Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Information, opinion and pandemic

Américo T. Bernardes\(^a, \ast\), Leonardo Costa Ribeiro\(^b\)

\(^a\) Physics Department-ICEB, Universidade Federal de Ouro Preto, Ouro Preto/MG, Brazil
\(^b\) Economy Department-FACE, Universidade Federal de Minas Gerais, Belo Horizonte/MG, Brazil

**Abstract**

The world's population suffers a COVID-19 pandemic. By September 2020 nearly 1 million people had died. These are official numbers. The real cases might be much higher, due to under-reporting in many countries. Different strategies were adopted by national governments. Neglecting what was defined by sanitarian authorities, some politicians, at the beginning of the pandemic, declared that it would be a little flu, without consequences, lighter than seasonal flues. Some politicians propagated medicines with no scientific support. In many countries and regions, people became confused. The population's reactions to these political positions may facilitate or block the virus spread.

In this paper, we propose a model connecting the spreading of opinions with the propagation of a pandemic. We discuss how conflicting opinions can diffuse in the pandemic environment and the influence it has on the population's behavior; how it may cause a greater or smaller number of infected individuals.

© 2020 Elsevier B.V. All rights reserved.

1. Preface

I (atb) met Stauffer for the first time at the Statistical Summer School held in São Carlos/SP in 1988 (or 1989). After some meetings in Brazil, Stauffer accepted me in Cologne, for a postdoc in 1995. It was a very productive year. The initial research motivation was amphiphilic molecules self-assembly, but rapidly Stauffer pushed me to study population evolution.

At the end of the nineties, Stauffer became interested in econophysics and sociophysics. After researchers from Ceará published a study about elections [1], we wrote a paper showing how a recently introduced model for opinions diffusion could explain the results [2]. Our article has been presented in the Conference for Computational Physics 2001, which was held in Aachen in the first days of September. During the conference, we discussed that the model could be implemented on a scale-free network, which at that time had been recently published by Barabasi–Albert [3]. Back in Cologne, this culminated in a work with János Kertész and Stauffer and which was published in [4].

We stayed in contact, doing some exotic Physics, until his retirement. Always in Rio de Janeiro or Niterói, also in Buenos Aires or Breslau. After his retirement, Stauffer starts studying history. At some moment he asked me for information about the presence of Nazis in Natal/RN during the second world war.

Stauffer made an immense contribution to the computational physics community in Brazil. He was an example of a strange combination of morbid humor and tolerance. He was very dedicated to Science but also very interested in the life of people and environmental issues. I am not sure, but I think that Stauffer is the only scientist that acknowledged a beach for inspiration in a paper...

\(\ast\) Corresponding author.

**E-mail address:** atb@ufop.edu.br (A.T. Bernardes)

https://doi.org/10.1016/j.physa.2020.125586
0378-4371/© 2020 Elsevier B.V. All rights reserved.
2. Introduction

The idea of this paper arose when reading the book Mathematical Modelling of Zombies by Robert Smith [5]. In the first chapter, he discusses the spreading of media information from an article in which a zombies’ invasion was modeled. When reading this book, we asked ourselves about the role of information (and opinions) on the population’s behavior facing an epidemic. How would the population behave if the society were polarized between conflicting opinions?

Nowadays, we live in a world attacked by a new virus, SARS-Cov-2, with dozens of millions of infected people, and about a million deaths. The numbers increase day by day. Maybe this is the worst pandemic confronted by humankind since the 1918 Flu Pandemic. COVID-19 is a serious disease caused by the SARS-CoV-2 virus, of the coronavirus class, which had the first case reported in December 2019 and spread throughout the world.

The impact of COVID-19 on human daily routine and the global economy is ubiquitous, not to mention its huge death toll. Such a global event with a deep impact on the social organization also attracted the attention of the scientific community that focused its efforts to help to understand the spreading of the disease, its effects on the human body, and to mitigate the pandemic impacts. As a consequence of the scientific community focus, the number of articles published in 2020 (that is not finished yet) increased to almost the double of the average of last years on Web of Science1 as shown in Fig. 1. In addition to the increase of its volume, there was also a repositioning of the scientific areas: articles related to engineering and internal medicine raised their positions in the top ranking while those related to mathematical models decreased their share: from 33.1% to 11.8% in 2020.

This share reduction can be due to the lack of disruptive-new mathematical models for disease spreading which since Ross’ [7] seminal paper have followed a path of incremental improvements of the original one [8]. He proposed a coupled system of three nonlinear ordinary differential equations with no explicit solution to model the temporal evolving of the total susceptible, infected, and remove (SIR) population. More recently, the focus on SIR models became on implementing incremental changes on the original model with the intent of making it more realistic. Usually, adding a huge volume of empiric information to the model to better fit it to real disease spreading curves. [9–12].

To date, there are no proven drugs or vaccines for the treatment of COVID-19. While the scientific community debates the causes and studies alternatives to combat this terrible moment, searching for vaccines and medicines, the recommended strategies to content the pandemic are non-pharmaceutical interventions such as social isolation and quarantine, avoiding people agglomeration, personal hygiene, and use of masks. This would cause that transmissibility, represented by the basic reproduction number $R(t)$, decrease with time. If the value of $R(t)$ is less than 1, it implies that the pandemic is contained, and the number of infected, and consequently the number of deaths, decreases with time. On the other hand, for $R(t)$ greater than 1, it means that the pandemic is expanding.

However, the non-pharmaceutical attitudes are daily confronted with fake news and anti-scientific alternatives, such as the case of using anti-parasite medicines or even to drink disinfectants. Important political leaders, some communicators, or even members of diverse religions contest the efficacy of the non-pharmaceutical attitudes recommended by sanitary authorities. We are living in a critical moment. Despite warnings from several health institutions, some governmental authorities adopted measures to relax social isolation, opening schools, public parks, malls, and even sports stadiums, which reversed the declining rate. This may cause a new outbreak in many regions in September 2020.

Nonetheless, not only some leaders deny those attitudes of social isolation or sanitary caring, but we also watch the abandonment of social isolation by the population when the numbers of infected people decrease. There is a conflict of

---

1 Those articles were got from Web of Science through the same methodology proposed by Walters et al. [6] and using the following query: TS = (“Mathematical” or “Agent-based” or “Simulation” or “Network” or “SIR”) and TS = (“Epidemic” or “Disease spread” or “Influenza” or “flu” or “covid” or “corona”) and TS = (“Global” or “Pandemic”).
opinions and confusion in the society. Thus, opinions and information may have an important role in the spreading of this pandemic.

Diverse approaches have been proposed in the last decades to model opinions or information diffusion. In the beginning, these models represented a population of individuals that could have two discrete opinions (an Ising-like model). The convincing of an individual was achieved by the sum of the opinions of its neighbors (see, as an example [13]). Some of these models were based on strategies of cellular automata evolution. Another approach was proposed by Serge Galam, where a community is divided into some subsets and the opinions initially win in the subsets until a majority is formed. Galam succeeded in explaining with this class of models the victory of Trump in the American elections in 2016 [14]. Different from this approach, where an opinion of the neighbors convinces an individual, was the one proposed by Sznajd-Weron and Sznajd [15]. In their model, a pair of individuals who share the same opinion can convince their neighbors, in a dynamical process towards each other, in contrast with the inwards dynamics of other models. For a review of the many models and variants, we suggest [16].

While some models of opinion diffusion do not consider external influences, there are others where an individual's opinion can be changed by a factor which is not the opinion of a neighbor or a neighboring cluster. With the advent of the internet and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance. Recently, some movies discussed the internet's role and the massive use of social networks, external factors gained extreme importance.
The probability to connect a node to a previously added node is proportional to the number of links of that node. This is called preferential attachment and in the end, one has a SFN with $L$ nodes.

Opinions are defined in the continuum interval $O_i \in [1, -1]$. The limits denote values for the most controversial opinions. The two most connected hubs receive the limit values which do not change in the simulation. An individual may have an opinion closer either to one or to another hub. Or he/she can also have no opinion. In this case, the $O_i = 0$. In our model, the value 1 means absolute opposition to sanitary measures, including social isolation, and $-1$ means obedience to the WHO recommendations, for instance.

After the network is formed, all the sites are set to $O_i = 0$. Then, the two most connected hubs receive the states 1 and $-1$. If there exist two or more hubs with the same number of links, we choose that one in crescent numerical order in the list of nodes. After defining the two poles, we assign opinions to their neighboring sites. The opinion for each $j$ one is defined as:

$$O_{nn} = O_{hub} + (R - 0.5) \epsilon$$  \hspace{1cm} (1)

where $R$ is a random number $R \in U(0, 1)$, and $\epsilon$ is a real parameter which denotes the strength of convincing in a given simulation. A new random number $R$ is generated every time it is required in all the simulation steps. We used a linear congruential generator to do this. If $O_j > 1$ (or $O_j < -1$) it is set to 1 (or $-1$). At this time, values were assigned only to those hubs and their nearest periphery. The others remain zero.

The random network is created by randomly selecting pairs of nodes from the total of $L$ nodes and attaching them with a probability given by a Poisson distribution with average $V$. It is important to mention that with this procedure, some people may not have neighbors or contacts in the real/physical world. She/he has connections in the opinion’s network, but not in the physical world.

The variable $S_i$, which denotes the health condition, can assume three values: susceptible $S_i = 0$; infected $S_i = 1$; and removed or recovered $S_i = 2$. An infected person can infect a susceptible one with a probability $\beta$ per one contact. After being infected, she/he remains in this state for $\tau$ time steps (which can be thought of as days, for instance), and then she/he recovers. For each time step, a counter $t_i$ defines the time of infection of node $i$. This state remains unchanged and cannot be infected again. This is the simplest version of the SIR model. It is well known that the curve for recovered people has an inflection point when the number of infected persons reaches a peak. At this moment, the pandemic starts weakening.

### 3.2. Dynamical process

In the same way, as usually done for disease propagation simulations, we start with one infected person (randomly chosen which state was set to 1). Different from the traditional SIR simulations, we couple the two networks as follows.

Each person in the random network has $n$ neighbors (defined as described above). Traditionally, she/he has a probability $\beta$ to transmit the disease. However, since we focus on the effects of opinions in the pandemic propagation, we assume that her/his opinion will define a probability of contact between people, calculated by:

$$P_{contact,i} = (1 + O_i)/2$$ \hspace{1cm} (2)

It does mean that if in a given moment the opinion of a person is $O_i = -1$ she/he avoids contact with anyone. On the other hand, if her/his opinion is $O_i = 1$ she/he will contact all her/his neighbors at a specific moment. Notice that, since the values of opinions change with time, this behavior also may change.

If opinions impact the population's behavior, we propose that in a similar or symmetric way, the population’s health situation will impact on the opinions.

The spread of opinions in the Sznajd model is produced by the existence of neighbors with similar opinions. We visit a node $i$. If $O_i = 0$ nothing happens. For $O_i \neq 0$ we chose randomly a site $j$ in this nearest neighboring. Neither $i$ nor $j$ can be the two hubs described above (the most connected). They do not change their opinions during a simulation. They are already convinced and nothing can change it.

If $O_j = 0$, meaning that this person has no opinion about the pandemic, $i$ tries to convince $j$ with a probability $P_i = 1/k_i$, where $k_i$ is the connectivity (number of nearest neighbors) of $i$. If she/he succeeds, the opinion of $j$ is set to

$$O_j(t+1) = O_j(t) + (R - 0.5) \epsilon + \delta$$ \hspace{1cm} (3)

where

$$\delta = \left[\frac{N_{S,j} - N_{I,j}}{k_{RN,j}}\right] \ast R \ast \epsilon$$ \hspace{1cm} (4)

$N_{S,j}$ is the number of healthy (susceptible) neighbors $S_{k,j} = 0$ of node $j$, and $N_{I,j}$ is the number of infected neighbors $S_{k,j} = 1$ of node $j$. It means that if the number of healthy neighbors is greater than that of infected neighbors, the opinion $O_j$ of $j$ tends to the direction of those against social isolation. On the other hand, if $N_{I,j} > N_{S,j}$, $O_j$ will move in the direction of those in favor of sanitary precautions. $k_{RN,j}$ is the number of nearest neighbors of $j$ in the random network. As we have mentioned above, it might occur that $j$ has no neighbors in the RN. In this case, her/his opinion does not change.
\[ |O_i - O_j| \leq \epsilon \]  
\[ O_{nn,i}(t + 1) = O_{nn,i}(t) + O_{ij}(t) \cdot R \cdot \epsilon + \delta \]  
\( O_{nn,i} \) is the opinion of the nearest neighbor. \( \delta \) has the value calculated in Eq. (4). Notice that nothing changes if a person is in one of those hubs described above. Also, if \( O_i > 1 \) (or \( O_i < -1 \)) it is set to 1 (or -1).

The basic process starts with an infected person. We choose a node at random and set it to \( S_i = 1 \). We check if it has nearest neighbor in the RN. If not, we choose another one. The basic algorithm to this model is:

- After defining the first infected person, we enter in a loop of \( t \) time steps. In each time step, we visit \( L \) nodes chosen at random. Not necessarily all the nodes are visited.
- For each node \( i \) we check its status. If \( S_i = 0 \) or 2, we go to another node.
- If \( S_i = 1 \) we visit its periphery (the nearest neighbor nodes in the random network) with probability given by Eq. (2).
  - If \( S_{nn,i} = 0 \) we set it to \( S_{nn,i} = 1 \) with probability \( \beta \) and set \( t_{nn,i} = 1 \).
  - If \( S_{nn,i} = 1 \) or 2, we do not change it.
- After checking the nearest neighbors, we set \( t_i(t + 1) = t_i(t) + 1 \).
  - If \( t_i \geq \tau \) we set \( S_i(t + 1) = 2 \).
- When the evolution of the pandemic is concluded at this time step, all the opinions are updated following those procedures described in Eqs. (3) or (6).
- Return to the beginning.

This procedure is repeated until reaching the maximum number of time steps. In the simulations described below, we simulated the system until the number of infected is zero and the average of opinions evolves linearly (explained below).

4. Results

Since we have a model with so many parameters, it is important to isolate some of them, in order to better observe the effect and connection between opinions and the pandemic’s dynamic.

In that follows, we set the same size parameters for both of the two networks. Each node corresponds to the same person in both networks. We performed simulations for a population of \( L = 100,005 \) individuals, with \( m_0 = 5 \) and \( m = 4 \) for the SFN (\( m_0 \) is the initial nucleus of the SFN and \( m \) is the number of nodes increased at each step of the network construction). The random network is formed by using \( V = 5 \), meaning on average 5 neighbors for each node. All the simulations started with the two clusters of conflicting opinions already formed (as explained above), and the rest of sites without opinions; \( O_j = 0 \) for \( j \notin \{ \text{the chosen hubs and their neighboring nodes} \} \). All the simulations started with the same seed for the random number generator, and we can compare the results’ evolution.

We have defined the infection probability \( \beta = 0.1 \). As we have stated above, at each time step \( L \) nodes randomly chosen are visited, not necessarily all the nodes; and \( \epsilon = 0.05 \). We changed the value of \( \tau \) to have different strengths for the propagation of infections. The greater this value, the more likely the infections are to propagate (an individual remains infected for more time and it is more probable to infect neighbors). Values of \( \tau \) are defined in terms of time steps (which are an arbitrary time scale). As we have mentioned above, it was not our objective to compare our results with those observed in a real pandemic expansion, although some new SIR variants could implement the basic features here proposed.

Fig. 2 shows the results for six simulations. In four of them we have connected opinions and infections (solid lines). In the other two (dashed lines), we did not take into account the opinions in the individual’s behavior concerning social distancing. In the left part of this figure, the evolution of the percentage of infected people in the entire population is shown. In the right plot, the evolution of the average of opinions is shown. Since for two cases we did not consider connections between opinions and infections, only four simulations are shown in the right plot. The basic difference between the simulations is the value of \( \tau \), a parameter which defines the time a person remains infected and may transmit the disease. Each specific simulation is represented by a solid line of the same color in both plots.

As one can observe in the left plot, the percentage of infected persons starts with zero and grows, reaching a maximum, and then decreases, which is the traditional SIR model result. We opted to not include in this plot the percentage of susceptible and recovered (or removed) because our main interest is to show the interplay between infections and opinions. In the cases where opinions have been considered as influencing the populations’ behavior (solid lines), we performed simulations for four different values of \( \tau \), respectively 7, 14, 21, and 28 time steps. In the cases where opinions do not influence the population’s behavior, we performed simulations for \( \tau = 7 \) and 14. In the later cases, we want to compare two simulations: either considering opinions or taking into account the opinions in the population’s behavior.

The evolution of infections depends on the parameter \( \tau \), but also on the populations’ behavior, either against or in favor of social isolation. The basic transmission number is related to the slope of the infection function.
In the right part of the figure, the evolution of average opinion is shown. Since in the beginning of the simulations the number of infected people is zero, the number of individuals with opinions against social isolation increases, and the average increases. As we mentioned in the model definition, the value 1 represents the maximum against social isolation and sanitary attitudes. With time, the number of infections increase in the same way for all the simulations, and this forces the reduction of opinions favorable towards the relaxation of social contact, due to the connections between opinions and the numbers of infected people as described in Eqs. (2), (3), and (6). For higher $\tau$ values, the number of infected people remains higher for longer times, and it forces the reduction of opinions against the social distancing. As we can observe, for the highest $\tau = 28$, the mean value of opinions reduces until the majority of individuals are in favor of social distancing: the mean value becomes negative. It is important to note that the evolution of the opinion average, after the number of infected individuals vanished, evolves linearly with time.

By comparing the percentage of infected people either considering (solid line) or not opinions (dashed lines), as is shown in the left plot, we observe that the existence of opinions in favor of social distancing reduces the transmission number, and flats the curves, as we can observe by comparing the curves in Fig. 2. We observed a reduction in the number of infected persons, but it does not seem to be relevant. The main factor is the curve's flattening, which is desirable since it is related to the support capacity of the health system. For shorter $\tau$ the reduction is much more significant.

5. Conclusions

In this paper, we introduced a model for pandemic diffusion taking into account the existence of conflicting opinions concerning the individual behavior. We live in a very turbulent moment, where politicians and other leaders claim that COVID-19 is not a serious obstacle, and the individuals react in different ways. While some people follow these leaders, others listen to the sanitary authorities.

Our model is a combination of the Sznajd model for opinions diffusion and the SIR model. Different from the traditional version of the Sznajd model, in our case opinions are defined in a continuous interval between two opposite positions. The Sznajd model is conceived in a scale-free network, while the SIR model is defined in a random network. Each node in each network represents the same person. The interconnections between the two models are made by a contact probability between neighbors in the SIR model, which depends on an individual’s opinion. Concomitantly, in the Sznajd model, these opinions depend on the relation between the number of healthy and infected neighbors.

At the beginning of the simulations, given the reduced number of infected persons, opinions against social isolation grow. However, there are opinions in the society in favor of sanitary attitudes and they influence the pandemic expansion. The number of infected persons increases slower than that situation in which opinions have not taken into account. The existence of opinions in favor of social isolation flattens the curve and reduces the transmission number. For a longer duration of the pandemic, the opinions against social isolation may reduce until it becomes a minority in the population.

Although it is a very simple model, we think that it reveals important aspects of the present situation of a pandemic.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
References

[1] R.N.C. Filho, M.P. Almeida, J.S. Andrade, J.E. Moreira, Scaling behavior in a proportional voting process, Phys. Rev. E 60 (1999) 1067–1068, http://dx.doi.org/10.1103/PhysRevE.60.1067.

[2] A.T. Bernardes, U.M.S. Costa, A.D. Araujo, D. Stauffer, Damage spreading coarsening dynamics and distribution of political votes in sznajd model on square lattice, Internat. J. Modern Phys. C 12 (02) (2001) 159–167, http://dx.doi.org/10.1142/S0129183101001584.

[3] A.-L. Barabási, R. Albert, Emergence of scaling in random networks, Science 286 (5439) (1999) 509–512, http://dx.doi.org/10.1126/science.286.5439.509.

[4] A. Bernardes, D. Stauffer, J. Kertész, Election results and the sznajd model on barabasi network, Eur. Phys. J. B 25 (1) (2002) 123–127, http://dx.doi.org/10.1140/e10051-002-0013-y.

[5] R.J. Smith, Mathematical Modelling of Zombies, University of Ottawa Press, 2014.

[6] C. Walters, M.M. Meslé, L.M. Hall, Modelling the global spread of diseases: A review of current practice and capability, Epidemics 25 (2018) 1–8, http://dx.doi.org/10.1016/j.epidem.2018.05.007.

[7] R. Ross, An application of the theory of probabilities to the study of a priori pathometry—Part I, Proc. R. Soc. Lond. Ser. A Math. Phys. Eng. Sci. 92 (638) (1916) 204–230, http://dx.doi.org/10.1098/rspa.1916.0007.

[8] R.M. Anderson, Discussion: The Kermack–McKendrick epidemic threshold theorem, Bull. Math. Biol. 53 (1) (1991) 3–32, http://dx.doi.org/10.1006/bulm.2003.0039.

[9] P. Nadler, S. Wang, R. Arcucci, X. Yang, Y. Guo, An epidemiological modelling approach for covid-19 via data assimilation, Eur J. Epidemiol. 35 (8) (2020) 749–761, http://dx.doi.org/10.1007/s10654-020-00676-7.

[10] A. Soares, R. Bassanezi, Stability analysis of epidemiological models incorporating heterogeneous infectivity, Comput. Appl. Math. 39 (2020) 246, http://dx.doi.org/10.1007/s40314-020-01293-6.

[11] S. Ribeiro, A.C. e Silva, W. Dátilo, A. Reis, A. Góes-Neto, L. Alcantara, M. Giovanetti, W. Coura-Vital, G.W. Fernandes, V. Azevedo, Severe airport sanitarian control could slow down the spreading of Covid-19 pandemics in Brazil, PeerJ 8 (2020) e9446, http://dx.doi.org/10.7717/peerj.9446.

[12] T.M. Rocha Filho, F. Sanem dos Santos, V.B. Gomes, T.A. Rocha, J.H. Croda, W.M. Ramalho, W.N. Araujo, Expected impact of Covid-19 outbreak in a major metropolitan area in Brazil, http://dx.doi.org/10.1101/2020.03.14.20035873.

[13] K. Kacperski, J.A. Hoyst, Phase transitions as a persistent feature of groups with leaders in models of opinion formation, Physica A 287 (3) (2000) 631–643, http://dx.doi.org/10.1016/S0378-4371(00)00398-8.

[14] S. Galam, The trump phenomenon: An explanation from sociophysics, Internat. J. Modern Phys. B 31 (10) (2017) 1742015, http://dx.doi.org/10.1142/S0217979217420152.

[15] K. Sznajd-Weron, J. Sznajd, Opinion evolution in closed community, Internat. J. Modern Phys. C 11 (06) (2000) 1157–1165, http://dx.doi.org/10.1142/S0129183100000936.

[16] C. Castellano, S. Fortunato, V. Loreto, Statistical physics of social dynamics, Rev. Modern Phys. 81 (2009) 591–646, http://dx.doi.org/10.1103/RevModPhys.81.591.

[17] P. Sobkowicz, Discrete model of opinion changes using knowledge and emotions as control variables, PLoS ONE 7 e44489.

[18] J.R. Majmudar, S.M. Krone, B.O. Baumgaertner, R.C. Tyson, Voter models and external influence, J. Math. Sociol. 44 (1) (2020) 1–11, http://dx.doi.org/10.1080/0022250X.2019.1625349.

[19] J. Cui, Y. Sun, H. Zhu, The impact of media on the control of infectious diseases, J. Dynam. Differential Equations 20 (1) (2008) 31–53, http://dx.doi.org/10.1007/s10884-007-9075-0.

[20] W. Kermack, A. McKendrick, A contribution to the mathematical theory of epidemics, Proc. R. Soc. Lond. Ser. A Math. Phys. Eng. Sci. 115 (772) (1927) 700–721.