Abstract: Dynamics and Development of the International System:

A Complexity Science Perspective

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Abstract

In this article I discuss the outcome of an exploratory research project based on complexity science concepts and theories; this research is focused on the Great Power war dynamics in the time period 1495 - 1945. According to this research, the international system has self-organized critical (SOC) characteristics. A critical point is the attractor of the international system. The war dynamics of Great Powers can be illustrated by a power law. As a result of a driving force, the international system is constantly being pushed toward this critical point. The security dilemma is a booster of this driving force. Tension and frustration build up in the international system as a result of various system thresholds, and are periodically discharged through wars. The SOC characteristics of the international system result in a punctuated equilibrium dynamic. The punctuations produce new international systems, each with its specific characteristics. A quantifiable development of the international system toward a condition of increased stability and reduced resilience can be observed. In addition to SOC characteristics, the international system exhibits characteristics of a chaotic system. Chaos, order and development are closely linked. The SOC dynamics generate a process of social expansion. It is possible to explain the social integration of Europe from this perspective.

Keywords: complexity science, international system, great powers, self-organized criticality, punctuated equilibrium, stability, resilience, chaos, order, social expansion

Introduction

Research of historical events and developments provides some evidence for the existence of system effects and patterns in the dynamics of social systems (Arenas et al. 2000, 3466, Boulding 1987, Cederman 2003, Goldstein, 1988, Houweling et al. 1988, Jervis 1997, Richardson 1960). These patterns concern for example economic interactions and inter state war dynamics. However, these patterns are not robust and often 'sensitive' to the researcher's perspective, and are as a result frequently disputed. The fact that 'underlying' mechanisms - which can explain these assumed patterns - can most often not be identified, contributes to these disputes.
Complexity science - a relatively new scientific discipline originating in physical sciences - can probably be useful in the identification and explanation of (presumed)

patterns in social systems. The spontaneous emergence of macro patterns and macro behavior are typical of complex systems (Amaral et al. 2004, Paczuski et al. 1999, Strogatz 2001, Watts 2003). The spontaneous order in these systems is not the result of the purposeful behavior of the elements (actors[1]) of a complex system or the influence of a central organizing authority: Such patterns are a form of self-organization (Ottino 2004). The patterns in complex systems are the result of rule-based interactions between actors at the micro level of the system. These rules evolve - adapt - under the influence of the experience and the learning abilities of the actors constituting the system (Holland 1995, 1998), and as a result of the development of the structure of the complex system, changing the 'setting'. Furthermore, complex systems can be identified by how they may or may not be analyzed: decomposing the system and analyzing its subparts do not necessarily give a clue to the behavior of the whole (Ottino 2004).

It seems that social systems could qualify as complex systems: Social systems consist of a relatively large number of actors, which interact on the basis of changing rules.

Complexity science is a collection of concepts and theories concerning the identification and explanation of patterns in complex systems. Many of these explanations still are speculative; our knowledge of complex systems is still restricted.

Some efforts have been made to explain various patterns in social systems on the basis of complexity science concepts and theories. So far, most often these attempts have failed and often delivered confusing results, adding to the earlier mentioned disputes.

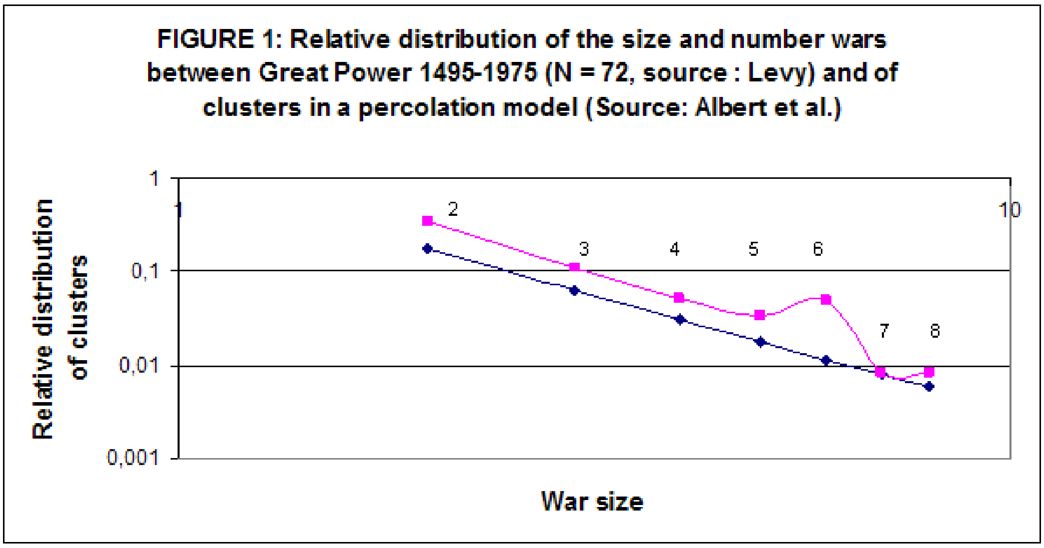
In this article I will discuss some hypotheses based on recently finished exploratory research, using various complexity science concepts and theories. This research is focused on the Great Power war dynamics in Europe during the period 1495 until 1945 and mainly based on Levy's dataset (Levy 1983). This delineation is based on three considerations. First, concerning the 'subset' of Great Powers: Great Powers can be identified accurately with the help of various criteria (Levy, 1983, 16-19), and the Great Power System constitutes a dominant subsystem in the international system, playing a major role in the transformation of the international system and the structuring of international order (Levy 1983, 10). Second, concerning the time frame 1495 - 1945: 1495 is generally considered the starting 'date' of the Great Power System (Levy 1983, Tilly 1992); the choice to restrict my research to the year 1945 is based on the consideration that our present international system - the fifth international system, as I will explain later - is still developing. Furthermore it is relevant to notice that until the Second World War, the Great Power system was predominantly a European system. European Great Powers - in fact - dictated the war dynamics of the international system: only two out of seventy wars between Great Powers[2] took place outside Europe[3]. Third, concerning the use of Levy's dataset: Levy's dataset provides data 'covering' the longer term development of the international system, contrary to the Correlates of War (COW) datasets[4].

In this article, I will argue that - during the period under investigation - the international system had self-organized critical - and punctuated equilibrium characteristics, and that a chaotic attractor influenced the war dynamics of the international system. These 'mechanisms' resulted in various patterns. Furthermore, I will argue that these complexity 'mechanisms' - SOC, punctuated equilibrium and chaos - are complementary and provide a consistent framework for the explanation of the war dynamics and development of the international system. Finally, I will discuss some implications of these findings and propose some directions for further research.

Self-organized Criticality

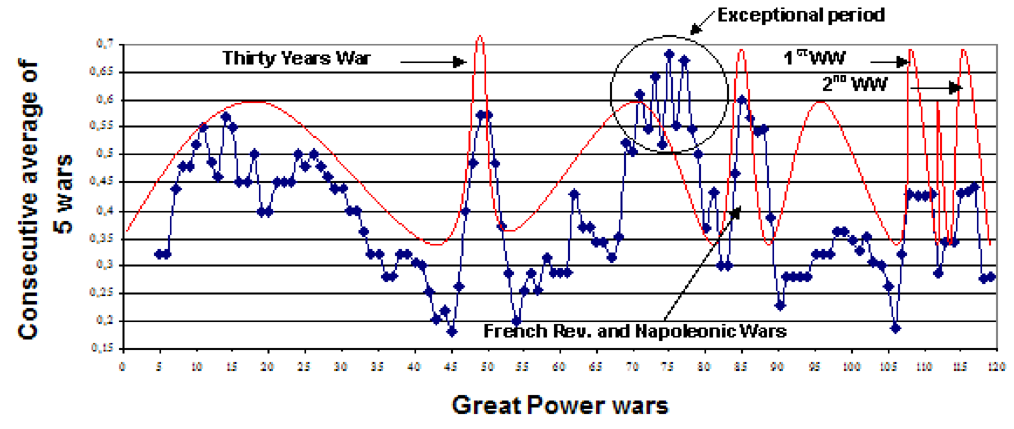
One of the hypotheses following from my exploratory research is that the dynamics of the international system show SOC-characteristics. A SOC-system is a dynamic system in which a driving force - more or less constantly - 'pushes' the system towards a critical condition. Thresholds in these systems enable the accumulation of tension and frustration; this accumulated tension and frustration is released regularly, according to a typical statistical distribution. The release of tension and frustration allows a new accumulation process. In this chapter I will identify - and explain - these SOC-characteristics in more detail, and discuss the findings and quantitative analysis which support this hypothesis.
For SOC to be applicable, four requirements must be met. First, a critical point has to be the attractor of such a system (Bak et al. 1988, Newman 2005, 12, Sornette 2003, 395-439). It is typical for systems in a critical condition that the size and number of clusters (wars in the context of this research) have a fractal distribution, and can be shown with a power law[5]. Second, the system needs a driving force which more or less constantly pushes the system towards this critical point. Third, the system needs to be a threshold system: Thresholds enable the build-up of tension and frustration, and result in a necessary separation of timescales[6] (Sornette 2003, 402-404). Fourth, the system needs to be perturbed more or less regularly, as a result of which cascades erupt (in fact the earlier mentioned 'clusters'), resulting in the release of the tension and frustration that has been accumulated in the system. These SOC-characteristics result in an oscillating dynamic around the critical point.
Because the international system - and Great Powers constituting this system - are the level of analysis of this research, I assessed if it is possible to describe the distribution of the number of wars between Great Powers with a particular size, as a power law[7]. In this approach 'size' is defined as the number of Great Powers participating in these wars (with a minimum of two). A power law[8] can indeed be identified; a finding which is consistent with the 'first' SOC-requirement as discussed in this chapter[9].
However, a significant distortion of this power law is evident for wars in which six Great Powers participated[10]. I will discuss this distortion later, and argue that this phenomenon can be attributed to the Great Power war dynamics during a specific time period (1657 - 1763), during which the 'normal' - that is chaotic - war dynamics of the international system where temporarily disrupted.
As mentioned, a power law is a characteristic distribution for the size and number of clusters in systems in a critical condition (Newman 2005, Stauffer 2003, Turcotte et al. 2002). It is striking that this particular power law has, except for a certain disruption, an identical coefficient as the power law that describes the distribution of clusters in a theoretical percolation model at its critical point[11]. The below figure shows both power laws: a power law of the size and number of wars between Great Powers, which is based on Levy's dataset (Levy 1983), and a power law of the size

and number of clusters in a theoretical percolation model at its critical point (Albert and Barabási 2002, 65).
A power law is indeed identified - suggesting the existence of a critical point - but it is not clear 'what' the critical point of the international system is or represents. I will discuss this critical point later - not in this chapter - because further explanation of some characteristics of the international system is required first.



In order to gain a better understanding of the dynamics of the international system, I examined how the fractions - the relative size - of Great Power wars have developed over time. The fraction of a Great Power war can be calculated by dividing the number of Great Powers that participated in a particular Great Power war, by the total number of the Great Powers constituting the international system at the time of that particular war. During the period under investigation (1495 –1975), the number of Great Powers fluctuated between four and eight (Levy 1983, 48). If all Great Powers constituting the international system participate in a war, the fraction of that specific war is exactly one.
In order to obtain a more regular graph, I repeatedly calculated the progressive mean of five consecutive war fractions. The value of the Great Power war corresponding with number '1' (see x axis) is the mean of the fractions of the first five Great Power wars in Levy's data set (Levy 1983, 88-91), the number '2' corresponds with war numbers 2 – 6, etc. The results are shown in below figure. The thick line is a schematic, simplified illustration of the typical dynamic that can now be identified.

FIGURE 2: Great Power war fraction dynamic of the International System 1495 - 1975 (N = 119, source: Levy)



Although this figure still shows a somewhat fickle graph, a punctuated equilibrium dynamic can be identified. In a punctuated equilibrium dynamic punctuations interrupt relatively stable periods. Typically, during punctuations more fundamental development of these systems takes place, leading to qualitatively 'new' systems (Anderson et al. 2004, Gersick 1991, Gould 2002, 75-80, Paczuski et al. 2003, 6, Somit and Peterson 1989). In the punctuated equilibrium dynamics of the international system four punctuations can be identified: (1) the Thirty Years War, (2) The French Revolutionary and Napoleonic Wars, (3) the First World War and (4) the Second World War. Furthermore it is possible to identify five relatively stable periods between these punctuations. These relatively stable periods I define as 'international systems'. I will elaborate on these international systems and their characteristics in the next chapter: I will discuss the typical form of the lifecycles of these international systems, the development of various quantifiable characteristics and some qualitative differences, e.g. the rules and institutions which typify these consecutive international systems.

TABLE 1

International system	Period	Punctuation	Period
1	1495 - 1618	The Thirty Years War	1618 - 1648
2	1648 - 1792	French Revolutionary and Napoleonic Wars	1792 - 1815
3	1815 - 1914	First World War	1914 - 1918
4	1918 - 1939	Second World War	1939 - 1945
5	1945 - ……		

Some initial observations can be made: (1) According to this perspective, the First and Second World Wars are not two phases of the same war, as is often assumed by various historians (Goldstein 1988, 340-341): two separate punctuations can now clearly be identified, (2) wars constituting punctuations not only have an exceptional large fraction, but an extreme intensity as well[12], and (3) again a distinct disruption of this pattern is visible: a series of wars with a large fraction and intensity between the first and the second punctuation. I shall discuss this disruption later; it can be argued that this disruption is closely linked to the disruption in the power law I have identified. I denote this disruption as 'the exceptional period', referring to the qualitatively different war dynamics during this timeframe.

Next I will discuss the driving force of the international system. After investigating some alternatives, I assume that two 'components' are central to the driving force of the international system: (1) the security dilemma - which is intrinsic to our anarchic international system (Holsti 1995, 5) - and (2) the degree in which the rules and institutions of an international system are an accurate reflection of the interests of Great Powers constituting the international system. The security dilemma and an (increasing) 'mismatch' in the international result in a more or less steady increase of the level of tension and frustration in the international system[13].

During the lifespan of an international system, the tension, frustration, and discontent with the arrangements - e.g. rules and institutions - of that particular international system will gradually increase. Initially, a new international system reflects the interests, power relations and hierarchy of the Great Powers constituting the system. During the lifecycle of an international system, its functionality and configuration will become progressively outdated. The lifecycles of states, especially of Great Powers, and the differentiated growth and development of states will contribute to the system's obsolescence (Gilpin 1981). As a result of these developments the sense of insecurity and the level of discontent with the status quo will steadily grow. Various positive feedback loops are at play. These developments have an impact on the connectivity of the international system. At the end of the lifecycle, the international system comes close to an anachronism, constantly fuelling the security dilemma, and the level of tension and frustration in the international system.

This driving force enables a necessary separation of time scales. The 'components' of this driving force interact at a relatively slow time scale, constantly increasing the level of tension and frustration in the international system. The dynamics of wars operate at a much faster pace, releasing the tension and frustration within a relatively short time span.

So far I have identified and discussed two out of four SOC-components of the international system. The third component - thresholds, enabling the build up of tension and frustration - can be identified as well. The rules and institutions of international systems - and the interests of states - have a threshold effect and allow the build up of tension and frustration in the international system. From 1495 onwards the rules and institutions in consecutive international systems have increasingly restricted the use of violence as a legitimate instrument of foreign policy. As a result of this development thresholds have become more pronounced and effective[14].

Finally, it is possible to identify 'triggers' in the international system, that initiate 'avalanches' - in this context wars - that release the accumulated tension and frustration in the international system. These triggers can be small incidents. A typical and easy recognizable example of such a trigger is the 'starting shot' for of the First World War: the shooting in 1914 of Franz Ferdinand in Sarajevo. This

'small' incident resulted in a disproportionate - non-linear - reaction from the international system: From a complexity perspective the international system was 'organized' in a critical condition.
Now all four SOC-components - except for the critical point itself - of the international system have been identified. In below table these components are summarized.
In the next chapter I will discuss the punctuated equilibrium dynamics of the international system in more detail.

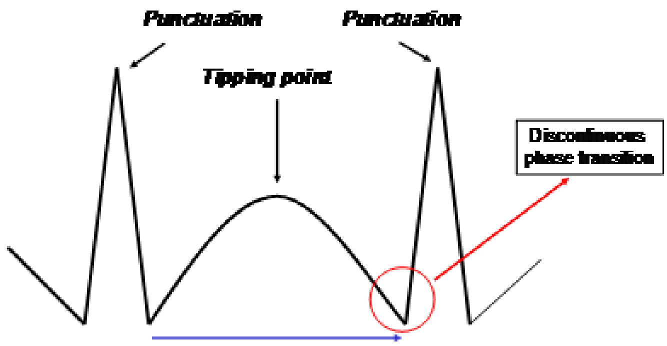
TABLE 2

SOC-component	Description
Power law and critical point	A power law representing the distribution of the size and number of Great Power wars. The critical point as such is not identified.
Driving force	The steady accumulation of tension and frustration, including a positive feedback mechanism as a result of the security dilemma of the (anarchic) international system
Thresholds	Rules and institutions regulating the use of power and wars between states
Cascades	Great Power wars, triggered by 'regular' incidents

SOC, Punctuated Equilibrium Dynamics and Life Cycles of International Systems

In the preceding chapter I have shown that the SOC-dynamics of the international system result in a punctuated equilibrium dynamic: relatively stable periods - international systems - are punctuated by large scale and intense wars, resulting in more fundamental development of the international system.
Between two punctuations, normally only wars with relatively moderate fractions seem to take place. These periods can be qualified as reasonably stable, and during these relatively stable periods the rules of the international system and corresponding institutions develop only gradually, if at all. Furthermore, during these relatively stable periods, a sort of pattern can be identified. Immediately after a punctuation, the fractions of Great Power wars have a minimal, almost zero, value. Subsequently, the war fractions increase until they approach a local maximum, which I call the 'tipping point' of an international system. Beyond this tipping point, the war fractions start to decline, and again approach a minimal - almost zero - value. Next, a sudden - very steep - increase of the Great Power war fraction takes place: The next punctuation starts. Such an increase in the fraction of Great Power wars - from 'zero' to the size of the system is called a discontinuous phase transition (Watts, 2003).
The fraction dynamics during the lifecycle of an international system are schematically shown in below figure.

FIGURE 3: Life cycles of international systems



Based on the typical fraction dynamics of consecutive internationals it is possible to identify - graphically - three tipping points.

TABLE 3

International system	Period	Tipping point
1	1495 - 1618	1514
2	1648 - 1792	1774
3	1815 - 1914	1856

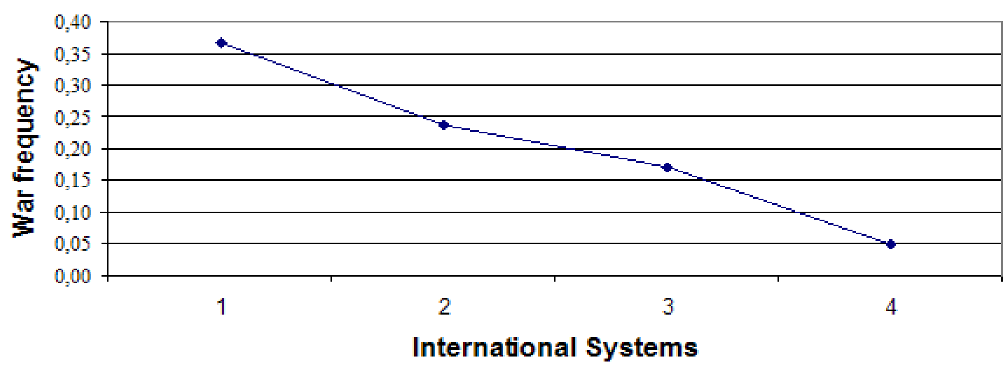
It is however not possible to identify a tipping point during the life cycle of the fourth international system: Between the First and Second World War only one Great Power war took place in Europe (The Russian Civil War).

The four consecutive systems have not only specific qualitative, but also some quantitative characteristics. I have defined, quantified, and analyzed a number of system variables: A number of them evolve regularly. The number of wars in consecutive international systems and the war frequency[15], for example, evolve linearly. Furthermore, very strong relationships exist between various variables. Some have correlation coefficients with a high value. These quantitative characteristics support the hypothesis that a punctuated equilibrium - as discussed in this article - is not an artifact[16].

I have defined two important properties of international systems: stability and resilience. This particular approach is based on ecosystem research (Brown et al. 2001, 649, Gunderson 2002, 25-62, Holling 2001, Pimm 1991, Scheffer et al. 2001). Both properties are - as I will show - useful viewpoints from which to acquire a better understanding of the dynamics and development of the international system.

I have defined stability as the ability of the international system to sustain itself in a condition of rest, that is to say, in the absence of Great Power wars. The frequency of wars during the lifespan of each consecutive international system is indicative of the stability of these systems. The frequency of wars during the lifespan of an international system can be calculated by dividing the number of wars during the lifecycle of that particular system in question by the duration of its lifecycle, its lifespan. The lifespan of an international system can be calculated by determining the difference between the start year of the punctuation that ended the lifecycle of that system and the end year of the preceding punctuation. It shows that the war frequencies during the lifespan of consecutive international systems decrease linearly. This implies - in accordance with this definition of the stability concept - a linear increase in the stability of consecutive international systems.

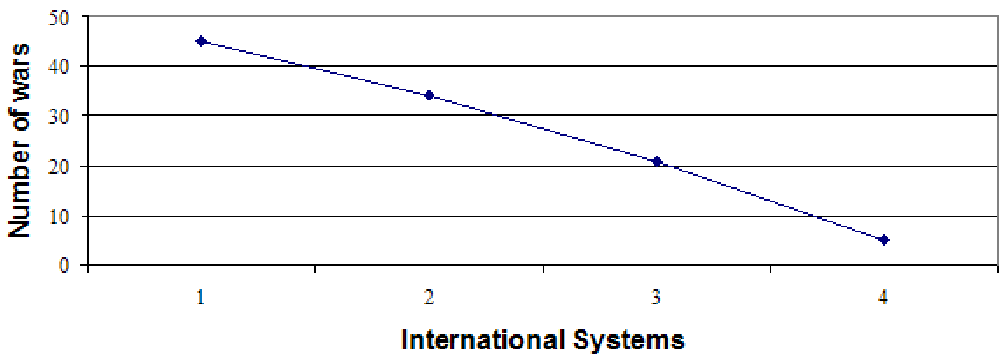
FIGURE 4: Increase of the stability of the International System (the frequency of Great Power wars in consecutive International Systems (N = 105, source: Levy)



The, what I call, ‘status dynamics’ of the international system are another indication of the development of the stability of the international system. The status dynamics of the international system concern the number of states that acquire or lose their Great Power status. Based on Levy’s dataset, it is possible to determine that the status dynamic decreases over time (Levy 1983, 47). During the first four international systems (status changes during punctuations are excluded), respectively eight, five, three, and zero status changes occurred. Two of the three status changes during the third international system concerned the United States (1898) and Japan (1905). This not only emphasizes the increase in stability of the European system, but also signals the increased impact of non-European states on the dynamics of the international system. It is remarkable - and possibly no coincidence - that most status changes occur in the ‘vicinity’ of the tipping points of consecutive international systems.

I have defined resilience of the international system as the ability of an international system to sustain itself within a particular stability domain[17], a particular international system in the context of this research. The absolute number of wars that is required to ‘push’ an international system out of its stability domain is an indication of the resilience of that particular system. Based on the evolution of this variable, it can be determined that the resilience of the international system has decreased over time. Again, an almost linear relationship can be identified.

FIGURE 5: Decrease of the resilience of the International System (the absolute number of Great Power wars in consecutive Internationa Systems) (N = 105, source: Levy)



Another indication of the development of the resilience of the international system is the decrease in the lifespan of consecutive international systems. However, the lifespan of the second international system is, from this perspective, an exception. It can however be argued that the relatively long lifespan of the second system is related to the exceptional dynamics - the distortion - in the period 1657 – 1763. These exceptional dynamics - it can be argued - have resulted in a lengthening of the lifespan of the second international system. This exceptional period will be discussed later.

The table below shows the development of the stability and resilience of consecutive international systems[18].

TABLE 4

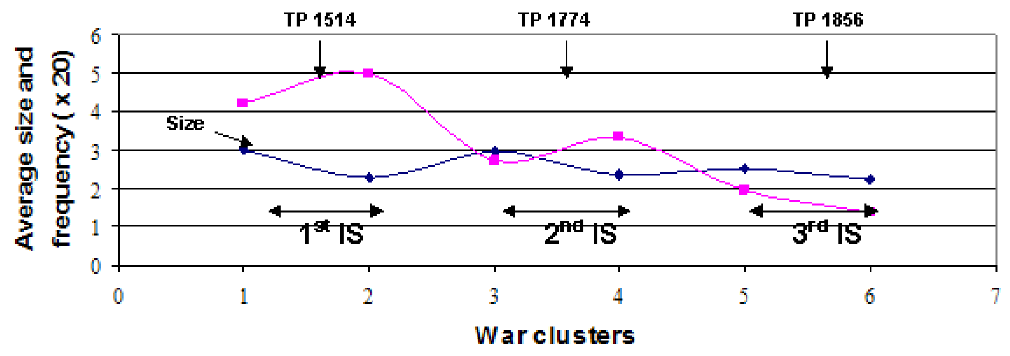
Quantification of the stability and resilience of consecutive international systems

		Stability		**Resilience**	
International system	Period	War frequency	Status dynamic	Number of Great Power wars	Lifespan (years)
1	1495 – 1618	0.37	8	45	123
2	1648 – 1792	0.24	5	34	144
3	1815 – 1914	0.17	3	17	99
4	1918 – 1939	0.05	0	1	21

The dynamics during the lifecycle of each consecutive international system can be analyzed in more detail. The separation of a lifecycle into two phases, separated by the tipping point, makes it possible to discern two war clusters during the life cycle of an international system: One before and one after a system's tipping point.

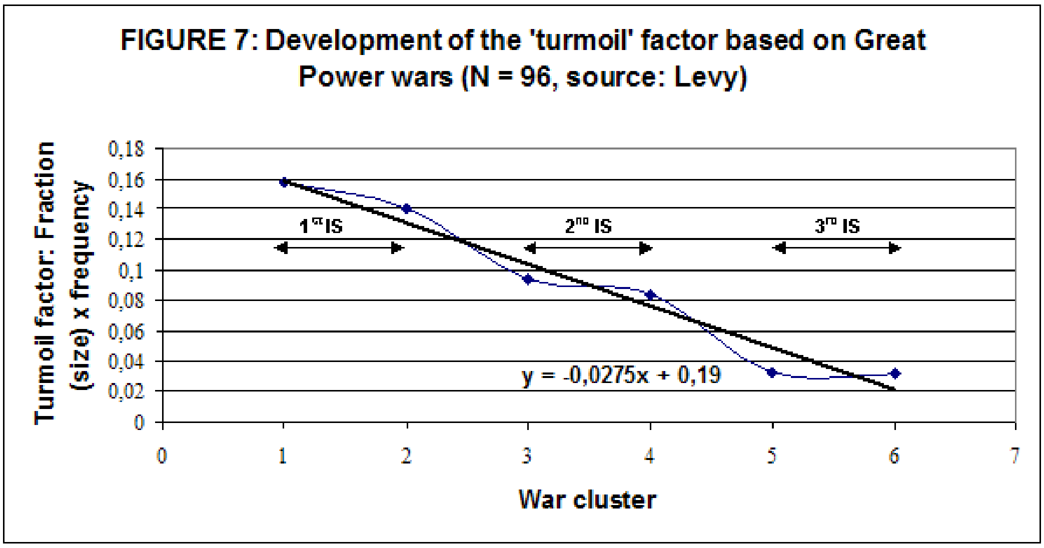
As mentioned, I have determined the tipping points of the first three systems graphically, using the fraction dynamics diagram: They fall in, approximately, 1514, 1774, and 1856. When the war frequency of these six clusters is calculated, a clear pattern is visible. The following figure shows this pattern and its development (upper line).

FIGURE 6: Development of the average size and frequencies of clusters of wars between Great Powers, before and after the respective tipping points, 1495 - 1914 (N = 4, 26, 17, 3, 4, 4, source: Levy)



This pattern shows that the war frequency after the respective tipping points in consecutive international systems have a higher value, compared to the war frequency before the respective tipping points. In other words: The stability[19] of consecutive international systems decreases during the second phase of the lifecycles of consecutive international systems.

A similar - but reciprocal - dynamic can be identified for the fraction dynamics before and after the respective tipping points of the consecutive international systems. The average fraction of wars between Great Powers after a system's tipping point is always smaller then the average size of wars before these tipping points. Next I have defined the 'turmoil' factor of an international system, based on the average fraction and war frequency of war clusters, as the product of the values of these variables. Not surprisingly - given the reciprocal development of both variables in time - the turmoil factor shows a linear - and decreasing - development.



This typical dynamic provides further evidence for the hypothesis that the punctuated equilibrium dynamics of the international system (figure 2) are not an artifact, and for the existence of tipping points, which separate two specific phases during the lifecycles of an international system.

A relevant question is how the life cycle of an international system can be explained: What mechanism(s) bring about these regular cycles? I will discuss two possible - speculative - explanations.

It can be argued that the connectivity of an international system initially - immediately following a punctuation - is low, restricting the size (fraction) of Great Power wars: Due to a lack of connectivity interaction between Great Powers still is restricted. In time, the connectivity of an international system increases, including clusters of conflict prone relations between Great Powers. As a consequence of this development - it can be argued - that the size of Great Power wars increase as well.

A similar dynamic - an increase of cascades as a function of the connectivity of a network - is demonstrated by Watts with simulations with a "*simple model of global cascades on random networks*" (Watts, 2002). Watts demonstrates that due to an increase of the connectivity in these types of systems, the size of cascades will increase as well, until a certain degree of connectivity is achieved, and cascades will start to decrease in size (see appendix for a more detailed explanation of Watts his framework). This dynamic implies that the typical dynamic in these systems shows a tipping point. Watts argues that beyond a certain degree of connectivity, the size of cascades starts to decrease as a result of the increased local stability of the system. If the connectivity is further increased, cascades will approach a 'zero' size, and next, 'unexpectedly' a system sized cascade will occur, comparable to a punctuation in this context.

Watts his model provides a useful framework to study the war dynamics of the international system, however, isomorphism is an important issue and further validation of this approach is required. On the basis of Watts' simulation results it could be argued that Great Power wars are comparable to cascades, and that the tipping points in the life cycle of international systems can be attributed to a connectivity effect as well. This means that 'half way' the lifecycle of an international system, the increasing local stability of the international system will increasingly start to inhibit the size of Great Power wars. Finally - at the end of the life span of an international system - Great Power wars will be 'suppressed' completely. However -despite this 'restricting' development - the steady increase in the level of tension and frustration continues and the ultimate relieve of this tension can only be achieved by a system wide war, a punctuation. As I said, further research is required to validate this explanation.

Another explanation for the existence of a tipping point in the war dynamics of an international system could be that 'half way' the life cycle of an international system, the system starts to fragment as a result of the status dynamics of Great Powers. Some Great Powers lose their position and power to dominate the international system, and 'new' Great Powers are not yet capable to fulfil a dominant role in the international system in accordance with their power and interests. As explained the power and interests of new Great Powers are not (sufficiently) embedded in the (existing) rules and institutions of the international system. The observation that the Great Power war frequencies and the average fraction of war clusters before tipping points of consecutive international systems, are respectively in- and decreased is consistent with the assumption that the international system has become more fragmented. It can be reasoned that - as a result of this fragmentation - the steady build up of tension and frustration can not be relieved through wars with relatively large fractions, and the international system as a result 'compensates' with an increase in the frequency of (smaller) Great Power wars. In other words: a higher war frequency after the tipping point ensures relieve of tension and frustration through smaller Great Power wars.

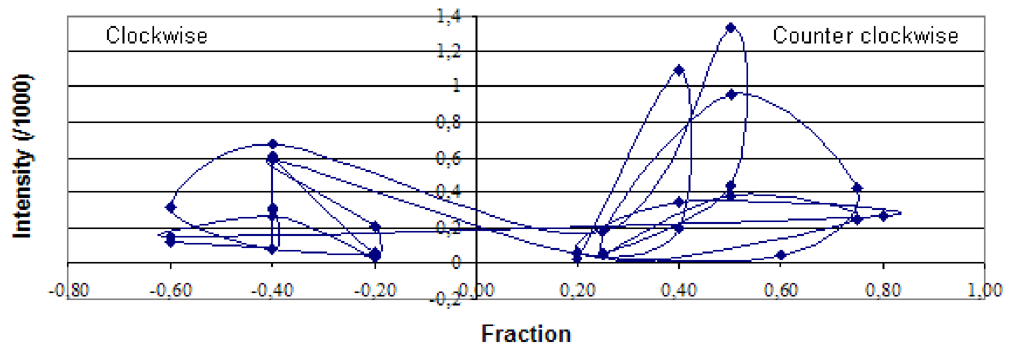
At first sight these two explanations contradict: in the first explanation the existence of a tipping point is explained as a consequence of the increase of the connectivity of an international system, in the second explanation, the existence of a tipping point is attributed to the fragmentation of the international system as a result of the status dynamics of Great Powers. These two 'contradictory' explanations could possibly be reconciled if a strict distinction is made between the development (dynamics) *of* the network of relations between Great Powers (the first explanation), and the development (dynamics) *on* the network of relations between Great Powers (second explanation). Further research is required.

Chaos

In order to get a better understanding of the war dynamics and the development of the international system, I have constructed a series of 'phase states'. With this approach it is possible to determine - and visualize - the development of various characteristics (variables) of a dynamic system. I use two variables in these phase

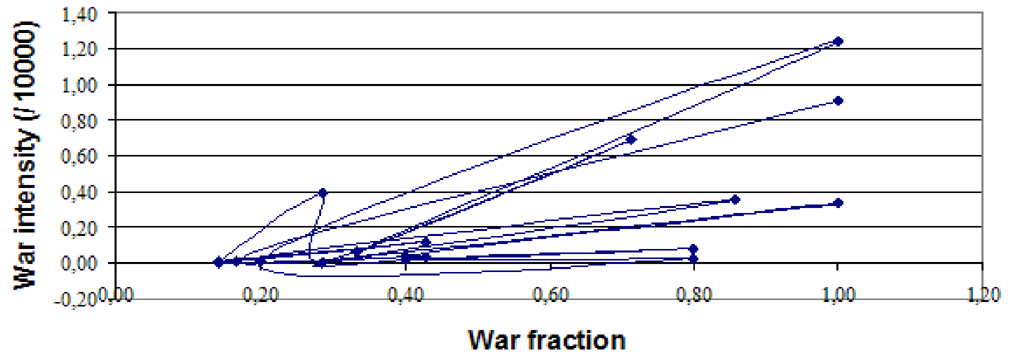
states: The fraction and the intensity of consecutive Great Power wars.
It seems that ‘normally’ the development of these two variables can be typified - and visualized - with circular trajectories. A closer look reveals that sometimes these circular trajectories have a clockwise direction, and sometimes a counter-clockwise direction. However, this typical circular war dynamic is disturbed during the period 1657 – 1763. During this specific timeframe a ‘zigzag’ pattern characterizes the war dynamics in the phase state. This period coincides with the exceptional period identified in the previous chapter.
The figure below is an illustration of the phase state of circular trajectories during the first international system (1495 – 1618). A closer look reveals seven circular patterns; four are counter-clockwise, and three are clockwise[20]. During the period around 1550 and during the years from 1610 until the first punctuation (1618), these circular patterns were somewhat distorted.

FIGURE 8: Phase state of the fraction and intensity of Great Power wars constituting 7 circular trajectories (N = 34) during the 1st International System 1495 - 1618, differentiating between clockwise (left) and counter clockwise trajectories (Levy)



In the next figure, the zigzag pattern in the phase state of the exceptional period (1657 – 1763) is clearly visible. During the subsequent periods (life spans of international systems), circular patterns again appear in the phase state of the international system.

FIGURE 9: Phase state of the size (fraction) and intensity of Great Power wars (N = 21) during the exceptional period, 1657 - 1763 (Source: Levy)



I assume - this is a hypothesis - that the clockwise and counter-clockwise circular patterns indicate the existence of a chaotic attractor, dominating the war dynamics of the international system. A chaotic attractor has a fractal structure and is characteristic of chaotic systems (Gleick 1988, Kaplan et al. 1993, Lorenz 1993, 111-160, Strogatz 1994, 301-347). Chaotic systems are deterministic systems, with a great sensitivity for the initial conditions of the system, and with highly unpredictable dynamics as a result (Kendall 2001, Strogatz 1994, 320). The unpredictable dynamics of these systems are a result of the interplay between at least three degrees of freedom (variables) (Strogatz 1994, 10).
'Small' deviations from these circular patterns (here, I am not referring to the zigzag patterns during the exceptional period) can be contributed to the influence of a stochastic component. By a 'stochastic component' I point at random incidents and factors influencing the dynamics and development of the international system.
In order to determine if these seven circular trajectories develop according to a specific 'logic' (pattern), I have calculated the average fractions of wars constituting the respective circular trajectories during the first international system. The result is shown in below figure. Again, a clear pattern is discernable: The amplitude of this graph decreases and almost approaches a value of 'zero' when the first punctuation is reached. The similarity with the war cluster patterns discussed in previous chapter is remarkable. Further research is necessary to explain this typical dynamic and to determine if similar mechanisms underlie these patterns.

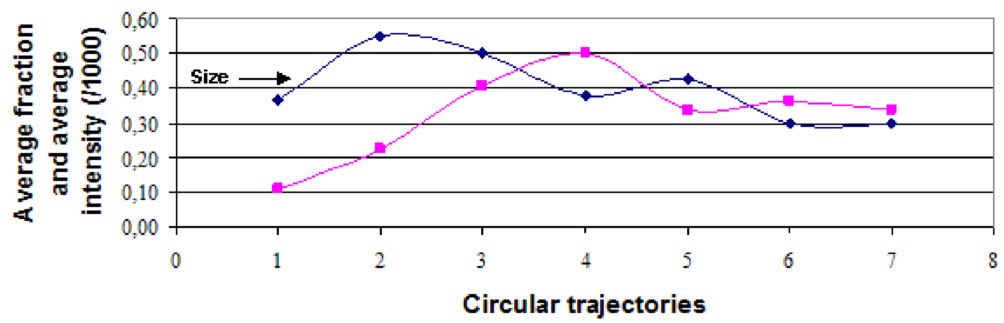


FIGURE 10: Development of the average size (fraction) and average intensity of Great Power wars belonging to 7 circular trajectories (N = 34) during the 1st International System 1495 - 1618 (N = 45, source: Levy)

An important question is whether the exceptional zigzag dynamics during the exceptional period can not only be explained from a system perspective, but from a historical perspective as well. This indeed seems to be the case.

During the exceptional period 1657 – 1763, the interactions and dynamics of the international system were to a high degree dominated by the intense rivalry between Britain and France: both Great Powers were maneuvering and fighting for a hegemonic position in Europe. In 1763, the end of the Seven Years War, Britain finally achieved supremacy (Schroeder 1994, 3-11).

As a consequence of this rivalry, international relations were simplified. From a system perspective - it can be argued - this intense rivalry resulted in a decrease of the number of degrees of freedom, determining the dynamics of the international system. As a result, the international system temporarily stopped functioning as a chaotic system; the number of degrees of freedom was reduced to two and the dynamics and interactions between states became highly predictable as a result. During this timeframe decisions of Great Powers to start or to participate in a (Great Power) war only depended on two actors (Britain and France); 'third' Great Powers were not taken into consideration.

During the exceptional period Great Power wars tended to have an 'all or nothing' character. The war frequency during the period in question was relatively low, but the fractions of these wars were mostly high. It looks as if Great Powers were reluctant to start a war, because they were aware of the high risk - the 'certainty' - of escalation.

I presume that a direct relationship exists between these simplified war dynamics, often resulting in large and intense wars, and the distortion of the power law, especially the overrepresentation of Great Power wars with a size of six (see figure 1).

Synthesis

SOC, Punctuated equilibrium dynamics, chaos, and the development of the international system towards a condition of greater stability are closely linked. The SOC-characteristics of the international system result in a punctuated equilibrium dynamic. This punctuated equilibrium dynamic - and resulting pattern - implies a certain order in the war dynamics and the development of the international system. On the other - that is a paradox - chaos (normally) dominates the war dynamics - the size (fraction) and intensity - of consecutive Great Power wars. Chaos - by definition - implies an intrinsic unpredictable development of the international system at this level of analysis. This implies that in the international system order and chaos go hand in hand, however at different levels of analysis: SOC and punctuated equilibrium dynamics at the level of the international system, and chaotic dynamics at the level of consecutive Great Power wars. Chaos obviously creates order in the international system[21].

I have argued that during a specific time period (1657 - 1763) the chaotic dynamics of the international system were temporarily disturbed as a consequence of a simplification of the interactions between Great Powers constituting the international system; I am referring to the intense rivalry between Britain and France. Furthermore I have suggested that a relationship exists between the simplified war dynamics during the exceptional period and the distortion of the power law discussed in the first chapter. In order to test this hypothesis (the attribution of the distortion in the power law to the war dynamics during the exceptional period), I have excluded the Great Power wars which took place during the exceptional period from further analysis, and determined the characteristics of the resulting - adjusted - power law. This adjusted power law is shown in below figure. Now, a significant better fit with the power law of the distribution of clusters in a theoretical percolation model at the critical point is achieved.

FIGURE 11: Relative distribution of the size and number of wars between Great Power 1495-1975, the exceptional period (1657-1763) excluded (N = 57, source: Levy) and of clusters in a percolation model (Source: Albert et al.)

The results of this 'adjustment' supports the hypothesis that a close relationship exists between chaos and SOC, and that by 'default' a chaotic attractor dominates the war dynamics of the international system, at least during the period under investigation (1495 - 1945).

So far I have not specified the critical point of the international system: What is or represents the critical point, the attractor of the SOC-dynamic of the international system? In order to specify the critical point of the international system I - again - refer to Watts framework and his simulation results (Watts, 2002).

Watts not only identified a specific pattern in the global cascades in his system, but found that - as a result of a combination of the connectivity of the system and the thresholds in this system (determining the transition point of individual actors in the system, see appendix) - global cascades at a certain point become impossible. At that point the local stability prevents global cascades altogether. Watts defines this point as the upper-phase transition of the system[22]. I assume that such an upper-phase transition exists in the international system as well, and that this 'point' has been crossed in Europe in 1945; the Second World War was in instrumental in this development. As a result of the 'crossing' of the upper-phase transition wars in Europe have become 'impossible': the current system conditions - more specific the local stability of the European system - 'prevent' the outbreak of wars in Europe. This research makes it possible to explain - and even quantify - the development of a security community in Europe, as defined by Karl Deutsch (Deutsch 1957).

After the Second World War, the United States and the Soviet Union ensured Europe's security, each in its own sphere of influence. By doing so, the rivalry between European states was neutralized, enabling cooperation between Western European states, the integration of economic and political structures, and (after 1989) cooperation with other European states. NATO, the European Coal and Steel Community, the European Economic Community and, later, the European Union, embedded Europe above the upper-phase transition, outside the 'cascade window' of Watts' framework. However this position 'above' the upper-phase transition can not be taken for granted. Due to an increase of the rivalry between European states the security dilemma - and the driving force - could be re-activated resulting in wars between European states. Until Europe is integrated in effective political structures, based on a shared understanding of vital common interests (Axelrod 1984, 1997), this integration process will be in a critical phase.

I assume that until 1945 the upper-phase transition was the attractor of the international system; from a SOC-perspective this 'point' was the critical point of the system. In fact - it now becomes clear - that this SOC-dynamic obviously results in a process of social expansion (the steady increase of the stability of consecutive international systems is consistent with this observation).

Further research - based on the complexity perspective developed in this research and focused on the development of the state - could result in the identification of a similar process of social expansion, albeit at another level of analysis (Spruyt 1994, Tilly 1992).

Implications

In this chapter I will discuss some implications of the findings of this exploratory research.

The observation that an emergent - self-organized pattern - in the war dynamics of Great Powers can be identified, implies the existence of an autonomous - system level - process, and even a certain degree of predictability. Predictability of war dynamics (in the current international system) and the development of the international system, require that the conditions of the present international system are identical to the conditions during the research period (1495 - 1945). This implies - to name a prerequisite - the existence of a security dilemma, an important component of the driving force of the international system. A security dilemma 'exists' - not (now) in Europe but at a global level - and it seems as if the war dynamics of the international system are 'accelerating'. Furthermore, the (war) dynamics now seem to become more chaotic (unpredictable): it can be argued that between 1945 and 1989 the international system was dominated by the intense rivalry between the United States and the Soviet Union - not only enabling the integration of Europe - but simplifying the interactions between states in the international system as well; as was the case in the exceptional period. Based on these observations - and the hypotheses resulting from this research - it can be argued that the size (fraction) of Great Power wars will initially increase, until the tipping point of the current international system is reached. However, it could be that the exponentially increased level of connectivity at 'individual' level of the international system - e.g. as a consequence of the Internet - affects this system level - self-organized dynamic - further research is necessary.

This form of predictability - in combination with some other patterns (e.g. the ratio of the size and number of Great Power wars, which can be calculated with the power law discussed in this article and the increase of the stability and the decrease of the 'turmoil' factor) - does not imply that the timing, location, intensity and size of wars can be predicted. It should be remembered that at this level the international system has chaotic characteristics: as explained a chaotic system is intrinsically unpredictable.

The observation that a self-organized dynamic generates wars raises the question if - and to what degree - 'realistic' (policy) assumptions are indeed realistic. From a 'Realistic' perspective, wars are - and should be - the outcome of rational cost-benefit calculations (Gilpin 1981). This research suggests that wars are - at least were - unavoidable and follow a certain pattern, and are not 'seriously' influenced by human decision-making at the micro level. It seems that these 'realistic' cost-benefit calculations would be better characterized as rationalizations and sense-making in hindsight (Weick 1979, 1995).

In this respect another finding of this research is disturbing as well: namely that war(s) can not be 'managed' or controlled. The assumption that wars can be controlled is undermined by the finding that 'normally' a chaotic attractor dominates the war dynamics of the international system. As explained, war dynamics are unpredictable as a consequence, seriously restricting our efforts to control wars.

In the introduction of this article I explained that a complex system can not be understood or explained by analyzing the subparts of such a system. This research shows that it is a safe assumption to consider the international system a complex system. Possibly, this property of the international system explains that it is very difficult - maybe even impossible - to identify patterns and regularities in the interactions between states by analyzing its subparts, e.g. the war dynamics between particular states. Future research should validate this - and some other - observations, and try to assess if these 'bottom up' research results are complementary to these research findings, may be resulting in the identification of 'new' patterns and mechanisms.

The research findings discussed in this article could well add to the development of complexity science. Some of the new insights into the dynamics and functioning of the international system are possibly applicable to other complex systems as well, contributing to the further development of complexity science. For example, the explicit relationship between SOC, punctuated equilibrium dynamics, chaos and development, as appears to be the case in the international system, could well be intrinsic to other complex systems. Such a relationship is suggested in, for example, evolutionary dynamics of biological systems (Bak 1996, Paczuski et al. 1996, 415, Solé et al. 1999, 158, Turcotte et al. 2002).

Another possible application of the findings of this research concerns the assumed 'positioning' of complex systems 'at the edge of chaos'. In complexity science it is suggested (Kauffman 1995, 86, Solé et al. 1999) that complex systems function optimally at the edge of chaos, in a condition between complete order – where the flexibility of the system is restricted, and the system's ability to adjust to new circumstances is problematic – and a condition of complete disorder, where the system lacks minimal structures to ensure the system's viability. For social systems, a position at the edge of chaos - acting as an attractor - seems to be a valid assumption as well.

Appendix: Watts' Framework

Research by Watts provides a number of useful findings and the outline of a conceptual framework that possibly is useful for an explanation of the dynamics and development of the international system. Watts has determined with a series of simulations with a '*simple model of global cascades on random networks*' that global cascades in this category of systems (networks) are only possible in the case of a specific regime (Watts 2002, 5768, 5770). Here, 'regime' means a combination of the control parameters of these systems. Furthermore, Watts makes clear that these cascades manifest themselves according to a particular pattern.

The global cascades in Watts's model can, in principal, have any size; they do not necessarily have a size corresponding to the size of the system (Watts 2002). I presume that these cascades can be compared with wars in the international system.

Two parameters determine when, and under what conditions, the system represented in the model has a regime that supports cascades. These parameters are the connectivity and the thresholds of the elements (actors) comprising the system. Connectivity is defined by Watts as the number of connections (relations) connecting the average actor to other actors (Watts 2002, 2003). Actors in Watts's model have a certain condition. This condition is determined not only by the number of connections of an actor, but also by the threshold rules these actors apply. The threshold rule defines when (that is, at which fraction of the total number of connections) the actor will change his condition – that is, from stable to unstable, or vice versa – or his point of view. In this model, the condition of the actors of the system is determined by the condition of other, connected, actors. Watts uses the term 'local dependencies' for this mechanism.

An example will help to clarify this important mechanism. An actor with viewpoint A and a threshold rule of 0.6 is connected to ten other actors, of whom a fraction of 0.5 hold viewpoint A while the other half hold viewpoint B. The actor will change his viewpoint to B when one other actor changes to this viewpoint. In this case, with a connectivity of ten and a fraction of 0.5, one connected actor suffices to initiate a change of viewpoint.

Watts calls the collection of actors that need only one connected actor to change their condition, a 'vulnerable cluster' (Watts 2002, 5767). Watts demonstrates with his model that it is not the size of these vulnerable clusters that determines the size of cascades, but the degree of connectivity of the network constituting the system (Watts 2002, 5769). Watts makes an important difference between the dynamics *on* the network (the cascades) and the dynamics *of* the networks, that is, the development of the connectivity and of the threshold rules of the network itself. The development of the size and configuration of vulnerable clusters is indicative of the dynamics of the network.

Watts uses a series of simulations to demonstrate that cascades are impossible under three conditions, namely when (1) the thresholds are too high, (2) the connectivity of the network is too limited, or (3) the connectivity is too high. Under the last condition, the local stability of the system is so great that the global connectivity is hindered, precluding the occurrence of cascades.

In the case of a well-connected network, the change of point of view on the part of a single connected actor most often will not be enough to result in a change of viewpoint. The following example also demonstrates this "connectivity effect."

Again, the actor in question has A as his viewpoint, a threshold rule of 0.6 before switching to viewpoint B, and a fraction of 0.5 connected actors with viewpoint A (and B). However, in this case the actor is connected to 100 other actors. If one of these actors changes his point of view to B, the actor in question will not be affected. The actual fraction holding viewpoint B has now risen to only 0.51, which is well below the actor's threshold. A greater connectivity results in greater system stability.

In Watts's model, two phase transitions can be identified: a lower and an upper one. These transitions define the cascade window of the system. The lower-phase transition is related to the minimal connectivity required for cascades to happen, while the upper-phase transition is related to the point – the connectivity in combination with the threshold value – where cascades become impossible as a result of the high connectivity of the system.

States in the international system also have some degree of connectivity: In the context of my research, I am concerned with the network of interest and power relationships between states. This network is more or less formalized or institutionalized. Furthermore, states use threshold rules for the application of, for example, the use of violence against other states. These thresholds are, as discussed, embedded in international law, and in various coordination mechanisms and institutions. It is realistic to assume that states base their point of view on the use of violence and their position in international issues to a high degree on the points of view of other connected states. Local dependencies, as defined by Watts, are also applicable to the condition of states.

Watts shows that if the connectivity of the network is increased, the cascades in his model develop a particular pattern. Initially, when the lower-phase transition is crossed, cascades are rather small. This is a consequence of the low connectivity of the network. Then, when the connectivity is increased, the cascades increase in size until they reach a certain point. This point can be considered a tipping point.

If the connectivity is further increased, the size of cascades will decrease. From the tipping point onward, the local stability of the network will restrict the size of cascades. The cascades will approach a size of almost zero, and spontaneously increase to the size of the system itself. In the words of Watts, "triggering a cascade of universal proportions" that exceeds the size of the underlying vulnerable cluster. This type of phase transition is called 'discontinuous', because the size of cascades jumps from almost zero to the size of the system itself (Watts 2003, 242). These cascades are very rare and of exceptional size, and are a consequence of the unique configuration of the system near the upper-phase transition. The condition of the system can be defined as critical[23].

A discontinuous phase transition comes into being despite the local stability of the system. The vulnerable cluster is spontaneously triggered by an incident. As a result of the unique configuration of the system, actors more or less simultaneously change their viewpoint, or change from a stable to an unstable condition. The ensuing chain reaction changes the viewpoints of a large number of actors, affecting not only those who are part of the vulnerable cluster, but initially also more stable actors. For this reason, the size of the cascade will exceed the vulnerable cluster.

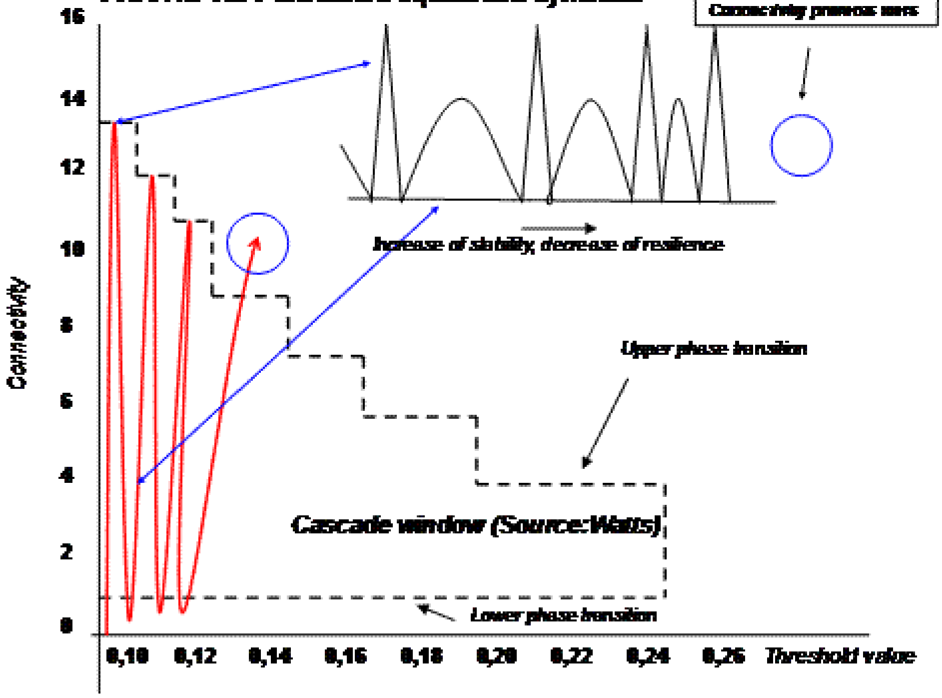
The cascade profile of Watts's model shows some remarkable similarities with the fraction dynamics of the international system, as discussed in the preceding section. I assume that a similar mechanism underlies the dynamics in the international system. Initially, after a punctuation, the connectivity of the new international system is limited, restricting the size of wars. The limited connectivity of the international system at that stage is the effect of the preceding punctuation, which has destroyed the old, outdated network. After the punctuation, new rules, coordination mechanisms, and institutions are introduced, and the network of interests and power relations is initially still limited. The level of tension, frustration, and discontent with these new arrangements is also low.

As the connectivity of the network increases, the size of wars increases, until the tipping point is reached. As a consequence of the increased local stability of the international system, the size of wars starts to decrease to almost zero. The international system now nears the upper-phase transition, and a disruption – an incident – triggers a discontinuous phase transition: The next punctuation has started. As a consequence of the critical condition and the tight coupling of the international system, a minor incident, which activates the vulnerable cluster, suffices to initiate the punctuation. The 'starting shot' of the First World War – the murder of Archduke Franz Ferdinand in Sarajevo in 1914 – is both a striking example of this mechanism and symptomatic of the critical position of the international system at that time: The system was poised at a discontinuous phase transition.

During the wars (which constitute a punctuation), the connectivity of the international system will be partially destroyed and the tension relieved, as a result of which the international system will slide back into the cascade window. Eventually, the punctuation will bring forth a new international system. Consecutive punctuations, followed by slides back into the cascade window, and subsequently a growth in the connectivity, result in an oscillating dynamic.

I now presume that the upper-phase transition - as discussed in this article - with its unique network configuration, is the attractor of the international system. The oscillating dynamics of the international system around this attractor is visualized schematically in the illustration below. In it, the cascade window, which is based on the model and simulations of Watts, is also clearly visible. The figure in the right-hand corner is a simplified and schematic diagram of the accompanying punctuated equilibrium dynamics; the similarities with the fraction dynamics shown in figure 2 in this article are evident.

FIGURE 12: Punctuated equilibrium dynamics



Furthermore, it is possible to reason that also the thresholds of the international system have increased structurally over time. In this context, I refer for example to the rules that are applicable for the use of organized violence in the international system. This increase is the effect of the increased interdependence of states in the international system (Holsti 1995, Scott 1982), the increased effectiveness of international law and institutions, the subjective models that states apply to the use of force, and a decrease in public support for the use of violence against other states (Castells 1996, 454).

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Endnotes:

1. In this research I use the expression ‘actors’, in stead of ‘elements’.
2. In the period 1495 - 1975 Levy identified 119 Great Power wars. 114 out of these 119 Great Power wars took place before 1945. I differentiate between *Great Power wars*, wars with at least one Great Power participating - and *wars between Great Powers*, wars with at least two Great Powers participating. The second category constitutes 70 wars in the period 1495 - 1945 (Levy, 1983, 70-73).
3. It concerns the ‘War of the American Revolution’ (1778 - 1784) and the

'Russo-Japanese War' (1939). Because the 'War of the American Revolution', in fact was a war between European Great Powers on American soil, this war between Great Powers is - for this reason - included in the analysis discussed in this article. On the basis of a sensitivity analysis I have determined that this 'inclusion' has no effect on the patterns identified in this research.

4. Correlates Of War datasets are more detailed, e.g. including other than Great Power wars, but are only restricted to a limited timeframe, starting in 1816 (Gibler, 2004, Singer 1972, 1987).

5. I am not suggesting that a power law distribution can only be produced by a SOC-dynamic. Other mechanisms could result in such a statistical relationship as well (Newman, 2005). The size and number of earthquakes and (snow) avalanches can be shown with power laws as well; these typical dynamics are attributed to the SOC-characteristics of these systems (Hergarten 2003).

6. This means that the accumulation of tension and frustration in the international system operates at a much slower time scale, compared to the faster timescale typical for the release of this tension and frustration through Great Power wars.

7. For a power law distribution, the probability that a given variable x has a particular value, p(x), is equal to Cx^{-n} over a reasonably wide range of x, with C and n positive coefficients. This implies that a graph of a power law is a straight line on a log-log plot.

8. In Richardson's power law, 'size' is defined as the number of battle casualties (Richardson 1960); in my opinion has Richardson's research a different focus and is aimed at a different level of analysis (Cederman, 2003, Richardson, 1960).

9. I assessed if a power law applies to cooperative clusters - alliances - in the international system as well: that is the case as well. I have based this analysis on the Correlates of War dataset (Gibler et al. 2004).

10. The remaining distortion of the power law for large wars can be neglected: the 'tail of the power law' - is 'noisy' because of sampling errors; as is often the case with power laws (Newman 2005, 3).

11. Percolation theory deals with clustering, criticality, diffusion, fractals, phase transitions, and disordered systems. It provides a quantitative and conceptual model for understanding these phenomena (Stauffer 2003).

12. The intensity of great-power wars reflects the number of battle deaths compared to the population as a whole (Levy 1983, 78).

13. Initially, I assumed that alliance and power dynamics and inter state wars fulfilled the role of driving force in the international system. A closer look, however, showed that this is not the case. Based on an analysis of the Correlates of War data sets (Gibler 2004, Singer 1972, 1987), it can be determined that power forming and alliance dynamics are to a high degree synchronized with the war dynamics of the third and fourth international system: These dynamics do not result in a necessary separation of time scales. The development of the power dynamics can be determined by quantification of the change of the Composite Indicator of National Capability (CINC) indexes of Great Powers constituting the international system (the CINC index contains annual values for total population, urban population, iron and steel production, energy consumption, military personnel, and military expenditure of all state members. I used version 3.02 (1816-2001) (Singer 1972, 1987). The alliance dynamics are quantified by assessing the number of new and disbanded formal alliances (Gibler et al. 2004, Version 3.03 of this data set was used).

14. The outcome of preceding punctuations are respectively the sovereignty principal and the Vienna

Congress – respectively the 'results' of the Thirty Years War and the French Revolutionary and Napoleonic Wars – and the League of Nations and the United Nations, institutions generated by the First and Second World Wars.

15. The war frequency of international systems is calculated by dividing the number of Great Power wars during a lifecycle by the life time of the respective international systems.

16. I have calculated the (average) values of various quantitative characteristics e.g.: the number of Great Power wars and the average war intensity of consecutive international systems and the life span of these systems, based on the punctuated equilibrium dynamic which can be identified. Great Power wars constituting punctuations are not included in these calculations because I consider these wars of a fundamental different category. Next I have determined the correlation coefficients of the (average) values of these variables. It then becomes clear that some - most - of these correlation coefficients have remarkably high values, suggesting a statistical relationship between the development of these variables in time. These correlation coefficients do not prove 'anything' but provide 'circumstantial' evidence that a punctuated equilibrium dynamic 'exists' and that the development of some variables is closely related.

17. A stability domain is a preferred condition of a system, with specific parameters, otherwise called an 'attractor'.

18. Great Power wars outside the European continent with only one European participant are excluded from this overview. It concerns eight wars in the period from 1856 until 1939. This is a fundamentally different category of wars, indicative for the globalization of the international system, but obscuring the process of social expansion in Europe. Great-power wars constituting punctuations are excluded because of their different function.

19. Again, the war frequency is used as an indicator for stability. The war frequency is calculated by dividing the number of wars in the respective clusters, by the length of the lifespan of the particular phases, before or after the respective tipping points.

20. In order to visualize the different 'directions' of circular trajectories I have given the fractions of wars constituting clockwise trajectories a negative value; these trajectories are shown in the second (left) quadrant of figure 8.

21. It can be argued that the non-chaotic dynamic during the exceptional period disturbed the steady decrease of the lifespan of consecutive international systems; if the lifespan of the second international system is 'adjusted', the correlation matrix of the system variables shows an significant increase in the value of various correlation coefficients.

22. The lower-phase transition is the point when global cascades become possible: below this point global cascades are impossible because of the low connectivity of the system (see appendix). An example: A global war - a war with a global reach - is not possible when the international system does not have a minimum connectivity; a spanning cluster can be formed.

23. According to a system dynamics approach, a system in a critical condition is 'tightly coupled' (Perrow 1999, 62-100), that is, the system has a correlation length corresponding to the size of the system.