network analysis, as surveyed by Labatut and Bost (2019). Some have focused on the general logic of constructing character networks and on the various network metrics that may be used to comment on the texts (Elson, Dames, and McKeown 2010; Rochat 2014; Waumans, Nicodème, and Bersini 2015; Bonato et al. 2016). Some have focused on specific texts or genres, such as Greek tragedy

(Rydberg-Cox 2011), *Alice in Wonderland* (Agarwal et al. 2012), the *Iliad* (Kydros, Notopoulos, and Exarchos 2015; Venturini et al. 2017), or the *Odyssey* (Miranda, Baptista, and de Souza Pinto 2018). While there are numerous studies of this kind, they have not become mainstream and tended to be published as conference papers or in digital humanities venues. We can draw a distinction between these approaches and those which, using the same tools, have focused on historical texts and attempted to explain their network properties in the light of the historical context, such as Alstola et al. (2019), for example, on Neo-Assyrian votive inscriptions. Another such example is the book by Kenna, MacCarron, and MacCarron (2017) on the quantitative analysis of myth, which addresses the use networks in the context of comparative mythology.

While all the above are somewhat connected to economics through the use of networks, there is another related domain of import from an economic standpoint: predicting the box office performance of movies. Although it pertains to films, the actual analysis relies on scripts, scenarios, and various movie features, and in that sense recoups the question of understanding literature. Indeed, while some studies consider movie reviews or social network effects in order to understand their box office sales, others focus on the film's attributes and story. In the recent survey by McKenzie (2022), out of 26 studies that looked to explain movie performance as a function of the movie's attributes, 22 used AI or machine learning and only 4 followed a more traditional econometric approach (Derrick, Williams, and Scott 2014; Bharadwaj et al. 2017; Hofmann-Stölting et al. 2017; Del Vecchio et al. 2021). This points to the fact that there is no agreed-upon valid underlying model for the audience's taste in movies. Related research includes the way in which one can automatically associate a written story to an analysis framework; for example Mourchid et al. (2019) looks into how to map the semantics of character interactions to multiple network representations.

The main drawback of this line of research is symmetrical to the issues we raised in relation to game-theoretical approaches: there is much data, but no model. Since there is no fundamental logic as to why the networks thus analyzed should have a particular form, much of this research ends up commenting various network metrics in light of otherwise known features of the text. As Venturini et al. (2017) conclude: "the approaches that we outline above do not attempt to produce new knowledge about the literary text and advance the understanding of Homer's epic".

1.3 Author-Audience Games, and What to Look for in a Text?

One way to relate both angles we have discussed so far is to not consider the games described within the text, but rather the game that the text itself plays. Brams (1994) mentionned in passing that the game between the author and the reader could be worth exploring, using the then nascent field of psychological games or information-dependent games. The idea had been brushed upon in literary research, wihout formalization (Popovici 1984). More recently, Sack (2013) looked into the manner in which the narrative depends on the network structure of the text, which relates the author's craft with the reader's perception. Lauwers, Deneire, and Eelbode (2015) leveraged game-theoretical ideas in order to propose a formal approach to the evaluation of the quality of literary work, conscious of the writer's strategy.

With the only economic theoretical research work that has addressed the question, Ely, Frankel, and Kamenica (2015) give a detailed modeling of suspense and surprise, contrasting the two, and apply it to the study of sports games. Depending on the games rules, which affect the probability of scoring and the significance of the score changes each time, suspense or surprise are maximized. They also propose that this approach be applied to literary works, and give some theoretical examples, but no actual application. One important aspect of the model is that for suspense and surprise to be operative, one needs to sometimes realize a bad outcome: some stories need to end badly, if one is to maintain suspense. Studies in how we receive text show that one is affected by surprise and by the fullfilment of expectations as well (Miall 1989, 1998, 2006).

Psychological research shows that it is not surprise about the narrative arc that matters, because knowing the end of a story does not negatively affect the enjoyment out of it (Leavitt and Christenfeld 2011). In fact, the whole of ancient Greek tragedy is based on mythical stories that everyone knew about, so that there could not be any surprise as to what would happen (Romilly 1998). Ancient Greek playwrights sometimes treated exactly the same subjects as others had before, just like a movie "reboot" today. Romilly actually proposes to define Greek tragedy as knowing something bad is going to happen, knowing precisely what is going to happen, but not when and how it is going to happen. This does not preclude a notion of suspense and surprise, due to what she terms the "theatrical illusion" or "literary illusion": the fact that one can relive all the moments in an action that one nevertheless knows well. There is however a specific aspect in Greek tragedy, the fact that one does not even need to have seen or read it previously in order to know what will happen, because it is always announced in the play.

In all, if it is not the story that matters, then it must be the details in the way in which it is delivered. Human or anthropomorphic behavior, as told in stories, relies at the core on decisions at every instant. Among all the dimensions along which one could project a literary work, we can therefore focus on characters' decisions, by tracking them systematically. These decisions, big and small, effectively constitute the architecture of a story. This approach will contrast with that of focusing on a particular decision in a literary work, as has been the case with applications of game theory to literature, or considering all characters interactions indiscriminately, as has been the case with chararacter network analysis.

2 The Case of Ancient Greek Tragedy

In order to define a finite corpus of texts to analyze, we choose to concentrate on ancient Greek drama, for several important reasons. First, drama, as opposed to narrative, creates a neat distinction between the actions that takes place on stage, and stories or narratives that may exist within the play. As we need to systematically identify decisions, it is easier to do so based on what is represented than trying to infer such decisions from a more or less precise narrative. Second, ancient Greek theater from the 5th century BC is the oldest form of drama whose texts are available to us. Third, as we mentioned earlier, ancient Greek theater represented stories that were already known to the audience, and as a result we can discount any effect due a surprise in the narrative arc. Finally, plays were shown a single time, in a competition, where the playwright and their rich sponsor gained significant prestige if they won; this insures that the plays were written with the objective of pleasing the public.

2.1 Greek Theater in Context

The first tragic contests in Athens are reckoned to date back to 534 BC, during the tyranny of Pisistratus (Saïd and Trédé [1990] 1999), but pre-theatrical forms of spectacle of a dramatic nature are likely to have taken place from the second millennium BC onward, for example in Crete. In the archaic period (8th century to the beginning of the 5th century BC), religious manifestations would have associated the games of actors, costumes, and spectators, and perhaps would have combined actors, costumes and an audience, in the form of dithyrambs on heroic themes. The theater texts we have today all come from Athens, starting in the 5th century. Although playwrights continued being active later in the hellenistic period (3rd century BC to the 1st century BC), scholars in Alexandria at that time established a canonical corpus from the Classical period, the source of most of what has been transmitted to us, and the works available to us are concentrated in the 5th and the 4th centuries.

Even though the very word of "theater" comes from the greek θεάομαι, for "watching with attention", theater in 5th century Athens was much more than a simple representation, as it was deeply embedded in a religious and political background. Attending a theater representation was fondamentally the same thing as attending the people's Assembly (Villacèque 2013). The plays could however not be qualified as politically engaged, as they did not address contemporary events (Vernant and Vidal-Naquet [1972] 2001). Theater plays were represented only once, during the Great Dionysia, in a high-stake competition where each playwright was sponsored by a rich Athenian. The text followed complex language metric constraints, in particular for the chorus.

In the 5th century, Athens was the driving force behind the effervescence of classical Greece. The city created the bases of democracy in 507, and improved its mechanisms over time. Strengthened by its victory of 479 against the Persians, it created a maritime empire with the League of Delos, intended to prevent future attacks, which extended to the Black Sea. In 454 the league's massive treasury was moved to Athens; and a large part of the resources resulting from this empire were centralized, which allowed the city to redistribute considerable wealth, with, among other things, the holding of major festivals and the construction of many monuments, such as the Parthenon. Athenian hegemonic power clashed with Sparta and its Peloponnesian League in the last third of the 5th century, but neither this conflict, nor the constraints of the war, nor the Athenian defeat in 404 and subsequent political upheavals stopped the holding of festivals and theater contests. Theater was associated with the city at the center of its empire: during the procession of the Great Dionysia before dramas were played, the sons of the Athenians who had died in combat paraded to honor them, and the tribute collected from the members of the league was exhibited on stage (Saïd and Trédé [1990] 1999). At each important step in the history of Athens in the 5th century, one can associate particular plays as illustrations: Debnar (2005) relates Aeschylus's *Persians* with the importance of the sea for the city, the *Orestia* with the foundations of democracy and the justification of imperialist behavior, Sophocles' *Ajax* with war and the prominent role of many Athenians as rowers, Euripides' *Heraclids* with the start of the Peloponnesian War and the need for Athens to defend its territory, *The Suppliants* with the consequences of the battle of Pylos and of the ensuing peace, and finally Sophocles's *Philoctetes* and the Euripides' *Orestes* with the multiple reversals which took place between the Peace of Nicias in 421 and the expedition to Sicily.

2.2 Decisions in Tragedy and their Identification

The question of decisions in classical literature has been addressed extensively, and often in relation to the notion of will or free will, from "Homeric psychology" (Snell 1953; Dodds 1951; Darcus Sullivan 1995) to later literature. In particular, these works identified the origin of agency in Greek thought with tragedy, and the genre was later closely studied in relation with decision and free will (Vernant and Vidal-Naquet [1972] 2001; Ponchon 2007; Mishliborsky 2019; Cowley

2001; Segal 1986; Sewell-Rutter 2010). At a more micro level, some focused on the detailed mechanics of character interactions without specifically addressing decisions (Mastronarde 1979; Bain 1981). For example, Mikalson (1989) looked into invocations of the gods to which no one responds in tragedy. Looking at decisions from the somewhat distant perspective of the narrative arc, in order to find the characters' expression of agency and free will, can leave a lot of room for interpretation without pointing to precise instances of decisions. Hence, the way classics has approached decision in ancient texts is not directly useful to us, and we need to define a more appropriate methodology.

We can turn to ancient philosophy, which can give us an almost contemporary account of how will and decision could be understood. Indeed, the notion of decision has been studied by Aristotle in the *Eudemian Ethics* and in the *Nicomachean Ethics*. Aristotle considers three levels at which decisions operate, in a broad sense. First, there is the commitment which is a rational act and which takes place over time (προαίρεσις); it is a form of self-conditioning. This underlies desire or will, at the second level, and from there we want something (βούλομαι). Finally, the actual decision concerns the practical implementation of this will, and the necessary trade-offs in preferences, through deliberation (βουλεύω), and this decision takes place at a given instant and does not extend over time. It is a given reaction to a given situation. The decision does not always require a preliminary choice which frames it, since it can emanate from an initial appetite. Mendel (1998) summarized this chain of events fairly concisely: "*being-willing-acting*".

One particular aspect of drama is that it stages situations. We can hence establish a distinction between a will or a decision directly expressed by a character and one that would be reported within a dialogue. Will and decision occur at a specific point in time and can hence be precisely identified. We will therefore focus on the decisions that take place on stage, and not those that are simply related.

In light of the definition of decision we have proposed, we need to look for all expressions of will, however they may be formulated, and all subsequent decisions, since a decision necessarily depends on a prior expression of will. A decision could be in opposition with an expression of will, or go along with it. Indeed, once a character expresses a will, they may eventually execute it. In many other cases, another character may execute it, or refuse to execute it. We can hence characterize the decisions: they can be an acceptance, a refusal, or a limited (or conditional) acceptance. The expression of the decision itself can also be done by an action or by words, or both (one does something, or one says that one is going to do it, for example). A decision can itself also give rise to another decision: indeed, a character may accept or refuse, for example, that another character has agreed to take an action. Decisions or expressions of will can further be categorized as a function of their importance from the standpoint of the characters. This categorization is semantic, and necessarily relies on an interpretation of the text, not only that of the decision *per se*, but also the surrounding context. In most cases, there is not much ambiguity as to what degree of importance can be attached to a character's actions in a particular situation.

Some actions, even though they can be categorized as expressions of will, may be taken into account separately. The reiteration of a will, in particular, corresponds well to a will, in the sense that it can be at the source of the expression of a decision, but it is based on a first expression of this will, and is logically linked to it. It therefore seems appropriate to distinguish this case. Likewise, specifying a will more precisely reflects is akin to an expression of will, but at the same time linked to a prior expression of the same will.

3 Building the Optimal Play Architecture

Based on our description of ancient Greek theater, and based on the type of information we may be able to structure out of theater plays, we can build a formal representation of how a play operates. Given precise definitions for characters, for various interactions, and in particular for decisions, since we expect they would have a certain importance, it is possible to define a strategy that the author would follow relative to the audience. This is not considering the potential strategy in interactions between characters, from their own perspectives, since these strategic behaviors fall under semantic aspects of the play. Rather, the strategic aspects we are interested in are concerned with how the author optimally decides to distribute character interactions and events throughout the play, in order to please their audience. There are naturally many literary and artistic dimensions in the writing of a play, which all affect the degree of pleasure that the audience will experience, and which are difficult to capture in a formal approach. Based on our discussion of the notion of surprise, and of the importance of the details of the execution of a play, we will concentrate on how the audience may be surprised through the articulation and the structure of the play's elements. Our model would in fact also be applicable to novels or stories, but in order to fully account for the wiring of this type of work, one would need to model the occurrences of descriptions as well as the function of an omniscient narrator. Hence, we choose to specifically focus on theater, where narration emanates from the interactions between the characters.

While Ely, Frankel, and Kamenica (2015) provided specific definitions of suspense and surprise, we will rely on the more general framework of psychological game theory, which has recently been surveyed in Battigalli and Dufwenberg (2020). Generally, these games diverge from the usual framework of game theory in that the payoffs may depend on the players' beliefs. The study of games where the payoffs may depend on the players' beliefs was first addressed in the late 1980s, and the complex mathematical framework left some issues unaddressed (Gilboa and Schmeidler 1988; Geanakoplos, Pearce, and Stacchetti 1989). More systematic proofs for the existence of equilibria, in a more general framework were later provided (Battigalli and Dufwenberg 2009; Battigalli, Corrao, and Dufwenberg 2019). In the case at hand, we will consider that the audience has some beliefs, both about the real or empirical probability of events happening and about the author's strategy. This latter dependency makes the author/audience game a psychological game. The game we will consider between the author and the audience is nevertheless very simple, because the play is represented only once, and the audience votes immediately after; as a result, there is no separate action that the audience may apply a strategy to, apart from simply more or less appreciating the play.

We consider the game between two players, the writer w and the audience a. The writer decides certain events, and the audience's utility depends on these events. In turn, the writer's utility is a function of the audience's utility. We will in fact consider that the writer's utility is simply equal to the audience's. The writer plays, but the audience cannot play, they hence enter the game only through the expression of their utility. A play structure may be defined as a series $(\tau_i, C_i, I_i, A_i, D_i)_{i \leq N_E}$, where $(\tau_i)_{i \leq N_E}$ are the times when actions take place, $(C_i)_{i \leq N_E}$ the character involved, $(I_i)_{i \leq N_E}$ the semantic importance attached to the situation, $(A_i)_{i \leq N_E}$ the type of action, which may be an expression of will or a decision, and $(D_i)_{i \leq N_E}$ the nature of the decision if the action is a decision. There are N_C characters.

First, we concentrate on a simple model for a character's decision between two alternatives, then we look into how the semantic importance of outcomes may play a role and interact with the decisions. Next, we extend the model to multiple outcomes, so as to reflect the selection of which character may act at a point in time. Finally, we examine the timing of events.

3.1 Simple Character Decision Model

We begin by treating the case of an action that consists in a binary decision, in which the writer needs to surprise the audience without either systematically stepping away from the usually observed conventions of normal life. We will denote this particular form of writer-audience interaction with D, for decision. We are interested in the probabilites that are applicable to outcomes at a particular juncture, which the writer can decide, and these outcomes can take values in $\Omega_D = \{u, d\}$ (up or down); we will denote with p the probability of $\{u\}$. We set π_D^0 the probability that is observed in reality, or estimate based on experience, and we will write $\pi_D^0 = \pi_D^0(u)$ for commodity. We also write π_w^1 for the probability distribution that representes the writer's first-order belief about what they will play, and π_a^1 is the audience's first-order belief about what the writer will play. We consider two components in the expression of the audience's utility derived from experiencing theater.

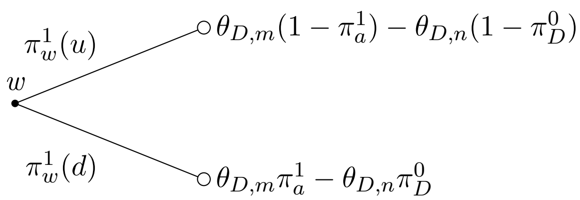
- There is a straight benefit $U_{D,m}$ from surprise which is proportional to the distance between the outcome and the audience's belief about the writer's strategy, which we write $U_{D,m}(\omega) = \theta_{D,m}\left(1 - \pi_a^1(\omega)\right)$.
- However, the fact that conventions are actually respected in the observed outcome is also beneficial in the highly conformist Greek society, so there is a conformism benefit $U_{D,n} = -\theta_{D,n}\left(1 - \pi_D^0(u)\right)$.

The total utility of interest to the writer is hence $U_D = U_{D,m} + U_{D,n} + U_{D,t}$. With this setup, we can show the following first result:

Proposition 3.1 (Simple Decision)**.** *At the equilibrium, the writer will allocate the following probability for the event* $\{u\}$*:*

$$p_D^* = \frac{1}{2} - \frac{\theta_{D,n}}{4\theta_{D,m}}(1 - 2\pi_D^0).$$

Proof. We obtain the following tree for the writer's decisions, where we show a unique utility outcome, since utilities are the same for the playwright w and the audience.



At the equilibrium, the expectations are rational and the writer's actual strategy correspond to their own first order belief and to the audience's. As a result we can write the expected utility as a function of the probability $\pi_w^1(u) = \pi_a^1(u) = p$. We can express $G_D(p) = \mathbb{E}[U_D]$ as a function of p:

$$G_D(p) = 2\theta_{D,m}p(1-p) - \theta_{D,n}\left(p(2\pi_D^0 - 1) - \pi_D^0\right).$$

Since we have $\frac{\partial^2 G_D}{\partial p^2} = -4\theta_{D,m} < 0$, we can solve for the first order conditions to find $p^* =$

$\arg\max_{p\in[0,1]} G_D(p)$, and we obtain:

$$p_D^* = \frac{\theta_{D,m} - \frac{\theta_{D,n}}{2}(1-2\pi_D^0)}{2\theta_{D,m}}$$
$$= \frac{1}{2} - \frac{\theta_{D,n}}{4\theta_{D,m}}(1-2\pi_D^0).$$

□

Then at the optimum $G_D = G_D(p^*) = \frac{\theta_{D,m}-\theta_{D,n}}{2}$, and $p_D^* = \frac{1}{2} - \frac{\theta_{D,n}}{4\theta_{D,m}}(1-2\pi_D^0)$. In this case, we can see that the optimal probability for the writer to choose $\{u\}$ depends on π_D^0 in a straightforward fashion: we have $p_D^*|_{\pi_D^0=0} = \frac{1}{2} - \frac{\theta_{D,n}}{4\theta_{D,m}}$ and $p_D^*|_{\pi_D^0=1} = \frac{1}{2} + \frac{\theta_{D,n}}{4\theta_{D,m}}$. The optimal probability increases or decreases as a function of the empirical probability, but the magnitude of this effect is modulated by the ratio $\frac{\theta_{D,n}}{\theta_{D,m}}$.

We can see that the expected utility is a linear and increasing function of the preference parameter θ_m. Hence, if the parameter θ_n driving the degree of conformist preferences is constant across situations, while θ_m, the appetite for surprises, may depend on the situation, then in situations where the expected gain is greater, the writer's optimal probability is closer to $\frac{1}{2}$. Indeed, if $\theta_{D_1,m} > \theta_{D_2,m}$ for two decision situations D_1 and D_2, then $G_{D_1} > G_{D_2}$, but also $\left|\frac{1}{2} - p_{D_1}^*\right| \le \left|\frac{1}{2} - p_{D_2}^*\right|$, for the same $\pi_{D_1}^0 = \pi_{D_2}^0$. In all generality, even if the audience's expected empirical probability is extreme, the probabilities for the binary outcome are close to $\frac{1}{2}$, as far as the preference for conformism is limited.

3.2 Importance of Outcomes

The junctures at which actions take place can be semantically classified as important or not, and we now focus on the writer's decision to make a particular action important or not, a situation we will denote as I (for importance). While in reality there would be a continuum, we simplify it down to two cases $\{h, l\}$ (high and low importance). The fact that a situation would be important or not plays itself a role in the audience's utility, in addition to the fact that a more important action will magnify the utility attached to the writer's strategy for that action. We capture the two contributions from conformism and surprise, related to the audience's beliefs about the writer's strategy, as well as constant terms c_h and c_l for the underlying's action utility. The parameters M_h and M_l with $M_h > M_l$ capture the magnification of important actions. The utility related to the author's choice pertaining to importance can hence be written:

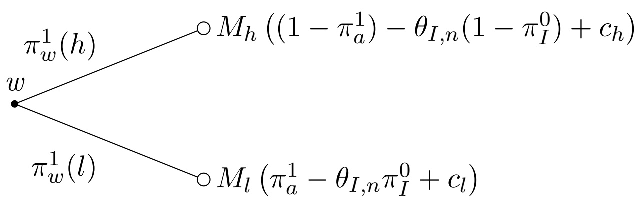
$$U_I(\omega) = (M_h\mathbb{I}_{\omega=h} + M_l\mathbb{I}_{\omega=l})\left(1 - \pi_a^1(\omega) - \theta_{I,n}(1-\pi_I^0(\omega) + (c_h\mathbb{I}_{\omega=h} + c_l\mathbb{I}_{\omega=l})\right).$$

With these assumptions, we have the following proposition:

Proposition 3.2 (Importance of Decision)**.** *At the equilibrium, the writer will allocate the following probability for the event* $\{h\}$*, corresponding to a high importance:*

$$p_I^* = \frac{1}{2} + \frac{M_h c_h - M_l c_l - \theta_{I,n}\left(M_h(1-\pi_I^0) - M_l \pi_I^0\right)}{2(M_h + M_l)}.$$

Proof. We have the following game:



Solving for the optimum at the equilibrium where $\pi_w^1 = \pi_a^1 = p$, we find the optimal probability that maximizes utility, based on first-order conditions:

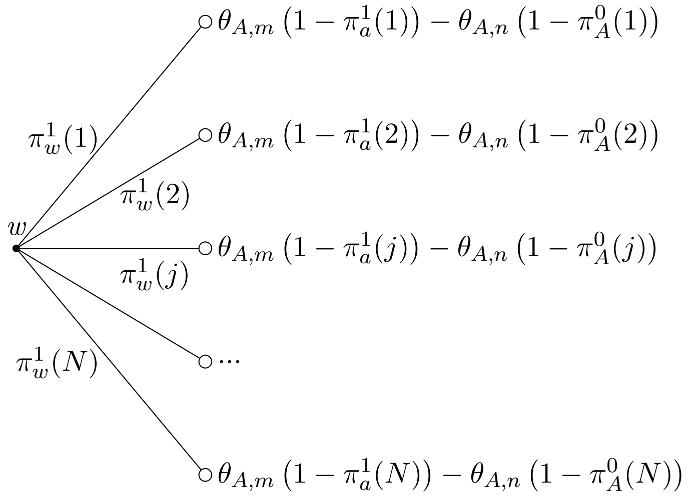
$$p_I^* = \frac{1}{2} + \frac{M_h c_h - M_l c_l - \theta_{I,n}\left(M_h(1-\pi_I^0) - M_l \pi_I^0\right)}{2(M_h + M_l)}.$$

□

If $\theta_{I,n} = 0$, then we have $p_I^* = \frac{1}{2} + \frac{M_h c_h - M_l c_l}{2(M_h+M_l)}$, so that with our basic assumptions $p_I^* > \frac{1}{2}$. In fact, if $M_h = M_L = 1$, and there is no particular amplification effect due to importance, but the underlying gain is greater on actions with more importance, then $p_I^* = \frac{1}{2}(1 + c_h - c_l) > \frac{1}{2}$. On the other hand, if $\theta_{I,n} > 0$ and $M_h = M_L = 1$, then $p_I^* = \frac{1}{2}\left(1 + c_h - c_l - \theta_{I,n}\left(1 - 2\pi_I^0\right)\right)$. Hence, if variations in expected utility across particular junctures in a drama are driven by a varying appetite for surprise, according to Propositions 3.1 and 3.2, then it will be optimal for the writer to allocate more importance to these situations, and, as a corollary, the situation outcome should tend to be less driven by expectations based on the underlying reality.

3.3 Optimal Playwright Strategy with Multiple Choices

We now consider a more general situation, denoted by A. The choices in this more general situation could represent which character acts next, for example. We only consider the contributions from conformism and surprise, The playwright may pick one action out of a range of N possibilities, where the outcomes are expressed as follows:



We have the following proposition, which reduces to Proposition 3.1 with $N = 2$:

Proposition 3.3 (Multiple Action Choices)**.** *At the equilibrium, the writer will allocate the following probability among a list of alternatives indexed by* $j \in [1..N]$*:*

$$p_j^* = \frac{1}{N} + \frac{\theta_{A,n}}{2N\theta_{A,m}}\left(N\pi_A^0(j) - 1\right).$$

Proof. At the equilibrium, rational expectation allow us to consider that $\pi_w^1 = \pi_a^1 = p$. The writer's expected utility can therefore be written:

$$G_A\left((p_j)_{j\leq N}\right) = \theta_{A,m}\sum_{j\leq N} p_j(1-p_j) - \theta_{A,n}\sum_{j\leq N} p_j\left(1-\pi_A^0(j)\right).$$

Solving for the optimal strategy hence requires solving the following optimization program:

$$\max_{p\in\mathbb{R}^N} \sum_{j=1}^{N}\theta_{A,m}p_j(1-p_j) - \sum_{j=1}^{N}\theta_{A,n}p_j\left(1-\pi_A^0(j)\right)$$
$$\sum_{j=1}^{N} p_j = 1$$
$$\forall j \in [1..N], p_j \geq 0.$$

Using Kuhn-Tucker multipliers at the first-order conditions, at the optimum $(p_j^*)_{j\leq N}$ there exists $(\mu_j)_{j\leq N} \geq 0$ and λ such that for all $j \leq N$:

$$\theta_{A,m}(1-2p_j^*) = \lambda - \mu_j + \theta_{A,n}\left(1-\pi_A^0(j)\right),$$

and $\mu_j p_j^* = 0$. In addition, the condition that $\sum_{j=1}^N p_j = 1$ leads to:

$$\sum_{j\leq N} \mu_j - N\lambda = \theta_{A,m} + (N-1)(\theta_{A,n} - \theta_{A,m}).$$

If we assume that $p_j^* > 0$ for all j, then $\mu_j = 0$ and $p_j^* = \frac{1}{2} - \frac{\lambda + \theta_{A,n}\left(1-\pi_A^0(j)\right)}{2\theta_{A,m}}$. Then, since $\lambda = \frac{\theta_{A,n} - 2\theta_{A,m}}{N} + (\theta_{A,m} - \theta_{A,n})$, we obtain:

$$\begin{aligned} p_j^* &= \frac{1}{2} + \frac{2\theta_{A,m} - \theta_{A,n}}{2N\theta_{A,m}} - \frac{\theta_{A,m} - \theta_{A,n}\pi_A^0(j)}{2\theta_{A,m}} \\ &= \frac{1}{N} + \frac{\theta_{A,n}}{2N\theta_{A,m}}\left(N\pi_A^0(j) - 1\right). \end{aligned}$$

□

The condition $p_k^* > 0$ is equivalent to $2\theta_{A,m} > \theta_{A,n}\left(1 - N\pi_A^0(j)\right)$. Even if $\pi_A^0(j) = 0$, the condition is satisfied if $2\theta_{A,m} > \theta_{A,n}$, so that under these conditions, then every outcome has a certain probability of occurrence, which is all the more likely if the empirical probability of occurrence is larger. If π_A^0 is uniform, then we have $p_j^* = \frac{1}{N}$ for all j.

Let us consider a situation where only a subset ϕ of the N outcomes has a positive empirical probability, that is for $j \in \phi$, $\pi_A^0(j) = 0$. We assume that $2\theta_{A,m} > \theta_{A,n}$. We have $\sum_{j\in\phi} \pi_A^0(j) = 1$. We further assume that the empirical probabilities are the same across the possible outcomes, so that for all j, $\pi_A^0(j) = \frac{1}{|\phi|}$. In this case, we have for $j \notin \phi$:

$$p_j^* = \frac{1}{N}\left(1 - \frac{\theta_{A,n}}{2\theta_{A,m}}\right),$$

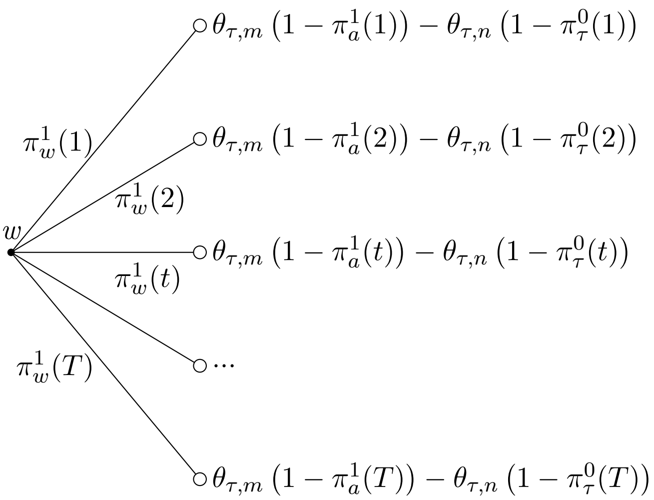
and for $j \in \phi$,

$$p_j^* = \frac{1}{N}\left(1 + \frac{\theta_{A,n}}{2\theta_{A,m}}\frac{N - |\phi|}{|\phi|}\right).$$

This simple example shows that, according to Proposition 3.3, outcomes that would be impossible in reality are given some weight as a function of the preference for surprises. The outcomes that are possible receive a lower probability than in reality.

3.4 Timing Distribution

The amount of time that takes place between actions worth of interest for the public is also part of the optimization that the playwright may carry out. In a fairly general setting, this problem is comparable to the so-called "hangman's paradox": how can a prisonner waiting to be hanged (over a finite period of time) be maximally surprised when the day arrives? Borwein, Borwein, and Maréchal (2000) tackled the maximization of surprise through time from a mathematical perspective, outside of a formal game-theoretic framework, and show that the optimal timing has an exponential-like form, but is very close to a uniform distribution. In the case of events taking place in a play, one cannot rely on pure randomness, because, as for the other determinants of the play's structure, the audience is likely to have certain expectations. We consider that when an event takes place, it is chosen out of a list of possible event times, which, in all generality, could be any one of the next verses in a play. This set is finite, and we write the payoffs corresponding to each choice in a manner very similar to the multiple choice we modeled previously. We write T for the number of possible times when events may take place, and $t \in [1..T]$.



Unlike in the case when one alternative j is selected by the playwright out of N alternatives, when this selection bears on an event, the audience experiences all the prior negative choices until the event actually takes place. Hence, if the playwright choses a time t for some event, then the audience will have experienced the fact that the event did not happen for all times $k < t$. The utility derived from this experience is hence not only dependent on the realization of the event at time t, but also on its non-realization at times $k < t$. The audience's utility if the event is realized at time t, as well as the writer's, is therefore of the form $\theta_{\tau,m}\sum_{k<t}\pi_a^1(k)+\theta_{\tau,m}(1-\pi_a^1(t))-\theta_{\tau,n}\sum_{k<t}\pi_\tau^0(k)-\theta_{\tau,n}(1-\pi_\tau^0(t))$. If $t=1$ is chosen, there is no prior non-realization.

Proposition 3.4 (Optimal Timing Choice)**.** *At the equilibrium, the writer will allocate the following probability among possible timings for an event indexed by* $t \in [1..t]$*:*

$$p_t^* = \left(\frac{2}{3}\right)^{t-2} p_2^* - \frac{\theta_{\tau,n}}{3\theta_{\tau,m}} \sum_{k=0}^{t-3} \left(\frac{2}{3}\right)^k \left(2\pi_\tau^0(t-k-1) - \pi_\tau^0(t-k)\right),$$

with $p_1^* = \frac{1}{2} - \frac{\lambda + \theta_{\tau,n}(1-\pi_\tau^0(1))}{2\theta_{\tau,m}}$ *and* $p_2^* = \frac{1}{3}(1+p_1^*) - \frac{\theta_{\tau,n}(2\pi_\tau^0(1)-\pi_\tau^0(2))}{3\theta_{\tau,m}}$*, and where* λ *is such that* $\sum_t p_t^* = 1$.

Proof. At equilibrium, we can also assume that $\pi_w^1 = \pi_a^1 = p$, as in prior cases, and we can write the writer's expected utility as follows:

$$G_\tau\left((p_t)_{t\leq T}\right) = \sum_{t=2}^{T} p_t \sum_{k<t}\left(\theta_{\tau,m}p_k - \theta_{\tau,n}\pi_\tau^0(k)\right) + \sum_{t=1}^{T} p_t\left(\theta_{\tau,m}(1-p_t) - \theta_{\tau,n}(1-\pi_\tau^0(t))\right).$$

The optimal strategy requires solving:

$$\begin{aligned}
&\max_{p\in\mathbb{R}^T} \sum_{t=1}^{T}\theta_{\tau,m}p_t(1-p_t) - \sum_{t=1}^{T}\theta_{\tau,n}p_t\left(1-\pi_\tau^0(t)\right) + \theta_{\tau,m}\sum_{t=2}^{T}p_t\sum_{k<t}p_k - \theta_{\tau,n}\sum_{t=2}^{T}p_t\sum_{k<t}\pi_\tau^0(k)\\
&\sum_{t=1}^{T}p_t = 1\\
&\forall t\in[1..T], p_t \geq 0.
\end{aligned}$$

Using Kuhn-Tucker conditions, at the optimum p^* there are $(\mu_t)_{t\leq T} \geq 0$ and λ such that:

$$\lambda - \mu_1 = \theta_{\tau,m}(1-2p_1^*) - \theta_{\tau,n}(1-\pi_\tau^0(1)),$$

and for all $t \in [2..T]$:

$$\lambda - \mu_t = \theta_{\tau,m}(2-3p_t^*) - \theta_{\tau,n}(1-\pi_\tau^0(t)) - \theta_{\tau,m}\sum_{k<t}p_k^* - \theta_{\tau,n}\sum_{k<t}\pi_\tau^0(k),$$

with $\mu_t p_t^* = 0$ for all $t \in [1..T]$.

We consider the difference between these expressions taken at $t+1$ and t, and obtain:

$$\mu_t - \mu_{t+1} = \theta_{\tau,m}(2p_t^* - 3^*p_{t+1}) - \theta_{\tau,n}(2\pi_\tau^0(t) - \pi_\tau^0(t+1)).$$

If we assume that for all t, $p_t^* > 0$ so that $\mu = 0$, then we get for $T > t \geq 2$:

$$p_{t+1}^* = \frac{2}{3}p_t^* - \frac{\theta_{\tau,n}(2\pi_\tau^0(t) - \pi_\tau^0(t+1))}{3\theta_{\tau,m}},$$

and

$$p_1^* = \frac{1}{2} - \frac{\lambda + \theta_{\tau,n}(1-\pi_\tau^0(1))}{2\theta_{\tau,m}}$$

and

$$p_2^* = \frac{1}{3}(1 + p_1^*) - \frac{\theta_{\tau,n}(2\pi_\tau^0(1) - \pi_\tau^0(2))}{3\theta_{\tau,m}}.$$

We can express the general term p_t^*, for $t > 2$, as:

$$p_t^* = \left(\frac{2}{3}\right)^{t-2} p_2^* - \frac{\theta_{\tau,n}}{3\theta_{\tau,m}} \sum_{k=0}^{t-3} \left(\frac{2}{3}\right)^k \left(2\pi_\tau^0(t-k-1) - \pi_\tau^0(t-k)\right).$$

The value of λ can be determined thanks to the condition that $\sum_{t=1}^T p_t^* = 1$. □

In order to have $p_1^* > 0$ and $p_2^* > 0$, for any values of $\pi_\tau^0(1)$ and $\pi_\tau^0(2)$, it is sufficient to assume $\theta_{\tau,m} - \theta_{\tau,n} > \lambda$ and $\theta_{\tau,m} > 2\theta_{\tau,n}$. In other words, $\theta_{\tau,m}$ needs to be large enough relative to $\theta_{\tau,n}$, so that the preference for surprise takes precedence over conformity.

If we assume that there is a t such that $p_t^* > 0$ and $p_{t+1}^* = 0$, then we have $\mu_t = 0$ and $\mu_{t+1} > 0$, and

$$p_{t+1}^* = \frac{2}{3}p_t^* + \frac{\mu_{t+1} - \theta_{\tau,n}(2\pi_\tau^0(t) - \pi_\tau^0(t+1))}{3\theta_{\tau,m}},$$

so that

$$\mu_{t+1} = \theta_{\tau,n}(2\pi_\tau^0(t) - \pi_\tau^0(t+1)) - 2\theta_{\tau,m}p_t^*.$$

The condition that $\mu_{t+1} > 0$ is equivalent to $p_t^* < \frac{\theta_{\tau,n}}{2\theta_{\tau,m}}(2\pi_\tau^0(t) - \pi_\tau^0(t+1))$. So, if p_t^* as expressed by the recurrence expression falls below a certain level, then it is null.

In order to simplify the analysis, if in addition we assume that $\pi_\tau^0(t) = \pi_\tau^0(t+1) = \pi_\tau^0(t+2)$, we obtain, since $p_{t+1}^* = 0$:

$$\mu_{t+2} - \mu_{t+1} = 3\theta_{\tau,m}p_{t+2}^* + \theta_{\tau,n}\pi_\tau^0(t).$$

Hence, $\mu_{t+2} \geq \mu_{t+1} > 0$, and we must have $p_{t+2}^* = 0$. We can see that if the empirical probabilities are flat, once after a certain time the optimal probability reaches zero, it stays at zero afterwards. Unlike in the case of a choice among multiple alternatives that does not extend through time, it is possible here that only the first alternatives receive a positive probability.

Notwithstanding these particular dynamics, we can see that the optimal timing of an event hence looks similar to a discrete geometric distribution, modulated by the empirical probability π_τ^0, until it reaches a low level under which it is likely to become null. If we consider the case where the audience's expectation is that $\pi_\tau^0(l) = 1$ for some particular time l, then $p_1^* = \frac{1}{2} - \frac{\lambda+\theta_{\tau,n}}{2\theta_{\tau,m}}$, $p_2^* = \frac{1}{3}(1 + p_1^*)$, and for $2 < t < l$, $p_{t+1}^* = \frac{2}{3}p_t^*$. At time l, $p_l^* = \frac{2}{3}p_{l-1}^* + \frac{\theta_{\tau,n}}{3\theta_{\tau,m}}$, and at time $l+1$, $p_{l+1}^* = \frac{2}{3}p_l^* - \frac{2}{3}\frac{\theta_{\tau,n}}{\theta_{\tau,m}}$. The high empirical probability translates into a relative increase of the optimal probability at that time l, which is then compensated by a commensurate drop in the following probabilities. However, if l is large enough, the geometric decline in p_t^* as t increases makes the variations negligible.

If the underlying empirical probability is itself geometric, we have $\pi_\tau^0(t) = c_q q^t$, for some $0 < q < 1$. In this case, we can calculate p_t^* for $t > 2$, if the parameters are such that this expression for $p_t^* \in [0, 1]$:

$$p_t^* = \left(\frac{2}{3}\right)^{t-2} \left(p_2^* + \frac{\theta_{\tau,n}}{\theta_{\tau,m}} c_q q^2 \frac{2-q}{3q-2}\right) - \frac{\theta_{\tau,n}}{\theta_{\tau,m}} c_q q^t \frac{2-q}{3q-2}.$$

Note that we always have $\frac{2-q}{3q-2} > 1$. We write $\eta = \frac{\theta_{\tau,n}}{\theta_{\tau,m}} c_q \frac{2-q}{3q-2}$ for simplification; the condition $p_t^* > 0$ is equivalent to:

$$\left(\frac{2}{3q}\right)^t > \frac{4}{9} \frac{\eta}{p_2^* + q^2 \eta}.$$

Hence, if $q < \frac{2}{3}$, then if the condition is verified at some point t_0, it will be verified for $t \geq t_0$. If η is small enough and $\eta \left(\frac{4}{9} - q^2\right) \leq p_2^*$ then the condition is always verified. If $q > \frac{2}{3}$, then there may be a t for which the condition is not verified.

Although there is a complex relationship between the underlying empirical probability and the optimal distribution, we have seen that for simple or regular underlying distributions, th optimal timing is close to a geometric distribution. The parameter of $\frac{2}{3}$, however, is not directly exploitable in practice. Indeed, the scale is arbitrary: it could be in terms of verses, words, or seconds. The total number of possible periods T, as understood by the audience and the playwright, could be expressed in any of these units. Nevertheless, the geometric decline, or exponential distribution as an approximation, appears to be a fundamental feature of this optimal distribution.

4 Decision Data in Ancient Greek Theater

While we have operated so far on a rather abstract notion of decision and event within theater plays, these notions can be applied to actual theater texts. Any expression of will or decision based on our definition can indeed be exactly mapped to an excerpt from the text, and to the characters involved. In this section, we begin by describing how we parsed and analyzed the text in order to obtain the dataset. Then, we examine the importance of characters' decisions, in relation with their predictability. Next, we focus on the way in which a character network is constructed through their decisions. Finally, we look at the timing of particular events.

4.1 Categorization of the Textual Data

All the actions of interest to us, expressions of will, decisions, and contextual elements, are generally interrelated. A decision will logically emanate from an expression of will, or some other decision. From an expression of will, there can also be a reiteration of this will. The same expression can also contain several of these elements at the same time, as for example the acceptance of a request which would be expressed by a request towards someone else. A straight expression of will, especially if it is not combined with another type of action, therefore appears in principle *ex nihilo*, while most other actions are dependent on previous actions. All these elements are hence organized in logical sequences of actions, as a network, and typically start from the expression of a will. We have also qualified the corresponding decisions: they may be important or not from the perspective of the character, they may be a factual error, and they may constitute a direct or indirect lie, intended to manipulate other characters. Each decision, according to our definition, also corresponds to an acceptance or to a refusal. A decision may also be expressed as an action by the character, independently of whether it is also communicated verbally or not.

For example, when Ajax states his intentions in the eponymous play, he expresses his will, which concerns himself only. In doing so, he is actually lying, since he intends to kill himself. This expression of will can be qualified as important, because it is from Ajax's standpoint:

> AJAX. – Then I will find some isolated spot, and bury this sword of mine, most hateful weapon, digging down in the earth where none can see[1].

In *Philoctetes*, Odysseus asks Neoptolemos to do something. This expression of will is not very important for either men. We can also note that Odysseus, as one of the leaders of the Greek army in Troy, has a much higher social standing than the young Neoptolemos, unproved in battle:

> ODYSSEUS. – Come, it is your task to serve as my ally in what remains, and to seek where in this region there is a cave with two mouths[2].

The young man responds and accepts to do what he was asked, which is an acceptance decision, not of much importance given the triviality of the task. In this case, Neoptolemos also expresses his acceptance decision as an action, since he physically does what Odysseus was asking:

> NEOPTOLEMOS. – King Odysseus, the completion of the task that you set me is not

[1]Sophocles, *Ajax*, 657-659; translation from Sophocles (1893).

[2]Sophocles, *Philoctetes*, 15-16; translation from Sophocles (1898).

> far off, for I believe I see a cave like that which you have described[3].

Expressions of will may lead to a refusal. In *Ajax*, the hero and military leader asks that he be killed, an expression of will. In this case, Ajax's request is flatly refused by the group of his sailors, subordinates, and by his captive slave (and mother of his child):

> Ajax. – Ah, you clan staunch in maritime skill, who embarked and stroked the oar-blade upon the brine, in you, in you alone, I see a defense against suffering. Come, slay me on top of these!
>
> Chorus. – Hush! Speak words of better omen! Do not cure evil by prescribing evil; do not increase the anguish of your mad disaster. [. . .]
>
> Tecmessa. – Ajax, my lord, I beg you, do not talk this way[4]!

Out of the 42 non-fragmentary plays which were represented in Athens in the 5th century, on which texts are available, we parsed a sample of 17 using the logic above. This includes all of Sophocles, all of Aeschylus and three plays from Euripides, in order to cover the largest time span as possible. We relied on the editions of the texts from Crane (2012), and we systematically identified decisions in the Greek text. One can rely on an annotation logic for the purpose of creating a usable dataset for cliometric analysis, along the lines of Mugelli et al. (2017), but without modifying the primary sources from Crane (2012) by inserting annotations, and rather keeping the annotations separate. Both can be combined automatically when necessary, with a pipeline logic (Burns 2019). This makes the entire work reproducible and modifiable, and if some annotations relating to decisions were to be changed, it would be immediate to measure the impact that this would have on the empirical results. This approach also allows for the automated lexicological analysis of decision language in relation with all the categorzations, although we have not used this possibility in the case at hand. We hence have a set of plays indexed by $j \in [1..N_P]$ where N_P is the number of plays in the sample. In each play j, there are characters indexed by $k_j \in [1..N_{C_j}]$, where N_{C_j} is the number of characters in play j. The characters interact through different actions, in particular expressions of will and decisions take place through time in each play j, at instants τ_{i_j}, where these instants can be measured in number of verses through the play. We have $i_j \in [1..N_{E_j}]$, where N_{E_j} is the total number of actions taking place in each play.

Table 1 shows various metrics across the 17 plays in our corpus. The date estimates (BC) for

[3] Sophocles, *Philoctetes*, 25-27; translation from Sophocles (1898).

[4] Sophocles, *Ajax*, 356-368; translation from Sophocles (1893).

the plays are obtained from Demont and Lebeau (1996). We can see that we have a sizable corpus of decisions, but there are some substantial variations across plays. More than half of all decisions are acceptance, so that in fact there are quite a few refusals; tragedy indeed often relies on characters not doing what they were asked. Further, we can see that over two thirds of the expressions of will are qualified as important, which is also fitting with tragedy, with many life-and-death situations. The aggregate rate of acceptance for decisions is close to $\frac{1}{2}$, as Proposition 3.1 led us to expect. In addition, the share of important decisions is well above $\frac{1}{2}$, as we anticipated from Proposition 3.2. Some of the variation in acceptance rates among plays can be associated to a trend over time, whereby Athenian theater put characters more and more frequently in decision situations, whose outcome was less and less certain, according to some historical research (Gauthier 2022).

Table 1: *Expressions of Will and Decisions in Each Play of the Corpus*

				Form of Expression			Qualification			
Author	Play	Date	Count	Will	Reiter.	Precision	Important	Error	Lie	Acceptance
Aeschylus	*Agamemnon*	458	27	78%	22%	0%	52%	0%	11%	56%
	Eumenides	458	30	77%	17%	7%	87%	0%	0%	83%
	Libation Bearers	458	24	67%	25%	8%	67%	4%	12%	96%
	Persians	472	16	94%	0%	0%	31%	0%	0%	94%
	Prometheus Bound	457	31	87%	13%	0%	39%	0%	0%	71%
	Seven Against Thebes	467	10	70%	30%	0%	90%	0%	0%	50%
	Suppliant Maidens	463	31	87%	13%	0%	52%	0%	0%	61%
Sophocles	*Ajax*	445	41	83%	12%	5%	83%	0%	10%	41%
	Antigone	442	19	68%	32%	0%	95%	0%	0%	42%
	Electra	414	43	72%	16%	12%	67%	16%	5%	60%
	Oedipus at Colonus	401	64	70%	28%	2%	70%	0%	0%	58%
	Oedipus Tyrannus	426	58	81%	14%	5%	78%	5%	2%	57%
	Philoctetes	409	48	77%	17%	6%	75%	0%	2%	62%
	Trachiniae	450	35	83%	14%	3%	66%	9%	3%	71%
Euripides	*Hekabe*	424	34	88%	6%	6%	76%	0%	12%	74%
	Herakles	414	26	77%	23%	0%	77%	0%	0%	50%
	Medea	431	31	77%	23%	0%	77%	3%	3%	42%
	Total or average		568	79%	18%	4%	70%	3%	4%	62%

4.2 Predictability of decisions

Social status was, in archaic and classical Greece, a significant factor in interpersonal relations, and characters themselves may hence be categorized. While this categorization may not be directly relevant from the standpoint of the dynamics in a play, it seems intuitive that the behavior one may expect from various characters should depend on their status, along various dimensions that were relevant for the ancient Greeks. Studies in the structure of archaic Greek societies point out the importance of wealth and certain notions of nobility (Duplouy 2005, 2007, 2014). The authority of men over women (Damet 2012), or of older people over the young (Corvisier 1986), have also been examined. In classical Athens, status can be perceived as a whole range of distinct situations, ranging from slaves to wealthy magistrates (Kamen 2013).

The statuses of the characters strongly in fact interact with the play structure. Indeed, in general and with a few exceptions, the bearers of more authority have a greater presence on stage. Table 2 displays the volume of words allocated to various character categories across our entire theater corpus. We can observe that men occupy two thirds of the speaking time, which constitutes an imbalance in relation to the natural sex ratio, presumably around 50%. Women, in relation to their share of the population, are under-represented in theater. In relation with the estimated age pyramid we briefly discussed earlier, we can also see that older characters are over-represented in these texts. Although only a fraction of the Athenian population of the 5th century could be categorized as belonging to the aristocracy, they took over the stage. We can see in the table that aristocrat characters pronounced close to 50% of the words in the corpus. In contrast, while slaves represented a large part of the population, they have almost no existence on stage compared to the free. *Xenoi*, foreigners, on the other hand, seem to benefit from a share in the dialogues equal to what we can estimate their share in the general population to be, although they tended not to be in a position of authority. We can associate this more intense presence with the special attention that the tragedy pays to the characters put in this situation[5]. In addition to a greater presence on stage, some types of characters express their will more densely, in relation to their speech time. The frequency of will expression, for nobles or royal characters, is much higher than for the others, for example.

Table 2: *Relationship Between Character Categorization, Speech Time, and Will Expressions*

Category Type	Category	Nb Characters	Nb of Words	Pct of Words	Nb Wills	Freq of Wills
Gender	Female	57	51,397	32.6	155	3.0
	Male	123	106,127	67.4	281	2.6
Age	Child	3	225	0.1	0	0.0
	Young	38	34,459	21.9	112	3.3
	Mid	102	73,321	46.5	203	2.8
	Old	37	49,519	31.4	121	2.4
Xenos	No	149	127,978	81.2	307	2.4
	Yes	31	29,546	18.8	129	4.4
Royal (Elite)	No	110	82,971	52.7	151	1.8
	Yes	70	74,553	47.3	285	3.8
Slave	No	158	143,910	91.4	399	2.8
	Yes	22	13,614	8.6	37	2.7
Divine	No	161	143,921	91.4	383	2.7
	Yes	19	13,603	8.6	53	3.9

Note: The frequency of will expressions is measured per thousand words.

The importance of statuses in ancient Greek society, combined with the fact that they had an

[5]"In tragedy it is not uncommon to find, expressed perhaps in different words, the situation of the man living in a foreign land, deprived of his civil rights, who must accept rigorous limitations on his ability to act and assert himself in society." See Citti (1988), p. 456.

impact on the dynamics of the play, leads us to consider that the audience must have had some clear prior expectations concerning how status affected the relations between the characters, and in particular their decisions.

Table 3 displays several logistic regression fits, relating the probability of acceptance to a series of factors. The factors include characters' categorization, and in particular, differences between characters who interact. The factors also include information on the history of the characters expressing a will and of the characters making the decision. They include whether the decision is expressed as an action, and the type of will expression, and also include additional information, such as the year when the play was first presented. The variables of the form "# of verses/speakers dist" track the number of verses/speakers since the character expressing a will last expressed one. The variables "# Wills Expressed/Addressed" capture the number of wills expressed by, or addressed to, the character up to that point in the play. The flag "In Chorus" signals that the character expressing the will is the chorus. The status differences, of the form "Status Diff - Slave", for example, take the value of 1 when the character having expressed a will possesses the characteristics in question, here a slave, while the character to whom the will is addressed does not, hence here not a slave. The variable takes the value -1 in the reciprocal situation.

We examine three distinct regressions:

- The first one takes into account decisions categorized as non important, and uses status difference-related factors, in addition to whether the decision is physically expressed as an action, and not simply verbal;
- The second regression also looks at unimportant decisions, but allows many more explanatory variables, including the form of will expression and the character's history of will expression and past instances of being obeyed, for example;
- The third regression is only applied to decisions classified as important, and relies on the same status difference-related factors as the first one.

Although the coefficients for the status-related factors are generally not significant, in the first regression, their signs are consistent with what the statu differences would imply. For instance, divine entities, when addressing humans, are more likely to be obeyed. So are warriors with respect to other people, and free persons to slaves. For these factors, similar patterns are observed in the second regression, but not with the third regression, for which the coefficients do not seem in line with the meaning of the statuses. In all cases, the fact that a decision is physically expressed through an action makes it more likely to be accepted. The adjusted R-squares for the

Table 3: *Logistic Regression of Acceptance Probability on Character and Situation Characteristics in Tragedy*

	Dependent variable:		
	Acceptance		
	logistic		
	Unimportant Decisions	Unimportant Decisions (Full)	Important Decisions
	(1)	(2)	(3)
Form of Expression: Réitération		3.897*	
		(2.217)	
Form of Expression: Volonté		2.481	
		(1.890)	
Action	2.652***	2.906***	1.445***
	(0.673)	(0.905)	(0.251)
Year		0.031	
		(0.020)	
# of verses dist.		−0.013	
		(0.025)	
# of speakers dist.		0.142	
		(0.112)	
# Wills Expressed		−0.679***	
		(0.257)	
# Wills Expressed/Accepted		1.090***	
		(0.420)	
# Wills Addressed		−0.053	
		(0.254)	
# Wills Addressed/Accepted		−0.094	
		(0.439)	
In Chorus	−0.422	−1.012	−0.176
	(0.937)	(1.170)	(0.368)
Status Diff. - Gender	−0.226	0.444	−0.348
	(0.613)	(0.741)	(0.255)
Status Diff. - Age	0.538	−0.238	−0.108
	(0.627)	(0.765)	(0.225)
Status Diff. - Slave	−1.398	−1.861	0.351
	(1.330)	(1.703)	(0.438)
Status Diff. - Foreigner	1.649**	1.305	0.220
	(0.749)	(1.030)	(0.247)
Status Diff. - Divine	2.284	2.385	0.011
	(1.728)	(2.265)	(0.422)
Status Diff. - Warrior	1.224*	0.817	−0.419
	(0.742)	(0.863)	(0.267)
Status Diff. - Aristocrat	−0.203	0.380	0.126
	(0.758)	(1.090)	(0.242)
Constant	1.115***	13.122	−0.522***
	(0.418)	(8.496)	(0.156)
McFadden R^2	30%	44%	11%
Share of Erroneous Predictions	10%	8%	34%
Observations	164	164	342
Log Likelihood	-44.156	-34.920	-210.152
Akaike Inf. Crit.	108.312	107.840	440.304
Note:			*p<0.1; **p<0.05; ***p<0.01

regressions show us that the status-related factors account for most of the explanatory power, by comparing regressions 1 and 2. In addition, we can see that, in spite of using many variables, unimportant decisions remain somewhat difficult to predict. Important decisions, on the other hand, appear particularly unpredictable. Statuses are essentially useless in trying to determine the outcome of an important decision.

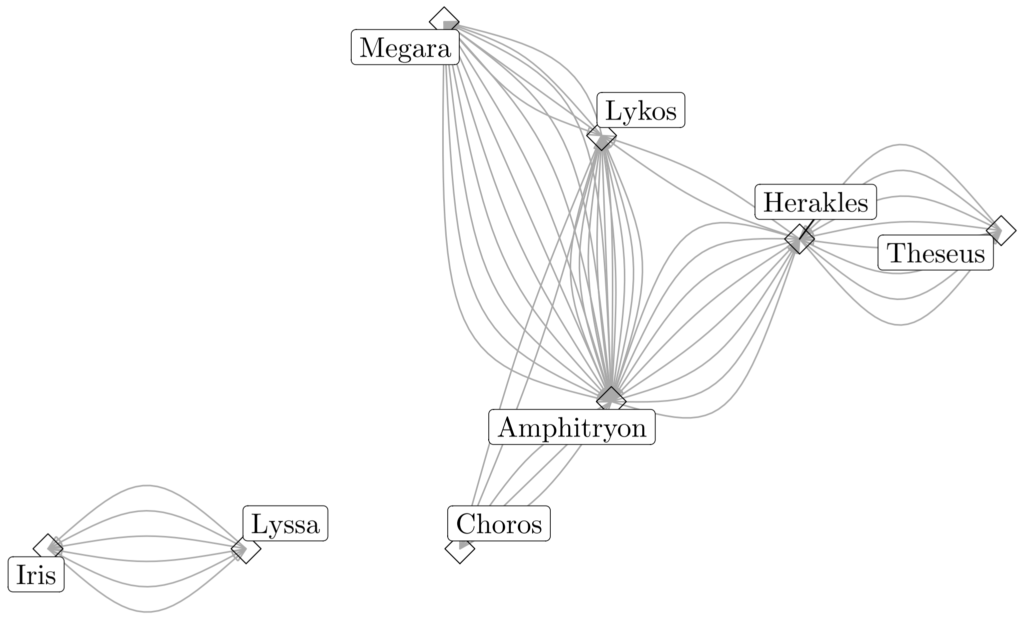
In the context of normal social relations within ancient Greece, the status differences should lead to very distinct outcomes. For example, when a free person or a noble orders that a slave do something, the probability that the slaves refuses is close to zero; and when older people ask something of younger people, they tend to be obeyed. As it was implied by Propositions 3.1 and 3.2, we can see that situations of greater semantic importance, for which it makes sense to assume a greater contribution to overall utility, are systematically more random and more remote from the empirical probabilities: the probabilities of outcomes are closer to $\frac{1}{2}$. This observation is consistent with the audience's preference for surprise over conformism.

4.3 Character Network of Decisions

Many analyzes of the networks effectively constructed in literature rely on very simple ways to relate the characters, which has the advantage of being automatically obtained, but does not necessarily convery much meaning. In their survey, Labatut and Bost (2019) essentially define the nature of relstionships as co-occurrences, which may be refined based on various automated processing approaches. For example Kydros, Notopoulos, and Exarchos (2015) look at co-occurrences of characters in the Iliad, which they group according to their allegiance. Similarly, Bonato et al. (2016) simply track the occurrence of character names within a span of 15 words in the text. Some research has tried to make the relationships more meaningful. For example, Agarwal et al. (2012) proposed to distinguish "social events" in text from other co-occurrences of character names. In such a social event, the characters are describe as being together and interacting in some form, rather than simply being referred to in a description, for example. In our approach to the theater texts, expressions of will and the associated decisions create links between characters, which are semantically more meaningful than simple co-occurrences. Indeed, the characters's interactions form a network as the play progresses, whereby each decision, in response to an expression of will, create a directed edge between two characters. An example character network based on decisions is shown in Figure 1, representing Euripides's *Herakles*.

We can consider all the play-specific networks together, as a single network with multiple components. We will write $d_{k_j,j}$ for the number degrees in such a network, which corresponds to

Figure 1: *Network Representation of the Character Decision Relationships in Herakles*



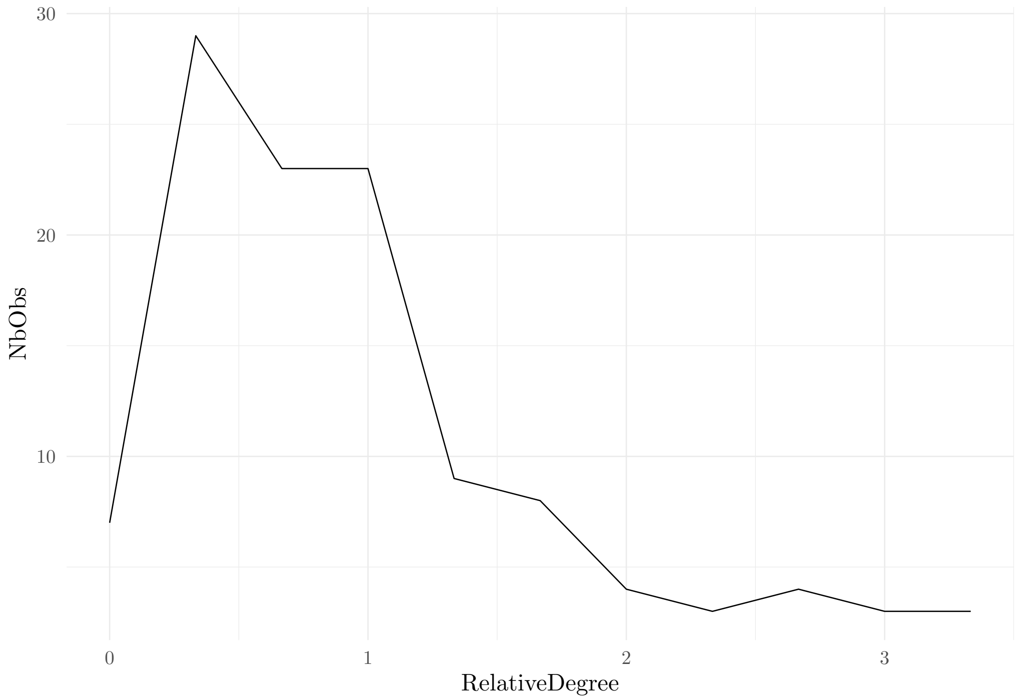
Note: Iris is a goddess, messenger of the gods, and Lyssa is the goddess of rage. Megara is Herakles's wife, and Amphitryon is his father. The chorus is composed of old companions of Amphitryon. Lykos is the tyrant of Thebes, having usurped Herakles's kingdom while the hero was in Hades.

the number of decisions made by character k_j in play j. We can look at the distribution, across all plays in the sample, of the relative degree for each character, which we defined as:

$$r_{k_j,j} = N_{C_j} \frac{d_{k_j,j}}{\sum_{k=1}^{N_{C_j}} d_{k,j}}.$$

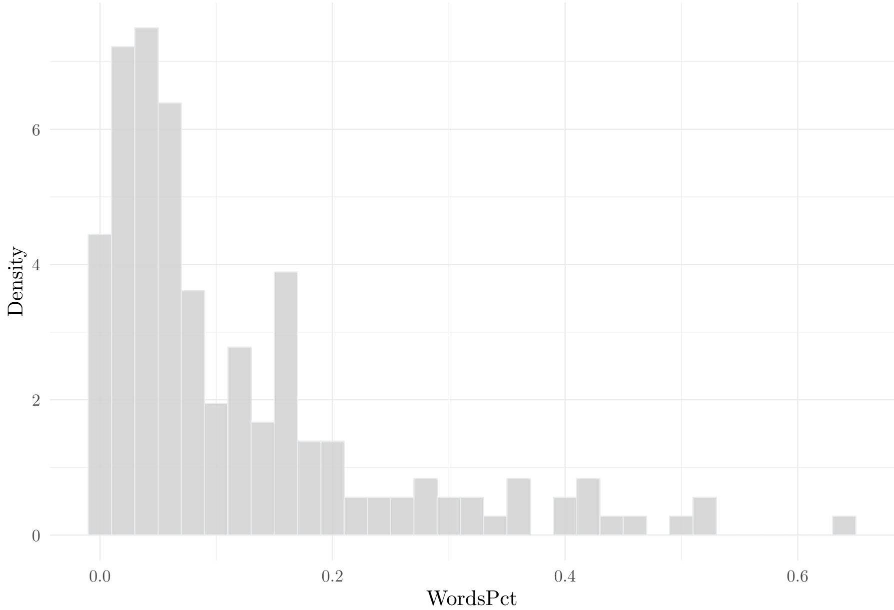
This ratio normalizes the number of degrees for a given character to the total number of degrees in the play, and further scales this value by the number of characters in the play. In this way, when $r_{k_j,j} = 1$, it implies that a character gets a uniform share in the decisions that may be made in the play. Higher or lower values than 1 reflect more or less decisions than a uniform allocation would imply. Figure 2 shows the relative degree distribution across all plays in the sample, and we can see that the mode of that distribution is seemingly below 0.5, and that it is fairly spread out. This distribution is also not indicative of a typical degree distribution that would be strictly decreasing. In particular, preferential attachment as a generating mechanism leads to a power law for the degree distribution (Barabási and Albert 1999), while random attachment leads to an exponential distribution (Deng et al. 2011). We know that in multiple choices, the optimal strategy is for the playwright to effectively broadly distribute the empirical probabilities. Across all the characters in a play, some of them are semantically recognized as important, and the audience would expect those to be in a position to make decisions. Other characters, such as slaves or people who are not of a noble family are not expected to play much of a role. Optimally, they still must have some probability of making decisions, according to Proposition 3.3. Hence, one should expect the number of decisions for a character to be rarely very high, since no character would have a very high optimal probability of being chosen; but one should also not expect the number of decisions for a character to be very low, since, through mixing, all characters get some time in the light. In consequence, it is logical that there would be some maximum in the degree distribution away from the bounds.

Figure 2: *Plot of the Relative Degree Distribution for All Characters in the Sample*



If decisions, around which the plot is articulated, are allocated to characters according to the type of distribution shows in Figure 2, then one can expect a logical consequence in terms of speech time. Indeed, if exposing and discussing decisions takes a given amount, then the shape of the distribution of the words allocated to characters should follow a comparable pattern. We can define the prevalence of a character as the proportion of words they have, relative to all the words in that play. Figure 3 shows the distribution, across all characters, of their share of words. We can see that it is fairly comparable to the distribution in Figure 2. It is also broadly distributed, and hence there is substantial mixing of characters of varied importance.

Figure 3: *Distribution of the Share of Words Pronounced by Each Character in a Play*

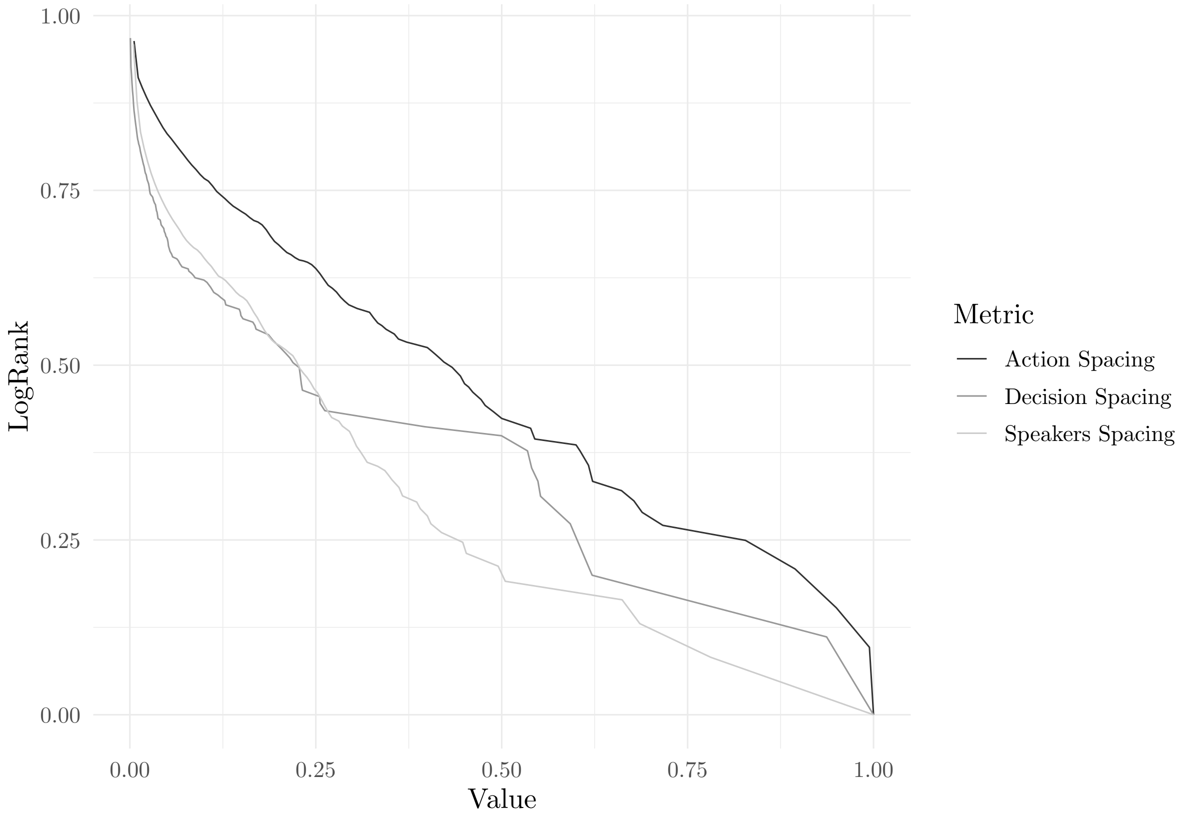


Note: The horizontal axis is the number of words pronounced by each character relative to all words in the play.

4.4 Timing Distribution of Events

Some of the research in character networks also addressed timing-related aspects, since they pertain to the construction of the network over time. For example, Waumans, Nicodème, and Bersini (2015) paid a close attention to the manner in which dialogs created interactions between characters in novels, and looked at the spacing between dialogues in *Les Misérables*, *A Game of Thrones*, and *Harry Potter and the Philosopher's Stone.* They do not, however, qualify the form of these distributions. Figure 4 plots the cumulative distributions of the time between different types of events in a logarithmic scale, across our entire corpus of theater texts. The time between the events is measured as the number of verses. The shape of these curves is not particularly regular, but it is apparent that, apart from the left-hand side for very short time intervals, they are somewhat straight, especially the curve for the timing between actions. A possible contender for a distribution fit matching the plot in Figure 4 could be a power law, or a truncated power law, as well as an exponential.

Figure 4: *Comparison of the Distributions of Action, Decision and Speaker Spacing in Log/Value Scale*



Note: For each dataset, value and rank are scaled between 0 and 1. The space between the events is measured in verses.

Establishing the type of distribution followed by empirical observations, however, requires appropriate tests. For power laws, in particular, Clauset, Shalizi, and Newman (2009) showed that one should not rely on the shape of a curve on a logarithmic scale. Alstott, Bullmore, and Plenz (2014) have developed computer packages implementing the recommended fits, which we used to obtain Table 4. We excluded the smallest observations from the data, as we have established according to Proposition 3.4 that the optimal timing distribution does not follow a regular pattern for small time increments. We can observe that, for the timing of actions, the data is more likely to follow an exponential distribution than a power law, in accordance with the proposition, although that preference is not strongly significant. For decision timing and speaker timing, there is no clear preference of one distribution over the other. Decision time data is more sparse and less regular, as we could see in the Figure. The timing of the alternance of speakers does in fact not play as structural a role in a play, as compared to the timing of actions.

Table 4: *Summary Statistics on Distribution Fits Where the 15% Shortest Times are Excluded*

Statistic	Speakers Spacing	Action Spacing	Decision Spacing
Lambda Exp	0.051	0.032	0.003
Alpha Pow	2.265	1.095	0.749
Alpha Trunc	1.116	0.000	0.748
Lambda Trunc	0.018	0.017	0.000
Trunc vs Pow R	0.577	1.047	2.552
Trunc vs Pow p	0.170	0.046	0.915
Trunc vs Exp R	0.791	0.576	1.166
Trunc vs Exp p	0.028	0.164	0.085
Pow vs Exp R	0.313	-0.287	1.161
Pow vs Exp p	0.755	0.774	0.246

Note: The distribution names in the tests are abbreviated as follows: *Exp* = exponential, *Pow* = (pure) power, *Trunc* = power law with exponential decay. *R*: ratio of goodness-of-fit; a positive number means that the first law of the two is preferred. *p*: significance level; the probability that the preference would be due to randomness.

5 Conclusion

Trying to put literary prowess into a few equations is difficult to qualify otherwise than as a reductionist attempt. Nevertheless, this has been tempted from different angles, as we saw. The modeling of the choices characters face in narratives, with game theory, is one such angle, and it has been followed by many literary specialists, less so economists. Understanding the construction of stories through the networks they form, a very empirical approach, hes remained the purview of physicists and complex systems specialists. It seemed, *a priori*, that there was no way in which these perspectives could be bridged.

We have seen that, in fact, one could consider the manner in which writers create surprise or adhere to conventions, in order to define theoretically optimal ways to arrange stories. The game between the writer and the audience or readership has been considered in literature analysis, although not in a formal fashion. By treating this game formally, we were able to determine some simple rules of thumb, applicable to theater. Based on ancient Greek theater, the oldest form of theater available, we showed that the simple patterns we expected based on the theoretical developments could be confirmed.

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