



Minireview

Setting the agenda: Different strategies of a Mass Media in a model of cultural dissemination



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ABSTRACT

Day by day, people exchange opinions about news with relatives, friends, and coworkers. In most cases, they get informed about a given issue by reading newspapers, listening to the radio, or watching TV, i.e., through a Mass Media (MM). However, the importance of a given new can be stimulated by the Media by assigning newspaper's pages or time in TV programs. In this sense, we say that the Media has the power to "set the agenda", i.e., it decides which new is important and which is not. On the other hand, the Media can know people's concerns through, for instance, websites or blogs where they express their opinions, and then it can use this information in order to be more appealing to an increasing number of people. In this work, we study different scenarios in an agent-based model of cultural dissemination, in which a given Mass Media has a specific purpose: To set a particular topic of discussion and impose its point of view to as many social agents as it can. We model this by making the Media has a fixed feature, representing its point of view in the topic of discussion, while it tries to attract new consumers, by taking advantage of feedback mechanisms, represented by adaptive features. We explore different strategies that the Media can adopt in order to increase the affinity with potential consumers and then the probability to be successful in imposing this particular topic.

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1. Introduction

Many times, people get involved in discussions about certain issues that do not arise only from their own daily experiences, in the sense that these seem to behoove the social group to which they belong, such as discussions about their country's macro economy, regional elections, etc. Due to the complexity and variety of those issues, and in many cases the remoteness with the situation, people resort to Mass Media in order to get informed about these ones and to know the opinion of specialists in these topics. People become interested in these issues because the Media is supposed to reflect the interests and concerns of their social environment.

Following Giddens [1], we find several theoretical approaches to the role of a Mass Media in the field of sociology. A Media seen as social stabilizer, which keeps and reflects the dominant culture, is the basis of the functionalism theory. As Giddens says, several reasons lead sociologists to move away from this approach: One of them is that the functions mentioned above appear wholly positive. In contrast to functionalism, the conflict theory sees the Media as a less benign force within society: It is a powerful agent whose ideology justifies or legitimizes the interests of the owner group of the Media. The ideology of a Media can be explicit, as for instance, in the editorial line of many newspapers, but in most cases it is implicit in the TV time or newspaper's pages that the Media spends to discuss a particular issue. The imposing of a topic in public opinion is what is called "to set the agenda", widely analyzed by McCombs [2,3]. As it can be read in Ref. [3], "*the press*) may not be successful much of the time in telling people what to think, but it is stunningly successful in telling its readers what to think about". However, during the coverage of a given issue, the Media can suggest its point of view to the audience.

We analyze this idea in an agent-based model of cultural dissemination (the Axelrod's model [4], see Section 2), where each individual is characterized by a set of features representing its cultural profile, who interact proportionally to their degree of similarity (Homophily). Specifically, in this work, we analyze the case where a Mass Media has a given purpose: It is interested in "setting the agenda", i.e. make the largest amount of agents discuss about a given topic, as for instance, a particular policy issue, and impose its point of view. To pursue this goal, in our model the *MM* is able to modify the topic of discussion in each feature following different strategies. This acts as a feedback mechanism in order to be more appealing to the majority of the agents and increase the probability of interaction with them, in line with the reported in Ref. [5] where individuals sharing common attributes tend to be more similar.

In this work, we interpret each agent's value of a given feature as the main interest in this particular topic, as for instance, its favorite sport or its opinion about a policy issue. The Axelrod's model is very well suited to study the influence of a *MM* over a given population because each feature could be naturally interpreted as the section of a given newspaper. For instance the New York Times present the following sections: World, US, Politics, N.Y, Business, Opinion, Technology, Sports, Health, Science, Arts, Fashion and Style, and Food.

1.1. Previous works

Previous works in this topic basically follow two approaches: a fixed Mass Media, whose cultural state is constant in time and represents a Media who has no feedback with the population, and a fully adaptive Mass Media, which varies its cultural state adopting the most popular trait in each feature.

From a social point of view, a constant Mass Media represents a Media who imposes the topic of discussion in all features regardless the society concerning. From the physical point of view, it acts as an external constant vector field who drives the states of the agents. This modeling approach was followed in Refs. [6,7]. In the first one, the authors studied the combined dependence of the stationary states with the number of traits per feature (Q) and the probability of interaction with the *MM* (B). They counter-intuitively found that the Mass Media induces cultural diversity when the interaction parameter B is above certain threshold. In the second work, the combined effects of a fixed *MM* and a cultural drift (modeled as random perturbations) were analyzed. They also included an extra feature which makes the interaction between the *MM* and the agents always possible. An interesting twist was followed in Ref. [8] where the Mass Media is characterized by two parameters: a non-null overlap with all agents and a confidence value of its information. The first parameter is related to the concept of "propaganda", by which the *MM* can interact with all agents, included those cases where there is no cultural similarity. The second parameter is intended to model the level of credibility of a *MM* which, according to the authors, is directly related to its level of influence. A similar approach was followed in Ref. [9], where the authors incorporate the influence of the Mass Media as a non-pairwise interactions among agents, following the proposal of Ref. [10] for the Axelrod's Model.

The other approach includes feedback processes between the Mass Media and the social community. In all the cases, the Media adopts the most popular point of view in each feature. From a social point of view, this modeling approach is closer to the functionalism theory described in Ref. [1], where the Media is supposed to reflect the dominant culture of a society. On the other hand, from the physical point of view, the Media only catalyzes the dynamics toward consensus of the population, i.e., the Media does not induce any particular state. This problem was initially faced in Ref. [11] following an Axelrod's model, where two different variants were proposed: A global field where each feature of the *MM* adopted the most popular point of view of the population and a filter model, where the feedback is indirectly modeled in the interaction between agents. In Ref. [12], the authors proposed three different ways in which the Mass Media could be modeled: as an external field (as a fixed Mass Media), as a global field (where the *MM* adopts the most popular point of view of each feature for all of them, making it time dependent but uniformly distributed in space) and as a local field (where the field adopted the most popular point of view among an agent's neighbors, i.e. it is non-constant in space and time). In Ref. [13], the authors also systematically investigated the indirect feedback mechanism as proposed in Ref. [11]. It is important to remark that, in all cases, the feedback between the *MM* and the population was present in all the features.

Many other studies have been made in the context of the Axelrod's model. The role of the social contact network in the dynamics with a fixed *MM* was also investigated in Ref. [14], where the effects of intra and inter-links of a social network with community structure were analyzed. In Ref. [15], the microscopic dynamics toward equilibrium was analyzed when the underlying network is scale-free in its degree distribution. In the same modeling scenario, a model of cross-cultural interaction through Mass Media interactions was investigated in Ref. [16], where two (fully adaptive) Mass Media act over two different interconnected populations. In this model, one of the Mass Media reflects the dominant cultural state of a given population and influence the other one. The study of social interactions and the presence of a Mass Media was also explored in the context of other models, as for instance, the Deffuant's model [17], the voter model [18], and the Sznad's model [19,20].

1.2. Our contribution

As was mentioned above, we consider the Axelrod's model (see Section 2) as the best candidate to study the social influence of a Mass Media, because of the natural interpretation of Media's cultural state as the sections of a given newspaper. We also mentioned that the previous works follow basically two approaches: a fixed and a fully-adaptive Mass Media. While a fixed Mass Media is an oversimplification of its actual role in a society, mainly because of the absence of a feedback mechanism between the Media and the population, a fully adaptive implementation suites very well to the functionalism theory of Media's influence, but, as Giddens says [1], this theory has fallen into decline in the recent decades, because it presents the Media in a very naive way, as an external agent without ideology or purposes, who only reflects the dominant culture.

In this work, we model the Mass Media as an external agent with some features fixed and the rest adaptive. Despite the apparent little difference between our model and the approaches mentioned above, we consider that our interpretation and representation of the Media fits better within the conflict theory of Media's influence [1] and within the works of McCombs [2,3]. Here, the Media influences the population with a given purpose: To put a special topic to be discussed by public opinion, i.e., to set the "agenda" on a particular feature, and impose its point of view. From now on we will refer to this peculiar value of the selected feature as the Mass Media's topic (*MMT*). Simultaneously, it will try to adapt the rest of its features in order to attract a great number of consumers. We will explore two different strategies in order to do that: A conservative one, where it looks for increasing the number of followers, from a well established group of them, and an aggressive one, in which the Mass Media targets all those individuals which have not attached yet. From now we call *Followers* to those agents who adopt the *MMT*. We will explore the different collective dynamics which emerge with these strategies. We compare the results with the case where the *MM* does not follow any strategy, i.e., it is constant in time.

The work is organized as follows: In Section 2 we describe the model that we implemented for our numerical simulations, describing the different strategies that the Mass Media can adopt, and the definition of the observables analyzed. In Section 3 we show the main results concerning as well as the equilibrium properties and the dynamics toward the equilibrium of different Mass Media's strategies. In particular, we will be interested in the total number of followers as a function of time and their self-similarity and similarity with the Mass Media. In Section 4 we present the conclusions of the work.

2. The model

In this work, there are two main actors, both described within the Axelrod's model: On the one hand we have a population of agents which interact amongst them and, on the other, the Mass Media, which interacts with all the members of the population.

2.1. The Axelrod model

The Axelrod's model [4] is an agent based model which assumes that the cultural state of each individual can be described in terms of a set of attributes such as political orientation, religion, sports preferences, etc. The interaction mechanism between agents is pairwise based and rests on two fundamental hypothesis:

- Homophily: the probability of interaction between two individuals is proportional to their cultural similarity.
- Social influence: after each interaction, the agents become more similar (see Section 2.1.3).

The success of the original model is due to the emergence of a non-intuitive stationary collective behavior: a transition between a monocultural global state, in which all the agents are identical, and a state of cultural diversity, characterized by the coexistence of regions with different cultural states.

2.1.1. The population

We implement the Axelrod's model with N agents placed in the nodes of a two-dimensional grid, with rigid walls, i.e., the system is finite. Following [4], the cultural state of each agent can be represented by a vector $v = (v_1, v_2, \dots, v_F)$ where F stands for the number of features. Each component v_i is a nominal variable corresponding to a certain cultural feature and can adopt Q different values, representing the different traits in a specific feature. We interpret the value of a given feature as the main interest in this particular topic, and this interpretation is analogous that we give to the Mass Media's state, as we describe below.

2.1.2. The Mass Media

The Mass Media is modeled as an external agent, with the same number of features and traits than the agents, which, in principle, can interact with all of them with probability B . In this work, the Mass Media's state represents the sections of a newspaper, and each feature's value, the main theme covered in each topic. The *MM*'s state has a fixed value in the first component, i.e., $v_1^{MM} = 1$, and represents the *MMT* defined above. The other features fluctuate in time according to different strategies, as we detail below.

In our work, when the Mass Media interacts with an agent, it imposes the *MMT* to that agent. This means that the Mass Media treats the first feature as priority. This type of interaction is not present between two agents, where all the features are taking equivalently, and none of the agents has a particular interest about a given feature. In Section 2.1.3 we can see in more detail the interaction described above.

In what follows, we will call *Followers* to those agents in the population who share the *MMT*, i.e., agents with $v_1 = 1$, independently of the other features' values. On the other hand, the *Non-Followers* are those agents with $v_1 \neq 1$. In order to increase the interaction probability with the majority of the population and potentially increase the amount of *Followers*, the Mass Media can change the other features according to one of the following strategies:

- The Followers Strategy (*FS*): In the non-fixed components of its cultural vector ($v_2 - v_F$), the Mass Media adopts, at each time step, the most abundant value among those agents who share the *MMT*, i.e., *Followers* agents. This is a conservative strategy and its main goal is to increase the amount of *Follower* from a well consolidated crew.
- The Non-Followers Strategy (*NFS*): In the non-fixed components, the Mass Media adopts the most abundant value among those agents who do not share the *MMT*, i.e., *Non-Followers* agents, in order to maximize the probability of interaction with them, and convince them rapidly. In opposite of *FS*, this is an aggressive or conqueror strategy.

In all cases, we compare our results with the case of a Fixed Mass Media (*FMM*), where all the features of the Mass Media remains constant in time, similar to the one analyzed in Ref. [6].

2.1.3. Dynamics

The dynamics of the model is the following:

- Select one element i from the lattice.
- Select another element j , which with probability B , $j = MM$, and with probability $(1 - B)$, j is one of the nearest neighbors of i , selected at random.
- The probability of interaction between agents i and j , $P_{i,j}$, is given by the fraction of shared features, $P_{i,j} = \frac{1}{N} \sum_{k=1}^F \delta_{v_k^i, v_k^j}$. We will refer to this probability of interaction as the *overlap* between agents i and j .
- Here we distinguish two types of interactions:
 - If the interaction is between lattice's neighbors and $0 < P_{i,j} < 1$, then with probability $P_{i,j}$ the agent i picks at random a feature v_k^i and adopts the corresponding trait of the agent j , v_k^j .
 - On the other hand, if the interaction is between an agent and the *MM*, with probability $P_{i,j}$ the agent adopts the first feature's value. If this particular feature is shared, then the agent i picks at random a feature v_k^i and adopts the corresponding trait of the *MM*, v_k^{MM} , analogous to the agents' interaction described above.
- We repeat this task for all the agents in the system, updating the changes synchronously. This is what we call a time step.
- After a time step, the Mass Media's state is updated according to the current strategy.

2.2. Observables

In order to study the behavior of the system according to the different strategies quoted above, we define the following observables:

- **Fraction of Followers (F/N):** It is the fraction of agents who share the first feature's value with the Mass Media. The fraction of Followers is the main observable in order to evaluate the effectiveness of each strategy. As it can be noticed this quantity can only be defined in this modeling approach (i.e., when we have only one feature fixed).
- **The normalized size of the biggest fragment (S_{\max}/N):** It represents the largest group of connected agents who share the first feature's value. (S_{\max}/N) is a standard quantity in order to study collective properties in the Axelrod's model. The two classical stationary solutions, consensus and cultural diversity, can be easily identified by studying the behavior of (S_{\max}/N) as function of the system's parameters.

It is important to remark that being a Follower agent only implies that it shares the first feature's value with the Media, independently of the others. It is interpreted as it adopts the *MMT*, but maybe it is not interested in the other Media sections. On the other hand, it is important to stress at this point that, given an ensemble of realizations, the features' values different to the one corresponding to the *MMT* will be homogeneously distributed amongst all the elements of the space of realizations. On the other hand, depending of the values of B and Q , the feature corresponding to the *MMT* will end to attain the value "pushed" by the Media.

In order to have a map of all stationary solutions of the model, we will plot a Mass Region Diagram (*MRD*), where we calculate the average value of (F/N) as a function of B and Q . With this, we can explore how effective is the Mass Media to convince as many agents as it can. On the other hand, we will plot a Maximum Cluster Region Diagram (*MCRD*) where we calculate the average value of (S_{\max}/N) as a function of B and Q [21]. It takes into account cluster properties, and it is not necessarily a cluster composed by Followers. Both region diagrams have been made for all the strategies defined above.

We are also interested in studying the average similarity among the Followers, so we define the following quantities:

- The mean homophily between the Mass Media and the Followers:

$$H_{MM}(t) = \frac{1}{N'} \sum_i^{N'} \left(\sum_{k=1}^F \delta_{v_k^i, v_k^{MM}} \right) \quad (1)$$

where the first sum is over the N' Followers and the second one over the amount of features. This quantity takes into account the average similarity between the Followers and the Mass Media.

- The mean homophily among the Followers:

$$H_F(t) = \frac{1}{M'} \sum_{i < j}^{M'} \left(\sum_{k=1}^F \delta_{v_k^i, v_k^j} \right) \quad (2)$$

where M' stands for all the pairs of Followers that can be formed, and the first sum is over all agents (i and j) who are Followers. This quantity expresses the average similarity among Followers.

As the states of the agents vary with time, these observables are time-dependent and will bring useful information about the dynamical behavior of the system.

3. Results

We performed numerical simulations using a two-dimensional finite grid of 50×50 nodes (total number of nodes $N = 2500$). In each node i , ($i = 1, \dots, N$), an agent with a given cultural vector v_1, \dots, v_F is placed. The number of features is $F = 10$ and represents the typical number of sections of a newspaper (for instance, in the web edition of New York Times, the main newspaper's sections are thirteen: World, US, Politics, N.Y., Business, Opinion, Tech, Science, Health, Sports, Arts, Fashion and Style, and Food. In the international edition of "El País" from Spain there are ten sections).

3.1. Equilibrium properties

In this section we study the characteristics of the stationary states. In these states the overlap between any pair of agents (including the Mass Media) is zero or one. This implies that a Follower agent finishes to share all features' values with the *MM*. In this model, the system always reaches a stationary state.

In Fig. 1, we plot the Mass Region Diagram (*MRD*) and the Maximum Cluster Region Diagram (*MCRD*) for the Followers Strategy and Fixed Mass Media (*FS* and *FMM*), respectively. In all cases we decide that a given pair of values (B, Q) belongs to a particular region, if the average value of the corresponding observable fits with the requirements of each region. We average over 50 events for each case.

Three regions can be identified in the *MRD* corresponding to different kind of stationary solutions:

- I **Consensus identical to the *MM***: the **average** value of the agents that have the same cultural state than the *MM* is above the 90% of the population. This region points out the hegemony of the *MM*.
- II **Absolute dominance of *MM***: this region is characterized by a dominant mass, identical to the *MM*, whose size in **average** is above the 50% and below the 90% of the population.
- III **Relative dominance of *MM***: this region is characterized by a dominant mass, identical to the *MM*, whose size in **average** is above the 10% and below the 50% of the population.

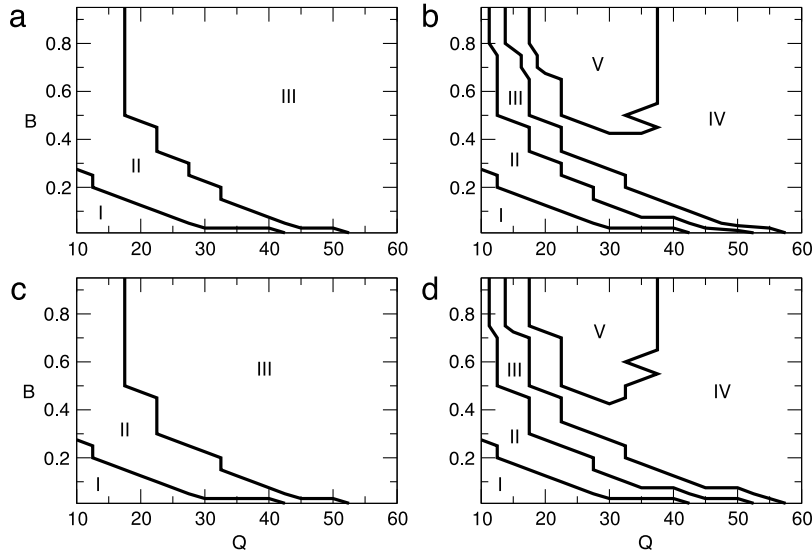


Fig. 1. Region diagrams. Mass Region Diagram (Left panels, (a) and (c)) and Maximum Cluster Region Diagram (Right panels, (b) and (d)) for a Fixed Mass Media (*FMM*, top panels, (a) and (b)) and Followers Strategy (*FS*, down panels, (c) and (d)). Five regions can be identified according to the degree of dominance of a given state which are detailed in the main text. The region diagrams corresponding to the Non-Followers Strategy (*NFS*) are not shown because there is only one solution in the range of analyzed parameters: consensus with the *MM* (Region I).

These regions can also be found in the *MCRD*, if we replace the term *mass* for *cluster*, i.e., we find a maximum cluster whose relative size in average is above the 90% (region I), between the 90% and the 50% (region II), and between the 50% and the 10% of the population (region III). In all these cases, the maximum cluster corresponds to a Mass Media's state. However in the *MCRD*, two more regions can be identified:

IV Fragmentation: there is no dominant clusters of agents. The size of the biggest cluster is in average smaller than the 10% of the population.

V Local relative dominance: this region is characterized by a dominant cluster which in more than the 50% of the events has a different state respect to the Mass Media's one, and its size is in average above the 10% and below the 25% of the population.

For the values of B and Q explored in the region diagrams, the average fraction of *Followers* always exceeded the 10% of the population, although it does not necessarily form a unique cluster: This is why the region IV in the *MCRD* and the region III in the *MRD* can coexist. On the other hand, it is important to note the presence of a region dominated by a cluster whose state is different to the Mass Media's one that we call region V. This region was reported in Ref. [21] for a Fixed Mass Media, and it acquires more relevance in networks with long-range interactions. We find this region also for the Followers strategy's *MCRD*.

An important observation of Fig. 1 is the absence of a region diagram corresponding to the Non-Followers Strategy (*NFS*). We have not plotted it because, with this strategy, there is only one stationary state: consensus similar to the Mass Media. This is a fingerprint of this strategy: it is able to produce consensus for any values of B and Q . In this strategy, the Mass Media adapts its non-fixed features in order to maximize the interaction probability with those agents who do not share the *MMT*. Therefore, the Media is able to make all agents become *Followers*. Once this task is completed, the Mass Media produces no further changes in its state. The remaining dynamics corresponds to interactions between agents in order to reach total consensus according the Axelrod model's dynamics. Even though this strategy shows only one equilibrium solution, its dynamical behavior shows a dependence with the parameters of the system, as we will show in the next section.

On the other hand, for a Fixed Mass Media (*FMM*) and the Followers Strategy (*FS*), both region diagrams are qualitatively similar: the dominance of the Mass Media state is absolute for low Q and B (left-bottom corner) and it loses preponderance when Q and B increases. In the top-right corner of the plots ($Q \simeq 60$ and $B \simeq 0.9$) the average number of agents who share the *MMT* is between the 10% and the 50%, but there is no cluster in the system bigger than the 10% of the lattice's population. Also, for both Fixed Mass Media and Followers Strategy's *MCRD*, the region V is present, i.e., the maximum cluster is orthogonal to the Mass Media, but its size does not exceed the total amount of *Followers* present in the system.

In what follows we will analyze which are the main characteristics and differences between the collective dynamical behavior of the population for the different strategies followed by the Mass Media.

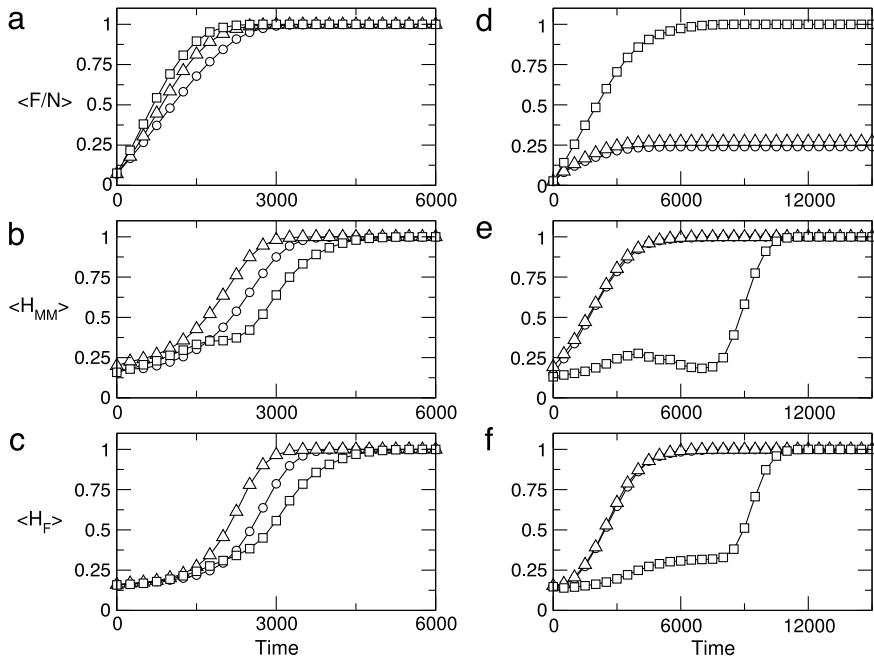


Fig. 2. Dynamical behavior of the strategies. $B = 0.01$ and $Q = 20$ (left panels) and $Q = 60$ (right panels). Fraction of Followers ($\langle F/N \rangle$, panels (a) and (d)), mean homophily respect to the Mass Media, $\langle H_{MM} \rangle$ (panels (b) and (e)), and mean homophily among Followers, $\langle H_F \rangle$ (panels (c) and (f)) as a function of time. The bra-ket notation denotes averaging over 1000 events. Squares denote NFS, triangles FS and circles FMM.

Table 1

Approximate values of τ , H_{MM} , and H_F at the time of reaching consensus, in the first feature, for each strategy and $Q = 20$. Bra-kets denote average over 1000 events.

Strategy	$\langle \tau \rangle$	$\langle H_{MM} \rangle$	$\langle H_F \rangle$
NFS	2200	0.35	0.40
FS	2400	0.80	0.70
FMM	2800	0.80	0.70

3.2. Dynamical properties of collective states for different strategies

In the analysis of equilibrium states, we have seen that a Fixed Mass Media and the Followers Strategy show similar region diagrams, while for the Non-Followers Strategy the system evolves to a consensus with the Mass Media for all values of B and Q . Given these known equilibrium properties, the questions we would like to face in this section are two:

1. How is the dynamics toward equilibrium of the system and the Mass Media for each strategy?
2. Do the Mass Media's followers form a homogeneous or a heterogeneous cultural group?

With this in mind, we analyze the temporal evolution of the system for a case of low probability interaction with the Mass Media ($B = 0.01$) and two different values of Q : $Q = 20$ and $Q = 60$. For $Q = 20$, all the strategies reach the consensus of the whole population, meanwhile, for $Q = 60$, only NFS does. We analyze the collective behavior of the population in both cases in terms of $\langle F/N \rangle$, H_{MM} , and H_F .

When we analyze the fraction of Followers as a function of time (Fig. 2 panel (a)), we can observe that all strategies behave quite similar in the low Q regime ($Q = 20$), being the Non-Followers Strategy (NFS) the fastest and the Fixed Mass Media (FMM) the slowest strategy to reach the 100% of Followers, as it can be seen in Table 1, where we define τ as the time when $\langle F/N \rangle$ reaches the value of 1. However, the strategies produce differences among the Followers in terms of self similarity and similarity with the Mass Media. If we look the behavior of H_{MM} , at the panel (b) of Fig. 2 and Table 1, we can see that at the time $\langle F/N \rangle = 1$ the Followers in the FS and FMM are closer to the Mass Media than when we implement the NFS. Similar behavior is found for $\langle H_F \rangle$ (Fig. 2 panel (c)), showing that at the time of reaching consensus, the Mass Media which adapts to their followers produces a more homogeneous crew of them with respect to the case of the one which adapts to the Non-Followers agents. The Followers attained by this strategy form a more heterogeneous group until they become completely similar.

In the region of large Q ($Q = 60$), we find an unexpected non-monotonic behavior of $\langle H_{MM} \rangle$ (Fig. 2 panel (e)) for the Non-Follower Strategy (NFS): At the time when $\langle F/N \rangle \simeq 0.75$ (Fig. 2 panel (d)), it starts to decrease until the fraction of Followers become 1, when it starts to increase again. This means that in this region (when the amount of Non-Followers is less

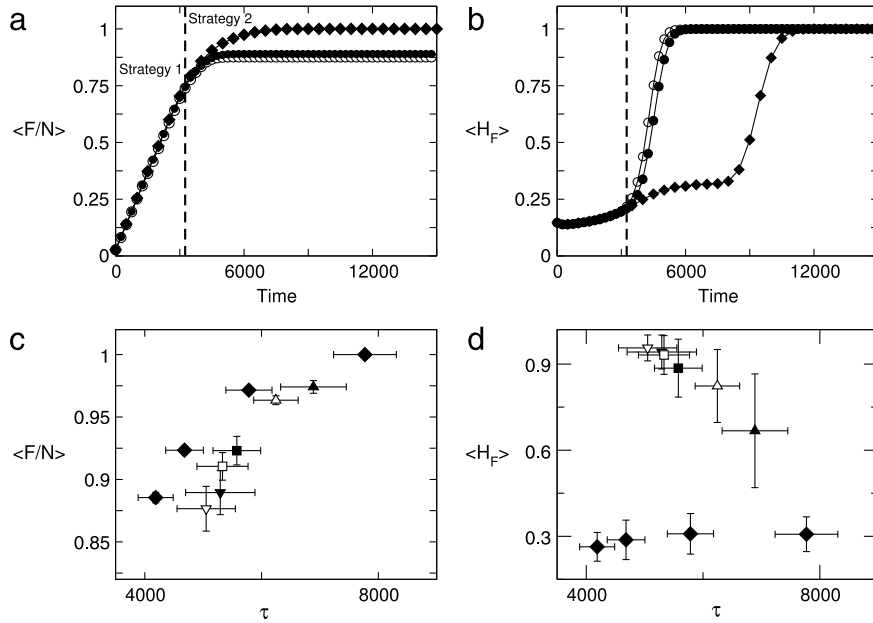


Fig. 3. Combination of strategies. Panel (a), Fraction of *Followers* (F/N), panel (b) homophily among *Followers* (H_F), both as function of time for Non-Followers Strategy (diamonds) and a combination of two strategies starting with NFS until $(F/N) = 0.75$: Followers Strategy (FS, empty circles) and Fixed Mass Media (FMM, full circles). In all the cases, $Q = 60$ and $B = 0.01$. Panel (c), $\langle F/N \rangle$, and panel (d), $\langle H_F \rangle$, as function of the time of reaching the asymptotic value of (F/N) , τ . The diamond symbol stands for NFS, empty symbols for NFS followed by FS, and full symbols (except diamonds) for NFS followed by FMM. The change of strategy is done at different values of (F/N) for the NFS: 0.75 (triangles down), 0.85 (squares) and 0.95 (triangles up).

than the 25% of the population, but greater than zero), the similarity between the *Followers* and the Mass Media is very low. In addition, in order to convince this last 25% of the agents, the Mass Media takes a similar time interval (about 4000 time steps) as it took to convince the 75% of the population. What is happening in this region? The Mass Media tries to increase the probability of interaction with the *Non-Followers* changing its state. The *Non-Followers* can be distributed throughout all the lattice and they have very different cultural states among them. At the same time, when the Mass Media adapts to them, it departs from the *Followers*, which constitute the majority of the system. In addition, the high degree of similarity between the Mass Media and a small group of *Non-Followers* does not favor the homogenization of the *Followers* group, as can be seen in Fig. 2 panel (f), where $\langle H_F \rangle$ remains constant during this time-lapse ($\langle H_F \rangle \simeq 0.30$). Once all the agents become *Followers*, both $\langle H_{MM} \rangle$ and $\langle H_F \rangle$ grow monotonically until they reach the value of 1 (i.e., agents shares all feature's values with the Media). In Appendix A, we show a more detailed description of this behavior, analyzing a single event.

Concerning the case of a Fixed Mass Media and Followers Strategy for $Q = 60$, both $\langle H_{MM} \rangle$ and $\langle H_F \rangle$ increase monotonically as it was observed for $Q = 20$, but in this case, these strategies are unable to reach consensus. FS only reaches a little more than the 25% of *Followers*, and FMM gets a percentage slightly below of that. The similarity among *Followers* and between the *Followers* and the Mass Media is identical for both strategies: they reach $\langle H_{MM} \rangle = 1$ and $\langle H_F \rangle = 1$ at almost the same time than they reach the largest amount of *Followers* that they can get.

3.3. Optimal combination of strategies

The analysis performed in the previous sections tells us that even though the Non-Followers Strategy is the best one in terms of reaching consensus, it takes a lot of time in convincing the last fraction of agents. It happens because the Mass Media can change its state very sharply in order to maximize the overlap with the *Non-Followers*, which are just a few and are very different among them. But what would happen if the Mass Media changes its strategy when the homophily among *Followers* stops growing (i.e., when $\langle F/N \rangle \simeq 0.75$ for $Q = 60$)? Is it possible to reach consensus when the second strategy is not the NFS? Is there an optimal balance between maximizing the amount of *Followers* and minimizing the time to do this?

3.3.1. Temporal combinations

In this section we analyze how the system behaves when the Mass Media changes its strategy at a given time. In Fig. 3, panels (a) and (b), the Mass Media starts with the Non-Followers Strategy (NFS) until it reaches the 75% of *Followers* and then, it remains as a Fixed Mass Media (FMM), or implements the Followers Strategy (FS). In panel (a) we can observe that, when the combination of strategies is implemented, the Media is not able to reach the 100% of *Followers*. On the other hand, the asymptotic fraction of *Followers* reaches a value closer to 0.90, being slightly larger when the second strategy is FMM, but none of these cases can improve the NFS, which reaches that amount of *Followers* in less time. However, we can observe

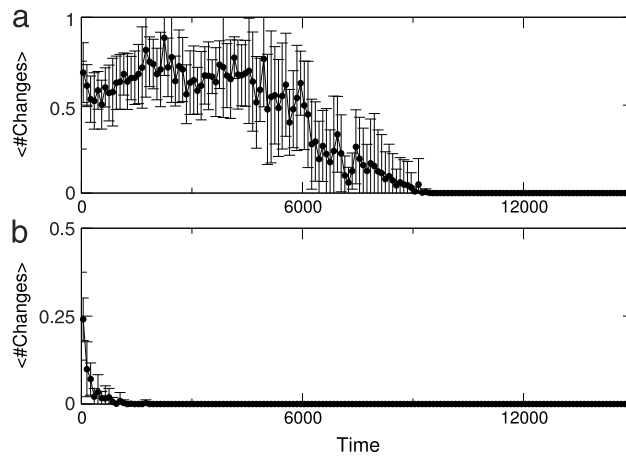


Fig. 4. Average number of changes. Average number of features that the Mass Media changes. Each point represents the mean value of changes over 100 time steps and this quantity is averaged over 50 events. Panel (a) stands for NFS and panel (b) for FS, both with $Q = 60$ and $B = 0.01$.

that the combination of strategies produces that $\langle H_F \rangle$ begins to increase monotonically when the change is done, in contrast to what is observed when the Media applies a *pure NFS*, where it remains practically constant.

In Fig. 3, panels (c) and (d), we explore different values of $\langle F/N \rangle$ in which the Media changes its strategy. We plot $\langle F/N \rangle$ and $\langle H_F \rangle$, respectively, at the time τ , which is the time spent to reach the asymptotic value of $\langle F/N \rangle$ when the Media applies a combination of strategies, and we compare them with the transitory results obtained when only the *NFS* is applied. It is important to remark that the asymptotic fraction of *Followers* is always 1 for the *NFS*. In panel (c), we can observe that the *NFS* is always the faster strategy to reach a given amount of *Followers*, but the combination of strategies produce a better homogenization when that value is attained (see panel (d)). It implies that if the Media adopts a combination of strategies, it relaxes the condition of full consensus, but the system reaches a stationary state (when $\langle H_F \rangle = 1$ and $\langle F/N \rangle$ is maximum) faster than when a *pure NFS* is applied. However, if it wants to reach a given amount of *Followers* regardless of their homogenization, the *NFS* is the best strategy.

3.3.2. Structural combinations

In the previous sections, the Mass Media always kept fixed the first feature while it was able to change the values in the others according to the different strategies defined above. However when we analyze the mean number of changes that the Mass Media does per time step, we found that, on average, the *NFS* changes are less than one feature per time step, while *FS* changes even less (and it is more similar to a Fixed Mass Media, as we have seen at their respective region diagrams), as we can see in Fig. 4. This suggests that similar results can be found if we let the Mass Media change just one of the features at a time. This can be seen as a combination of strategies in the features space where one feature adapts to the population meanwhile the others remain fixed. We analyze variants of the *Non-Followers* strategy in two different cases: When the adaptive feature is always the same (fixed) and when it is chosen randomly in every time step. In all cases, the first feature remains constant.

In Fig. 5 we plot $\langle F/N \rangle$, as well as $\langle H_{MM} \rangle$ and $\langle H_F \rangle$ as function of time for the two cases. We analyze the system for $Q = 60$ and $B = 0.01$ and compare it with the cases of *NFS* and *FMM*, respectively. We can observe that one adaptive feature is a sufficient condition to reach consensus for $Q = 60$ and $B = 0.01$, which is impossible if all features are fixed (*FMM*), as we have seen in Fig. 1. In particular, if the adaptive feature is randomly chosen, the dynamics of the system is almost the same that in the case of *Non-Follower Strategy (NFS)*. On the other hand, if the adaptive feature is fixed, also the system is able to reach consensus in regions of the parameter space where a Fixed Mass Media is unable to do it, but the convergence time is larger than the one expected for a full *Non-Followers Strategy*. On the other hand, this strategy favors the homogenization of the *Followers* group, as it can be observed in the behavior of $\langle H_{MM} \rangle$ and $\langle H_F \rangle$ in Fig. 5.

4. Conclusions

In this work we have proposed a new way to model the influence of a Mass Media onto a system of social agents. Here, the Media has a specific purpose: To put on the agenda a particular topic, i.e., to make people discuss a given topic and impose its point of view, represented by a fixed feature's value. This way to model the Media fits better within the conflict theory of Media's influence [1] and within the works of McCombs [2,3], which we consider that describe better its actual role in a society. In order to achieve this goal, the Media takes advantage of the other features which are adaptives in order to increase the probability of interaction with potential consumers, according to different strategies. In one of them, the Mass Media takes the most popular value of each feature among the *Non-Followers* which was named the *NFS (Non-Followers Strategy)*. In the other one, the Mass Media takes the most popular value of each feature among the *Followers* and we called

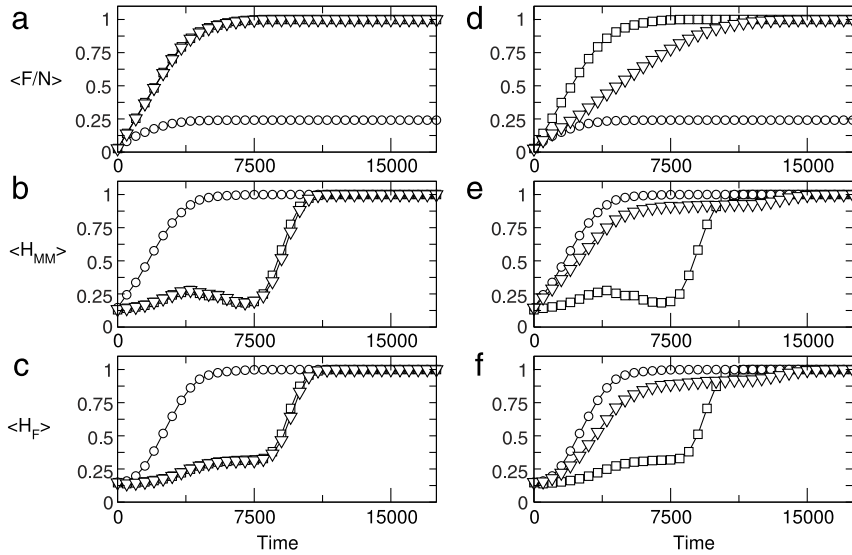


Fig. 5. Combination of strategies 2. Dynamical behavior when the *MM* has only one adaptive feature for $B = 0.01$ and $Q = 60$. Fraction of *Followers* ($\langle F/N \rangle$, panels (a) and (d)), mean homophily respect to the *MM* ($\langle H_{MM} \rangle$, panels (b) and (e)), and mean homophily among *Followers*, ($\langle H_F \rangle$, panels (c) and (f)) as a function of time. Left panels: the adaptive feature is randomly chosen at each time step. Right panels: The adaptive feature is always the same. Squares denote *NFS*, circles *FMM*, and triangles a Mass Media with one adaptive feature. Bra-kets denote average over 1000 events.

it the FS (*Followers Strategy*). We compare both with the standard cases where the Mass Media is fixed in time and then it does not follow any strategy at all (*FMM*).

When the *MM* applies the *Non-Followers* strategy, it is able to reach consensus for all values in parameter space, which is not the case of the *Followers Strategy* or when the *MM* is fixed. The problem with this strategy is that it takes too much time to reach that consensus due to the fact that the Mass Media ends up adopting particular agents' state in order to convince the last *Non-Follower* agents. These sharp changes produce that the similarity between the *Followers* and the *MM* decrease during this time, while in the other strategies it always shows an increasing behavior. It also produces that the *Followers* form a heterogeneous group until the last agent is convinced.

In order to improve the *NFS*, we explored different combinations of strategies: We have found that if the Mass Media combines strategies in a temporal manner, it can reach a large amount of *Followers* (close to 90%) with a monotonous increase in their homogenization, but still a pure *NFS* is the faster way to reach a given amount of *Followers*. We have also found that, when the combination is in the Feature Space (i.e., when some features are fixed and others are adaptive), the change of only one feature per step is a sufficient condition in order to reach consensus (100% of *Followers*). Moreover, if the adaptive feature is selected at random, the system behaves quite similar to the case when the *MM* adopts the *Non-Followers* strategy. On the other hand, if the adaptive feature is fixed, it takes almost the double of time to reach the total amount of *Followers* but it produces a homogeneous group during the dynamics. The structural combination of strategies can be seen as a more economic way to have an adaptive *MM* that can reach consensus in all the parameter space.

This work is the first step in order to understand the formation of collective states when a Mass Media want to set the agenda and impose its point of view in a given feature. Future extensions of this work should include the consideration of complex networks of interaction, and the presence of two or more Media in a competitive context.

Acknowledgments

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Appendix A. Microscopic description of *NF* strategy

In this appendix we describe the peculiar behavior of the *NFS*: It is very good to collect *Followers* quickly but it loses a lot of time in trying to convince the last fraction of the population. We can see in detail this behavior and understand the counter-intuitive dynamics of this strategy by analyzing a single representative dynamical event. In Fig. A.6, panel (a), we compute $\langle F/N \rangle$, $\langle H_{MM} \rangle$, and $\langle H_F \rangle$, as function of time for a single event with $Q = 60$ and $B = 0.01$. In panel (b), we compute the average changes that the *MM* does as function of time. The average is over 100 time steps.

If we see first $\langle H_{MM} \rangle$, we notice that it does not present the smooth decreasing behavior observed in Fig. 2 panel (e), when $\langle H_{MM} \rangle$ represented the average over many events. In a single event, we can see that this decreasing region is replaced by a “noisy” region, which extends from $t \simeq 4000$ to $t \simeq 8000$ in this particular event. In this region, less than the 25% of the

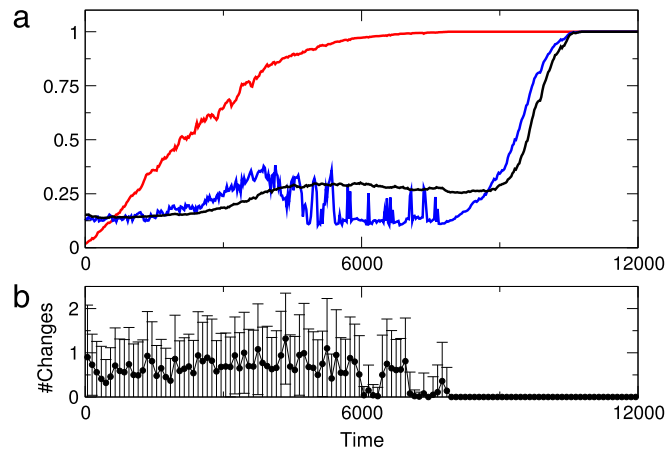


Fig. A.6. Dynamical behavior of single event of the Non-Follower Strategy. $B = 0.01$ and $Q = 60$. Panel (a) Fraction of *Followers* (F/N , red line), mean homophily between *Followers* and the *MM* (H_{MM} , blue), and mean homophily among *Followers*, (H_F , black) as a function of time. Panel (b) Average change of the *MM* as function of time. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

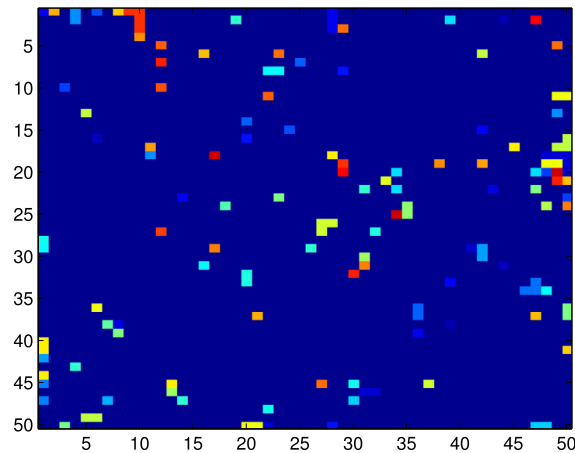


Fig. A.7. Snapshot. It corresponds to $t = 5000$, while the colors denote different values in the first component of the agents' states. The most abundant color represents the *Followers*. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

agents are *Non-Followers*, and it is natural to think that they are distributed over the lattice, i.e. they do not belong from the same cluster, as it is suggested by the snapshot of Fig. A.7. Then, when the *MM* looks for the most abundant Q for each feature, it finds that this one is not well defined, i.e. there is no value of Q for a given feature shared by a great number of *Non-Followers*. Instead of that, the *MM* finds a lot of Q values with the same frequency (this is also due to the fact that $Q = 60$, which decrease the probability that two agents share the same value of Q in a given feature). Therefore, the *MM* adopts a state which can be a mixture of different agents or, in the extreme case, a state equal to a single agent, except in the first feature. The latter situation becomes more likely when the number of *Non-Followers* tends to zero, being accurate when there is only one agent without convincing. By adopting a state similar to a very few agents, the *MM* departs from the great number of *Followers* present in the system, resulting in a decrease of H_{MM} , showing the “noisy” behavior with a lower bound in 0.1, which represents the minimum homophily between the *MM* and a *Follower*, which by definition, shares at least the first feature. At the same time, the sharp changes of the *MM* do not help to homogenize the *Followers* agents, which “become confused” by the *MM* messages and maintain constant a very low similarity among them (H_F).

The “noisy” region finishes at $t \simeq 8000$, when all agents become *Followers*. As it can be seen in Fig. A.6 panel (b), from this moment the *MM* does not change, adopting the state of the last *Non-Follower* convinced. So, both H_{MM} and H_F grow monotonically to a value of 1.0, when all agents finish to adopt the Mass Media's state. Before it has stopped to change, the average number of changes is slightly less than 1 change per time step, as it was observed in Section 3.3.2.

Appendix B. Dependence on F and N

We give here a brief discussion about the dependence of the strategies' behavior when we vary F and N . If we observe Fig. B.8, the variability of F makes the displacement of the first order transition in the Axelrod Model. It means that we can

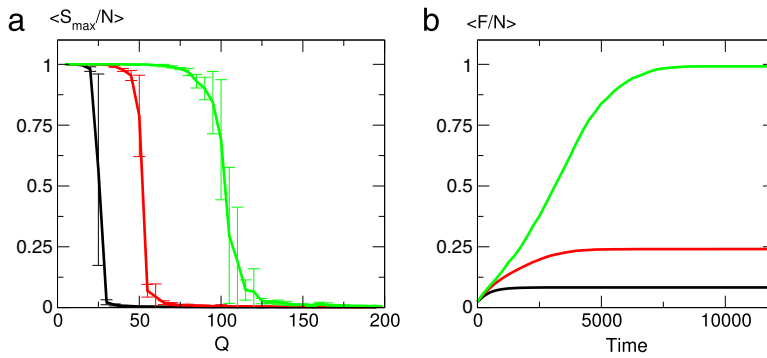


Fig. B.8. Dependence on F . Panel (a) corresponds to the relative size of the biggest fragment in a Axelrod Model without the presence of a Mass Media. Panel (b), the fraction of *Followers* of a *Fixed Mass Media*, for different values of F . In color black, $F = 5$, in red $F = 10$, and in green $F = 20$. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

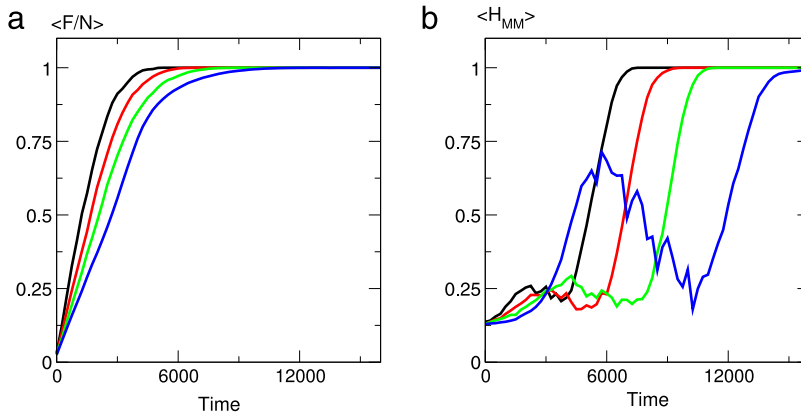


Fig. B.9. Dependence on N . Panel (a) corresponds to the fraction of *Followers*, and Panel (b), the homophily of the *Followers* respect to the *MM*, both for the *NFS*, for different values of N . In color black, $N = 400$, in red $N = 1024$, in green $N = 2500$ and in blue $N = 10000$. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

find monocultural asymptotic states for Q 's values larger than $Q = 60$ if F is increased. A larger value of F favors those strategies that do not reach the consensus for that value of Q . As for example, in Fig. B.8 we can observe that a *Fixed Mass Media* attaches more *Followers* when $F = 20$ than for the cases $F = 10$ and $F = 5$. If we want to observe for $F = 20$ results that are equivalent to $F = 10$ and $Q = 60$, we must set Q above the critical point in that case, as for example, $Q = 120$. In conclusion, the results present in this work are equivalent for other F values taking into account the displacement of the critical point.

On the other hand, we did not observe a great dependence when N is varied. Naturally the time of convergence of the system increase with N , as you can observe, as for example, in Fig. B.9, where the fraction of *Followers* for the *Non-Followers* strategy is calculated for various N . At the same time, the fluctuation of H_{MM} and H_F , for the *NFS* was observed to be sharper when N is larger (see for example, Fig. B.9). However, we observe qualitatively the same behavior of the strategies as for $N = 2500$.

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