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Cascading Processes and Path Dependency in Social Networks

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Abstract

To analyze social diffusion and cascading processes, a theoretical approach is presented that describes self-reinforcing mechanisms in path dependent social networks. This framework can be used to describe effects of individual behaviour on a micro level and institutions on a macro level, as well as multi-level spirals in micro-macro transitions that increase the potential risk for social cascades. With this setup it is possible to study the impact of major events (e.g. natural disasters, mass migrations, social movements) that trigger threshold and spill over effects, tipping points and cascading sequences, including informational cascades and inter-systemic cascades. This framework is applied to several examples of recent cascades that appeared in the North African protest movements and the effects of the Japanese earthquake and nuclear accident on political processes in other world regions (in particular Germany) as well as potential risk cascades of climate change that could affect natural and social systems in many parts of the world.

1. Introduction

Cascades can have strong effects when they occur. An example was the economic crisis of 2008 caused by reckless lending practices of financial institutions, followed by the Greek credit crunch where the interaction between rating agencies and governmental responses created an explosive situation. Another is the series of protests in North African countries in early 2011 where the food price is supposed to have contributed to instability in this region. The cascading potential of natural disasters is vividly demonstrated by the March 11, 2011 earthquake in Japan which triggered a chain of events. These include a tsunami wave travelling across the Pacific and a nuclear reactor accident spreading radioactivity into the atmosphere, forcing people to evacuate from the region, not to speak of potential implications for the power grid, stock markets, the oil price and the economy in general. The shock waves of the disaster even affected German politics by triggering the election of a Green Party Prime Minister in one of most conservative federal states. This indicates how many factors may combine in such a disaster with implications across continents.

How can these cascading effects be explained? It may be useful to refer to an everyday experience that vividly demonstrates how things can go wrong. In the TV comedy sketch "Das Bild hängt schief" the German humorist Loriot shows how human-environment interaction can result in a cascade that leaves a destroyed environment in the end. Starting with the attempt to align a skewed picture on the wall, Loriot's pedantry to create order keeps to trigger and to enhance a cascade that leaves the room in a chaos. He could have stopped the process with accepting the current state, but instead he is caught in his behavioural scheme that further enhances the cascade. Such behaviour of sticking to what one is used to do although one is free to choose alternatives (David 1985) has been discovered in economic contexts and described as path dependent behaviour.

In this paper expanded path dependency theory will be used to explain self-reinforcing processes in social dynamics. In that approach path dependent social networks will be considered in which connections of the social network and the tendency to follow the social network can be reinforced. The path dependency perspective can be used to describe single individual behaviour on a micro level as well as institutions on a macro level. Within this framework, a self-reinforcing path dependency spiral could increase the potential risk for social cascades with each step. With this setup it is possible to study the impact of triggering events (e.g. natural disasters, mass migrations, social movements), and find cascading sequences and tipping points.

In the following, general social network theory will be presented with a focus on network diffusion and threshold concepts. Then two types of cascades will be defined, informational cascades that explain a following behaviour of individuals and inter-systemic cascades that describe the spill over effects from one system to another. While the first one is more applicable to analyse the behaviour of demonstrators, the latter one is more adequate to describe the effects that are triggered by a natural disaster.

Then an expanded path dependency framework will be presented. The more people are affected by path dependency, the more they tend to follow others which can be described in special social networks. The self-reinforcing character of path dependent processes can be used to define path dependent social networks (PDSN). This framework is applied to several examples of recent cascades that appeared in the North African protest movements and the effects of the Japanese earthquake as well as potential risk cascades of climate change. In addition, we will briefly discuss potential future cascades induced by climate change. From these analyses in the PDSN framework an impression of people's tendency to act path dependently in these situations can be deduced. It is further shown how the PDSN concept can be used to describe social dynamics within groups and to explain observable cascades. We will then sketch a conceptual approach of the PDSN that may be used in the future as a basis for modelling and simulations.

2. The Context of Social Network Analysis

The study of social networks is increasingly shaping many fields of social interaction. Social network analysis (SNA) is an evolving methodology in the social sciences (Wassermann and Faust 1995), used to study a variety of social phenomena and processes. One focus is on how agents dynamically interact with each other and create their social environment by building linkages between the agents, who act as network nodes.

2.1. Diffusion on social networks

An active field of research is the dynamic spread of processes across a social network depending on the network structure. In this context some topologies are especially relevant, e.g. the small-world network which describes a network structure where everybody is closely linked to everyone else and thus a high diffusion rate of information is likely. Often researchers try to find the most central agents in a network, e.g. to optimize the spread of information across the network. The relevant network structure might change when switching focus between different dynamical processes. Unfortunately, "the relationship between network structure and dynamical consequences is anything but straightforward." (Watts 2004, p.256)

Particularly important is the study of diffusion processes. Models of network diffusion (Kempe et al. 2005) describe the spread of diseases (e.g. of the H1N1 virus) as well as the spread of social behavior patterns like innovations, practices and conflicts. These are similar to basic models for disease diffusion, as e.g. SIR-models[1] (cp. Kermack and McKendrick 1927) or models of "viral marketing". Different are models of "social contagion" (like Dodds and Watts 2004):

> "Unlike SIR-type models, however, which assume contagion to be a memory-free process, individuals making decisions are affected simultaneously by past as well as current interactions […]; hence, the cumulative probability of 'infection' exhibits threshold-like behaviour." (Watts 2004: 260f.)

This "threshold-like behaviour" might also be relevant when analysing diffusion of path dependency and social cascades related to it, because in path dependent processes history matters. There are different approaches using threshold models describing collective dynamics other than the stylized SIR-type (Granovetter 1978; Schelling 1978; Granovetter and Soong 1983; Dodds and Watts 2004). In a model of social contagion, for example, it can be shown that the diffusion rate, and thus

1 SIR stands for Susceptible – Infectious – Recovered.

the risk for global cascades (or epidemics in the viral terminology), relates to the topology of the network. In a sparse network global cascades are most likely when the network connectivity is neither too low nor too high (Watts 2002).

> "It is the latter condition that is surprising because in biological contagion greater connectivity always implies a greater possibility that a disease will spread. In social contagion, however, dense connectivity renders many individuals impervious to novel signals, thereby quashing cascades before they can even begin." (Watts 2004: 261)

Thus it is interesting to see which dynamics may result depending on the network connectivity and certain events (e.g. a disaster or credit crunch) that affect key variables in the emerging path dependent social network. Bonabeau (2002) presents arguments for analyzing emergent phenomena and emphasizes that agent-based models are useful to consider complex evolving processes and gather information on complex causalities to discover perhaps otherwise unoccupied connections.

Models of network diffusion, developed to analyze the spread of diseases, can be used to study the spread of social behaviour patterns, such as the proliferation of violence as well as the diffusion of technical and economic innovations or of environmental and social practices. A new field of research is the application of SNA to the spread of conflict (Flint et al. 2009; Maoz 2010).

2.2 Cascades in social networks

In pursuing their individual interests, collective interaction among multiple actors could lead to a "cascading sequence of events where an action taken by one actor provokes more intense actions by other actors" (Scheffran 2008). Social science research has focused on informational cascades that occur "when it is optimal for an individual, having observed the actions of those ahead of him, to follow the behaviour of the preceding individual without regard to his own information." (Bikhchandani et al. 1992:992) Likewise a cascade is described and modelled in a way that agents learn from the behaviour of other agents and thus follow them in the way they act (Bikhchandani et al. 1998), thus leading to a collective transition.

For instance, when in a line of agents the second agent follows the action of the first agent, the third one copies the behaviour of the former two, and so forth, until the whole line ends up in performing all the same action (Bikhchandani et al. 1992). The local rules of following neighboured or observed agents allows to study social dynamics, an approach that has been applied to phenomena like herding on financial markets (cp. e.g. Scharfstein and Stein 1990; Bannerjee 1992; Welch 1992). Real-world examples of informational cascades can be found everywhere, from the stock market and voting patterns to the fashion industry. One explanation why humans put so much attention to choices made by others is that "imitators may

have as high a long-run 'fitness' as optimizers" (Conlisk 1980:275). Richerson and Boyd (1992) showed that in many instances social learning is preferred by natural selection. If the choices and actions of others influence our own decisions, with an increasing size of the population tipping points in collective interaction may become more likely and undermine the stability of the whole system.

Tipping points are also relevant in inter-systemic cascades in human-environment interaction. According to Urry (2002:8) tipping points involve three notions: "that events and phenomena are contagious, that little causes can have big effects, and that changes can happen in a non-linear way but dramatically at a moment when the system switches". Seemingly "minor" events could provoke major qualitative changes of the system, which is characteristic for chaotic systems. A self-reinforcing chain reaction could increase the potential risk for social cascades that could put the whole system at risk.

Various tools have been developed in complex systems sciences that allow analyses of social phenomena in human-environment interaction (see Scheffran 2006). In particular, they could help to assess the impact of human responses to environmental change and the social interactions that result from these responses. For a large number of homogenous actors, methods from non-linear dynamics have been used to describe phenomena of complex adaptive systems such as self-organization or micro-macro phase transitions (see for instance, Helbing 1995; Weidlich 2000; Schweitzer 1997). Agent-based modelling (ABM) analyzes patterns of collective action emerging from large numbers of agents following particular rules of behaviour. Depending on stimulus-response mechanisms on the micro level, complex social patterns could emerge on the macro level. ABMs may be useful in situations where the future is unpredictable and traditional analytic methods for decision-making are least effective. Applications range from moving crowds and traffic systems to urban, demographic, and environmental planning (Billari et al. 2006). Unlike game theory, in which the selection of options is determined by the rule of optimizing utility, ABM selects rules to adequately describe real-world decisions. Multi-agent models have gained increasing interest in social modelling, taking into account the adaptive, disaggregated nature of human decision-making as well as collective responses to changing environments and management policies.

3. The Explanatory Framework of Path Dependency Theory

The theory of social networks and cascades can be related to path dependency, an established concept which implies that social actors tend to be locked-in on certain pathways of action around which self-enforcing mechanisms prevent individual change (Sydow et al. 2005, 2009; Beyer 2005; Kominek 2009). The terminology of

path dependency is promising as a basis for the analysis and modelling of social diffusion and cascading processes.

3.1. Theoretical context of path dependency

It is a common observation that on markets not necessarily the most efficient technology dominates but the one that historically has been ahead of others (Arthur 1989, 1994), as is the case for the QWERTY-keyboard, no matter whether it matches present efficiency criteria or not (David 1985, 2000, 2007). This phenomenon of path dependency can be characterized as "history matters", which implies that former events influence later ones and sequencing is relevant. Transferred into the social context (Mahoney 2000) and the political context (Pierson 2000) it is debated whether or not a sociological approach is necessary to expand the economic argument of rationality (Liebowitz and Margolis 1995) or is even applicable to institutional processes (Alexander 2001).

Present approaches focus more on the process-oriented view of path dependency, describing the relevance of a human-centred approach, e.g. in organizational studies (Sydow et al. 2005, 2009). In this context, a "path dependent process" is defined as a self-reinforcing process with the tendency for a lock-in (Sydow et al. 2005, 2009). While former approaches concentrated more on historical analyses (thus backward looking) of event sequences, the approach of "path creation" argues for more forward looking research considering the beginning of an evolving path and options to shape it deliberately (Garud and Karnøe 2001). Still all these approaches consider path dependency as a macro-level phenomenon involving agents in an aggregated way.

An extended approach connects the macro level phenomenon of path dependency to effects on single agents on the micro level (Kominek 2011), using concepts from social psychology (Chaiken and Trope 1999; Moskowitz et al. 1999). Accordingly, multi-level approaches can use path dependency as a diffusion variable in ABM for analyzing complex scenarios and no longer have to stick to a very simple understanding of path dependency (Welch 1992) or approach path dependency through simulating likewise phenomena (Janssen and Jager 1999). Thus, combining the micro level foundation for an informational cascade with path dependency theory, it generally can be said that the more an agent is affected by path dependency, the more likely it is to "follow" other agents and thus participates in an occurring cascade.

3.2. Path dependency in social networks

A deduction from the macro level phenomenon of path dependency (Kominek 2011) results in the following causality as perceived by the agents: The more an agent is affected by path dependency, the more the agent's behavior tends to resemble "ideal type path dependent" decision processes. This implies that the agent increasingly tends to follow external decision instances instead of optimizing according to own internal preferences. The agent's behavior of following others can be mapped in a path dependent social network (PDSN). The tendency to decide and act path dependently then could be described by the likelihood to follow one of the network neighbors in the agent's PDSN. The self-reinforcing characteristic of path dependent processes results in an increasing likelihood to follow others: When an agent behaves path dependently and follows one of the individual PDSN, the behavior to do so gets reinforced. This means that when the agent is in a comparable situation he/she tends to follow the PDSN again, even more than before.

Additionally when the agent follows a PDSN neighbor within the weighted social network the tendency to follow that special neighbor gets reinforced. This implies that the tendency to follow that neighbor again the next time in a similar situation, is more likely than before. In such a step of increasing tendency to follow others the amplitude of the single effect depends on the past events that already have coined such a behavior. While in the beginning of a new coined behavioural path the tendency to behave alike first may be very low but exponentially growing (primary-like socialization), later-on the tendency increases lesser (secondary socialization, Kominek 2009). Therefore, if an agent follows its new neighbor within the PDSN, the next time the neighbour would not be new anymore. And over the time, when the agent follows that neighbour more than once, the agent can appreciate that behaviour and maybe chooses the neighbour as an individual expert on some topic. E.g. if the agent asks a PDSN neighbour when having trouble with the computer, that neighbour can become the agent's personal computer expert over time. But if the advice of that potential expert has proven wrong, the agent may still listen to the advice the next time, but go the opposite direction. Therefore, the sign in front of the neighbor's influence is a result of the previous experience.

4. Examples of Applications

4.1. The protest movement in Egypt

One example for a cascade that can be described through collective group behaviour among path dependent agents is the spread of protest movements in Arabic

countries in North Africa and the Middle East in early 2011. Starting with riots in Tunesia which forced the president to flee, the revolutionary impulse expanded to Egypt and other countries, accelerated and multiplied by electronic media and social networks in the internet which facilitated the spread of experiences with this and other successful examples. In a reportage on German TV[2] an interviewed activist mentioned that their idea of a peaceful revolution goes back to the peaceful revolution in Serbia. This refers to a book written by Serbian experts on 50 steps towards a peaceful revolution, distributed through workshops on how to gain impact in the participant's home countries. Leading Egyptian activists have participated in those workshops prior to their revolution und used their training experience to start demonstrations in the slums of Kairo to win masses of following people who were discontent with their present situation. By the time they reached the centre of Kairo, they were such a crowd of demonstrators so that the police was unable to stop them. One example for intense following behaviour is the peacefulness of the demonstrations on the Tahrir Square in Kairo. Although defenders of the regime used violence against the crowd of demonstrators, the demonstration remained peaceful in their self-organized resistance, which ultimately was successful in bringing down the regime of President Mubarak.

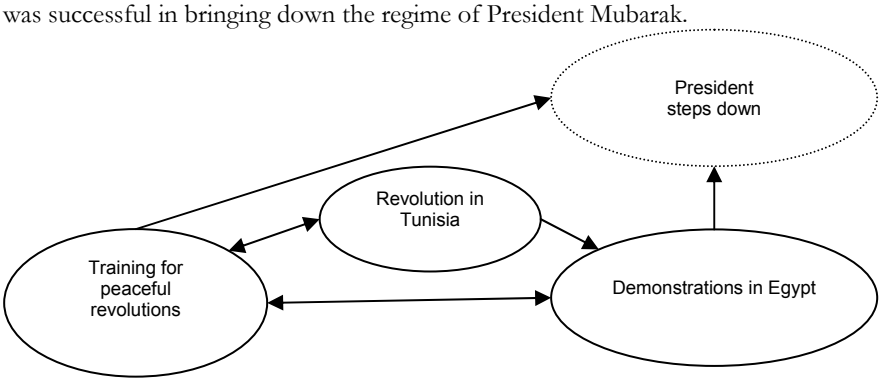

Figure: Cascading sequence of events leading to the revolutionary developments in Egypt

As deduced from path dependency theory a following behaviour can be described in a PDSN framework to assess how path dependency impacts on the resulting social dynamics evolve. When a social network related action is chosen, the likelihood to follow the path of other agents increases and the multiplier effect contributes to a mass movement.

2 http://www.daserste.de/weltspiegel/beitrag_dyn~uid,s0ekpanjotxhviem~cm.asp

If the demonstration for cheaper food and jobs is started in a poor neighbourhood, people watching are likely to have a positive connotation to follow neighbors on that topic and walk with them in the demonstration. If a person joins the group, agents who are neighboured to the person in their PDSNs are likely to follow. In a different suburb without a positive connotation to the topic, people would more likely go the opposite direction and agents who are neighbored to them in their PDSNs would tend to follow them, ignore the demonstration, or call the police.

When agents walk with a demonstrating group, this contributes to several reinforcing mechanisms: attracting more neighbors joining the group, strengthen the PDSN, raising media attention, increasing the relevance of the topic of the demonstration. Altogether, the group of demonstrators tends to grow in a swarming or cascading way until opposing tendencies prevail, e.g. counter-demonstrations, containment by the police or exhaustion by the demonstrators themselves. As long as the pro-demonstration factors prevail, the movement tends to increase. If demonstrators have a high tendency to follow police orders, they would likely stop demonstrating and go home as soon as the police appears. If the demonstrators are attacked, their "action portfolio" might switch from "peaceful demonstration for cheaper food and jobs" to "self-defense and survival". If so, the attackers may become "new" PDSN-neighbours with negative connotation, and other demonstrators would be likely to join in on defending their attacked PDSN-neighbours against the attackers.

Due to the intense correlation in their PDSNs, collective behavior could lead to rapid switching between different alternative modes of behavior, ranging from growing mass demonstrations to a sudden breakdown of the movement if a different behavior is spread. Thus, a once peaceful crowd can turn into a fighting mob, when being attacked.

The fact that the Egyptian demonstration on Tahrir Square remained peaceful when being attacked therefore indicates that the crowd remained self-disciplined and prevented single agent's switching from "peaceful demonstration" to "active defense".

This can imply that by the time the demonstrators have been attacked potential followers have been well focused on the peaceful strategy within their PDSNs and their path dependency has been very high. Another explanation could be herding instead of swarming, which would result in a collective mode of behavior in which demonstrators would not start to fight for their attacked companions but instead follow the mass at that time, disregarding individual participants. The high tendency to stick to herding and only help those attacked by medical support for survival indicates a strong path dependency.

Besides these structural factors that allow observing a high level of path dependency, it may have been mere luck that the analyzed protest did not cascade more into a violent and conflicting direction as it was the case in Libya.

4.2. Impact of the Japanese earthquake on German politics

The massive earthquake that hit Japan on March 11, 2011 directly affected the Japanese society but had a more severe indirect effect through the resulting tsunami wave which killed thousands of people and blocked rescue options. Both events together caused severe damages on the nuclear power plants in Fukushima which exploded and released significant amounts of radiation that affected large areas in neighbour regions. While the environmental effects have been fairly local, there have been global impacts and responses. For instance, national banks increased liquidity to prevent a serious recession as a possible consequence for the financial markets. Special export products dropped due to harmed production of some high-tech companies. Besides these local environmental and economic effects, social and political dynamics could be monitored far away from Japan, triggered by the cascading events of the earthquake.

Although Germany was not directly affected by Japan's earthquake, concerns over the risks of nuclear power peaked after the nuclear catastrophe in Japan, a country that was seen as one of the most advanced regarding the mastery of nuclear technology. This implies that the PDSN structures relating to the topic of nuclear power usage and risks of nuclear power disasters become increasingly recognized and reinforced. As a direct consequence, the German government immediately shut down the oldest nuclear power plants in the country for stress tests and launched an ethics commission to make recommendations on the accelerated phase-out of nuclear energy. Anti-nuclear energy protests boomed and parties were voted out of power that have been close to the nuclear industry, leading to the election of the first Green Party Prime Minister in one of the traditionally conservative federal states.

As this example demonstrates, natural disasters can cause a cascade of local and global action chains affecting society in different parts of the world. The likelihood of spill over effects from one system to the next depends on tipping points in systemic interactions that involves both natural processes and social relations. And these relatively local short-term effects are topped by long-term radiation effects across the globe from destroyed nuclear power plants.

4.4. Risk cascades of climate change

Climate change is a macro phenomenon that could simultaneously affect and challenge natural and social systems all over the world, thus containing the risk of multiple cascades connecting these systems. Considering climate change and its effects, there are many research efforts that measure, assess and model the natural processes, including atmospheric composition of gases and average global temperature,

ocean dynamics, water chemistry, biodiversity etc. In comparison, there is a deficit in understanding the social dynamics in response to climate-related events such as floods and droughts and whether there are cascading sequences and tipping points in climate-society interaction. The complex causal chains can be constructed through a network of interconnections based on the sensitivities between key variables and actions (see Scheffran 2011; Scheffran, Link and Schilling 2011).

Climate change could possibly induce a wide range of individual and collective responses. There are numerous actors involved that act according to their interests, capabilities and rules. Multi-agent settings are relevant when multiple regions, countries, businesses or citizens are affected by climate change and take individual or collective responses which lead to social interaction. At global levels of decision-making, the main actors are governments of nation states or groupings among them. At local levels, individual citizens and consumers are key players who affect or are affected by global warming. The multi-level process between local and global decision-making is connected through several layers of aggregation, with each layer having its own decision procedures for setting targets and implementing them into real actions. In a multi-agent setting, actors mutually adapt their targets, values, and actions to those of other players to change the outcome to their own favour. But besides deliberately changing the behaviour of oneself or others, structural effects such as those of the individual PDSN influence each agent's action. Thus, the collective outcome cannot be directly composed of individual targets and values but is a result of the social dynamics. Therefore, it is necessary to consider the steps in each agent's individual PDSN and the evolving dynamics.

While some dynamics may help a collective to jointly move forward, in the same instance, others may be affected to move in the opposite direction and some targets may not be reached. For instance, in natural disasters international aid may help affected people to survive and thus stabilize the social system. But aid in times of crisis may also lead to competition or even struggle of those in need, which happened in a few cases of natural disasters (WBGU 2007).

Within this setup it is possible to study the potential for cascading sequences of climate-related events (mass migrations, extreme weather events, food insecurity, social movements, and conflicts). On the other hand, this approach could be used to study the collective behavioural changes in a sustainability transition. Whether climate risk cascades will actually happen is hard to predict. It may well be possible that for the time being climate signals affect one layer in the causal chain but may not be strong enough to penetrate to other levels and thus fizzle out in the causal chain. With this analysis it is possible to estimate the probability of future destabilizing events occurring under specified conditions, which has implications for developing an early warning system. Climate change could also lead to "path creation" in the sense of inducing new pathways that support a sustainability transition (Garud and Karnøe 2001).

5. Conclusion

In this paper an expanded path dependency theory has been used to combine social network theory and the concept of cascading events. When people are affected by path dependency they tend to follow others, increasing the risk for social cascades. Therefore, it is on the one hand interesting to get information about the intensity of the influence of path dependency on single agent's action. On the other hand it is interesting to describe in detail, how cascades diffuse in social networks when the self-reinforcing mechanisms of path dependent processes are active.

In the case of the Egyptian demonstrations social dynamics could be redrawn in path dependent social networks. From that analysis it could be concluded that the path dependency and willingness to follow the masses of the demonstrating crowd or other demonstrators must have been very intense, because the demonstration remained peaceful after being attacked.

A cascade that leads to a nuclear disaster provokes political changes through spill over effects that increase opposition to nuclear power and induce a transformation of the energy system. That way external events as the earthquake or radiation problem in Japan can influence social structures and future policy of a different nation, as in the example of Germany. Although large impacting events as the earthquake in Japan may seem rare, explanations may help to better understand inter-systemic cascades and the connections and influences of non-social systems on social structures.

Furthermore, the framework may be particularly adequate to assess future risk cascades associated with climate change, and help to better understand, model, and simulate the associated complex social processes and their evolving dynamics. Thus, some key questions relevant for future research are: How do people react in scenarios of a (suddenly) changing environment? How do their institutions perform, for instance if the infrastructure breaks down and people's focus narrows down to the survival of individuals or families?

The effect of a new situation threatening a group of people either results in reinforcing social structures that enable people to increase speed, self-effort and altruism and reach a group's survival as in a disaster. Or it can result in competing and fighting structures as in the example of the revolutionary developments in Arabic countries. But in all cases it increases path dependency and thus the likelihood for social cascades.

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