國立交通大學

經營管理研究所

碩 士 論 文

以突變理論分析選舉行為—台灣兩千年總統大選

An Application of Catastrophe Theory to the analysis of Taiwan Presidential Election in year 2000

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摘　　要

本研究目的在於將突變理論應用在投票行為分析。透過研究建立出的突變選舉行為架構，用以分析兩千年總統大選中所發生的兩次重大變化—宋楚瑜興票案使原本領先的局勢變成三強鼎立的形勢；另外在經過選舉前不可公開民意調查資料的十天時間內，發生的事件使得棄保效應發生作用。

關鍵詞：突變理論、總統大選、選舉行為、策略性投票

An Application of Catastrophe Theory to the analysis of Taiwan Presidential Election in Year 2000

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ABSTRACT

The purpose of this thesis is to present a well-grounded approach for explaining changes observed in the election affording practitioners an analytical method that can capture both nonlinear and multithreshold characteristics. To accomplish this objective, we present catastrophe theory representation of the relationships among two events happening presidential election of the year 2000. In the following sections we discuss, in turn, the conceptual framework construction, the catastrophe theory model, model dynamics under catastrophe theory with an illustrative example, and the strategic implications of this perspective.

Keywords: Catastrophe Theory, Presidential Election, Voting Behavior, Strategic Voting

誌　　謝

論文的完成，最感謝的是指導教授毛治國博士。求學的過程能夠遇到好老師真是三生有幸的好福氣，在老師的指導下，不僅見識到學術的奧妙，也在人生態度上找到很好的典範。所謂「師者，傳道授業解惑也」，每每在請教完之後，都有電力又充滿格，可以繼續前進的動力。

撰寫的過程有如走一遭人生三意境「昨夜西風—衣帶漸寬—驀然回首」，幸而能在毛教授的提點之下，如醍醐灌頂，終能撥雲見日。而在面對困惑挫折上，也在毛教授的諄諄教誨之下，習得以積極的態度去正視挫折所可能帶來的成長機會，更專注在邏輯思考的完整性、系統性以及創新性。學步雖然慢，有著老師的耐心包容和支持，讓碩士生涯最後一部分能夠穩健踏實的完成。

也感謝書審唐瓔璋老師、曾芳代老師以及口試委員魏艾教授、彭錦鵬教授的所給與的建議與指教。另外，學長王皋雄、張順全、徐元良、學弟張庭鈞的協助，以及學校助理溫正菱、王詩晴的幫忙，使得論文得已順利完成。也感謝學姊淑惠、慧玲，以及所有關心的好友同窗親戚們的支持鼓勵。

最後以本文獻給親愛的家人，謝謝你們一直以來的支持。

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1. Introduction

In 2000, Taiwan's political landscape changed. The Democratic Progressive Party (DPP), used to be opposite party, won 2000 ROC presidential election. Opposition candidate Chen Shui-bian and his running mate Annette Lu emerged as the winners of the 2000 ROC presidential election. Chen trounced Vice President Lien Chan and independent James Soong as Taiwanese overcame any fears of an attack by Beijing.

There were two pieces of interesting changes during this election campaign: one is the long lead situation turns into well matched in strength after the financial disclosure of Soong; the other is the big twist of political state during the ten days before election that caused by strategic voting on Lien finally.

In observation of poll conducted by TVBS, right after the question of Soong's son who had a surprising amount of money deposited while he was impossible to earn this money during that age, the support rates of Soong dropped significantly.

Besides the James Soong's financial affair, there was another interesting change. There was a blackout period before the election regulated by Presidential and Vice Presidential Election and Recall Law passed in 1995, no individual or organization is allowed to publish polling information within 10 days before the election. Consequently, on election night the actual election outcome came as a shock to many voters: Chen Shui-bian won the presidency with 39.3% of the popular vote, James Soong with 36.8% and Lien with a disappointing 23.1%.

Researches related were applied to political theories which focused on only the social contexture or mainly on the criteria of individuals or election

events. Originally, the nature of change is a kind of catastrophe.

What is catastrophe？Catastrophe is one of so called New Sciences which includes Catastrophe, Chaos, and Complexity Theory. Complexity came from evolution and biology is applied to strategy and organization field recently. Rene Thom invented catastrophe theory in 1972. This model is a method of modeling things which changed suddenly by fits and starts.

Catastrophe theory helps to model discontinuous, abrupt changes in a behavior variable as the result of small, continuous changes in one or more other control variables. The mathematics of smooth, continuous change cannot cope well with changes which are abrupt or “sudden”. Models which result from the use of such mathematics tend to imply that sudden change is not permissible, or at least not reasonable, and yet sudden changes do occur.

Catastrophe theory allows for models for which abrupt change is not only permissible but also expected. Instead of experiencing the surprise of unexpected behavior, one could use catastrophe theory to help to explain and possibly prepare for sudden changes in which had only “qualitative” data in which “qualitative management decisions” had to be made (Karathanos,1994).Research related to catastrophe theory can be divided into three parts：mathematical bases、geometry of catastrophe sets, and application. In this thesis, researcher will focus on application.

This is the flowchart of this thesis.

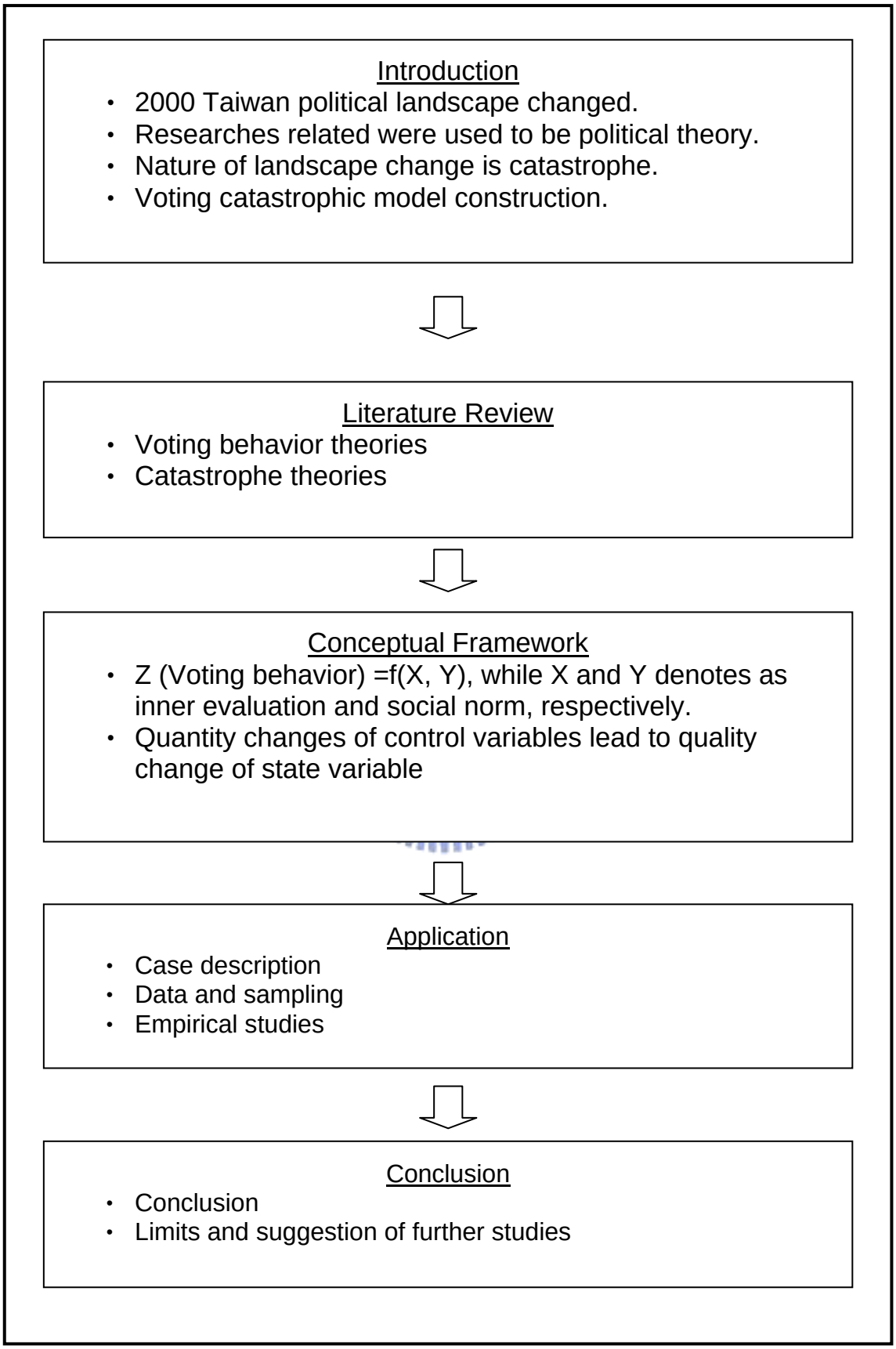

Figure1. Flowchart

2. Literature Review

2.1 Relevant studies

Researches on voting behavior are probing into policy orientation、party orientation、party identification、leadership and the election input resource, and so on (Andrew,2001;Matthew 2002). Maurice Duverger proposed that the election schema would influence the final survival numbers of parties and the stableness of forming a government in 1951. Recently researches enhance the application of Duverger's theory by applying to the possibility of strategic voting happening.

The short-term factors of voting behavior are economic、the charisma of party leader and public stands、election campaign style and efficiency、mass media. All the influential factors are under the contextual of psychological、social、economic、ideological. The most important voting theories are party identification model、rational choice model.

The party identification model is based on the voters' preference to party. Voters are treated as those who have identification to party and they think party is "their own". Voting becomes a way to realize party ideology rather than the product influenced by interaction of polices、characteristics、election activities and mass media report. In this model, the voters' attitude toward polices and leadership will be developed by party identification. Most of the time, party identification will be reinforced by group members and social experience. From this point of view, normal vote of a party can be calculated through party identification. But the shortage of this model is this model based on the stable party identification. Recently partisan de-alignment which means the decrease of party loyalty cause the normal mode of support rate drop even more collapse of the party.

Rational choice model change the focus from social and social group to individual. Voting behavior is treated as rational behavior. Voters are based on their self-interest to do their preferential choice. This model thinks voting is a way to reach people's goals.

2.2 Voting behavior Theories

2.2.1 Behavior=f (Personal characteristics, Environment)

There is another group dynamic theory taking both individual and contextual view points. Kurt Lewin relied on his formal theory of human behavior, field theory, to provide an answer in 1951. Field theory assumes that the behavior of people in groups is determined by aspects of the person and aspects of the environment. The formula $B = f(P, E)$ summarizes this assumption. In a group context, this formula implies that the behavior of group members (B) is a function (f) of the interaction of their personal characteristics (P) with environmental factors (E), which include features of group, the group members, and the situation. Lewin applied the Gestalt dictum “The whole is greater than the sum of the parts” to group. According to Lewin, whenever a group comes into existence, it becomes a unified system with emergent properties that cannot be fully understood by piecemeal examination.

2.2.2 Inner evaluation

At the core of political being is personality, which is a central psychological factor influencing political behavior. It affects other aspects of the thought process and is itself affected by life experiences, but personalities tend to be very stable in terms of amenability to change. People are motivated to act in accordance with their own personality characteristics, values, beliefs, and attachments to group (Cottam, 2004).

Beliefs and values are a little bit different. Beliefs are defined as associations people create between an object and its attributes. Beliefs reflect

what we think is true; values reflect what we wish to see come about, even if it is no currently true. Values and beliefs are closely related, and when we refer to political values and belief systems, we call it an ideology, which is “a particularly elaborate, close-woven, and far-ranging structure” of attitudes and beliefs.

Attitude is an enduring system of positive or negative beliefs, affective feelings and emotions, and subsequent action tendencies regarding an attitude object, which is the entity being evaluated. A standard definition of attitudes is that they are an enduring system of positive or negative beliefs (the cognitive component), affective feelings and emotions, and action tendencies regarding attitude objects, that is, the entity being evaluated (Cottam,2004). But, people often do things that are seemingly contrary to their own interests, values, and beliefs. (Forsyth, 1999; Cottam, 2004)

2.2.3 Social Norm

Group members’ interactions are organized and interconnected. Group members’ actions and interactions are also shaped by their group’s norms: consensual standards that descriptive what behaviors should and should not be performed in a given context. (Forsyth, 1999) Although norms, unseen and often unnoticed, lie at the heart of its most dynamic processes. Norms within a group are defined and renegotiated over time, and conflicts often emerge as people violated norms. When several members form a subgroup within the larger group, they exert more influence on the rest of the group. When people manage to place themselves at the hub of the group’s information exchange patterns, their influence over others also increases.

The strength of linking members to one another and their group-it’s group cohesion-defines its unity, oneness, and solidarity. Groups vary in their level of cohesiveness. At the individual level, cohesiveness derives from each member’s attention to other group members, whether this attraction is based

on liking, respect, or trust. And at the group level, cohesiveness reflects that' we- feeling" that joins people together to form a single unit. Thus, cohesiveness "contributes to a group's potency and vitality; it increases the significance of membership for those who belong to the group". (Forsyth, 1999)

Group also has social identity. This social identity amounts to a shared perception of themselves as members to the same group or social category. Social identity (also called collective identity) includes all self-conceptions that arise from membership in all kinds of social groups, including clubs, cliques, communities, and religions. The collective self also includes membership in demographic groups (e.g., I am a Taiwanese) if individuals consider these qualities important and relevant to their self-concept.

A group , in a very real sense, is alive：It acquires energy and resources from its environment, to maintain its structure, and grow over time. Some researchers challenged the existence of groups, but even they could not deny that people sometimes act differently when in groups (Forsyth, 1999). Some of these changes are subtle ones, but cause a big effect. Interacting with other people can also prompt us to gradually change our attitudes and values as we come to agree with the overall consensus of the group (Newcomb, 1943)

2.3 Catastrophe Theory

There are seven types of elementary catastrophes. Catastrophes in systems with only one state variable are "fold catastrophe"、"cusp catastrophe"、"swallowtail catastrophe"、"butterfly catastrophe". Catastrophes with two state variables are " hyperbolic umbilic catastrophe"、"elliptic umbilic catastrophe"、"parabolic umbilic catastrophe".

Table1. Seven Catastrophe Types

Catastrophe types	State variable	Control variable	Potential function
Fold	1	1	$V(x) = x^3 + ux$
Cusp	1	2	$V(x) = x^4 + ux^2 + vx$
Swallowtail	1	3	$V(x) = x^5 + ux^3 + vx^2 + wx$
Butterfly	1	4	$V(x) = x^6 + tx^4 + ux^3 + vx^2 + wx$
Hyperbolic umbilic	2	3	$V(x, y) = x^3 + y^3 + wxy - ux - vy$
Elliptic umbilic	2	3	$V(x, y) = \frac{1}{3}x^3 - xy^2 + w(x^2 + y^2) - ux + vy$
Parabolic umbilic	2	4	$V(x, y) = y^4 + x^2y + wx^2 + ty^2 - ux - vy$

Catastrophe theory treats system as dynamic. The system dynamics can change in an infinite number of incremental ways but for there are a limited number of structurally stable radical ways change can occur.

Ian F. Wilkinson1990 applied DOCAS(dynamic open complex adaptive system)to channels of distribution in particular. A key point concerns the extent to which earlier work has anticipated such currently fashionable ideas as evolutionary development, closed-systems models, ecological theories, process orientation, systems theory, dynamic formulations based on difference equations, emergent self-organization, coevolution, predator-prey relationships, spatial representations of urban development, and so forth.

Hibbert and Wilkinson (1994) apply chaos theory to the dynamics of marketing systems. Here, they give a good introductory overview of chaos theory; its relevance to marketing in general; and, in particular, its application to the understanding of DOCAS-based concepts such as those found in diffusion models, models of market evolution, or dynamic models of brand competition. Among other themes, their analysis shows how complex dynamics can occur in nonlinear marketing models (incorporating feedbacks and interactions) and how such complex dynamics respond to small changes in key variables (sensitive dependence on initial conditions or SDIC).

Kauffman applied biology to organization theory. There are researches applied the work to build a framework of corporate strategy in turbulent environment. These kinds of environments are characterized by nonlinear positive feedback, complexity and uncertainty.

Interest in developing more parsimonious approaches to the modeling of complex behavior has been stimulated by catastrophe theory (Thom 1975; Zeeman 1976, 1977) and its relative chaos theory (Gleick 1988). These approaches have become intriguing to researchers in behaviorally based disciplines such as economics (Alexander et al. 1992), and management (Oliva, Day, and MacMillan 1988; Sheridan 1983). The models' strengths are that they can capture complex behavior by using significantly fewer nonlinear equations than the number of linear equations needed to describe the same phenomena.

Cusp model is one of the simplest to be applied. The basic concept is that two control variables decide one system variable. Zeeman 1977 then shows the basic form of the deterministic cusp model generated by Z^3-ZY-ZX, where Z is dependent variable and XY are the independent variable. Z has two states and is discrete. This model draws out a folded area. When two control variables X and Y go to some level, Z will suddenly change to another state. This sudden change is defined as catastrophe. This has a very important meaning—quantities changes lead to quality changes.

Complex behavior is captured by movement in and around the folded area, which is characterized as one of the following five types (Thom 1975; Zeeman 1976, 1977).

Divergence. Looking at points F and G, we see that as the value of Y increases positively from the origin, small initial differences in the value of X can result in totally different behavior. In short, small differences in starting position can result in vastly different and opposite ending positions.

Catastrophe. Sudden, discontinuous shifts can occur along the dependent variable dimension. If the X and Y values are such that the edge of the fold is crossed, there is a sudden shift to the opposite surface, which implies a sudden change in behavior. The vertical shift up from C to D and down from D back to E exemplifies this behavior.

Hysteresis. Once a sudden shift occurs, a return to the former sheet will not occur even if the independent variable values return to the levels they were when the shift was made. There is a lag or hysteresis (inertia) in the process, which tends to keep behavior at its current level. Points C, D, and E demonstrate this effect.

Bimodality. Within the area of the fold delimited by the cusp, the dependent variable can take one of two different possible values for a given set of independent variables.

Inaccessibility. The middle connecting sheet shown as the darkened area is inaccessible and represents the area of least likely behavior.

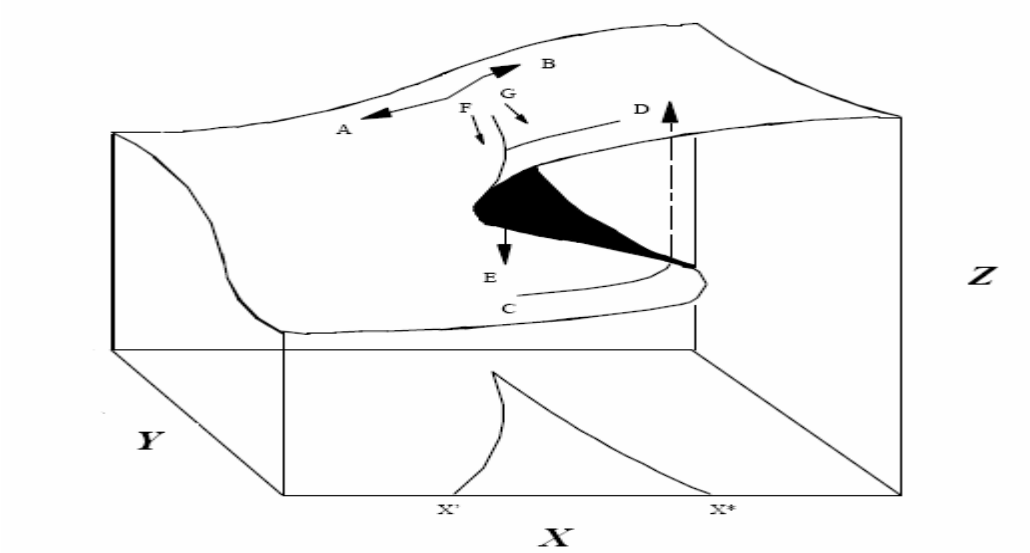

Figure 2. Cusp Catastrophe Model

The first empirical paper was Zeeman, Hall, Harrison, Marriage and Shapland applied to institutional disturbances: riots and takeovers in the United Kingdom prison. Then Oliva, Peters, and Murthy (1981) developed a collective bargaining simulation model. Sheridan and Abelson(1983)used and graphical approach to their study of employee turnover.

So far, many studies adopted catastrophe theory are related to natural science including climate prediction, cell automation, ecology vegetation, etc. Social science concerning catastrophe theory is now doing research in organization behavior and marketing field.

3. Conceptual Framework

3.1 Behavior= f (Inner Evaluation)

Under the simple situation without any other action, voting behavior is decided by attitude toward candidates. To be for or against a candidate depends on voters' inner-evaluation. While one's attitude toward a candidate inner-evaluate positively, he will incline to show his support to a candidate; vise versa. To be specific, voting behavior "Z" is the function of inner evaluation "X", while Z is either "for" or "against", and "X" is positive or negative. The relationship of voting behavior "Z" and inner evaluation "X" is presented in Figure 3

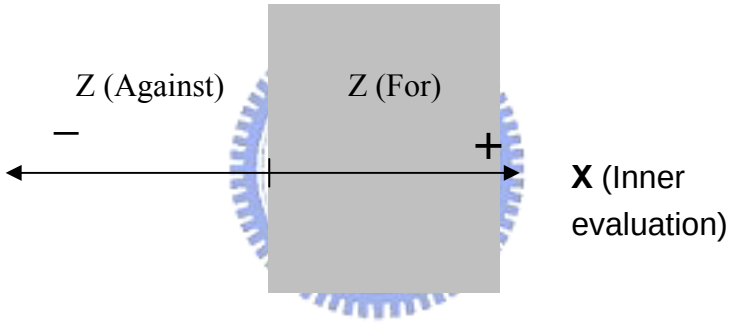

Figure3. When behavior is determined only by inner evaluation

3.2 Behavior=f (Inner Evaluation, Social Norm)

However, voters would act differently from their inner evaluation. Most of the time people are influenced by others surrounding them. Under this situation, social norm comes into play. Social norm, which will be denoted as symbol "Y", is the force of expectations perceived by the member in a social group about how all members should behave. Social norm Y is also a value system that has either positive or negative judgment.

Before performing a behavior, voters will consider about how social norm wants them to behave. While one's inner evaluation is in accordance with social norm, social norm will enhance the inclination of behavior performing.

Thus, if a voter inner evaluate a candidate C positive while social norm of C is positive, this voter will be more possible to vote for C. Similarly, it's more possible for this voter to be against C, if both inner evaluation and social norm is negative.

Nevertheless, inner evaluation and social norm would be of different attributes. If social norm and inner evaluation are not of the same attributes, to behave or not to behave, that is the question. If voters' inner evaluation on candidate C is positive while social norm is negative, he will confront with the resistance that may decrease his will to vote for. On the other hand, even if one's inner evaluation is negative, he will be persuaded by some reason of positive social norm such as party loyalty. The dynamic of interaction between inner evaluation and social norm can be analyzed on Figure 4.

There are four possible situations:

Quadrant I：positive inner evaluation X versus negative social norm Y: (X, Y) = (+,-)

Quadrant II：negative inner evaluation X versus negative social norm Y: (X, Y) = (-,-)

Quadrant III：negative inner evaluation X versus social norm positive Y: (X, Y) = (-, +)

Quadrant IV：positive inner evaluation X versus social norm positive Y: (X, Y) = (+, +).

Considering Quadrant II and Quadrant IV, those inner evaluation and social norm are of same attributes, social norm gives positive feedback to inner evaluation, which not only makes voters' behaviors following their original preference but also enhances.

On Quadrant I and Quadrant III, social norm eases the effect of inner evaluation, which is of different attributes from social norm, bon behavior, At Quadrant I (X, Y) = (+,-), the area of "for" behavior will be reduced which means negative social norm Y (-) weakens the effect of positive inner evaluation X (+) on behavior Z(for). At Quadrant III (X, Y) = (-, +), negative behavior zone Z (-) will be expanded which means Y (+) weaken the effect X (-)

on Z (-). A zone means Z (Against) expands and Z (For) reduces; B zone represents Z (For) expands and Z (Against) reduces. To differentiate for and against behavior, catastrophe line L could be found out.

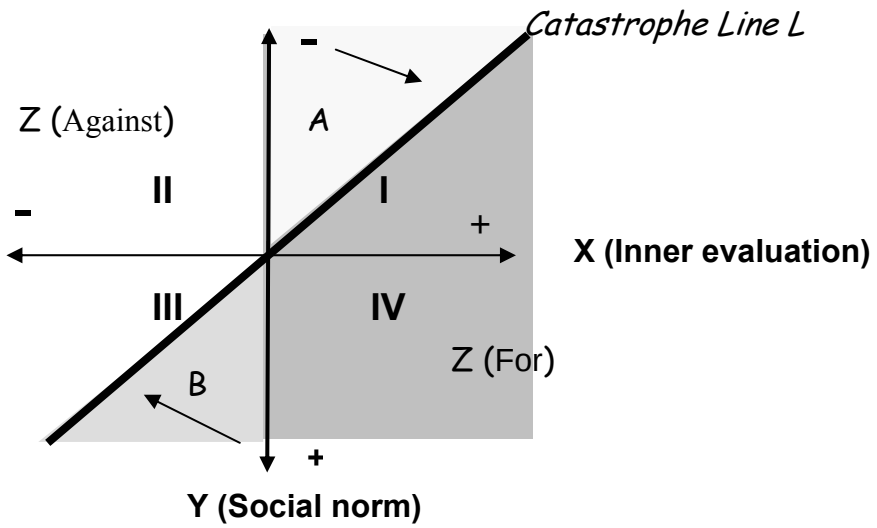

Figure 4. When behavior is decided by both inner evaluation and social norm

3.3 Behavior=f (Social Norm | Inner Evaluation= Constant)

The catastrophe of voting behavior is the main theme of this thesis. Assume that each individual has consistent characteristic, given inner evaluation X fixed. Catastrophe Line L is verified by previous experience.

3.3.1 Given Negative $X=X_1$

At the level of negative inner evaluation X_1, the shift of Y goes from Y_1^1 to Y_1^2 make a change of Z, from Z_1^1 to Z_1^2. The nature of Z_1^1 and Z_1^2 is totally different. Y decreases to some extent and Z transforms. The shift of Y means positive social norm is weakening from point Y_1^1 to point Y_1^2. But the change of Z means behavior “for” to “against”. Quantity change of social Y leads to the quality change of behavior Z

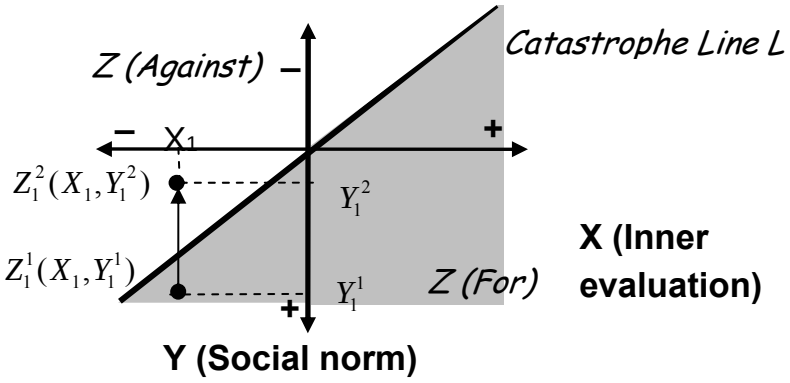

Figure 5 Z=f (Y| X=X1)

3.3.2 Given Positive X = X2

Regarding for positive inner evaluation X=X2, the change of positive social norm from Y_2^1 to Y_2^2 or to Y_2^3, final behavior Z becomes different. While positive Y_2^1 goes to negative Y_2^2, behavior Z_2^2 falls on the for zone; however, positive Y_2^1 goes to negative Y_2^3, behavior Z_2^3 locates at the against zone. We find out social norm Y cross over critical point Y^* reflecting the Catastrophe Line L, behavior will suddenly change.

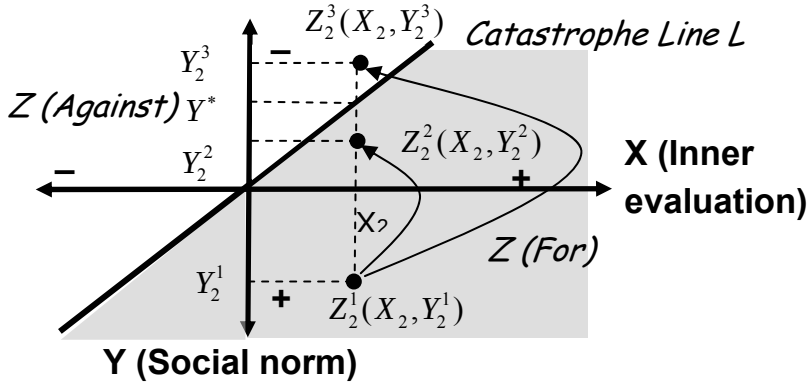

Figure 6 Z=f (Y|X=X2)

So far, the projection model of catastrophe behavior is demonstrated. Given inner evaluation consistent, we analyze change of social norm. After social norm strides over the critical point of social norm which is reflecting the Catastrophe Line L, the behavior Z changes suddenly. Catastrophe happens.

Take X_1 as an example to demonstrate catastrophe model. The dynamic of three dimension catastrophe voting model and its projection will be shown as follows. Given X_1 consistent, we will see shift of Y ($Y_1^1 \rightarrow Y_1^2$) make a change of Z ($Z_1^1 \rightarrow Z_1^2$). On the top of behavior model, we can see the process of Z_1^1 goes to Z_1^2 confronting a sudden jump. The different nature of Z_1^1 and Z_1^2 can be seen as different states on top of the model. The shift of Y means positive social norm is weakening from point Y_1^1 to point Y_1^2. But the change of Z means behavior "for" to "against". Quantity change of Y leads to the quality change of Z

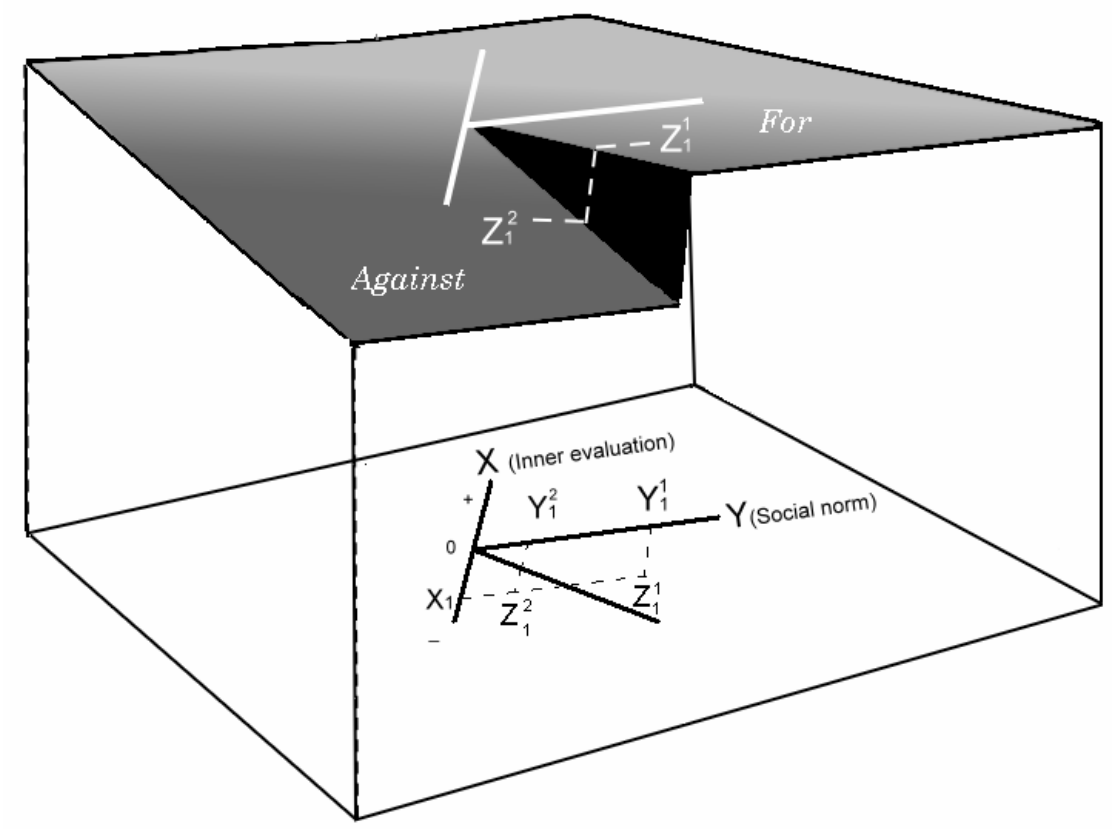

Figure 7 The three dimension catastrophe model

Researcher tries to plot the interaction as path dependence as follows:

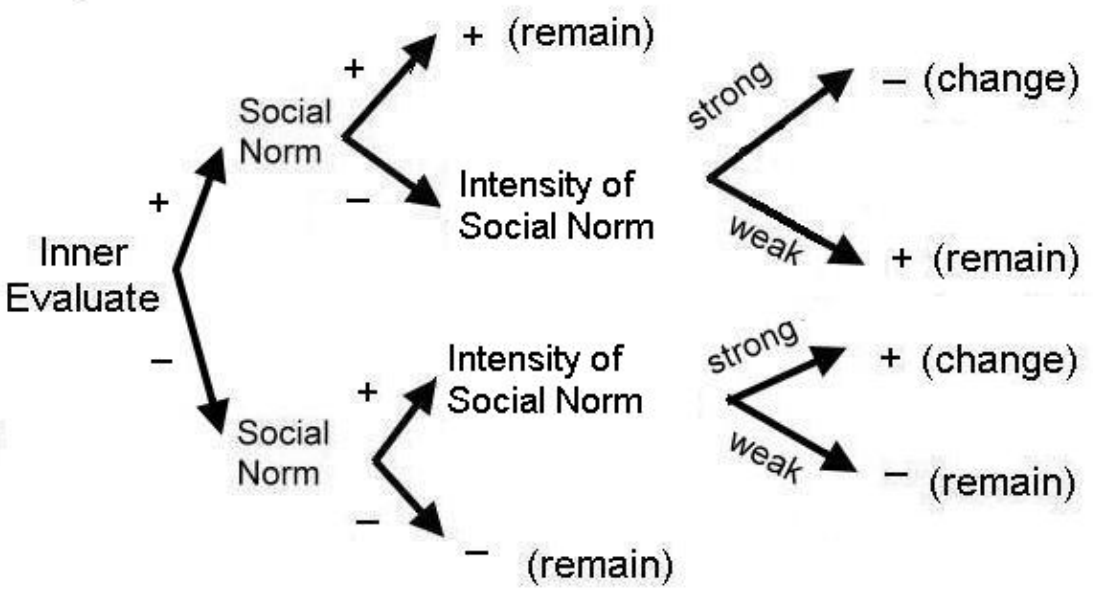

Figure 8 The interaction between inner evaluation and social norm

The first path is that both inner evaluation and social norm are positive. This outcome remains as the original-positive. The second path is positive Inner evaluation versus negative social norm. Then given inner evaluation constant, we can find out strong intensity of social norm will change the circumstance. It becomes negative. Otherwise, weak social norm won't make any change. Outcome remains the same as positive.

The fourth path inner evaluation and social norm are different. Strong intensity of social norm make outcome different. It changes to positive. The fifth path is weak intensity of social norm. It makes no change. And the final path is that inner evaluation and social norm remains the same attributes. The outcome remains the same.

3.4 The Operation of Catastrophe Model

In reality, Catastrophe Line L can be find out while X and Y are of the different attributes that makes behaviors Z in disagreement with inner evaluation X. If the intensity of Y is powerful to some extent，the behavior Z of

X will change.

A. The intensity of inner evaluation X is defined as -5,-4,-3,-2,-1, 0, 1, 2, 3, 4, 5
B. The social norm Y is defined as -5,-4,-3,-2,-1, 0, 1, 2, 3, 4, 5,
C. Voting behavior Z can be observed either for or against

For example, to someone, his inner evaluation to some object is located on X_2=2, and the social norm against the object Y_2= -4, the behavior Z_2 will be negative at Z (against) zone. After a period of time, the social norm against becomes to Y_1 is at point 4, and his inner evaluation changes to negative at point -2, the behavior Z_1 against the object will be for action.

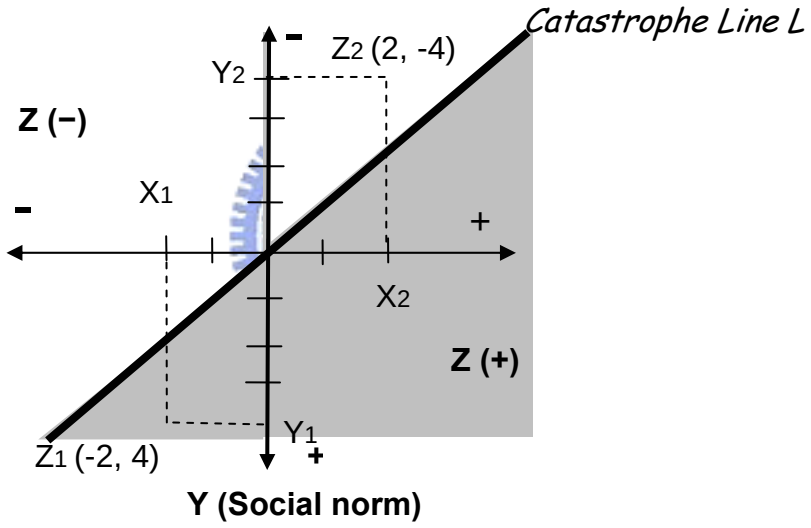

Figure 9 The operation of catastrophe model

4. Case Description

2000 ROC presidential election is a great reversion. This election is not only an ending of half a century ruled by Nationalist, but also a real case of strategy voting.

Chen and Lu of DPP had gathered 4,977,697 votes. Independent James Soong and running mate Chang Chau-hsiung placed a close second with 4,664,972 votes, while Lien Chan and Vincent Siew, candidates for the current ruling party Kuomintang (KMT), lagged behind in third place with 2,925,513 votes. Independents Hsu Hsin-liang and Chu Hui-liang garnered 79,429 votes, while New Party candidates Li Ao and Fung Hu-hsiang gained 16,782. Chen had 39 percent of the votes, Soong had 37 percent and Lien had 23 percent. The voter turn-out rate was 82.69%, approximately six percentage points higher than the 1996 presidential election. The election outcomes were listed below.

Chen also quickly weighed in on the question of cross-strait relations, saying he was willing to handle the issue with the highest measure of good will, and that in the future he hoped to open up communication, trade and transport ties with mainland China, and to build a bilateral mechanism of mutual trust in military affairs.

James Soong came in second place with around 4.6 million votes, but was still more than 1.5 million votes ahead of the KMT's Lien Chan.

4.1 Data and Sampling

Polls are the sampling measurement of information representing the social will. The purpose of using poll data is to understand the people’s behaviors state. There were many survey institutes including schools, government agencies, private organizations, and mass media. Data conducted by TVBS

poll center were open、complete、and neutral, even more, TVBS surveyed according to incident happening, that made the data itself more proper to analyze the response after events happening.

In this thesis, researcher uses TVBS Poll Center data surveyed by CATI (Computer Assisted Telephone Interview). Period of poll data concerned is from 8/15/1999 to 3/6/2000. Sources were obtained from sampling the last four characters of telephone number by RDD (random-digit-dialing). The biggest sampling size and the smallest one is 2092 and 938. Sampling error for n is ±3% at the 95% confidence interval. There were about average 23.17% undecided. From August 15, 1999 to March 18, 2000,,the average support rates(%) of Chen、Lien, and Soong are 24.8%、20.8% and 29.9% individually.

Before the comparison between poll data before election and election outcomes, considering there were undecided part and whose who didn't want to claim their stands, the distribution of these unknown part will be assumed the same as the known part. However, concerning the support rates of Hsu and Li were far behind the first three candidates, both poll and election outcome will be focused on the first tree candidates to recount the support rates. The sum of three candidates' support rate in poll and election outcome was 97.4% and 99.24%.

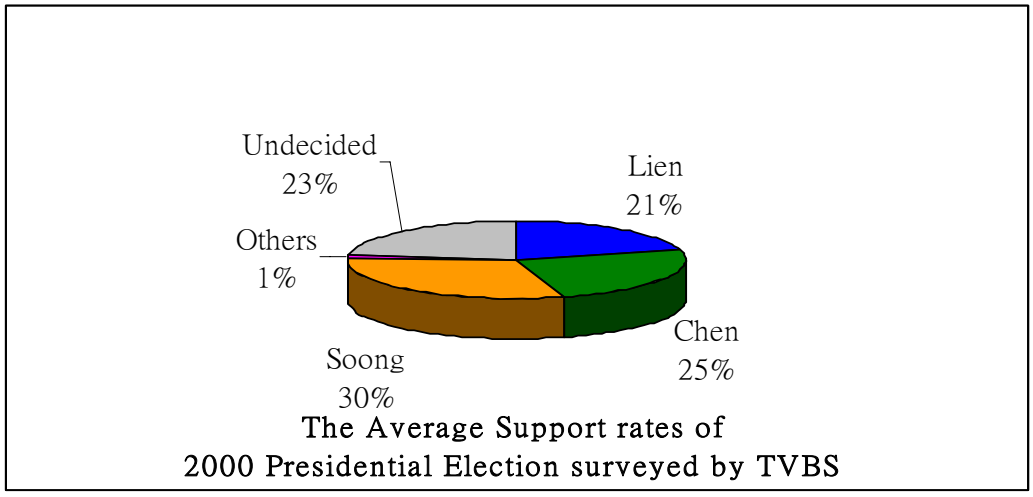

Figure 10 The average support rates of 2000 presidential election surveyed by TVBS

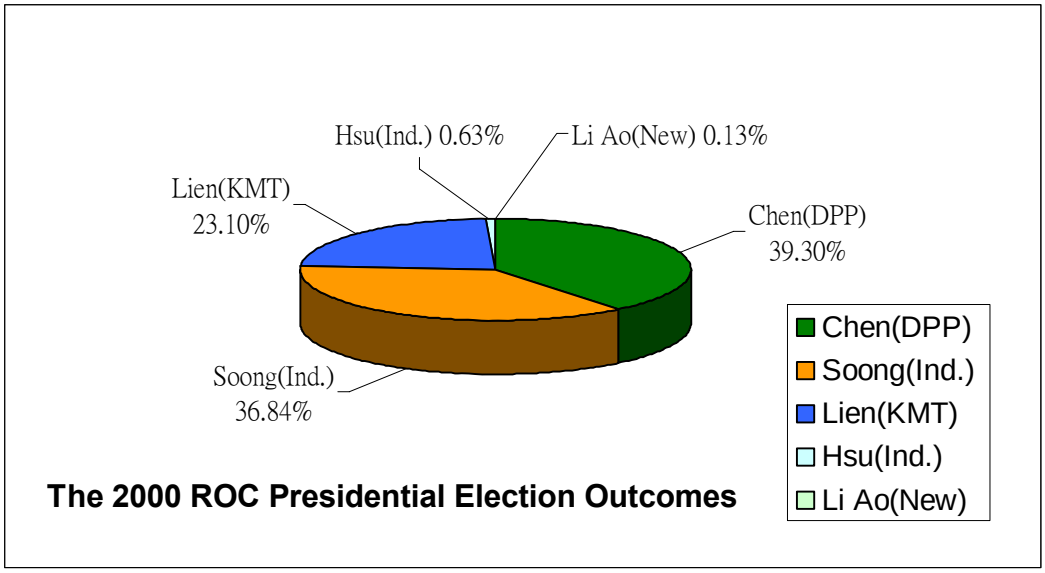

Figure 11 The 2000 ROC presidential election outcomes

Table2 The 2000 ROC presidential election outcomes

Presidential candidate	VP candidate	Political affiliation	Total votes	Percentage
Chen Shui-bian (winner)	Annette Lu	Democratic Progressive Party	4,977,697	39.30%
James Soong	Chang Chau-hsiung	Independent	4,664,972	36.84%
Lien Chan	Vincent Siew	Kuomintang (Nationalist Party)	2,925,513	23.10%
Hsu Hsin-liang	Josephine Chu	Independent	79,429	0.63%
Li Ao	Elmer Fung	New Party	16,782	0.13%
Votes cast	12,786,671	Valid votes	12,664,393	
Voter turnout	82.69%	Invalid votes	122,278	

Source is ROC Central Election Commission.

The assumptions of dealing with this data are (a) there's no bias in sampling method, (b) the distribution pattern of the undeclared was the same as the declared.

The purpose of this thesis is to demonstrate catastrophe model can be applied to voting behavior and after-event analysis, poll data and election outcome will be presented as the voters' behavior state. By analyzing behavior state (will be defined as Z) and Social Norm (will be defined as Y), the inner evaluation of voters can be obtained.

Originally to demonstrate the catastrophe model, having two control variables can infer to behavior state, but in this thesis, there are only behavior state data, therefore, how to realize the interaction between two control variables will be demonstrated.

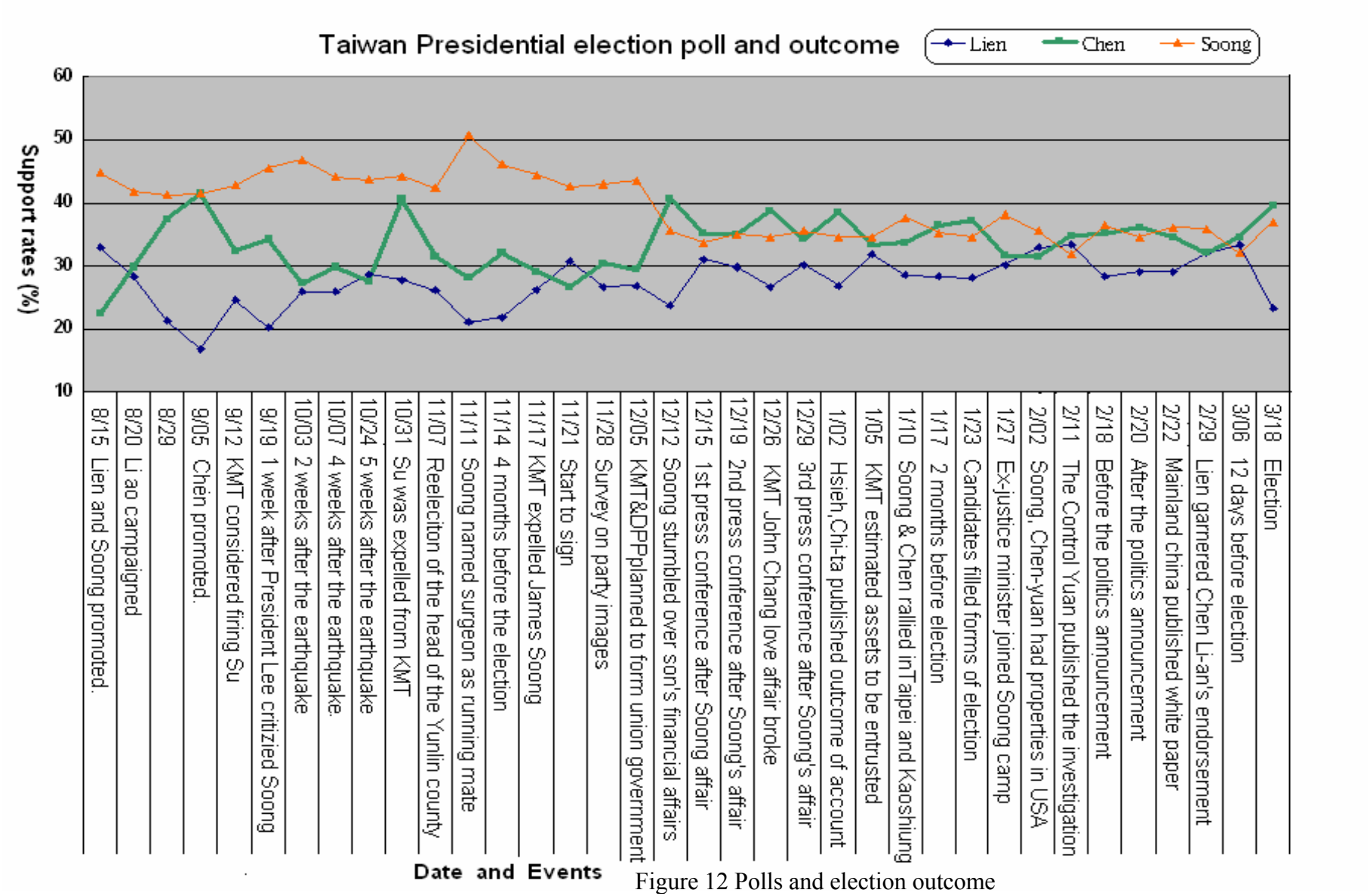

Figure 12 Polls and election outcome

5. Catastrophe Application

5.1 James Soong's financial affair

Before Soong was questioned about his son's financial affair, he had been considered as a clean politician and remained higher support rate than the second place Chen. Good time didn't last long. This leading trend was interrupted by the query came from the KMT Legislator Yang, Chi-shiung. On December 9, 1999, Chi-hsiung Yang held a press conference and revealed Soong's son, Soong Chen-yuan, who just had graduated from college and finished military obligation, deposited more than NT$100 million (about US$3.1 million) in his bank account in 1992. The younger Soong was just 24-years old and was jobless when he received the securities. The affair has had an immediate impact on James Soong's standings in opinion polls.

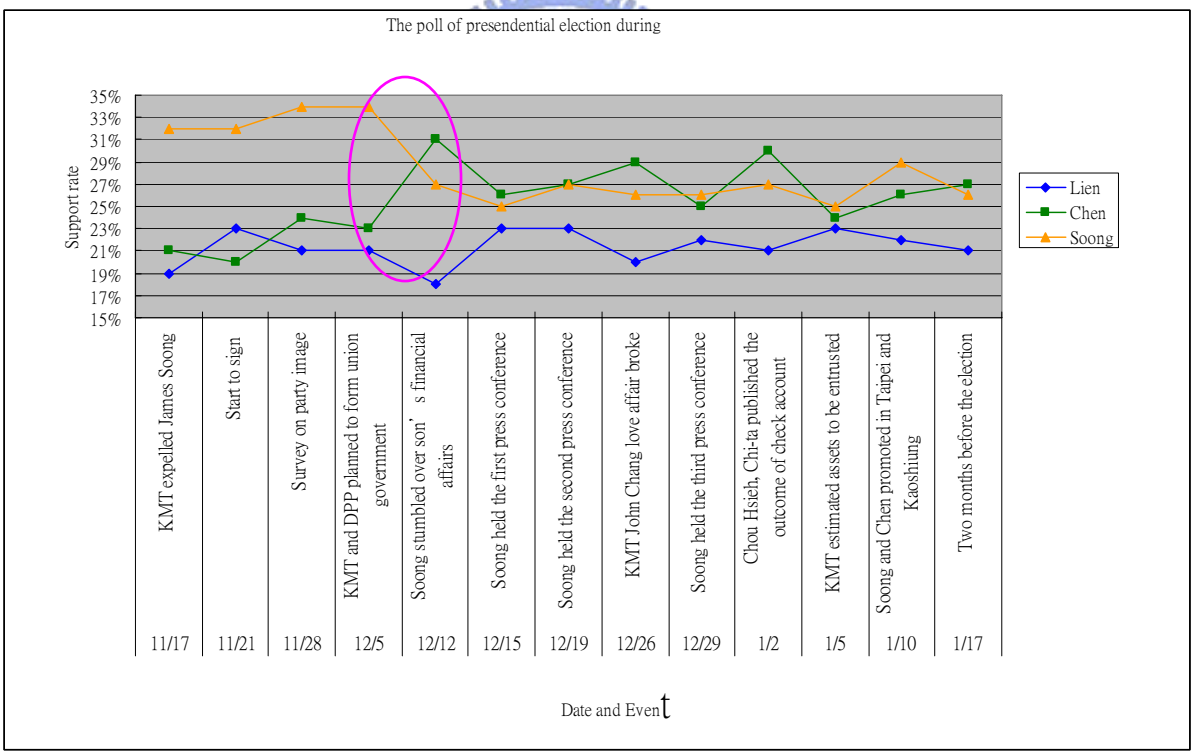

Figure 13 The polls from 11/17/1999 to 1/17/2000

Yang thought the money flows were related to that year's legislative elections and James Soong's pivotal role in the KMT election campaign. Soong was at that serving at secretary-general of the ruling party. Soong denied at first, and involved many people, Teng-hui Lee、the Chiang family、

Hsu Hsin-liang, into this affair. People thought he might expose a bigger scandal involving the KMT. Soong held three press conferences, but he couldn't explain clearly. Even more, he was vacillating in his explanation that disappointed his supporter. Soong stumbled over son's financial affair.

Based on the poll conducted by TVBS Poll Center, the support rate of Soong dropped down 7 percentage point from 34% to 27% only during three days after the financial affair broke, According to Presidential Election Update website, in a poll of 893 people conducted Friday by the United Daily News, Soong's support rating dropped to 24 percent, down 8 percentage points compared to a previous poll on November 30. Meanwhile, Chen climbed to 23 percent from 19 percent, and Lien increased his rating by one point to stand at 23 percent. Another poll of 1,069 people conducted by Gallip and commissioned by SET TV showed that Soong's ratings had dropped from 36 percent to 28 percent.

This impact on Soong's support rate was so huge that erodes quarter of his original support rate. Because Soong rose upon the image of honest and upright that makes difference from KMT's long-term "black-gold" burden. This affair broken made no difference and disappointed Soong's supporters.

KMT kept up firing on Soong's unfaithfulness and perfidy until they used the wrong strategy- property entrusted. This argument of property entrusted shifted the focus off the thorny problem that eased the pain of Soong camp on January 2nd. The poll data showed the supporters of Soong ran to Chen, after two weeks there are few supporters of Soong indlined to Lien. The Soong financial affair accidentally caused a new equilibrium of three forces.

Table 3 Support rates of candidates

Date	Events	Support Rates of candidates (%)		
		Lien	Chen	Soong
11/17	KMT expelled James Soong	19	21	32
11/21	Start to sign	23	20	32
11/28	Survey on party image	21	24	34
12/05	KMT and DPP planned to form union government	21	23	34
12/09	Soong's financial affair broke			
12/12	Soong stumbled over son's financial affairs	18	31	27
12/15	Soong held the first press conference	23	26	25
12/19	Soong held the second press conference	23	27	27
12/26	KMT John Chang love affair broke	20	29	26
12/29	Soong held the third press conference	22	25	26
1/02	Chou Hsieh, Chi-ta published the outcome of check account	21	30	27
1/05	KMT estimated assets to be entrusted	23	24	25
1/10	Soong and Chen promoted in Taipei and Kaoshiung	22	26	29
1/17	Two months before the election	21	27	26

Catastrophe analysis

This dynamic effect of financial affair that caused the support rate changing substantially can be analyzed by catastrophe voting behavior model. At first, Soong had good reputation that made his support rate higher than others. Not only those who liked Soong would vote him, but also those who disliked Soong might vote. Using catastrophe voting behavior model, we can denote the social evaluation as positive at Y1. Assume that under the condition of the intensity of social norm and inner evaluation are obtained, and the Catastrophe Line L is therefore be found, the catastrophe model can model the Thus, even those who inner evaluate Soong as negative at point X1, under the Catastrophe Line L assumption, they would behave as positive action to approve for Soong. Their behavior Z1 is the interaction of voter's

inner evaluation and social norm of Soong that falls at the region of approval.

This remained a long time. But after KMT legislator revealed the financial affair of Soong's son, the social evaluation changed from positive to negative immediately which is denoted as the shift from the point Y1 to Y2. At the negative social norm Y2, even those who inner evaluate Soong as positive like X2 would changed his original preference to behave disapproval. The behavior Z2 which was the interaction between positive inner evaluation X2 and negative social norm Y2 fell on against zone.

From top looked down to X axis, the change of social norm can be assumed from positive to negative, under the Catastrophe Line L assumption, support rates can be observed down from 34% to 27%. Those who judged Soong not well but attracted by his good reputation ran.

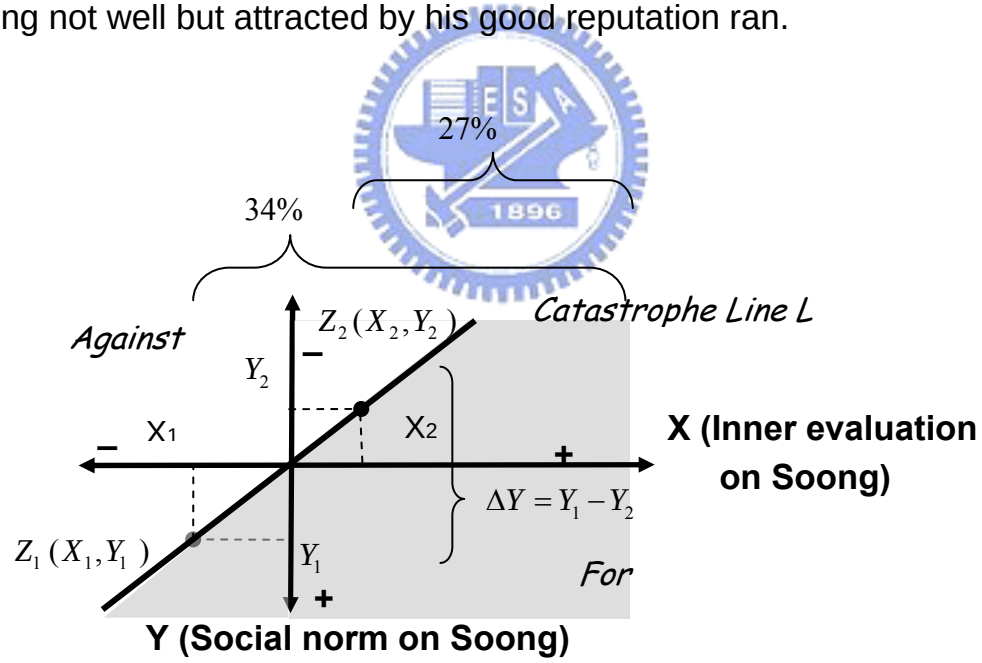

Figure 14 The catastrophe voting model of Soong's financial affair

In 3D model, those who originally inner-evaluate positively not so strong change their behavior. Phase goes straight from upper phase (for zone) to lower phase (against zone). This is the quantity changes of social norm leads to quality change of voting behavior.

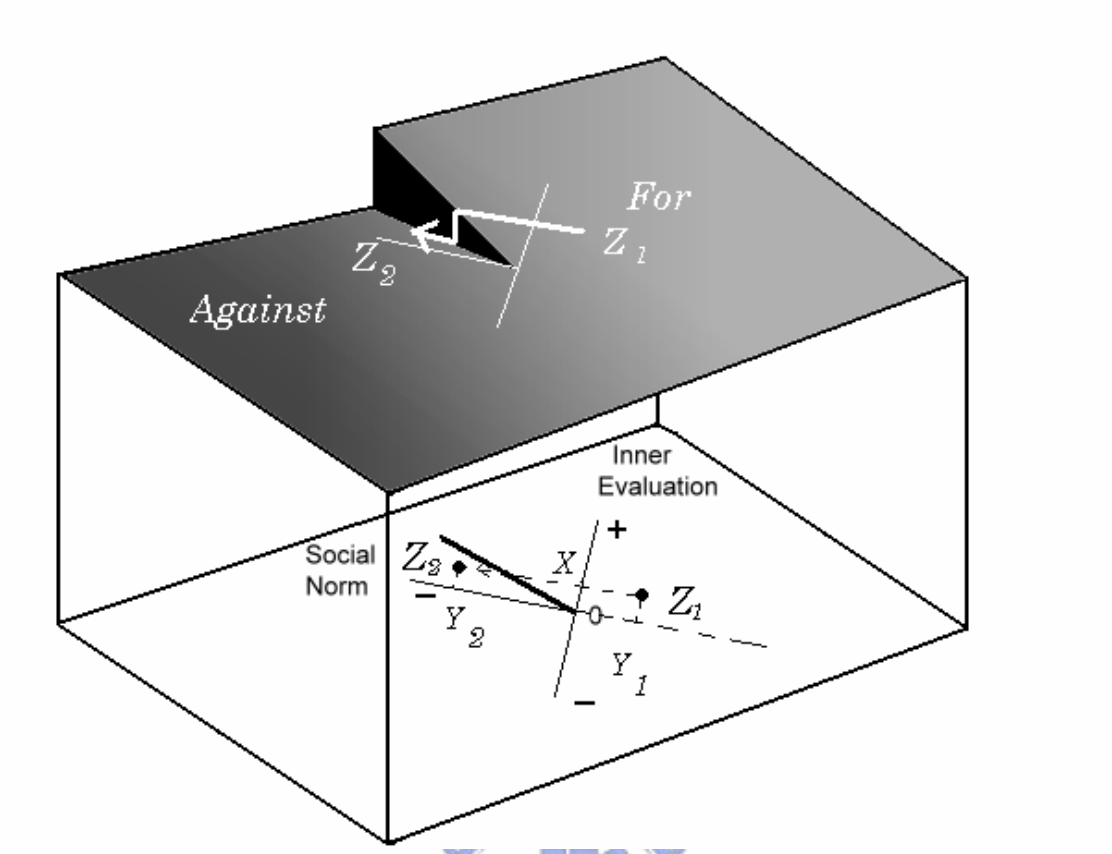

Figure 15 The three-dimension catastrophe voting model of Soong case

5.2 Strategy Voting

Originally, as time went by to ten days before election, this was the neck-and-neck presidential election. If there is any chance for strategic voting to occur and to have an effect upon the race, the following condition would have to hold. One candidate would have to be clearly behind in the race while the other two are in fierce competition. Based on the poll data ten days before the election, the support rates of the first-runner, Lien、Chen and Soong, were individually 33.33%、34.67%、32.00%. With the race as close as it was, there was little direction for voters to decide whose supporters should defect. In there was little reason to expect strategic voting. After the ten-day period (3/8-3/17) while poll couldn't be published, which is regulated by Presidential and Vice Presidential Election and Recall Law passed in 1995, the election outcome turned the tables. What happened during the ten blackout period became the key point to explain the marked shift in voter's preference.

Dr. Yuan-Tseh Lee gave in his resignation as the president of the Academia Sinica on March 3, 5 days before the election. Not only his resignation from Academia Sinica but also his agreement to be advisor to Chen convulsed the society. From March 10, Dr. Lee took his stands on Chen, the neutral voters and intellectuals were starting to lean on DPP. Till the night before election. March 17, the momentum of Chen was higher than ever by Dr. Lee's video support broadcasting.

After a week before the election, Chen gained a tremendous momentum after some of Lee Teng-hui's close friends claimed that Chen was the true follower of Lee Teng-Hui and after the president of the Academia Sinica, Nobel laureate Dr. Lee Yuan-Zhe, openly supported Chen. It looked as if Chen attracted more and more supports from central voters and elites and could be the front-runner. As the result, supporters of Lien and Soong started to wonder whether they should vote strategically. This competition became pan-blue against pan-green during the blackout period. The KMT camp claimed that Lien was still ahead in all the major polls, suggesting that Soong's supporters should vote strategically for Lien. The Soong camp, on the other hand, argued that Lien was running a distant third and that his supporters should vote strategically. Besides, PRC Premier Zhu Rongji issued hard line comments on Taiwan's presidential election like "Nothing doing without a deadline!" "Nothing doing without force!" The threat of mainland China aroused the antipathetic mind of Taiwan people.

Because the three front-runners gained over 97.4% support rates, to simplify the analysis, the size of total will be narrow down on the three candidate-Lien, Soong, and Chen. The support rate changes during the ten day blackout can be analyzed by figure 16 and table 4. Originally, 10 days before election, three candidates gained probably equal strength. After Chen's promotion by Dr. Lee and President Lee, even more, threat of mainland china,

the pan-green part of Lien's supporters changed to support Chen. The pan-blue part of Lien didn't want to see the pan-green winner, and they changed to Soong camp. This strategic voting behavior makes Lien loss about 10% support rates while 5% ran to Chen and 5% to Soong.

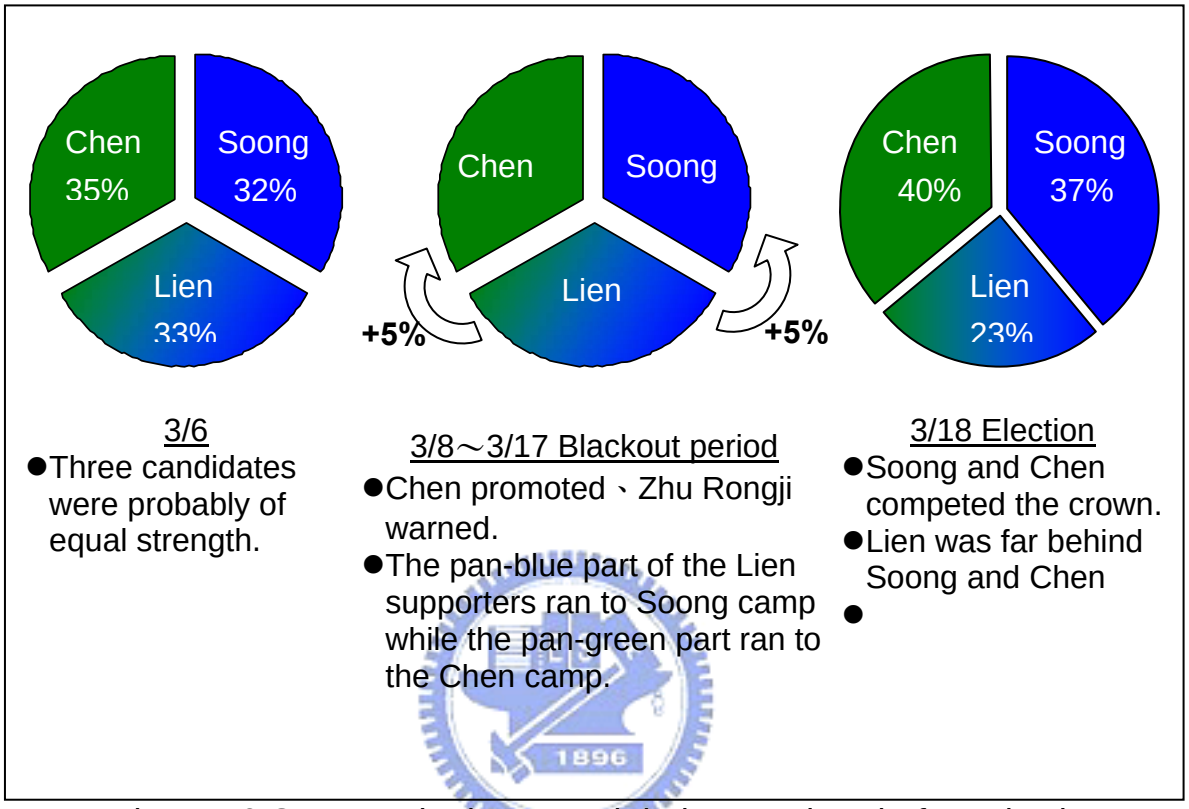

Figure 16 Catastrophe happened during ten days before election

Table 4 The comparison between polls and election outcomes

	3/6	3/18	Difference
Chen	35	40	+5
Soong	32	37	+5
Lien	33	23	-10

Many people thought Taipei city mayor Ma should take part of the responsibility. Taipei city mayor Ma Ying-jeoh, a KMT political star who had spread information before the election indicating the most poll results still showed KMT candidate Lien as the front runner. This movement can explain why pan-blue lost this battle to pan-green. Many KMT supporters believed they were misled by Mayor Ma to stick with Lien when he actually had the least chance of winning. The claim of Mayor Ma applied the brakes to this effect of strategic voting.

There are tow conditions that Chen may not win from strategic voting: one is the strategic voting makes more and more people to Soong, then Soong would win; or combining other strategies with Mayor Ma's statement, the outcome would not only retain original supporters of Lien but also attract more supporters from other camps that make Lien winner.

Based on data of March 6, we can find that ten percent loss of Lien (23%-33%) was equal to 5 percent gain of Chen(40%-35%) plus Shoong(37%-32%). Also take January 29 as a basis, we can find the coincidence of on the basis of March6. Nine percent loss of Lien (23%-32%) was equal to 8 percent gain of Chen (40%-32%) plus 1percent gain of Shoong(37%-36%). Strategy voting happens.

Catastrophe analysis

Vertical axis Y will represents social evaluation on Lien while horizontal X as self inner evaluation on Lien. Both X and Y are control variable of voting behavior. If personal inner evaluation is positive, then the behavioral acceptation zone will show as graph. Ten days before election, the social norm Y can be assumed as positive at Z_1，After ten blackout days, social norm on Lien weakened from Y_1 to Y_2 for the reason of Chen's promotion and there comes the sayings of "abandon Lien save Soong" or "abandon Lien, save Chen". Under the assumption of change from Y1 to Y2, according to Catastrophe Line L, the influence of X is X1-X2, and the influence made the support rate ran off 10%.

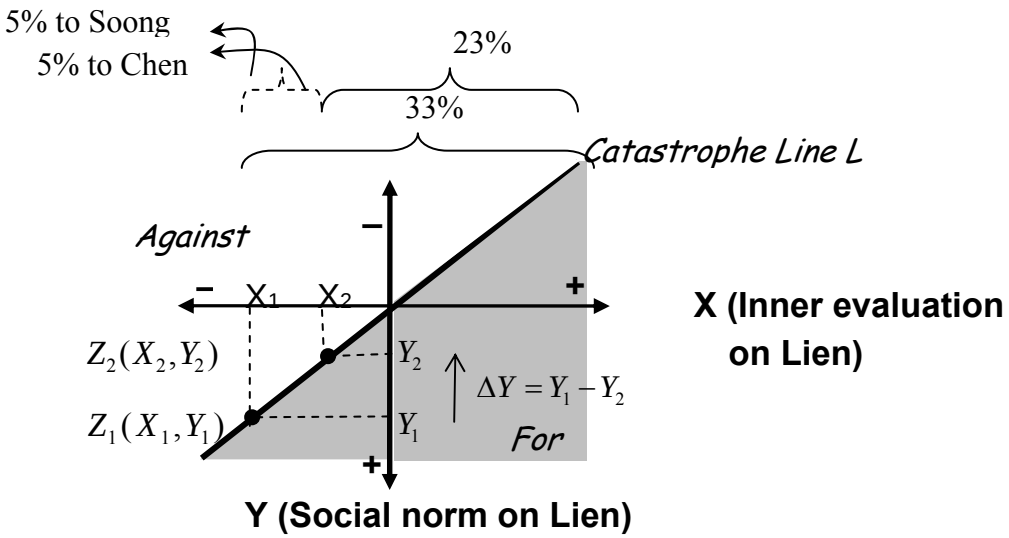

Figure 17 The catastrophe voting model of Lien's financial affair

Strategy voting happens. Because those who like lager the most, they don't want to spoil their ballots. In this case, Soong and Chen remained long –term higher level of support rate. If the difference |Soong-Chen| is very close, strategy voting will most likely happen. Then strategy voting will weaken the strength of herding. That can explain why Lien lost 10 percent so much. Look down to X axis, it shortens from 33% to 23%. People prevent invalid ballot from strategy voting. Herding leads to cohesion of group dynamics were weaken. Coincidently, the ten percentage loss was equal to percentage gain of Chen and Shoong.

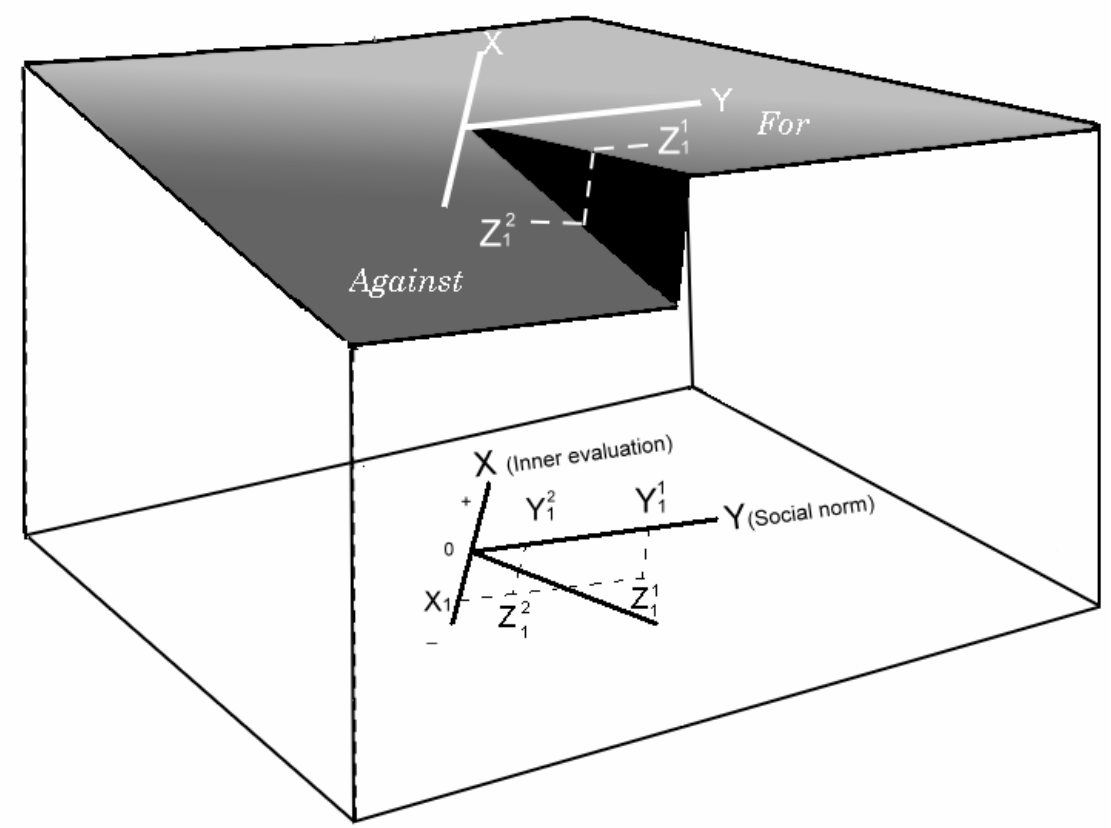

Figure 18. The three-dimension catastrophe voting model of Lien case

In three-dimensions, we can find out that social norm became weaker. Who stand at upper state (for zone) drops to lower state (against zone). Thus a sudden jump happens.

6. Conclusion and Recommendation

This thesis provides a new conceptual model to explain voting behavior. This is an application of catastrophe theory to analyze voting behavior. Original cusp catastrophe theory has cusp projection. In this thesis, researcher simplifies cusp projection to line projection. The difference between cusp projection and line projection is hysteresis. Researcher discusses sudden jump rather than hysteresis in voting behavior.

In this case, state variable has bimodality between vote and don't vote zone; also we can see sudden jump in Soong' scandal broke. It turns the phase from acceptation zone expansion to erosion. To go a step further, we use catastrophe approach to realize how strategic voting influences ballot.

Strategic voting behavior means that when there are three or more candidates competing in one certain election, voters, under rational consideration, think that their most favorite candidate has no chance of winning at all, and recognize that their voting for this candidate will cause their least favorite candidate to win; therefore, voters can only choose to vote for their second favorite candidate to avoid from their most undesirable outcome.

In the 2000 presidential election, the three major contenders of Lien Chan, Chen Shui-bian, and James Soong were equally competitive, which created a context of strategic voting. This study therefore used "strategic voting" as a main theme to investigate the voters' voting behavior in the 2000 presidential election. It was found that lots of KMT's votes shifted to the campaigns of either Chen Shui-bian and James Soong, which more or less demonstrated voters' low stability for partisan voting in this election, and to some degree was a result of voters' strategic voting behavior. It revealed that Lien Chan, who was considered the most competent, was always voters' second best choice before the election. That is, voters felt neutral towards Lien Chan, who was neither voters' most favorite candidate nor the least desired one, and

additionally Lien Chan had long been the weakest in the poll, which made him the most likely to be abandoned. The result of the election also showed that among the voters who adopted the strategy of “abandoning someone to save another”, fewest chose to “save Lien Chan.” Hence, voters did have “strategic voting behavior” in the 2000 presidential election, and Lien Chan obviously claimed the highest percentage of voters’ abandoned candidate.

After analysis mentioned above, we can conclude that while inner evaluation is of the same attribute of social norm, the state remain stable. If social norm and Inner evaluation are of different attributes, state goes to unstable. Then we should concern about intensity of social norm. If intensity of social norm is strong enough, the state will change to another state.

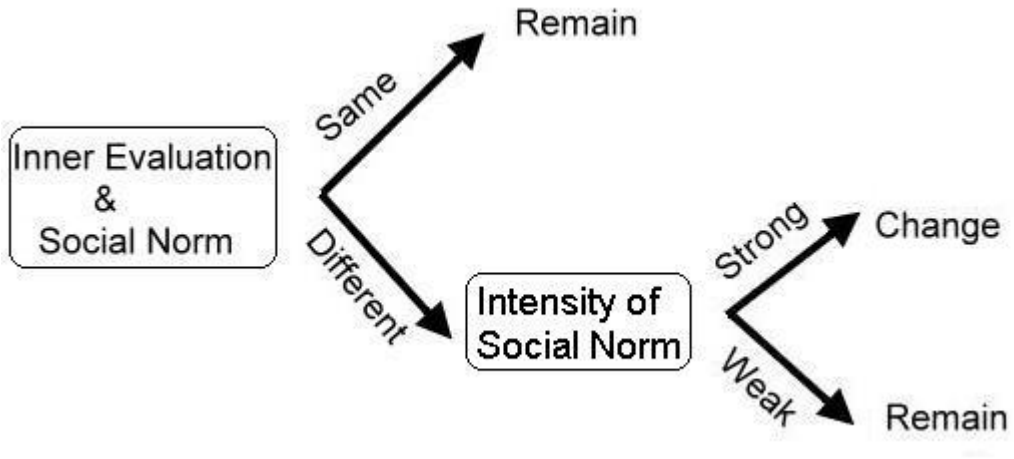

Figure 19 The interaction between inner evaluation and social norm

For further studies, using quantitative data could be a way to verify catastrophe. So far, there is no universal tool. The determinist model and probabilistic model is still in argument. However, how to measure the variables of catastrophe voting model is proposed in this thesis for those who are interested in voting behavior changes.

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Appendix

This is extraction of two pieces of working papers: “A Qualitative Analysis of the Cusp Catastrophe System” and “An Introduction to the Cusp Catastrophe System”. Original author is Prof. Chi-Kuo Mao.

突變系統的理論來源

突變論是複雜系統(complex systems)理論體系中的一支。它與同一理論體系中的渾沌(chaos)、耗散結構(dissipative structure)、協同(synergetics)、分形(fractal)，以及超循環(hypercycle)等理論，分別從不同的觀察角度與不同的解析層次，共同探討自然界如何通過自組織(self-organization)過程，產生出結構化的有序系統，以及這些系統如何因應環境的變遷完成它們的適應與演化。證據顯示，這一套複雜系統理論不僅可用來解釋自然界所發生的無機性物理化學現象，它們也可用來解釋具有生命的生物系統現象、人類組織與社會系統的行為，乃至人類認知系統的作用等。所以，它是理解無機與有機世界許多現象與行為的共通理論基礎。

突變論的理論基礎主要是借自「彈性結構不穩定性」的研究成果。任何一個承受外力的彈性結構物都可寫出一個勢能函數式(potential energy function)，它代表這一彈性結構物受外力作用後，儲藏在內部蓄而未發的潛在能量。由於彈性系統在受力狀態下，要維持它的穩定性的條件是：它的勢能函數必須維持極小值狀態，否則系統就會變成不穩定，甚至於崩潰。因此針對彈性系統的勢能函數，分析它的「臨界變動條件」(亦即使該函數從穩定狀態過渡到不穩定狀態的條件)的特徵，便可掌握彈性系統的突變行為特性。

1. 模式構成要件

A. 任何突變系統都是由一組系統狀態變數(state variable)，以及對這些系統狀態具有決定作用的一組控制因子(control variable)所組成。在彈性膠尺的例子中，膠尺受力後的形狀是我們所關切的狀態變數，縱、橫力則是控制因子。

B. 彈性膠尺受力變彎所構成的是突變系統家族中一個分支，稱為「尖角突變系統(cusp catastrophe system)」。它是由一個系統變數，兩個控制因子所組成的系統；並且系統中的狀態變數只有兩個解。在膠尺的例中，它受力後的形狀（狀態變數）只會出現兩種情況：不是上彎，就是下彎；而控制因子則有縱力與橫力兩項，所以它是一個標準的尖角突變系統。

C. 我們可以函數關係 F=f(x,a,b)來代表尖角突變系統。其中 x 是狀態變數，也是系統中的因變數；參數 a、b 就是控制因子，也是系統中的自變數。

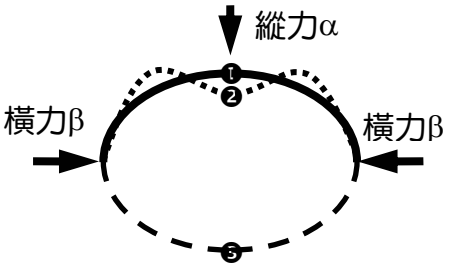
D. 尖角突變的狀態變數只有一個，但是有兩個解；而這兩個解中究竟哪一個解會出現，以及它們之間會如何相互轉化，則由兩個控制因子共同決定，所以尖角突變系統是一種「雙因子兩態轉化」的突變系統。

E. 任何「雙控制因子、系統狀態為具有二元轉化特性」的問題，它們在系統狀態的演變過程上，都具有「相似且穩定」的「定性」結構特徵，正因為這種結構特徵

的存在，使我們可以將它們歸納成一套規律，並當作一種模式來研究。

2. 現象描述

日常使用厚度很薄的塑膠尺，具有很好的彈性。我們可以根據這種塑膠尺受力後的變形過程，來說明所謂的突變現象。



圖一：彈性膠尺受力後變形過程

以下我們就來進行一項想像中的實驗。首先將一把薄形的塑膠尺，在它的兩端施加一對橫向壓力β，尺就會向上彎曲(如圖一粗實線)或向下彎曲。接下來將已經上彎的膠尺，在橫力β維持不變情形下，再向它的中央點❶施加縱向往下的力量α。然後逐步增強α，我們可觀察到：

A. 剛開始，膠尺只在受力點❶附近小幅度變形，亦即：受力點❶逐步位移到點❷位置(如圖一中之細虛線)。

B. 當向下的力量α超過某一門檻值後，膠尺就會突然下彈成為下彎的形式，而點❷也就突然向下彈跳到點❸的位置(如圖一中之粗虛線)。

歸納來說，膠尺在橫力與縱力交互影響下，所產生從點❶到點❷的位移屬於漸變過程，亦即：漸進增加的縱力，造成漸進增加的位移。從點❷到點❸的位移則是一個突變過程，亦即：漸進增加的縱力，產生不成比例的巨大位移。這種「作用力(因)的小幅變動，導致系統狀態(果)巨幅改變」的現象，就是所謂的突變現象。

3. 定性分析

彈性膠尺受到橫向壓力，會上彎或下彎；上彎與下彎就是膠尺兩種不同的系統狀態(system state)。現假設膠尺受到橫力作用後，它出現的初始狀態(initial state，以下簡稱初始態)為上彎。

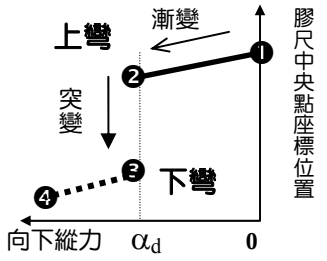
接下來將橫力β維持固定不變，但開始對膠尺中央點施加「向下」的縱力α。當縱力逐漸增強時，受力點❶會逐漸向下位移；而當縱力達某一門檻值α_d，這時下降到點❷的膠尺，會突然發生「跳躍性的位移」，急速彈降到點❸的位置，使膠尺從原先的上彎狀態變成下彎狀態（圖二－一）。這種突跳現象叫做突變的「門檻效應(threshold effect)」。通過突變點之後，再增強α的力量，雖向下位移可能繼續增加(從點❸下降到點❹)，但系統狀態將維持下彎而不再改變(圖二－一虛線)。

其次來看膠尺的初始態為下彎的情形。這時橫力β仍維持固定不變，但對膠尺施加「向上」的縱力α；則膠尺中央點的位置會先從點❺逐漸上升到點❻，而當縱力超過某門檻值α_u時，膠尺的狀態就發生突變，猛然從點❻向上彈升到點❼，成為上彎狀態（圖二－二）。相同的，通過突變點之後，再增強α的力量，雖向上位移可能繼續增加(從點❼上升到點❽)，但系統狀態也將維持在上彎而不再改變(圖二－二虛線)。

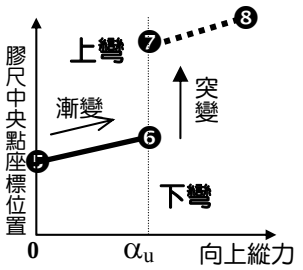
現將圖二－一與二－二以縱軸為基準，相互套疊得圖二－三。它的橫座標原點右側

是向上的縱力，左側是向下的縱力，而下彎的門檻值α_d與上彎的門檻值α_u，則是彼此錯開對稱分列於橫座標軸兩側。突變門檻相互錯開是突變系統最顯著的一個特徵，稱為突變過程的「滯後效應(hysteresis)」。以下就來說明它的意義。

膠尺從上彎態經由❶❷❸的途徑突變為下彎態，並停留在點❹之後，要再由下彎態回復回上彎態時，膠尺不僅不會在向下縱力的力量減小為α_d，也就是在原先發生下彎突變的點❸位置，就向上反彈回復為上彎狀態；它也不會在縱力減為零的時候就向上彈跳——因為這只是從點❸移動到點❺的過程(亦即向下縱力由α_d逐漸降低歸零的過程)，系統狀態並無改變。從圖二－三中可看出，膠尺的向上彈跳必須等到縱力的方向由向下轉變為向上，並且其力量增加為α_u，而膠尺中央點的向上位移也已經從點❺漸進到點❻之後，才會發生。



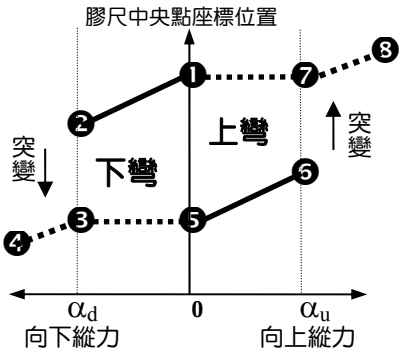
圖二-一



圖二-二

換句話說，系統狀態經過下彎的突變到達點❹之後，它要再回復為上彎狀態時，它的突變不出現在原先發生下彎突變的地方(也就是點❸的位置)，而是一直往右延遲到點❻的位置才發生。同樣的，當系統狀態已經突變為上彎到達點❽之後，要再回復為下彎狀態時，它的突變也不會出現在點❼，而是往左延遲到點❷才發生。這種突變一旦發生，要再回復原狀就必須「矯枉過正」的延遲現象就是突變過程的滯後效應。

以上是以縱力的變化所引起的系統狀態突變作為分析焦點。事實上，系統狀態的突變也可因橫力的變化而引發。亦即：假設膠尺的初始態為上彎，這時若向下的縱力α保持固定，則當橫力β逐漸減小到某門檻值時，該尺的狀態也會發生突然往下彈跳成為下彎狀態的突變。這種突變現象可稱為逆轉(reversal)效應。而當膠尺的初始態為下彎時，在相對應的條件下，另一方向對稱的逆轉效應也同樣會發生。



圖二-三

突變系統的系統行為（系統狀態）決定於它的能量函數。能量函數代表突變系統受到外來作用力後，積聚在系統內部蓄而未發的能量。要維持系統的穩定性，必須使系統所蓄積的潛在內能處於最小的狀態。

根據微積分的極值原理：當能量函數 V 的一階導數 $V'=0$ 時，系統的能量處在極小或極大的狀態，這時的解為系統的平衡解。不過，這個解雖平衡但卻不必然穩定(參見圖九)。這時必須再檢驗能量函數的二階導數是否符合 $V''\leq 0$ 的條件，才能確保系統能量為穩定的極小值。函數的極小解通常都位於線段的凹入點。由於凹入的線形在視覺上具有吸納、匯流的意象，因此突變系統能量極小狀態的穩定解，一般也稱為系統狀態的吸

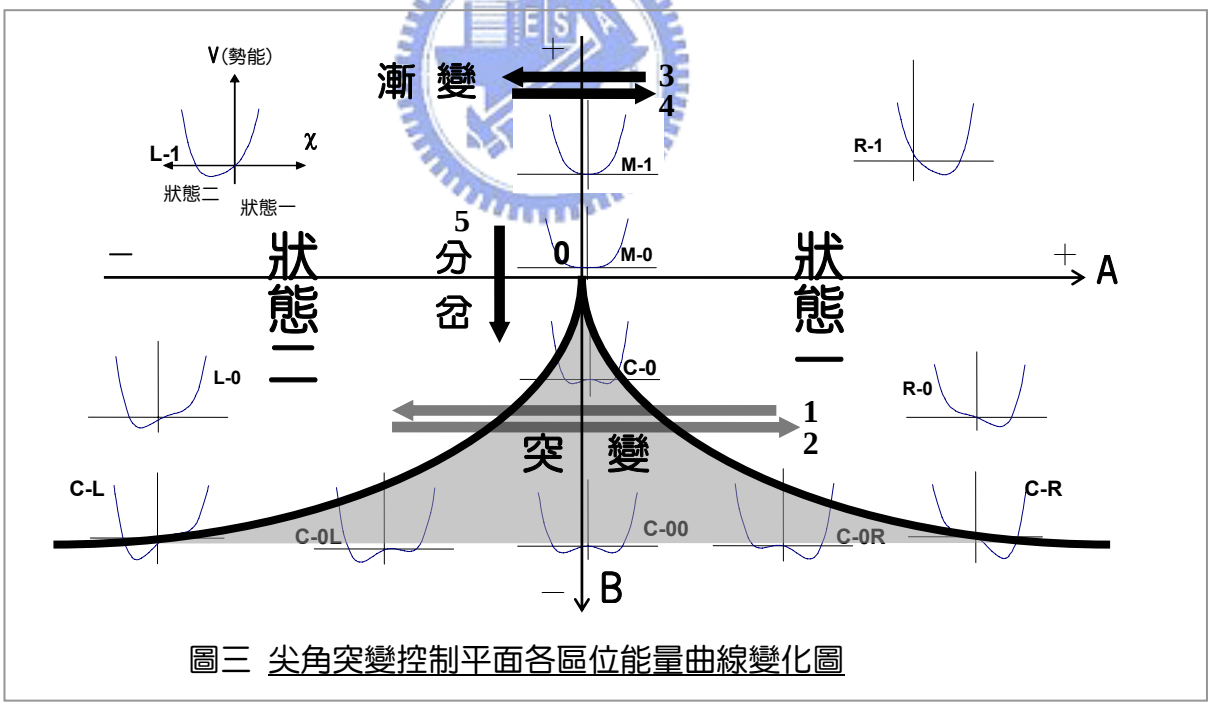
引子(attractor)。

任何突變系統的臨界突變、滯後、逆轉與分岔等行為，都是因為能量函數極小值(以下簡稱極值)的位置發生變化所造成；所以突變系統狀態變化的過程，其實就是系統能量函數極值的變動過程。換句話說，要掌握突變系統的行為特性，可從分析系統內蓄的潛在能量如何發生變化的過程下手。如果利用吸引子的概念來解釋，那麼因為能量函數的極值發生變化，等同於系統狀態吸引子的位置發生位移；所以突變系統的狀態出現變化，也可說是系統狀態受吸引子的拉動而引起的改變。

尖角突變系統的能量函數 V＝F(χ, A , B)是一條以χ為橫軸，V 為縱軸的曲線。由於能量函數曲線的形狀——包括：極值(或吸引子)的位置——決定於參數 A 與 B 的數值，因此要探討尖角突變系統的突變行為，焦點就須放在 A 、 B 這兩個參數身上。這也是為什麼突變系統能量函數的參數被稱為控制因子的原因。

4. 系統控制平面上能量曲線的變化

圖三是以控制因子 A、B 為橫軸與縱軸的尖角突變系統控制平面。居中的 B 軸左右兩側，分別是系統狀態一與狀態二投影區。下方傘狀陰影範圍則是兩態重疊的臨界區。圖中繪註於不同區域的小曲線圖，代表各該區域的能量曲線，顯示該區位系統狀態吸引子的特徵。



圖三 尖角突變控制平面各區位能量曲線變化圖

現利用位於圖三控制平面左上角的圖 L-1，來說明能量曲線圖的意義。能量曲線是以系統狀態變數χ為橫軸，能量函數 V 為縱軸所繪製的曲線圖。在 L-1 中，χ軸下方有「狀態一」與「狀態二」的註記，表示系統狀態χ只有狀態一與狀態二兩個解。L-1 中的能量曲線是將該圖所在位置的控制因子 A 與 B 的數值，代入尖角突變能量函數 V 後所得到的線形。L-1 的極值出現在屬於狀態二的左方，代表 L-1 所在的象限，亦即控制因子 A<0 但 B>0 的控制平面，屬於系統狀態二的範圍。至於圖三右上角 R-1 的情形則正好相反：

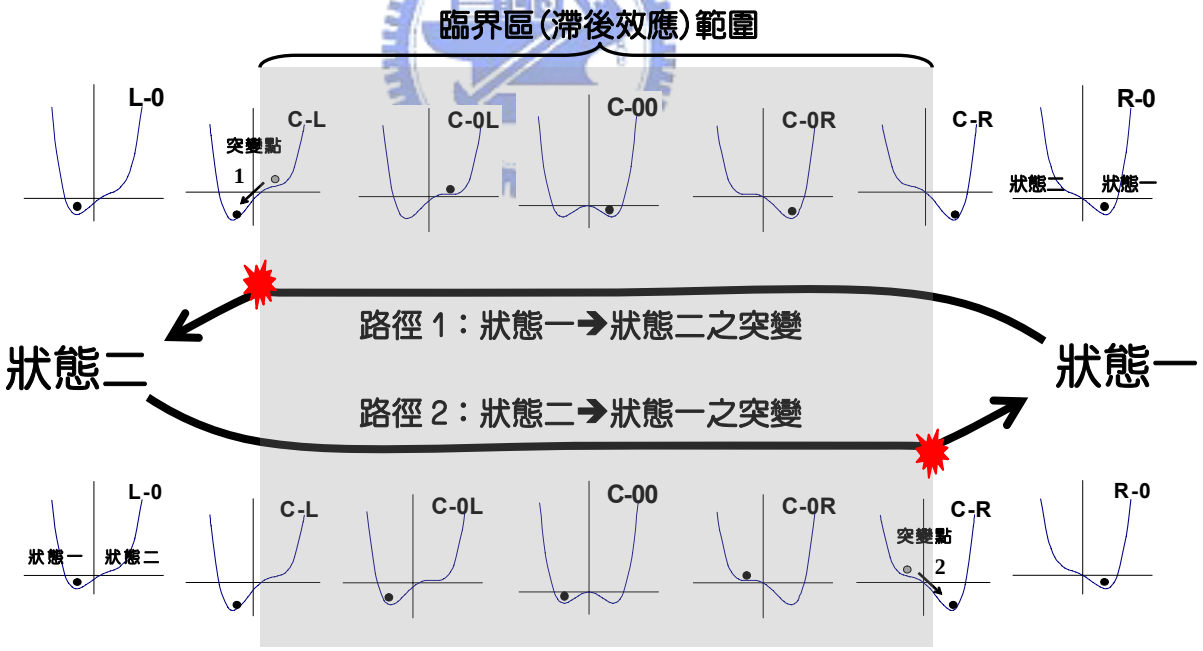
它能量曲線的極值出現在代表狀態一的右方；由於 R-1 位在控制因子 A>0 且 B>0 的象限內，因此代表該象限屬於系統狀態一的範圍。

圖三的控制平面上，除了能量曲線之外，也繪有註記為突變、漸變與分岔的箭頭，它們代表系統狀態不同的轉化途徑。以下就根據能量曲線的特性(亦即吸引子的轉移過程)，來說明尖角突變系統的突變、滯後、漸變與分岔等系統狀態轉化現象。

A. 突變過程與滯後現象

首先觀察能量曲線在狀態突變過程中所發生的變化。這是圖三中穿越過臨界區，標示有 1 與 2 號碼的兩條系統狀態演變路徑。其中路徑 1 是一個由狀態一演變為狀態二的過程；路徑 2 則是由狀態二反向變回狀態一的過程。

圖四把路徑 1 與路徑 2 沿途的能量曲線，按照它們出現的順序排列在圖的上下兩側，從右到左分別是：R-0、C-R、C-0R、C-00、C-0L、C-L 與 L-0。圖四也顯示了這些能量曲線圖，但把它們放在各自所屬的控制平面的位置上。例如：L-0 與 R-0 分別在臨界區範圍以外的左右兩側；C-L 與 C-R 則分別落在臨界區左右兩條邊線上；C-0L、C-00 與 C-0P 則落在臨界區範圍之內。圖四中每一能量曲線上都標示了一個小黑子，它代表能量曲線當時的穩定解，亦即系統狀態所在的位置。換句話說，黑子在縱座標右側時，代表系統屬於狀態一；反之則為狀態二。



圖四 突變路徑沿途的吸引子變化過程

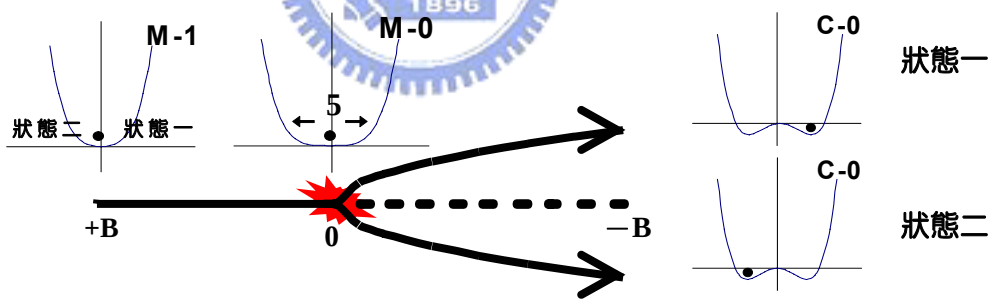
突變過程一。現按照R-0 到L-0 由右向左的順序，觀察系統狀態如何循著路徑 1，逐步從狀態一突變成為狀態二。首先R-0，因為它位在投影區之外的右側，所以能量曲線的極值與代表系統狀態的小黑子必然都落在屬於狀態一的右側。其次C-R，它剛進入投影範圍，代表系統狀態的小黑子並無任何移動跡象，但能量曲線的左側底部已開始發生蠢蠢

欲動的變化。接下來C-0R、C-00 與C-0L，雖小黑子尚未移動，但它們能量曲線左側的下垂度則變本加厲地增加(下垂度增加代表新吸引子的形成)；例如C-00 能量曲線已呈對稱形(新吸引子的規模已與萎縮後的老新吸引子相當)；而C-0L能量曲線的極值甚至已移到左側(新吸引子的強度已超越老吸引子)，小黑子的位移已是一觸及發。到了C-L能量曲線已經成為向狀態二傾斜的滑波(老吸引子消失，由新吸引子統一局面)，小黑子便順勢滑落到左側(系統狀態突變成狀態二)——其實C-L所在位置正是會發生狀態突變的投影區邊界線。最後進入L-0，能量曲線趨於穩定，系統被穩定地吸引在狀態二。

突變過程二。路徑 2 與路徑 1 正好相反，它是一個由狀態二突變為狀態一的過程。從L-0開始經C-L、C-0L、C-00 到C-0R，能量曲線左側的吸引子不斷抬高，右側吸引子則不斷下陷。然後在C-R(投影區的邊緣線上)，左側吸引子消失，右側吸引子將小黑子吸入，系統從狀態二突變成狀態一。最後進入R-0，能量曲線趨於穩定，系統穩定地停留在狀態一。

B. 分岔過程

在圖三中，另一組系統狀態變化的可能性是路徑 5。它所要探討的是當控制因子 A 固定為 0，而控制因子 B 順著縱軸往下走(亦即它的數值由 B>0 走向 B<0)時，系統狀態所將出現的分岔過程。從圖三知，系統沿著縱軸向下移動時，它的能量曲線從 M-1 的尖底吸引子，變成 M-0 的平底吸引子，最後變成 C-0 中央凸起兩側凹下的對稱性雙吸引子。圖五是加了代表系統狀態的小黑子之後的分岔過程能量曲線。



圖五分岔路徑沿途吸引子轉化過程

面對 M-1、M-0、C-0 這樣三條能量曲線，小黑子從 M-1 到 M-0，是走在沿 B 軸的吸引子上，但到了 M-0(也就是 B 軸的原點)時，再往前吸引子出現分岔。因為從 M-0(亦即原點)往前的 B 軸兩側，這時已經開始逐漸下陷，原軸線的位置變成相對隆起的陵線——對應於 C-0 能量曲線中央突起的部分；圖五中，從原點 0 往－B 方向的軸線也已改繪為虛線，代表它是不穩定、不可及的極大解——所以小黑子就不再能保持在 B 軸的路線上繼續前進，而必須在兩個分岔之間做出抉擇。

在分岔點（亦即原點）上，小黑子(系統狀態)究竟會走上哪一個岔道，並無任何必然的規律可循，而是決定於當時的偶然因素。因為只要小黑子在進入 M-0 平底鍋形的吸引子時，並非絕對的走在中央線上，而是受到極輕微的擾動，以致它的路徑發生極小向

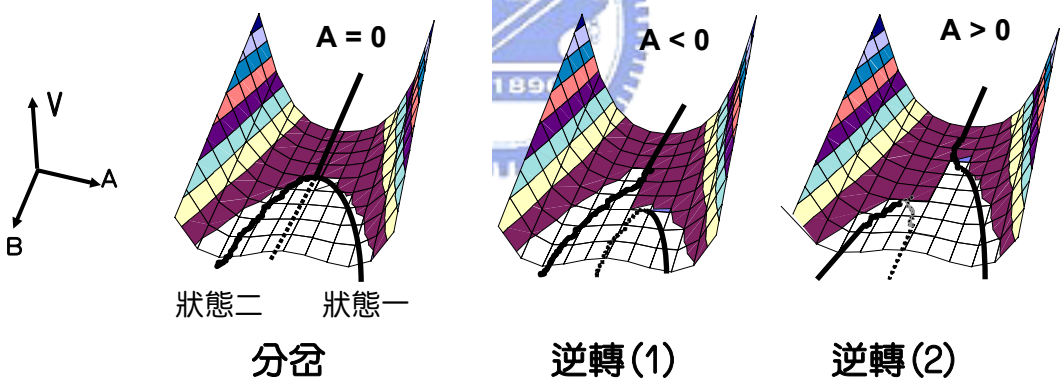
左或向右的偏離，那麼這一微小的偏離就會決定小黑子往後的走向。亦即：偏左就走上狀態一，偏右就走上狀態二。

因此，分岔現象具有以下的特性：(1)在分岔點之前，系統狀態決定於歷史；分岔點之後系統狀態的走勢則決定於偶然因素；(2)此一偶然因素決定的系統狀態則又成為下一階段歷史的起點。不過，此處所稱的偶然因素已無法從上述簡單的數學模式中去尋找解釋，而必須根據實際系統的個案特性中去理解。

2. 能量山谷、系統狀態與吸引子的關係

前面提到，突變系統能量曲線在控制平面的不同區位有不同的線形；並且從圖三開始，我們也運用能量曲線的概念，分別說明了突變系統狀態的演變過程。不過，要進一步了解「能量曲線在不同的區位有其『固定』不變的線型」的意義，我們可把狀態演變過程中所出現的相關能量曲線，以能量「斷面」的形式，各就其順序一字排開，使它們構成一個三維的能量空間圖，然後從中找出吸引子運動的軌跡，這樣就可清楚看出能量函數與控制平面區位間的關係，以及能量曲線與不同的系統狀態演變模式間，更視覺化的關聯性。由於三維的能量空間圖一般都呈現某種山谷的形狀，因此也可將它簡稱為能量山谷。以下就來說明，不同突變過程的能量山谷，在結構上的差異。

A. 分岔與逆轉過程



圖六 分岔與逆轉過程的能量山谷圖

圖六是在控制平面上所繪製的分岔與逆轉的三維能量山谷圖。首先說明它的座標關係。圖中斜向畚箕狀山谷的垂直軸(山谷的深度)是能量的高低，不同顏色的水平色帶是能量等高線。水平面的中央軸是控制因子 B 的軸線，橫軸則是控制因子 A 的方向。

分岔。以最左邊的分岔山谷圖為例，它就是由包括圖五的M-1、M-0、C-0 三個能量曲線作為山谷主要橫斷面所構成的能量空間圖。例如：山谷遠端拋物線形的斷面，其實就是M-1 能量曲線；圖中通過叉狀分岔交點的斷面則是M-0 能量曲線，它的底部相對於M-1 的尖形，已變得較為平坦；至於近端W形山谷口的斷面是C-0 能量曲線，它的中央部位已微微隆起成為小山脊。

分岔突變能量山谷的叉狀谷道軌跡，其實是沿途能量斷面極小值的連線，也就是分

岔突變吸引子的軌跡；至於山谷中心線近端的一段虛線，則代表能量斷面極大值的連線，因為它屬於滾動的小黑子無法停留的不穩定解，所以用虛線繪製。

現假設有一個隨重力滾動的球(亦即代表系統狀態的小黑子)，從畚箕狀山谷的遠端往近端滾動時，那麼小黑子在到達相當於 M-0 的斷面位置之前，它會筆直地走在山谷中心線的谷道上，但到了 M-0 之後，它便會被迫順勢轉向，轉入左側或右側的谷道中去——由於通過 M-0 之後，谷道變得比較開闊，且山谷的中心線開始逐漸隆起成為小山脊，致使原本單一的谷道從此岔開成為左右兩股；因此通過 M-0 之後的小黑子，即使可往前衝上微微隆起的小山脊，但對一顆會滾動的球來說，在脊線上不可能穩定地停留，所以它最後還是得向左或向右滑落到較低的谷道中去——於是小黑子的滾動軌跡，就自然只有圖中叉狀粗實線所示的兩個可能性了。

雖然任何一個的分岔系統吸引子的軌跡都有叉狀的兩條路徑，但對滾動的小黑子(系統狀態)來說，仍然只能選擇其中之一來走，不可能既在左又在右。至於究竟會選擇哪一條，前面已經說過，將決定於小黑子到達分岔點的時候，任何使它偏左或偏右的偶然因素。

再假設小黑子是從山谷的近端往內側遠端滾動時，能量山谷的結構雖仍是同一把叉子沒有改變，但小黑子的狀態這時就要看，它是從哪一個谷口進入山谷來決定：如果它是從狀態一的谷口進入山谷，那麼在從山谷前端進入後端，通過谷道的 M-0 斷面(這時該稱匯合口)的時候，小黑子仍會繼續保持狀態一；反之，如果小黑子從另一側谷口進入時，那麼它就會繼續保持為狀態二。因為從這個方向進入山谷的小黑子，整個行進過程都可視為始終走在相同的谷道上，沒有發生變換谷道的突變，所以系統狀態也沒有出現突變。

逆轉。圖六右側兩個逆轉的能量山谷圖，它們的特徵則是：從能量山谷內側往外延伸的谷道，在通過M-0 之後，只與左側(或右側)谷道相通；通往另一側山谷的通路，則被一小山脊擋住(圖中的虛線，代表極大值的連線)。換句話說，逆轉突變的吸引子軌跡是由兩條獨立的谷道所構成。如果小黑子從內往外滾，通過M-0 之後，它就逕自往左(或往右)自行轉彎，而不會出現任何抉擇問題。

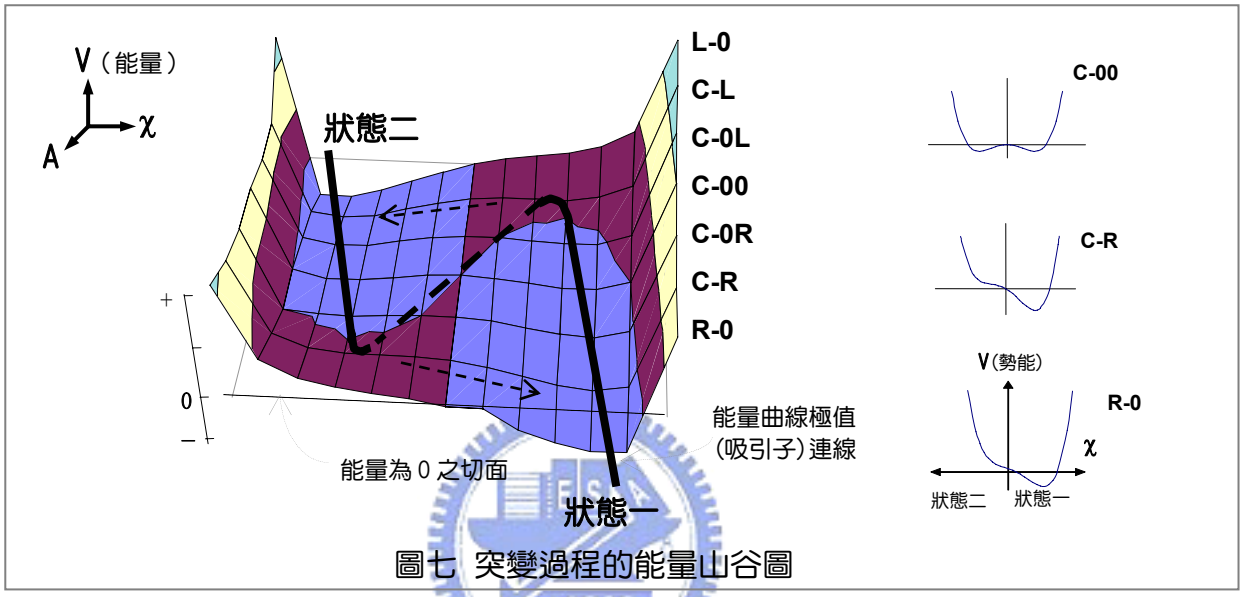
反之，小黑子如果是由外往內走，那就會出現兩種情形。一種是它從有連貫的谷道直通內側山谷的谷口進入時，那麼它就可從頭到尾一路都保持原有的系統狀態；否則，當它從另一山谷的谷口進入時，那麼到了該谷道的末端，亦即吸引子實線終點接上反轉虛線的地方，由於小黑子面對的地形一側是高的峭壁，另側是接到另一山谷的滑坡，這時小黑子就會自然滑落到另一邊山谷的谷道去，再繼續前進。這也就是完成了逆轉突變的過程。

在逆轉突變中，直通的谷道究竟會在左邊或右邊形成，決定於控制因子 A 的性質。當 A 為負值(<0)時，直通的谷道通向左邊；當 A 為正值(>0)時，直通谷道通向右邊。至於在逆轉能量山谷圖裡的虛線，同樣代表突起的山脊或滑坡形的山牆(亦即為不穩定的極大解)。從上面的討論也可推知，任何小黑子從近端谷道進入山谷，經由滑坡逆轉成

另一系統狀態後，它不再可能循著原路恢復成原來的系統狀態。因為逆轉過程中的滑坡，代表的是一個不可逆反應。從吸引子的軌跡來看，小黑子一旦發生逆轉突變，它即使再回頭仍然只有新山谷可走，而不是原本的來時路了，因為要回到來時路，小黑子必須從滑波形的山牆底部爬上去，但在突變模型的能量分析裡，這是不可行的。

B. 突變過程

圖七是突變過程的三維能量山谷圖。這一能量山谷其實是將圖四中的 L-0、C-L、C-0L、C-00、C-0R、C-R、R-0 能量曲線斷面，依序排列所構成。



圖七 突變過程的能量山谷圖

能量山谷圖右側方 L-0、C-L 等註記，就是山谷各橫斷面所屬的能量曲線。圖七右側是從圖四拷貝過來的其中三條能量曲線 R-0、C-R、C-00，可以發現它們與突變能量山谷相對應橫斷面的線形是一致的。至於圖中不同的色帶代表能量等高線；其中有一個註記「能量為 0 之切面」，相當於 R-0、C-R、C-00 等能量斷面橫座標所連接而成的平面，凡能量曲線低於橫座標的段落，在山谷圖中所著顏色為藍色。

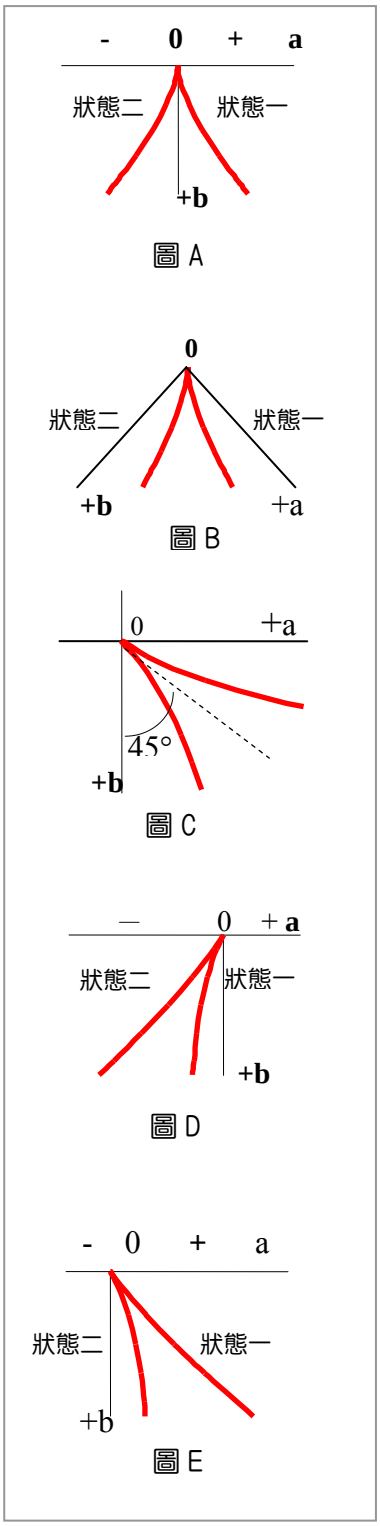
現觀察小黑子以壓著能量曲線各斷面最低點的方式，被推滾上山的過程。如果它是從 R-0 方向進入山谷(代表系統狀態是狀態一)，那麼在一路往上推的過程中，小黑子始終都有很明顯凹入的路槽可走；但到了 C-L 斷面時，路槽左側的路緣突然消失變成一個往左的大滑坡，小黑子便身不由己地往下滑落左側的山谷(系統狀態也因滑落而突變成狀態二)，然後再在新山谷的路槽中繼續前進。如果小黑子是從 L-0 方向進入山谷(這時系統狀態是狀態二)，那麼滑落的發生點在 C-R 斷面上，但滑落方向則是從左到右，而系統狀態也在滑落過程中突變成狀態一。

上述小黑子所走兩條路線的軌跡，就是圖三四的突變能量山谷中所繪的兩條粗實線，它們是能量曲線極小值的連線，也是突變過程吸引子的軌跡。如果把各突變能量曲線的極小值與極大值都連結在一起，就得到圖中的 S 曲線(不過，其中屬於極大值部分，是用虛線連結，代表該段落為不可及)。這一 S 曲線其實就是尖角突變系統狀態圖的側面，一般所見到熟悉的 S 曲線。

尖角突變模型的應用：臨界區座標軸的設定

尖角突變模式在應用上，如何在控制平面設定尖角的座標位置是一關鍵問題。尖角座標位置的設定決定於控制因子之間的關係。以下討論三種情形。

首先，當 a,b 兩因子間具有主從關係時，例如：系統行為基本上由 a 來決定(a 為主)，但 b 因子對 a 因子所決定的系統行為有一定的修正作用(b 為從)；不過，b 因子性質上為中性(亦即它對狀態 1 與狀態 2 具有同等影響力)。這時在 a 軸水平與 b 軸垂直的座標上，b 軸是以左右對稱的方式穿過尖角，如圖 A 所示。這種情形下，a 稱為正則因子(normal factor)；b 稱為中分因子(splitting factor)。其次，當 a,b 兩因子之間不是主從關係，而是對立的競爭關係時，則可有兩種表達方式：(1)圖 A 中的尖角不動，但將座標軸旋轉 45° ，如圖 B 所示；或(2)圖 A 中的座標軸不動，但將尖角旋轉 45°，如圖 C 所示。這種情形下，兩控制因子並稱為衝突因子(conflicting factor)，它們對系統的突變行為具有相同的影響力。



其三，若兩控制因子間雖非完全對立，但以 a 因子為主觀察時，b 因子對 a 有一定程度的相生或相剋關係時，則圖 A 中的尖角會發生偏向左側或偏向右側象限的現象。

例如，b 因子對於 a 因子發揮的是相生相成的效果——尖角將偏向左側象限（圖 D），使狀態一的範圍擴大——不僅 a 為正值的右側象限完全為狀態一，甚至 a 為負值的左側象限也有一部份成為狀態一。換言之，只要 a 為正值，狀態一必然出現；且即使 a 為負值時，狀態一仍可能出現，並且是 b 值越大，狀態一越深入 a 的負值區。反之，若 b 因子對於 a 因子所發生是相剋相抑的效果——則尖角偏向右側象限(圖 E)，狀態一的範圍被壓縮。也就是這時 a 因子對系統狀態的影響力減少。

這種情形下，a 因子稱為非對稱因子（asymmetric factor）；b 因子稱為分岔因子（bifurcation factor）。

當然如果 b 因子的相剋作用大到某個程度之後，它就會成為與 a 因子對立的競爭因子。亦即圖 E 的關係變成圖 B 或圖 C 的關係。