

Rapid #: -17257080

CROSS REF ID: **357617**

LENDER: **TFW :: Ejournals**

BORROWER: **BMU :: Main Library**

TYPE: Article CC:CCG

JOURNAL TITLE: International journal of disaster risk reduction

USER JOURNAL TITLE: International journal of disaster risk reduction : IJDRR

ARTICLE TITLE: Cascading disasters, information cascades and continuous time models of domino effects.

ARTICLE AUTHOR: Mizrahi S,

VOLUME: 49

ISSUE:

MONTH: 10

YEAR: 2020

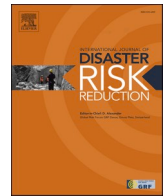
PAGES: 101672

ISSN: 2212-4209

OCLC #:

Processed by RapidX: 3/3/2021 3:47:14 PM

This material may be protected by copyright law (Title 17 U.S. Code)



Cascading disasters, information cascades and continuous time models of domino effects

Shlomo Mizrahi

Department of Public Administration and Policy, School of Political Sciences, University of Haifa, Israel

ABSTRACT

This paper develops a framework for analyzing the dynamics through which cascading disasters evolve, spread and come to control in situations of uncertainty and vulnerability. The framework first establishes the idea that disasters are inherently a social phenomenon rooted in the social structure and reflects the processes of social change. The core of such social structures and processes is the mechanism of collective action. We then explain the ways in which formal mathematical models in general, and game theoretical models in particular, can help analyze the dynamics of collective action, detect the core parameters through which they evolve and, in particular, identify the interactions between these parameters. We show that these dynamics may have different forms of development, which are usually non-linear and cyclic. The framework also emphasizes the major role of information and social learning in these dynamics.

1. Introduction

This paper develops a framework for analyzing the dynamics through which cascading disasters evolve, spread and come to control in situations of uncertainty and vulnerability. The framework first establishes the idea that disasters are inherently a social phenomenon rooted in the social structure and reflects the processes of social change [1,2]. The core of such social structures and processes is the mechanism of collective action. We then explain the ways in which formal mathematical models in general, and game theoretical models in particular, can help analyze the dynamics of collective action, detect the core parameters through which they evolve and, in particular, identify the interactions between these parameters. We show that these dynamics may have different forms of development, which are usually non-linear and cyclic. The framework also emphasizes the major role of information and social learning in these dynamics.

2. Disasters, crisis and cascading disasters

In order to analyze cascading disasters systematically, we first need a definition of disaster that the research community can agree upon. Perry [2] discusses the various approaches to, and conceptualizations of, disasters as they have evolved since the 1950s. Early definitions suggest that disasters are sudden events that disrupt normal routines and social order, causing severe damage and loss of life [3]: 67 [4,5]; 310 [6]; 655 [7]; 357; [2]. Later definitions emphasize the hazards that characterize disasters, meaning that a disaster is viewed as an extreme event that arises when a hazard agent intersects with a social system [8]. In this

approach, environmental hazard cycles and agents are the focus [1]: 347; [2]. This approach is close to the traditional geographers' view, which also defines disaster as "the interface between an extreme physical event and a vulnerable human population" [9]: 264). While more recent definitions in the hazard approach retain the hazard origins of disasters, they have begun to examine them in social terms, particularly with regard to vulnerability and resilience [2,10–13].

However, the approach that has come to dominate the field since the 1990s views disasters as a social phenomenon. It focuses on vulnerability as socially constructed and the idea of social change, all to the near exclusion of physical agents [1,2,14,15]. Therefore, this approach departs from the two discussed so far. In his definition of disasters Quarantelli (2000: 682) includes a variety of features. Disasters: (1) are sudden-onset events, (2) seriously disrupt the routines of collective units, (3) cause the adoption of unplanned courses of action to adjust to the disruption, (4) have unexpected life histories designated in social space and time, and (5) pose a danger to valued social objects. The entire concept is social: vulnerability is socially constructed by relationships in the social system and disasters are based on the notion of social change [16]: 226; [2].

An extended view of this approach looks at the cross-national or cross-cultural aspects of disasters [17]: 13) characterize disasters as a social event arising out of a process that involves a socio-cultural system's failure to protect its population from external or internal vulnerability. In a similar vein, [18]; 2005) views disaster as the collapse of cultural protections – captured in habits, folkways, laws, or policies – that either deflect or fail to deflect the threatening forces to which societies are exposed [2]. It follows that disasters flow from the normal

E-mail address: shlomom@poli.haifa.ac.il.

<https://doi.org/10.1016/j.ijdr.2020.101672>

Received 31 May 2019; Received in revised form 11 May 2020; Accepted 13 May 2020

Available online 21 May 2020

2212-4209/© 2020 Elsevier Ltd. All rights reserved.

functioning of social systems that take place when the life sustaining functions of the system break down [19]: 159). Therefore, researchers in that tradition see disasters as a subclass of a larger class – Barton called the larger type collective stress situations, while Boin, like Quarantelli and Rosenthal, uses the label crisis. In the current paper, we suggest collective action problems as the larger class.

Before we present this new idea, we refer to crisis research and its relationship to disaster research. A common definition of crisis is “a threat that is perceived to be existential in one way or another” [20]: 24). Crisis researchers typically focus on a temporal slice of the process through which a disaster emerges and eventually fades. They are mostly interested in the phase where intervention can still limit the effects of an emerging or escalating incident. It can therefore be fruitful to analyze cascading disasters using tools developed in the field of crisis research.

The crisis approach brings together ideas of vulnerability, risks, threats, triggers, processes, responses and outcomes. The core characteristics of crisis are threats, uncertainty and urgency [21]: 10). More specifically, we can speak of three dimensions – perceptions (of threats), information, and time. These are also vital dimensions and elements both in cascading disasters and in the dynamics of collective action. Hence, the significant added value we can get from integrating these three phenomena into one framework. Moreover, the crisis approach does not seek to identify specific factors that may cause a crisis, but, rather, proposes that escalating processes undermine a social system’s capacity to cope with disturbances [20]: 27). The ultimate cause of a crisis lies in the inability of a system to deal with the disturbance.

In this general context, Pescaroli and Alexander [22] define cascading disasters as follows: “Cascading disasters are extreme events, in which cascading effects increase in progression over time and generate unexpected secondary events of strong impact. These subsequent and unanticipated crises can be exacerbated by the failure of physical structures, and the social functions that depend on them, including critical facilities, or by the inadequacy of disaster mitigation strategies, such as evacuation procedures, land use planning and emergency management strategies. Cascading disasters tend to highlight unresolved vulnerabilities in human society. In cascading disasters one or more secondary events can be identified and distinguished from the original source of disaster” (p. 9).

A good example of a cascading disaster that conforms to this definition is a flash flood that disrupts electricity to an area. As a result of the electrical failure, a serious traffic accident involving the spilling of hazardous materials occurs. In this case, the traffic accident is a cascading event. If, as a result of the hazardous materials spill, a neighborhood must be evacuated and a local stream is contaminated, these are also cascading events. Taken together, the effect of cascading events can be crippling to a community [23]. Indeed, the Tōhoku earthquake of 11 March 2011 is considered an outstanding example of a cascading disaster. It affected three prefectures in northeast Honshu, the main island of Japan. Although only about 100 people died as a direct result of the earthquake, about 18,000 were killed by the ensuing tsunami. The most enduring consequence of this event may be the radioactive contamination resulting from the damage the tsunami inflicted on the Fukushima Dai’ichi nuclear reactors which, in the short term, forced the evacuation of 200,000 people from the surrounding area [22]. Further effects of these events included damage to the global supply chain, severe environmental damage and a worldwide impact on attitudes and policies about nuclear energy.

Clearly, the recent eruption of the Covid-19 pandemic has the characteristics of cascading disasters as the surrounding effects are tremendous both in time, space, uncertainty, social and economic aspects and hazardous conditions. We will demonstrate the applicability of the tools offered here to the analysis of this pandemic and its implications.

Combining the various definitions, we may conclude that cascading disasters are subtypes of the phenomenon of disaster, which, in itself, may belong to a larger class of phenomena such as crisis. On the other

hand, each phase in a cascading disaster where there is the potential of escalation may be regarded as a crisis. Therefore, a cascading disaster develops and escalates when local crisis situations in the chain are managed poorly, while the magnitude of the event intensifies as the chain develops and proceeds [24]. Viewing a cascading disaster as a chain or network of crisis situations means that the main characteristic that distinguishes cascading disasters from an isolated (“regular”) disaster is the accumulation of damage. Practically, it may be beneficial to analyze each phase in the chain or network in isolation where the impact of different nodes in the network may be regarded as inputs. Zuccaroa et al. [25] develop a network model with complex connections between the different nodes, yet they also propose an input-output model for analyzing each node in the network in isolation from the others. Indeed, network effects may inflict damage in a variety of areas in complex and non-linear ways. However, when planning a particular operating system or a strategy to cope with emergency or crisis situations, these effects can be considered inputs. Hence, each node or event in the chain may be analyzed in isolation from others. I will argue that in this kind of crisis situation, as in any isolated disaster, there are cascading effects but these occur at the social level and involve the development of a panic or the mobilization of efforts to deal with the crisis.

In addition, I would like to suggest that there is another category of disasters where the evolution is closer to the literal meaning of cascade – that is, an event that spreads disproportionately in time and space. One example is pollution that spreads disproportionately and in unexpected ways and creates cumulative damage. Another example is an epidemic or other social, technological, economic or political phenomena that spread and result in cumulative damage over time and space. Such dynamics usually develop like a snowball that gets bigger as it rolls downhill. The Covid-19 Pandemic is a good example of that type. Disaster and crisis research usually refers to these types of cascading disasters within the general category of disasters or cascading disasters. However, I suggest analyzing them in the context of collective action dynamics using continuous time models and information cascades. These tools are also effective for analyzing cascading effects at the societal level that occur within an isolated disaster or crisis.

Thus, we propose the following logic. Disasters and crises are fundamentally social phenomena and should be analyzed and understood as such [26]. At the core of most social phenomena we can identify the collective action dynamics that help explain them. These are the processes in which people engage or withdraw from effort to achieve a collective goal. The collective outcome may also influence people who have not invested effort and want to free ride on the efforts of others. The literature explores a variety of ways through which people deal with such problems and mobilize (or dismantle) a collective action. Such dynamics characterize disaster and crisis situations, meaning that they can be understood in the general context of the collective action phenomenon.

Cascading disasters are subtypes of the general categories of disaster and crisis. Therefore, collective action problems and dynamics also comprise the core of cascading events. I distinguish between two types of cascading disasters. One includes a set of events that develop in a sequence (a hierarchal chain or network) and result in cumulative damage over time and space. Another type of cascading disaster includes the disproportional spreading of a certain event through time and space, usually through a snowball dynamic. In the first type, collective action dynamics occur in each phase of the sequence and can help explain the evolution of the crisis at each phase. In the second type, we can utilize collective action models both to analyze the evolution of the snowball effect itself and to explain the societal dynamics within this process.

Specifically, we present four types of cascading dynamics in disasters:

- 1) Cascading disasters that spread through a snowball dynamic. Examples include environmental pollution, epidemics or other social,

technological, economic or political phenomena that spread and result in cumulative damage over time and space.

- 2) Cascading disasters where the damage spreads due to the development of mass hysteria or panic, or people failing to exert effort to effectively reduce the damage.
- 3) Same scenario as in (2), but information cascades and learning through common knowledge explain the mobilization of efforts to deal with the problem or the failure to do so.
- 4) Information cascades and common knowledge that help explain the mobilization of efforts to deal with the problem or the failure to do so in isolated phases of a disaster or crisis situations.

In the following section, I present two main tools – continuous time models and common knowledge modeling – in the context of collective action dynamics that can be used to analyze these four prototype dynamics. In the third section 1 demonstrate the application to the analysis of cascading disasters and dynamics.

3. Continuous time models and common knowledge modeling in the context of collective action dynamics

3.1. Continuous time models of the bandwagon effect and other collective action dynamics

Analyses of collective action dynamics often distinguish between the spontaneous and non-spontaneous evolution of collective action [27–29]. The second type is characterized by the involvement of social activists who mobilize large numbers of people. While purely spontaneous collective action is rare, there are mechanisms that fit this characterization quite well. One such mechanism is the “bandwagon” effect, also termed the “domino” or “snowball” effect, where individuals’ decisions about whether or not to participate in a collective action are influenced by the number of people currently involved in those efforts. Assuming that individuals recognize the need to protest or exert effort to achieve a collective goal, it follows that a larger number of participants reduces the costs of action and increases the chances of success [30–32]. Opponents of the collective goals, such as the government in the case of mass protest, who observe a large-scale movement are less likely to take violent measures to counteract the movement but, rather, will tend to be sensitive to public demands. Similarly, when many people join the efforts to increase the readiness for a disaster, the costs that each one has to pay decline as the collective efforts increase. Thus, players join collective efforts when the number of participants reaches a certain subjective threshold, meaning that the probability of non-participants joining the collective effort is proportional to the number of participants. This creates a cumulative effect that may lead to mass mobilization.

Individuals have different subjective thresholds for participation depending on their beliefs and structural conditions. Given a certain distribution of thresholds, the cumulative effect may drag an entire society into mass collective action or cause it to cease at a certain point. Granovetter [30] and Kuran [33] argue, for example, that since minor changes in individual thresholds may significantly affect the behavior of an entire society, models based solely on a simple aggregation of “beliefs” or “thresholds” have limited explanatory or predictive power. Indeed, the literature on the bandwagon effect focuses on explaining its basic rationale [27,31,32,34,35] or its disadvantages and limitations [30,33]. Other studies explain the ways in which social or institutional changes evolve through informational cascades [36,37] or belief cascades [38,39]. Nevertheless, these explanations refer to beliefs or thresholds that generate a kind of spontaneous bandwagon effect, but they do not analyze the bandwagon effect on the basis of specific structural parameters that influence these beliefs.

From a different perspective, a series of studies analyze processes that resemble collective action in the area of marketing. Hinz et al. [40] argue that seeding strategies have strong influences on the success of viral marketing campaigns, showing that seeding to well-connected

individuals is the most successful approach because these attractive seeding points are more likely to participate in viral marketing campaigns. On the contrary, Watts and Dodds [41] show that under most conditions that they consider, large cascades of influence are driven not by “influentials” – a minority of individuals who influence an exceptional number of their peers – but by a critical mass of easily influenced individuals. In the current paper, I argue that a critical mass of participants is necessary for successful collective action while entrepreneurs, or activists, may also have important roles in such dynamics.

A complex and systematic model of the bandwagon effect uses continuous time equations as well as rationales derived from epidemic theory [42]. Unlike most approaches, this model does not treat the bandwagon effect as a purely spontaneous process. Rather, it views the bandwagon effect as a process influenced by the ratio between the mobilization efforts of certain activists and the resources invested by those who are in a position to counteract this activity. These may be human agents, social structures or forces of nature. Furthermore, the model takes into account that while some people withdraw from collective action, others may join in. This complex modeling approach makes it possible to identify the conditions for specific types of the bandwagon effect. In keeping with the approach, a mathematical model for calculating the time that elapses until the dynamic reaches equilibrium is proposed. Since these conditions are only implicitly linked with individual preferences and beliefs, the model suggests that a given bandwagon effect can be explained and planned without knowing the exact preferences of the players. In other words, by aggregating individual beliefs and actions we are able to analyze the outcome of a certain bandwagon effect depending on a few structural variables rather than measuring individual beliefs and preferences in a given society. Furthermore, the continuous time model makes it possible to determine how long it takes the dynamic to converge to equilibrium.

A detailed model can be found in Gavious and Mizrahi [42]. The model also assumes that for every point in time the number of passive citizens who join the collective action during the next time interval is proportional to the interval length, the number of those who already participate, and the number of citizens. The rate of new participants joining the collective activity is influenced by the preferences of passive citizens, and is also strongly affected by the mobilization efforts of activists. It should also be noted that the participation rate increases as the number of citizens increases, because the participation rate is expected to rise as the number of potential participants increases. Similarly, the participation rate is expected to increase as the number of those who already participate increases. In other words, based on the bandwagon mechanism, it is assumed that people who do not participate will do so when the number of participants reaches a certain subjective threshold. For example, looking at the Covid-19 pandemic, different countries adopted similar strategies as mor countries joined the trend.

However, in collective action dynamics people may not only join collective efforts, but also withdraw from them. The rate of withdrawal from the collective action is significantly influenced by the resources invested by those who are in a position to counteract this activity.

The model highlights the key parameters in determining the rate and nature of the bandwagon effect, and suggests mathematical tools for calculating the resources required to achieve a certain level of collective action at a certain point in time. The model has characteristics similar to those of epidemic models, which counteract the exposure to and spread of infectious diseases. According to the same rationale, the bandwagon effect develops when people are exposed to others who are willing to take action and risk the consequences of their participation.

The main contribution of the model lies in the tools it proposes for explaining or actually planning a certain bandwagon effect without direct knowledge of the players’ beliefs and preferences. All that has to be known is the size of the population, the number of participants at the starting point, and the approximate ratio between the resources invested by those who try to mobilize collective action and those who are in a position (or have the motivation) to counteract it. The estimation

process involves varying interpretations, but it is easier than the precise identification of individual preferences and beliefs in society at large.

Furthermore, the theoretical framework allows us to draw several testable conclusions. First, the final size of the collective action does not depend on the number of participants at the starting point. The number of activists who initiate a mass movement does not influence the final results of their activity. The efforts invested by that group and the resources invested by those who counteract this activity are the key factors in predicting the outcome of this activity.

Second, the time it takes for the movement to reach its equilibrium size approximately depends on all of the parameters in the system, including the size of the entire population and the initial starting points. Thus, although a very small group of activists can successfully initiate a mass movement, it may take much more time to reach its maximal size compared to the initiation of a collective action by a large group of activists.

Third, the model shows that the ratio between the initial number of potential protesters and the leaving and joining rate determines whether the movement will decline from the very beginning or will grow to a certain maximal level and then decline to zero. Finally, we should emphasize that real-world applications of this theoretical framework do not require empirical measurement of individual preferences and beliefs. Therefore, such applications may improve our understanding of the shared mental models guiding individual behavior discussed by Denzau and North [39].

Further elaboration of continuous time models for the analysis of collective action dynamics is offered in Gavious and Mizrahi [43]. The models and the entire approach provide tools for explaining a wide variety of collective action dynamics either ex-ante or ex-post. Different empirical conditions may be expressed either in the structure of a specific model or in the values of the parameters in the models.

Similar to the bandwagon dynamic analyzed above, any collective action dynamic or cascading event is an interdependent system where pro and anti-mobilization forces interact in a way that is also simultaneous in its timing. The parameters for analysis are: (1) the number of participants in a collective action at a given point in time; (2) the amount of resources mobilized by those who are in a position to reduce that collective action at that point in time.

The additional amount of resources invested at a given point in time to counteract a collective action depends on (1) the willingness (or ability) to invest more resources at a given point in time depending on the resources invested until that point in time; (2) this willingness depending on the number of participants until that point in time; (3) the constant impact of certain conditions on the amount of resources invested to counteract the collective action at a given point in time.

The additional number of participants at a given point in time depends on (1) the impact of the resources invested to counteract a collective action on the willingness of additional people to join the collective action at a given point in time; (2) the impact of the number of participants until that point in time on this willingness; (3) the constant impact of certain conditions on the additional number of people joining the collective action at a given point in time.

Gavious and Mizrahi [43] demonstrate how two types of cycles may evolve in dynamics of collective action. One is a cycle without convergence that evolves under two different sets of conditions: 1) Anti-mobilization forces are very strong while potential participants prefer free-riding on the efforts of others; 2) Anti-mobilization forces are weak while potential participants calculate their moves according to the rationale of the bandwagon effect. The other type is a cycle with convergence that develops when anti-mobilization forces are weak and potential participants prefer free-riding on the efforts of others.

Hence, continuous time models provide relatively simple tools to analyze complex dynamics, which include simultaneous developments and the interactions of sub-dynamics. As such, they can be very useful for the analysis of cascading disasters. In the next section we elaborate on this point.

3.2. Collective action, common knowledge modeling and information cascades in cascading disasters

The dynamics of collective action are mainly about learning and the accumulation of information. It may therefore be useful to utilize a theoretical game framework to explain collective action dynamics by learning processes [43]. Basically, when a certain fact becomes common knowledge due to a certain event, people accumulate knowledge about the state of the world and act accordingly.

In the dynamics of collective action people learn from the actions of others [44]. suggest analyzing the learning mechanism in such dynamics using a theoretical game approach that is rooted in the framework of the literature on “common knowledge” (for example: [45,46]). According to this approach, when people watch other people participating in an action, they do not necessarily update their cost-benefit calculations or learn about the identity of others. Rather, given that they know other people’s beliefs, they use the actions of these people to learn about the state of the world, that is, a whole set of parameters external to the players themselves. This approach is a general conceptual framework for analyzing information processing in any dynamic of collective action and hence cascading events. It can accurately, yet simply, describe complex mechanisms of information processing. At the same time, it is general enough to rationalize individual behavior in a wide variety of collective action dynamics. A good example are the processes of learning and information updating during the recent Covid-19 pandemic. Governments all over the world watched the response of Asian countries where the pandemic hit first and updated their knowledge about the state of the world accordingly. Similar processes occurred within states.

[44] analyze three conceptual examples of collective action dynamics. The first analyzes a learning process that may explain the bandwagon effect. The second example concerns a learning process that may lead to the sudden eruption of a mass collective action. The third example explains the decline of a mass collective action after it has been successfully mobilized. The analysis shows that in such learning processes an error may occur and that people often learn about their ignorance.

Their analysis reaches two counter-intuitive conclusions. First, in analyzing a possible learning process that leads to the sudden eruption of a collective action, players may conclude that the chances of a successful collective action are high, although no player participated in previous stages of the game. In comparison, the rationale adopted earlier in this paper implies that if no one participates, people will infer that there are few chances of success, combined with high costs for doing so, and will not participate. Second, in analyzing a possible learning process that leads to the decline of a mass collective action, we show that players may conclude that there are few chances of success, even though all of the players participated in previous stages of the game. Again, this is not expected according to the rationale adopted earlier.

An event is common knowledge among a group of agents if each one knows it, each one knows that the others know it, each one knows that each one knows that the others know it, and so on [34,45,47]. When a certain fact becomes common knowledge, learning processes, which can be formally represented, are triggered. The literature on common knowledge presents several examples of the ways in which a fact that becomes common knowledge, meaning new information, influences behavior [46,48]. This reasoning is also the basis of Aumann’s [45] seminal paper concerning the inability of rational players to “agree to disagree” about the probability of a given event. The intuition for this is that, if a player knows that his/her opponent’s beliefs are different from his/her own, he/she should revise these beliefs to take the opponent’s information into account. Based on this conceptual example, a variety of applications to economic theory have been proposed [49–52].

This approach has been also used to explain dynamic information aggregation. Rob [53–55]; and Chamley and Gale [56] show how information externalities might cause agents to delay action inefficiently, because there is an incentive to wait for others to take costly action.

Caplin and Leahy (1998) suggest a search theoretic model with information spillovers showing that the delay until the first player acts is sub-optimally long due to information externalities. They provide examples in which social optimality demands immediate action, but the market produces an arbitrarily long delay. These models provide an appropriate setting for explaining the dynamics of collective action by dynamic information aggregation.

The application of the common knowledge approach to collective action dynamics is as follows. Players who decide whether to join a collective action face a complex decision that includes several variables. They do not simply count the number of participants but, rather, try to identify the “state of the world” in which they act. This state is composed of various structural parameters, external to the group, such as the natural and environmental conditions, government attitudes, the conflicts and coalitions in the political system, the international conditions, the socio-political situation, economic conditions, and other parameters that may be relevant to specific groups. Each player forms subjective beliefs concerning the state of the world that must exist before he/she decides to take action. These beliefs implicitly express the individuals’ cost-benefit calculations as well as their attitudes toward risk. In comparison, in the threshold models the costs and benefits attached to collective action constantly change according to the observed number of participants. For example, consider two states of the world – State 1 and State 2 – that are identical in all aspects except one—the attitudes of the government towards collective action, or towards the Covid-19 pandemic. State 1 represents a situation in which the government is flexible about collective action, or the pandemic, while in State 2 the government is determined to suppress mass collective action, or the pandemic. In such a case, a player who has all the information about the state of the world except the attitudes of the government cannot distinguish between State 1 and State 2. The less information a player has about his/her situation, the less he/she can distinguish between states of the world.

Starting from this point, players use other players’ actions (or inactivity) to learn about the existing structural conditions by distinguishing between different states of the world. This learning process does not include the creation of new facts or new structural conditions. For example, if an individual knows that the local government will invest a lot of resources to reduce the risks and costs of disasters, he/she does not have to rely on the number of participants in collective efforts when calculating the cost of action, as implicit, for example, in threshold models.

By assuming fixed structural conditions, the model allows us to focus on the learning mechanism itself. The basis for acquiring information is the prior beliefs of members in society about the type of information that each one has. In strong social networks, which typically characterize small communities that also face significant risks, members of society may know the identity, beliefs and type of information held by other people in society but they may be ignorant of certain structural conditions or the attitudes of the regime.

This theoretical game approach includes a few basic components. The conceptual term ‘*The state of the world*’ gives a detailed specification of the physical universe, past, present and future. It specifies the players’ preferences, mutual beliefs, subjective knowledge, strategies, and actions, as well as the rules of game and structural conditions. When a player cannot accurately observe all of the components that comprise a specific state of the world, he/she cannot distinguish between several states of the world with respect to a certain component. The player’s knowledge is formally described by a collection of mutually disjointed and exhaustive classes of states of the world. If two states of the world are in the same cell, the player who observes reality can tell which cell reflects this reality, but cannot distinguish the states that are in the same cell. Note also that the fewer the states of the world in each cell, the greater the player’s information about reality.

It is assumed that, given the existence of social networks through which social groups have some basic information about each other,

members of each group know the type of information held by other groups and their decision rule. Indeed, through these networks people can distribute all of the information they have, thus making the process of learning through actions redundant. But, in terms of game theory, such information may be considered “cheap talk,” which is costless pre-play communication that does not bind the players to the statements they make. Thus, its reliability is questionable. Therefore, people tend to rely on other people’s actions, rather than on talk, as an indication of these people’s preferences and beliefs.

[44] demonstrate the learning mechanisms in collective action dynamics through common knowledge updating. According to the rationale developed there, groups and societies do not necessarily imitate each other, nor do they necessarily think that there are better chances of success due to the greater number of participants. Rather, it demonstrates how different groups in society can learn from the actions of other groups about the state of the world that reflects reality, independently of the number of participants. Yet, when there is a probabilistic decision rule, an error may occur.

The model also suggests that social entrepreneurs may be distinctive only in the sense that they possess superior information. Since they are also more willing than their followers to take risks, they often trigger learning through common knowledge leading to a bandwagon dynamic.

3.3. Cascading disasters in the perspective of collective action and dynamic modeling

The applications of the models and dynamics described above to the analysis of cascading disasters, cascading events and cascading information are numerous. A cascading disaster in the form of a spreading event based on mobilization for collective action may develop through a bandwagon dynamic. It can be analyzed using the tools discussed here. Furthermore, using these tools we can also determine the available measures and actions needed to reduce the risk and damage of the disaster. For example, the rate and damage of a spreading epidemic is influenced by the natural characteristics of the disease and the efforts invested by many players to reduce its spread, perhaps by becoming immunized. The probability that joining the effort will prove effective increases as more people join in; hence the bandwagon rationale. At the same time, the natural characteristics of the disease function as forces that counteract the effort to reduce it. The interaction between these forces can be modeled using the continuous time model presented here. In a similar vein, other social, political and economic phenomena may develop through the bandwagon dynamic. Furthermore, we may utilize the common knowledge modeling approach to analyze such dynamics. Doing so will help us identify possible interventions that may influence the players’ information about the state of the world as well as their learning processes.

In many cascading disasters or crises, the extent of damage depends primarily on the ability to mobilize various kinds of collective efforts. Hence, it can best be understood in the context of collective action. The models developed here offer tools for analyzing the forces that support and slow down such processes leading to cycles with convergence or without convergence. Referring to the Covid-19 pandemic, it has been clear that levels of cooperation among citizens differed among societies as a function of social and institutional trust that influence the dynamics of collective action.

Cascading events often evolve due the sudden eruption of mass hysteria or panic, and may also cease in that way. The common knowledge modeling discussed in this paper provides effective tools for analyzing such dynamics based on information accumulation and learning processes [44]. demonstrate the sudden eruption of a mass collective action or the sudden entry of a large number of participants after a public announcement triggers learning processes. Yet, this is only one case. By changing the partitions and/or the decision rules or increasing the possible states of the world, we can have similar phenomena but with different timings. This possibility underscores the role

of leaders or the media in providing some basic information, which leads players to learn about the state of the world in which they operate. According to this argument, social leaders and the media do not convince people that they are in a bad situation nor do they always inform players about the preferences or expected actions of others. Rather, they make certain facts common knowledge, thus leading people to update beliefs by their own observations.

We should emphasize that the mechanism discussed so far does not explain changes in preferences. We assume that people's preferences are already shaped, meaning that they are willing to participate in collective efforts if they know that certain conditions are fulfilled. However, before the learning process starts, they simply do not know if this is indeed the case. In comparison, Kuran [33] argues that the sudden eruption of a collective action happens after preferences change but remain hidden. In many cases, people do not act because no one gives expression to the change in preference that has occurred. Following Schelling [31]; he attributes the sudden eruption of a collective action to certain focal points, but does not provide a mechanism to explain why it occurs at a particular point in time. This is exactly where this paper contributes the most.

The common knowledge modeling shows that people may learn something "active" from the passive behavior of others. There is a continuous learning process in which people infer that the conditions for collective action have been fulfilled, although no player participated in previous stages of the action. In comparison, the rationale adopted by existing models implies that when everyone is passive, no one will participate.

Another common knowledge mechanism analyzed by Ref. [44] shows how public announcements trigger a learning process that improves the players' knowledge about certain aspects of the state of the world, but also stresses their ignorance about other aspects. Thus, a learning process may make people aware of what they do not know and may therefore discourage participation in a mass collective action. Due to this ignorance, some people may leave the collective action even though all others participate, the collective goal has not been yet achieved and the conditions for joining the collective action are fulfilled. To some extent, this dynamic resembles the dilemma of joining demonstrations and protest against governmental policies regarding the Covid-19 pandemic. Due to the intense media coverage people became aware of what they do not know and hesitate to take action against government policies.

This focus on information problems as a reason for the decline of mass collective actions also has practical implications. In many cases, those interested in mobilizing a collective action believe that people withdraw from participation because they are satisfied with the outcome. By concentrating on the lack of information, such mobilization entrepreneurs can maintain the collective action by providing information that becomes common knowledge. By the same token, this rationale may serve those who want to stop disruptive collective actions during disasters or crisis situations. According to this example, they do not necessarily have to suppress the collective action but, rather, they can provide certain information that becomes common knowledge.

Thus, the framework presented in this paper contributes to the analysis of cascading disasters and crisis situations in two main aspects. First, we suggest that the problems and dynamics of collective action stand at the core of the evolution and development of cascading events, and therefore should also stand at the core of their analysis. Second, we present the ways in which continuous time models and common knowledge modeling can help analyze the dynamics of collective action and hence also cascading disasters and crisis situations. We believe that these ideas set the stage for the development of fruitful research programs and lively scientific discourse.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ijdr.2020.101672>.

[org/10.1016/j.ijdr.2020.101672](https://doi.org/10.1016/j.ijdr.2020.101672).

References

- [1] E.L. Quarantelli, A social science research agenda for the disasters of the 21st century, in: R.W. Perry, E.L. Quarantelli (Eds.), *What Is a Disaster? New Answers to Old Questions*, Xlibris, Philadelphia, 2005, pp. 325–396.
- [2] R.W. Perry, What is a disaster? in: H. Rodríguez, E.L. Quarantelli, R. Dynes (Eds.), *Handbook of Disaster Research* Springer, New York, 2007, pp. 1–15.
- [3] L.M. Killian, Some accomplishments and some needs in disaster study, *J. Soc. Issues* 10 (1954) 66–72.
- [4] A.F.C. Wallace, *Human Behavior in Extreme Situations*, National Research Council, National Academy of Sciences, Washington, DC, 1956.
- [5] H.E. Moore, *Tornadoes over Texas*, University of Texas Press, Austin, 1958.
- [6] C.E. Fritz, Disasters, in: R.K. Merton, R.A. Nisbet (Eds.), *Contemporary Social Problems. An Introduction to the Sociology of Deviant Behavior and Social Disorganization*, University of California Press, Riverside, CA, 1961, pp. 651–694.
- [7] G. Sjöberg, Disasters and social change, in: G. Baker, D. Chapman (Eds.), *Man and Society in Disaster*, Basic Books, New York, 1962, pp. 356–384.
- [8] I. Burton, R. Kates, G. White, *The Environment as Hazard*, Oxford University Press, New York, 1978.
- [9] P. Susman, P. O'Keefe, B. Wisner, Global disasters, a radical interpretation, in: K. Hewitt (Ed.), *Interpretations of Calamity*, Allen and Unwin, Boston, 1983, pp. 263–283.
- [10] D.A. Alexander, *Natural Disasters*, Chapman and Hall, New York, 1993.
- [11] D.A. Alexander, An interpretation of disaster in terms of changes in culture, society, and international relations, in: R.W. Perry, E.L. Quarantelli (Eds.), *What Is a Disaster? New Answers to Old Questions*, Xlibris, Philadelphia, 2005, pp. 25–38.
- [12] D. Mileti, *Disasters by Design: A Reassessment of Natural Hazards in the United States*, Joseph Henry Press, Washington, DC, 1999.
- [13] S. Cutter, Are we asking the right question? in: R.W. Perry, E.L. Quarantelli (Eds.), *What Is a Disaster? New Answers to Old Questions* Xlibris, Philadelphia, 2005, pp. 39–48.
- [14] G.A. Kreps, Disaster as systemic event and social catalyst: a clarification of subject matter, in: E.L. Quarantelli (Ed.), *What Is a Disaster? Perspectives on the Question*, Routledge, New York and London, 1998, pp. 31–55.
- [15] R.A. Stallings, Conflict in natural disasters: a codification of consensus and conflict theories, *Soc. Sci. Q.* 69 (1988) 569–586.
- [16] U. Rosenthal, Future disasters, future definitions, in: E.L. Quarantelli (Ed.), *What Is a Disaster? Perspectives on the Question*, Routledge, London, 1998, pp. 146–159.
- [17] F.L. Bates, W.G. Peacock, *Living Conditions, Disasters and Development*, University of Georgia Press, Athens, GA, 1993.
- [18] W.R. Dombrowsky, Again and again: is a disaster what we call a disaster? in: E. L. Quarantelli (Ed.), *What Is a Disaster? Perspectives on the Question* Routledge, London, 1998, pp. 19–30.
- [19] R.A. Boin, From crisis to disaster: towards an integrative perspective, in: R. W. Perry, E.L. Quarantelli (Eds.), *What Is a Disaster? New Answers to Old Questions*, Xlibris, Philadelphia, 2005, pp. 153–172.
- [20] A. Boin, P. t Hart, S. Kuipers, The crisis approach, in: H. Rodríguez, E. L. Quarantelli, R. Dynes (Eds.), *Handbook of Disaster Research*, Springer, New York, 2018, pp. 23–38.
- [21] U. Rosenthal, M.T. Charles, P. Hart (Eds.), *Coping with Crisis: The Management of Disasters, Riots and Terrorism*, Charles C Thomas, Springfield, IL, 1989.
- [22] G. Pescaroli, D. Alexander, A definition of cascading disasters and cascading effects: going beyond the "toppling dominos" metaphor, *Planet and Risk* 2 (3) (2015) 58–67.
- [23] F. May, Cascading disaster models in postburn flash flood, in: B.W. Butler, W. Cook (Eds.), *The Fire Environment – Innovations, Management and Policy; Conference Proceedings*, US Department of Agriculture Forest Service, Washington, DC, 2007, pp. 446–463.
- [24] D.A. Alexander, A magnitude scale for cascading disasters, *Int. J. Disaster Risk Reduct.* 30 (2018) 180–185.
- [25] G. Zuccarola, D. De Gregorio, N.F. Leonea, Theoretical model for cascading, effects analyses, *Int. J. Disaster Risk Reduct.* 30 (2018) 199–215.
- [26] L.M. Killian, Are social movements irrational or are they collective behavior? in: R. Dynes, K. Tierney (Eds.), *Disasters, Collective Behavior and Social Organization* University of Delaware Press, Newark, DE, 1994, pp. 273–280.
- [27] M. Taylor, *The Possibility of Cooperation*, Cambridge University Press, Cambridge, 1987.
- [28] I. Sened, Contemporary theory of institutions in perspective, *J. Theor. Polit.* 3 (1991) 372–402.
- [29] J. Knight, *Institutions and Social Conflicts*, Cambridge University Press, Cambridge, 1992.
- [30] M. Granovetter, Threshold models of collective behavior, *Am. J. Sociol.* 83 (1978) 1420–1443.
- [31] T. Schelling, *Micro Motives and Macro Behavior*, W. W. Norton, New York, 1978.
- [32] R. Karklins, R. Patersen, *Decision Calculus of Protesters and Regimes: East, 1993*.
- [33] T. Kuran, *Private Truths, Public Lies: The Social Consequences of Preferences, falsification*, Harvard University Press, Cambridge, Mass, 1995.
- [34] T. Schelling, *The Strategy of Conflict*, Harvard University Press, Cambridge, Mass, 1960.
- [35] J.M. Colomer, *Game Theory and the Transition to Democracy: the Spanish Model*, Edward Elgar, Aldershot, UK, 1995.
- [36] S. Bikhchandani, D. Hirschleifer, I. Welsh, A theory of fads, fashions, custom, and cultural change as informational cascades, *J. Polit. Econ.* 100 (1992) 992–1026.

- [37] S. Lohmann, A signaling model of information and manipulative political action, *Am. Polit. Sci. Rev.* 87 (1994) 319–333.
- [38] C. Zeeman, On the unstable behavior of stock exchanges, *J. Math. Econ.* 1 (1974) 39–49.
- [39] A. Denzau, D. North, Shared mental models: ideologies and institutions, *Kyklos* 47 (1994) 3–31.
- [40] O. Hinz, B. Skiera, C. Barrot, J.U. Becker, Seeding strategies for viral marketing: an empirical comparison, *J. Market.* 75 (6) (2011) 55–71.
- [41] D.J. Watts, P.S. Dodds, Influentials, networks, and public opinion formation, *J. Consum. Res.* 34 (4) (2007) 441–458.
- [42] A. Gaviious, S. Mizrahi, A continuous time model of the bandwagon effect in collective action, *Soc. Choice Welfare* 18 (2001) 91–105.
- [43] A. Gaviious, S. Mizrahi, Continuous time models of collective action and political change, *Constitut. Polit. Econ.* 11 (2000) 181–198.
- [44] A. Gaviious, S. Mizrahi, Information and common knowledge in collective action, *Constitut. Polit. Econ.* 12 (2000) 297–319.
- [45] R. Aumann, Agreeing to disagree, *Ann. Stat.* 4 (1976) 1236–1239.
- [46] J. Geanakoplos, Common knowledge, *J. Econ. Perspect.* 6 (1992) 53–82.
- [47] D. Lewis, *Convention: a Philosophical Study*, Harvard University Press, Cambridge, Mass, 1969.
- [48] M. Gardner, *Puzzles from Other Worlds*, Vintage, New York, 1984.
- [49] D. Kreps, A note on fulfilled expectations equilibrium, *J. Econ. Theor.* 14 (1977) 32–43.
- [50] J. Tirole, On the possibility of speculation under rational expectations, *Econometrica* 50 (1982) 1163–1181.
- [51] A. Rubinstein, The electronic mail game: strategic behavior under “almost common, knowledge”, *Am. Econ. Rev.* 79 (1989) 385–391.
- [52] S. Hart, Y. Tauman, Market Crashes without External Shocks. Working Paper 31/96, Faculty of Management, Tel-Aviv University, 1996.
- [53] R. Rob, Learning and capacity expansion under demand uncertainty, *Rev. Econ. Stud.* 58 (1991) 655–675.
- [54] A. Caplin, J. Leahy, Sectoral shocks, learning, and aggregate fluctuations, *Rev. Econ. Stud.* 60 (1993) 777–794.
- [55] A. Caplin, J. Leahy, Business as usual, market crashes and wisdom after the fact, *Am. Econ. Rev.* 84 (1994) 548–565.
- [56] C. Chamely, D. Gale, Information revelation and strategic delay in a model of investment, *Econometrica* 62 (1994) 1065–1086.