An Introduction to Structural Equation Modeling, Chaos Theory & Catastrophe Theory

Fundamentals and Application

By: Yu-Kai Huang

Outline

– Basic Idea of SEM
– Case Study
– Chaos Theory
– Catastrophe Theory
– Q and A

2009.04.08
Basic Idea of SEM (1/3)

• Categorical data
  – Nominal scale
  – Ordinal scale
  – Interval scale
  – Ratio scale

• Factor analysis
  – EFA & CFA

• Measure model
  – reliability
  – validity
Basic Idea of SEM (2/3)

Switching Cost → Behavior Intention

Service Value → Behavior Intention

Service Quality → Behavior Intention

Store Image → Behavior Intention

Satisfaction → Behavior Intention
Basic Idea of SEM (3/3)

Development of a Theoretical Model

Questionnaire Design and Data Select

Data Input (Sample Size and Matrix Type)

Parameter Estimation

Modification of the Model if Theoretically Justified

Final Model

References

$\chi_1 \rightarrow \lambda_4 \rightarrow \eta_1 \rightarrow \xi_1 \rightarrow \beta_1 \rightarrow \eta_2

\delta_1 \rightarrow \chi_1 \rightarrow \lambda_4

\delta_2 \rightarrow \chi_2 \rightarrow \lambda_5

\eta_1 \rightarrow \xi_1 \rightarrow \beta_1 \rightarrow \eta_2

\lambda_3 \rightarrow \eta_2

\gamma_1 \rightarrow \eta_1 \rightarrow \beta_1 \rightarrow \eta_2

\gamma_2 \rightarrow \eta_2

\eta_3 \rightarrow \zeta_3

\epsilon_1 \rightarrow y_1 \rightarrow \lambda_1 \rightarrow \eta_1 \rightarrow \beta_1 \rightarrow \eta_2

\epsilon_2 \rightarrow y_2

y_3 \rightarrow \zeta_3

x – measured independent variable
y – measured dependent variable
$\xi$ – latent exogenous construct explained by x-variables
$\eta$ – latent endogenous construct explained by y-variables
$\delta$ – error for x-variable
$\epsilon$ – error for y-variable
$\lambda$ – correlation between measured variables and all latent constructs
$\gamma$ – correlation between latent constructs $\xi$ (exogenous) and $\eta$ (endogenous)
$\phi$ – correlation between exogenous latent constructs $\xi$
$\beta$ – correlations between endogenous latent constructs $\eta$. 

$\chi_1$, $\chi_2$, $\chi_3$, $\eta_1$, $\eta_2$, $\eta_3$, $\zeta_1$, $\zeta_2$, $\zeta_3$, and $\lambda_1$, $\lambda_2$, $\lambda_3$, $\lambda_4$, $\lambda_5$ represent variables and parameters in the structural model.
Case Study – Retailing Delivery

On-line shopping ➔ Packing ➔ Delivery ➔ Pick-up points

Date (Time)
- D day
- D+1 day (00~15)
- D+1 day (16~24)
- D+2 day ~ D+9 day

Goods flow
- Information flow (upload)
- Information flow (download)

On-line shopping
- Packing
- Delivery
- Confluences
- Transportation
- Pick-up goods

Server
- (E-retailing)
- (DC-3PL)
- (DC-deliver)
- (DC-convenience store)

Server (E-map)
Server (RD provider)
Case Study – Retailing Delivery

Measure Model

Delivery service

Servicescape

Responsiveness

Order discrepancy handling

Service Quality

Satisfaction

Loyalty

Switching Cost

SAT1

SAT2

SAT3

0.59

0.62

0.57

0.72

0.42

0.15

0.45

0.60

0.32

0.53

0.52

0.60

0.58

LOY1

LOY2

LOY3

Measure Model

Measure Model

Measure Model
Logistics Service Quality Satisfaction Loyalty

0.61 (5.62)
0.85 (11.36) 0.35 (3.61)

LAT1
LAT2
LAT3

0.92 (18.3) 0.91 0.87 (15.93)

x^2/df=64.72/25
Normed fit index (NFI)=0.97
Goodness of fit index (GFI)=0.91
Adjusted goodness of fit index (AGFI)=0.93
Comparative Fit Index (CFI)=0.98

SEM Analysis

IPA Analysis

Quadrant 1 Concentrate here
IQ1
IQ2
OP1

Quadrant 2 Keep up the good wok
OC1
TI3
TI1
TI2
OC2

Quadrant 3 Low priority
ODH1

Quadrant 4 Possible overkill
ODH2
OP2

Performance
Importance

Quadrant 1 Concentrate here
Quadrant 2 Keep up the good wok
Quadrant 3 Low priority
Quadrant 4 Possible overkill
Chaos Theory (1/5)

Chaos Theory: New Frontiers of Science

A Brief Introduction

- Chaos theory finding the order in what appears to be completely random data.
- A chaotic analysis is a tool of the research of complex behavior that seems random but actually has some hidden order.
Chaos Theory (2/5)

Time series vs Parameter

Output (t+1) vs Output (t)
Chaos Theory (3/5)

Lyapunov Exponents  Butterfly effect

\[ X_{t+1} = a \cdot X_t \cdot (1 - X_t), \quad a = 4, \quad X_0 = 0.50001, \quad X_0' = 0.50003 \]

\[ \left| f^{[n]}(x + \varepsilon) - f^{[n]}(x) \right| \approx \left[ e^{\lambda(x)} \right]^n \varepsilon \]
Chaos Theory (4/5)

• 3 types of routes to chaos
  • Period doubling
  • Intermittent transition
  • Break of tours

Period doubling

Intermittent transition

Break of tours

Mirror Image
Chaos Theory (5/5)

Time series → Chaotic behavior (Random-like) → Deterministic function

Sensitive dependence to the initial conditions

Lyapunov exponents

Fractal

Fractal dimension
Catastrophe Theory (1/4)

Observe variable: $Z$ (loyalty)

Normal factor: $v$ (service quality)

Splitting factor: $u$ (switching cost)

Attractor

Repellor

Parameter space $C$

Manifold $M_f$

Path A

Path B

Path C

Path D

Path a

Path b

Path c

Path d
Path A
Path B
Path A
Path B

State Variable: x
Normal Factor: v
Splitting Factor: u

Fitting the CCM can be determined by fitting the probability density function

\[ f^* = k \cdot \exp \left[ \left( \frac{1}{4} x^4 - \frac{1}{2} u x^2 - v x \right) \right] \]
Catastrophe Theory (3/4)

The application of metaphysical uses induction method

Catastrophe Indication

Determine the Appropriate Catastrophe Model

Choose Critical Variables and Catastrophe Modelling

Fitting Catastrophe Model to Experimental Observations

Qualitative Analysis

Catastrophe flag detection (Gilmore, 1981)

System is inside the bifurcation set

- Bimodality
- Inaccessibility
- Sudden Jumps
- Hysteresis
- Divergence

The flag can be present outside the bifurcation set

- Divergence of linear response
- Anomalous variance
- Critical slowing down

7 different gradient systems (Thom, 1975)

- Fold
- Cusp
- Swallowtail
- Butterfly
- Hyperbolic
- Elliptic
- Parabolic

Determine the two sets of variables

- Behavioural variables
- Control variables (normal factor & splitting factor)

3 approaches to estimate catastrophe models

- The method of Cobb (Cobb, 1978)
- The method of Guastello (Guastello, 1982)
- GEMCAT (Oliva et al., 1987)

Catastrophe model dynamic analysis

Data collection

Multiplication regression (SEM)

Choose control variables

Cross section data

Time series data
Catastrophe Theory (4/4)

End of document.