# 國立交通大學

## 資訊管理研究所

## 博 士 論 文

國家競爭力的規則推導與呈現

**INDUCTION AND DISPLAYING OF RULES FOR NATIONS' COMPETITIVENESS**

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# 國家競爭力的規則推導與呈現

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## 摘　要

國家競爭力對形成政府策略與經濟發展日益重要。國家競爭力的規則推導與呈現，可做為經濟政策的制定與驗證的輔助。本研究基於 MCI-WCY 提出最佳化的模型，在 14 支指標中推導競爭力的層級規則，並將規則以‘IF-THEN’的格式表達 2001~2005 期間競爭力的型態，如進步型與退步。所推導的規則並可透過多元尺度法呈現在球上，提供使用者觀察國家在競爭力的分佈。最後，我們根據這些推導出來的規則，提出國家群組改進或維持競爭力的策略。

**關鍵字**：國家競爭力，規則推導，世界競爭力年鑑的主要競爭力指標 （MCI-WCY），最佳化，多元尺度法 (MDS)

# INDUCTION AND DISPLAYING OF RULES FOR NATIONS' COMPETITIVENESS

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## ABSTRACT

A nation's competitiveness becomes more and more important in forming government strategy and economic development. Induction and displaying of rules for national competitiveness is helpful in making and verifying economic policy. This study proposes an optimization model to generate rules for competitiveness classes based on 14 Major Competitiveness Indicators of World Competitiveness Yearbook. The obtained rules are composed of 'IF…THEN' format to imply dynamic competitiveness during 2001 ~ 2005. The implied types such as improving and depressing are helpful in understanding competitiveness changes of nations. Furthermore, the groups of nations are displayed on spheres based on the dissimilarity among nations. It helps users to observe visually the distribution of nations. Finally, we suggest the strategic implications for various groups of nations to improve or to sustain their competitiveness according to the induced rules.

**Keywords**: Nations' competitiveness; rule induction; Major Competitiveness Indicators of World Competitiveness Yearbook (MCI-WCY); optimization, multidimensional scaling (MDS)

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# Chapter 1 Introduction

## 1.1 Research Background

After long competition among nations, some nations have stayed highly competitive (for example the USA), or have stayed as highly non-competitive (for example ARGENTINA) [Feldstein, 2002]. Some have grown more competitive (for example MAINLAND CHINA) [Adams, 2006], while others have lost their competitiveness (for example ITALY) [Mascitelli, 2008]. Several attributes (such as export, inflation, unemployment, etc) may affect nations' competitiveness. This study, based on these attributes, induces the essential rules of explaining nations' competitiveness. The induced rules can be utilized to suggest possible strategies for a nation to improve its competitiveness. Some queries this study intends to answer are: "What are the most critical attributes of nations' competitiveness?", "If a nation wants to keep a high competitive level, what does it need to do?", "What are the essential attributes to be careful of if a nation wants to upgrade from a lower to a higher competitive position?", and "Which attributes restrict the progress of a less competitive nation?".

IMD (International Institute for Management and Development) is one of the most well-known research institutions of world competitiveness. Since 1989, IMD published World Competitiveness Yearbook (WCY), which has attracted considerable attentions from government and industries. Most of current researches based on WCY data set, however, cannot answer directly the queries as 'Why have some nations kept as highly competitive while some have stayed as highly non-competitive?', 'Why have some nations grown more competitive while others have lost their competitive?', and 'How the nations in various groups improve their competitiveness?'. Four reasons why current studies cannot be answered are [Zanakis, 2005; Oral 1996]:

(i) Too many attributes have been used. Current studies used the whole WCY data set (300 attributes) to do analysis. Since numerous attributes are strongly collinear with each other, it is difficult to find significant attributes to represent the competitiveness function by using traditional techniques such as regression analysis and neural network techniques. In addition, the quality of these 300 attributes is different from each other. Thus, it is not proper to treat them equally.

(ii) Lack of dynamic analysis. It is hard to have consistent data over a series of time based on 300 attributes of WCY. Current studies therefore did not perform dynamic analysis of competitiveness over time, which results in difficulty in answering the queries mentioned above.

(iii) Difficulty in inducing general rules. Some current studies have used regression and neural network techniques to find the factors of competitiveness. Parts of specific rules may be observed from simple regression results in small sectors (such as a rule that covers a few nations). However, it is difficult to induce general rules from a set of regression equations, since there are too many combinations that make possible rules [Zanakis 2005, Oral 1996]

(iv) Difficulty in explaining competitiveness groups. Decision tree is a widely used method to induce rules in many applications. However, its interpreting capability may suffer from too many branches when it is applied to national competitiveness. The decision tree method expands many branches due to multiplication of the number of attribute values and competitiveness levels. The more branches, the less nations are covered in a branch, i.e. the less interpreting capability it can have [Zanakis 2005; Quinlan 1986, 1993]

## 1.2 Current Approaches of Competitiveness Analysis

Two systematic approaches of analyzing national competitiveness are discussed below.

1. Ranking competitiveness: IMD is the representative that provides competitiveness scores for an individual nation by hierarchically and linearly aggregating more than 300

attributes. However, there are too many attributes to imply characteristics of competitiveness. Neither does it provide nation groups to illustrate competitiveness differentiation [IMD 2001, 2003, 2005].

2. Classifying competitiveness: Porter classifies nations into classes based on citizen's income capability and identifies significant attributes for each class. The classes are implied with labor intensity, efficiency, and innovation for economic development of nations. However, the income is not the only attribute to influence a nation's competitiveness. The income classes are not sufficient to make or verify competitiveness policy (Poter 2005; Garelli 2003).

Progressing into a higher class, preventing fall into a lower one, and sustaining his or her nation within a class are foci of competitiveness concerns. Either approach above only provides partial solutions. For instance, the former does not provide implications for competitiveness classes i.e. short of capability to clearly tell the competitiveness differentiation. This part, however, is important for competitiveness strategies. The later provides income classes that may not be considered as competitiveness classes. Following WCY [Garellie, 2003], national competitiveness is not necessary for wealth, power, and economic performance of a nation, which is explained below.

- A nation's competitiveness is not necessarily an indicator of wealth. Wealth can be the result of past competitiveness, for example due to accumulated capital and knowledge (such as the European industrialized nations). Wealth may also be in natural resources ready to be exploited (such as in oil-producing nations). As a consequence, a nation can be wealthy but not competitive.
- A nation's competitiveness is not necessarily an indicator of power. Since power can be the result of a combination of wealth and size (such as Japan which is not necessarily as competitive as it is powerful).

- A nation's competitiveness is not necessarily an indicator of economic performance. Since economic performance focuses on added value over the short-term (commonly expressed as GDP growth), it does not take into account the depletion of non-renewable capital (such as natural resources), the volatility of the economy, and the impact of non-tangibles (such as education, research, etc).

In this research we intend to identify significant attributes for competitiveness classes and dynamic change that nations evolve during 2001~2005.

## 1.3 Research Goal and Proposed Approach

The goal of this study aims to induce rules for competitiveness classification then find competitiveness types consist of classes during 2001 ~ 2005. A displaying sphere is proposed to help users to visually catch differentiation between competitiveness rules. Finally, the strategic implications are suggested for improving to higher competitive classes, preventing fall in competitiveness, and sustaining within a class. Figure 1.1 illustrates the approach. Users can realize competitiveness classes with 'IF...THEN' statements. The features of the study are listed below.

- The competitiveness scores are used to separate nations into classes by the K-mean method on competitiveness scores. Following Ulengin (2002), these classes are named as highly competitive ($G_4$), competitive ($G_3$), non competitive ($G_2$), and least competitive ($G_1$). The competitiveness scores of nations in classes follow the relation as $G_4 \geq G_3 \geq G_2 \geq G_1$. The details of implementation are described in Appendix A.
- A high quality and precise MCI-WCY data set, the so-called Major Competitiveness Indicators (MCI) is used, instead of a large WCY data set. The data set contains the 14 most reliable and consistent attributes, which covers 46 nations and 3 time periods (2001, 2003, 2005). They are analyzed for class implications, which are described next.
- An optimization model, instead of regression analysis and neural network techniques, is

proposed to induce general rules for competitive classes. These induced rules, expressed in ‘IF...THEN’ form, contain the essential attributes only, especially since they are formulated with conjunctive and disjunctive terms that increase flexibility when analyzing the complexity of competitiveness attributes.

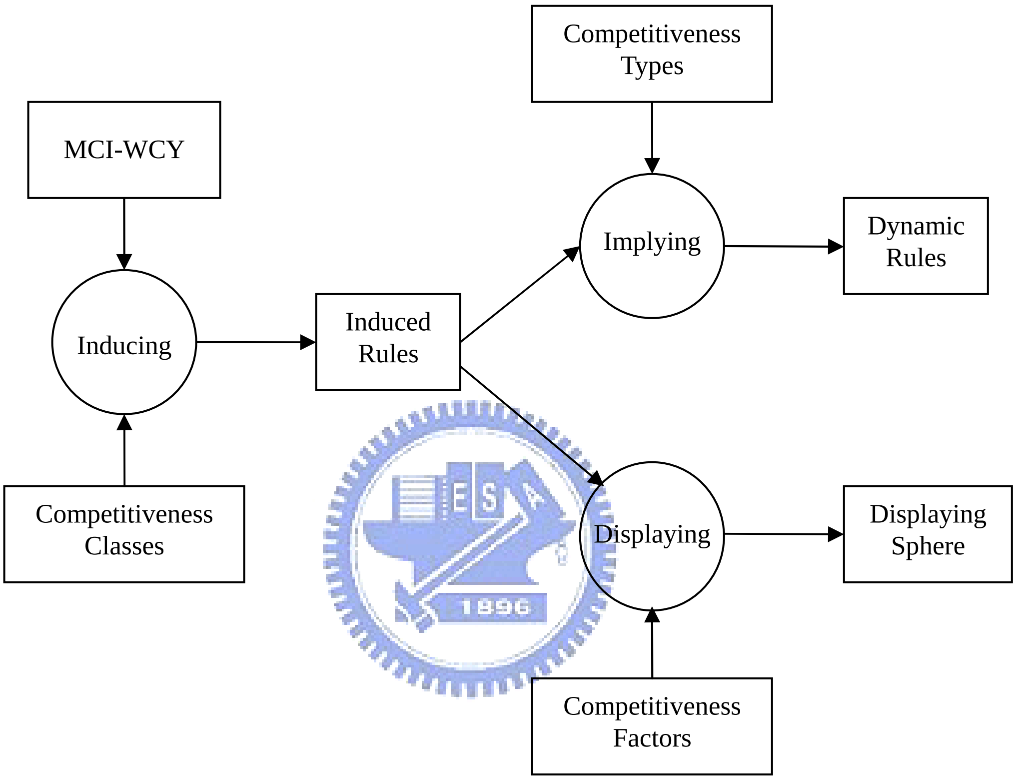



Figure 1.1: The process of approach

- Some competitiveness types labeled by such terms as upward, downward, and sustaining are formed with dynamic classes, which are helpful to realize dynamic change of nations. Figure 1.2 shows construction of competitiveness types based on classes where $G_i$, $G_j$, and $G_k$ classes are relative to the year 2001, 2003, and 2005. Finally, we answer our target queries listed above with the implications of these types.

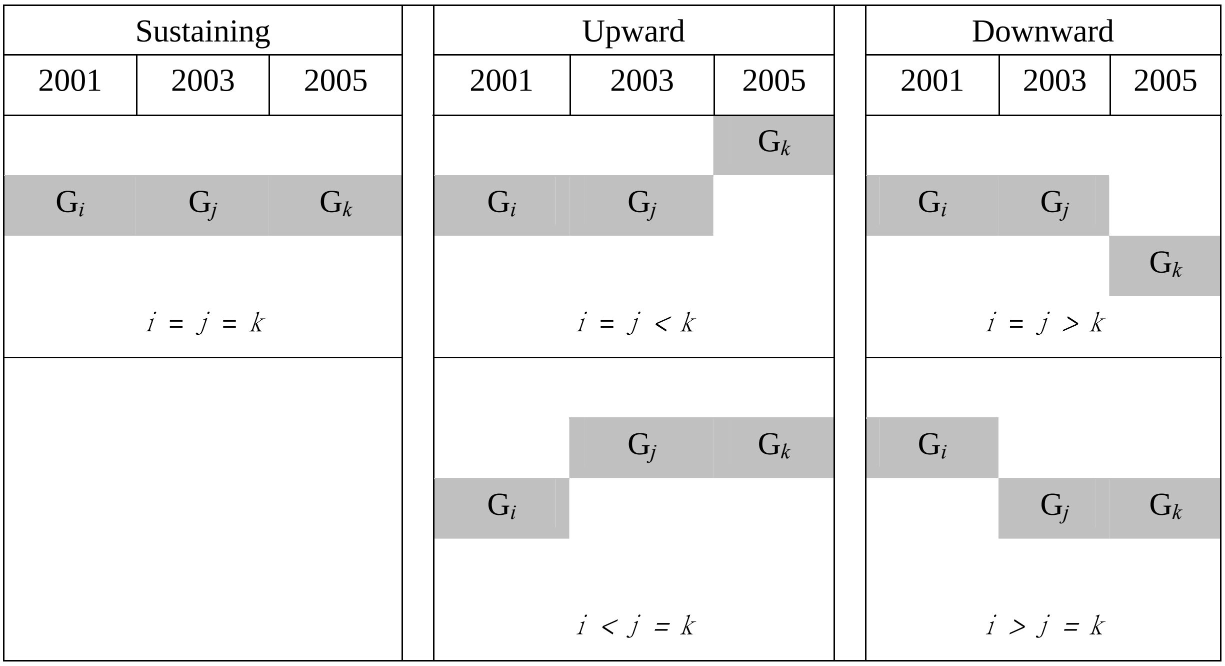



Figure 1.2: Competitiveness types of a nation's change during 2001~2005

- A displaying model is designed to transform nations with 4 consolidated competitiveness factors, government efficiency, economic efficiency, business efficiency, and infrastructure onto the surface of a sphere. Nations covered by an induced rule are located locally on a surface area of the sphere, which is presented in a conceptual sphere in Figure 1.3. Users can catch nations' differentiation by visual distance transformed from dissimilarity between nations. They can also find competitiveness direction by comparing with the top nation. Technically, the transformation is implemented by combining Multidimensional Scaling (MDS) and Integer Programming (IP) to make display available, which is described in Chapter 5.

- MDS is applied to transform high dimensional configuration to lower dimensions. After implementation, each nation is located at a point with 3 coordinates on a sphere. Users can see areas of surface to get the image of a rule.

- Integer Programming (IP) is applied to MDS computation to get optimal solutions.

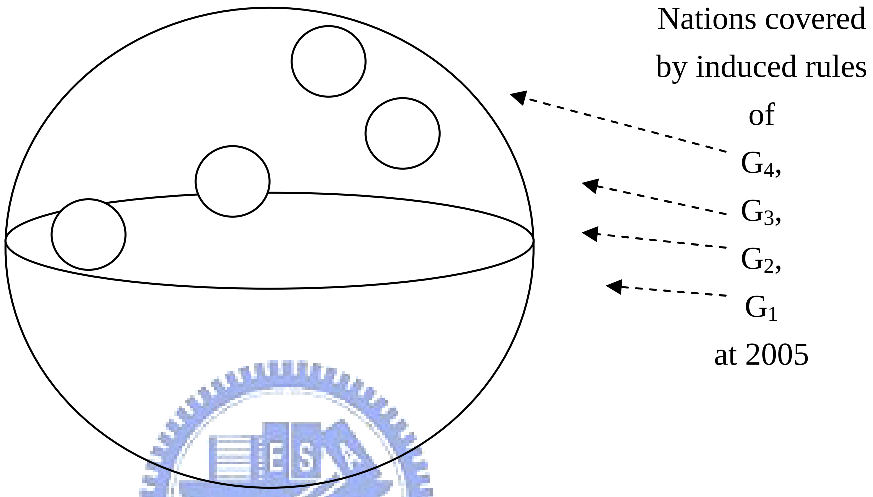



Figure 1.3: A conceptual sphere for 2005

## 1.4 Advantages of Proposed Approach

Our displaying sphere shows the competitiveness differentiation between nation groups and gives visual help for economic decision policy. Decision makers can realize the differentiation in terms of induced rules. The induced rules will respond to following typical queries about nations' competitiveness such as: (a) What are the most critical attributes of affecting the competitiveness? (b) If a nation (such as the USA or SINGAPORE) wants to keep at a highly competitive level, what do they need to do? (c) What are the essential attributes to care about if a nation wants to upgrade from a lower to a higher class? (d) Which attributes restrict the progress of a less competitive nation?

The induction rules have following features:

(i) The rules are expressed in 'IF...THEN' statement with conjunction and/or disjunction description.

(ii) Two criteria of a quality rule are used: the accuracy rate (AR) and the coverage rate (CR) (Pawlak 1999). A representative rule of a specific class should have high AR and CR. Such a rule should be supported by most nations within the same class and not cover nations in other classes.

(iii) The rules are induced by using the mixed 0-1 linear programming. The objective is to maximize AR and CR values. Globally optimal solutions are guaranteed.

## 1.5 Structure of the Dissertation

This paper is organized below. Chapter 2 discusses the MCI-WCY data set and the competitiveness types. Chapter 3 includes the data notation and rule propositions for induction. Chapter 4 presents induction rules and dynamic rules during 2001~2005. Chapter 5 proposes a displaying model for induced rules and showing differentiation by class nations. Chapter 6 compares the decision tree ID3 and the proposed method. Finally, concluding remarks discuss the results of this research and future work.

# Chapter 2 WCY Data Set and Literature Review

## 2.1 Specification of Nations' Competitiveness

Following WCY (Garelli, 2003), nations' competitiveness is defined as a measurement of each nation's ability to create and maintain an environment that sustains more value creation for its enterprises and more prosperity for its people. WCY divides the nations' competitiveness into four factors: economic performance, government efficiency, business efficiency, and infrastructure. More than 300 attributes are used together to represent these four factors. All these 300 attributes have the same weight in the overall consolidation of results, which lead to the overall ranking of nations. The WCY provides a competitiveness score for each nation by synthesizing all collected information into a few factors (IMD 2001, 2003, 2005).

## 2.2 Major Competitiveness Indicators (MCI-WCY)

MCI are selected by the WCY to analyze the performance of each nation independently of the others. They best reflect the changes in quantitative data over time. Their evolution in time series portrays competitiveness trends and how the nations compete in world market. The contents of these attributes are listed in Table 2.1.

## Table 2.1: Major Competitiveness Indicators (MCI) of WCY

| Symbol | Attributes | Abbreviation | Description | Units |
|---|---|---|---|---|
| $a_1$ | EXPORT OF GOODS & OF COMMERCIAL SERVICES | Export | Exports summation of goods and commercial services (calculated by per million population) | US$ billions |
| $a_2$ | COMPUTERS PER CAPITA | Computer | The average computers for any given 1000 people. | Number |
| $a_3$ | GDP PER CAPITA | GDP | Gross Domestic Product per person | US$ |
| $a_4$ | LISTED DOMESTIC COMPANIES | Company | The number of domestically incorporated companies listed on the country's stock exchanges at the end of the year | Number |
| $a_5$ | STOCK MARKET CAPITALIZATION | Stock | The value of all the stocks traded on a specific stock exchange (calculated by per million population) | US$ billions |
| $a_6$ | COMPENSATION LEVELS | Salary | Total hourly compensation for manufacturing workers (wages plus supplementary benefits) | US$ |
| $a_7$ | OVERALL PRODUCTIVITYS | Productivity | GDP per person employed | US$ |
| $a_8$ | CONSUMER PRICE INFLATION | Inflation | Average annual rate; the price increases as measured by the consumer price Indicators (CPI), which reflects the prices of a representative basket of consumer goods and services. | % |
| $a_9$ | UNEMPLOYMENT RATE | Unemployed | the ratio of the number of unemployed workers divided by the total civilian labor force | % |
| $a_{10}$ | DIRECT INVESTMENT FLOWS INWARD | Invest –in | Foreign direct investment flows inward (calculated by per million population) | US$ billions |
| $a_{11}$ | DIRECT INVESTMENT FLOWS ABROAD | Invest-out | Direct investment flows toward oversea, calculated by per million population | US$ billions |
| $a_{12}$ | REAL GDP GROWTH | GDP growth | A measure of the annual percent change in the level of production achieved in a given country as measured in constant prices | % |
| $a_{13}$ | CURRENT ACCOUNT BALANCE | Balance | The difference between a country's savings and its investment. If positive, the portion of a country's saving invested abroad; if negative, the portion of domestic investment financed by foreigners' savings (calculated by per million population) | US$ billions |
| $a_{14}$ | PRIVATE FINALCONSUMPTION EXPENDITURE PER CAPITA | Consumption | Household final consumption expenditure and final consumption expenditure of non-profit institutions serving households, incurred by resident on individual consumption goods and services | US$ |

## 2.3 MCI-WCY Data Set

Our research data comes from the data set of Major Competitiveness Indicators (MCI) in WCY for 2001, 2003, and 2005. The MCI-WCY data set covers 14 major competitiveness attributes for 46 nations from 2001 to 2005 (Table B.1, B.2, and B.3 of Appendix B) These data sets are the most continued, consistent, and reliable data chosen from MCI-WCY.

In order to induce rules of competitiveness, we need to convert the data set in Appendix B into discretized codes. Each attribute is divided into four levels: very high, high, medium, and low according to the value domain of that attribute. An equal frequency of nations in each $a_i$ level is adopted to implement the division, described in Appendix C. Following competitiveness classes in Phase (i) we divide 46 nations into 4 classes. The MCI-WCY data set in Table B.1, B.2, and B.3 of Appendix B are then converted respectively into Table D.1, D.2, and D.3 of Appendix D. Take USA in 2001 (in Table B.1) for instance, the $a_2$ value is 580.5 and the overall score is 100. Since such a $a_2$ value belongs to level 4 (according to the standard in Appendix C), we then denote $a_2 = 4$ at Table D.1.

## 2.4 Consolidated Competitiveness Factors

WCY divides national environment into 4 factors based on analysis of leading scholars and their own research and experience. Each factor has 5 sub-factors which highlight every facet of the areas analyzed. These 20 sub-factors comprise more than 300 criteria. The criteria may be hard data like GDP or soft data like manager ability, which all have same weight to its sub-factor. Finally, these 20 sub-factors are aggregated to make the total consolidation, which leads to the overall ranking of the WCY. The description of factors is listed in Table 2.2. The data set of the factors is listed in Appendix E.

**Table 2.2: Consolidated competitiveness factors**

| Symbol | Factors | Description |
|---|---|---|
| $f_1$ | government efficiency | Extent to which government policies are conductive to competitiveness. |
| $f_2$ | economic performance | Macro-economic evaluation of the domestic economy |
| $f_3$ | business efficiency | Extent to which enterprises are performing in an innovative, profitable, and responsible manner. |
| $f_4$ | infrastructure | Extent to which basic, scientific, and human resources meet the needs of business. |

## 2.5 Competitiveness Types for Nations

Examining the change of a nation's classes for years of 2001, 2003, and 2005, we may classify the 46 nations into 4 types and 18 groups as shown in Table 2.3 in the following ways.

(i) A nation is in group $G_{ijk}$, if the nation belongs to $i$, $j$, and $k$ class in the year 2001, 2003, and 2005 respectively.

(ii) If $i = j = k$ then $G_{ijk}$ belongs to a sustaining type. There are 27 nations in this type. For instance, the USA belongs to $G_{444}$ and INDONESIA belongs to $G_{111}$.

(iii) If $i < j = k$ or $i = j < k$ then $G_{ijk}$ belongs to an upward type. Only three nations are included in this type, where TAIWAN is $G_{334}$, THAILAND is $G_{122}$ and INDIA is $G_{112}$.

(iv) If $i > j = k$ or $i = j > k$ then $G_{ijk}$ belongs to a downward type. Seven nations are included in this type.

(v) If $i > j < k$ or $i < j > k$ then $G_{ijk}$ belongs to a mixed type. For instance, CHILE belongs to the $G_{323}$ and MALAYSIA belongs to $G_{232}$.

**Table 2.3 Competitiveness types of 46 nations**

| Types | Groups | Nations | Number |
|---|---|---|---|
| Sustaining type | $G_{444}$ | CANADA, DENMARK, FINLAND, HONG KONG, ICELAND, NETHERLANDS, SINGAPORE, SWEDEN, SWITZERLAND, USA, AUSTRALIA, LUXEMBOURG | 12 |
| | $G_{333}$ | BELGIUM, NEW ZEALAND, NORWAY, UNITED KINGDOM | 4 |
| | $G_{222}$ | MAINLAND -CHINA, CZECH REPUBLIC, HUNGARY, KOREA | 4 |
| | $G_{111}$ | ARGENTINA, INDONESIA, PHILIPPINES, POLAND, RUSSIA, TURKEY, VENEZUELA | 7 |
| Upward type | $G_{334}$ | TAIWAN | 1 |
| | $G_{122}$ | THAILAND | 1 |
| | $G_{112}$ | INDIA | 1 |
| Downward type | $G_{443}$ | AUSTRIA | 1 |
| | $G_{433}$ | GERMANY | 1 |
| | $G_{332}$ | FRANCE | 1 |
| | $G_{322}$ | SPAIN | 1 |
| | $G_{221}$ | ITALY | 1 |
| | $G_{211}$ | BRAZIL, MEXICO, GREECE | 3 |
| Mixed type | $G_{434}$ | IRELAND | 1 |
| | $G_{323}$ | ISRAEL, CHILE, JAPAN | 3 |
| | $G_{232}$ | MALAYSIA | 1 |
| | $G_{212}$ | PORTUGAL | 1 |
| | $G_{121}$ | COLOMBIA, SOUTH-AFRICA | 2 |

## 2.6 Review of Literatures of WCY Data Set

WCY data set has been widely used in ranking nations' competitiveness and in forming nations' strategy for development. Some studies based on WCY data set with 300 attributes are given below.

(i) Au (2006) used the WCY as a data set for finding plant locations for Hong Kong clothing suppliers. His results showed that China, Pakistan, India, Thailand, and Sri Lanka are the most prosperous locations (Au 2006).

(ii) Zanakis and Becerra-Fernandez (2005), based on WCY data sets, used data mining and multivariate statistical techniques to identify important factors associated with a nation's competitiveness. In their validation of methods, the stepwise regression had the best average minimum square error (MSE) and the best mean absolute error (MAE); while classification tree and regression (CART) performed the poorest (Zanakis 2005).

(iii) Pistorius (2001) used WCY rating and competitiveness factors to address the fact that SOUTH AFRICA's weak competitiveness was a threat to its national security. Following analytical results from the WCY, he proposed ways to improve innovation in raising SOUTH AFRICA's competitiveness in the future (Pistorius 2001).

(iv) Sheng (1999) used the WCY data set to discover that CHINA had a less certain economy, which was still far from controlling or dominating market and industries. He then proposed that CHINA and the UNITED STATES could cooperate as strategic partners, which might fit the UNITED STATES' long-term national interests (Sheng 1999).

(v) Oral and Chabchoub (1996) used WCY methodology and data sets to simulate competitiveness score and ranks. However, they could not reproduce results like those in the WCY.

# Chapter 3 The Proposed Method for Inducing Competitiveness Rules

Our method reduces competitiveness attributes into a subset that can be used to discriminate classes. It generates a rule in terms of binary operations which approximate to a certain degree of covering nations within a class and discriminating nations in the other classes. The operation is built on matching attribute values between the rule and nations. Binary variables are designed for covered and discriminated nations with 0 and 1. A sum of binary variables within a class and another sum of binary variables in the rest of classes are used for a rule's quality parameters. The ratios of the sums to the number of their respective nations are used as quality measurement for a rule. Since the obtained rules are presented by 'IF…THEN' format, users can easily tell the discrimination between classes.

The rule and data set are reformatted for matching operations described in Section 3.1, which presents a rule and data set with binary bits. Section 3.2 proposes the binary matching operations and the approximation degree of covered nations. Section 3.3 applies integer programming to implement the matching operations in Lingo 10. Followings include the proposed method and models.

## 3.1 Presentation of Data and Rules

Here we use the example 1 to illustrate the way of presenting the data and rules. Consider a sample data set in Table 3.1 with 5 nations ($N_1$, $N_2$, $N_3$, $N_4$, $N_5$), three attributes ($a_1$, $a_2$, $a_3$) and one class Indicators $g$. The domain values of $a_1$, $a_2$, and $a_3$ are {1, 2, 3}, {1, 2}, and {1, 2, 3, 4}. The domain value of $g$ is {1, 2, 3}.

**Table 3.1: Example 1 of presentation**

| | $a_1$ | $a_2$ | $a_3$ | g |
|---|---|---|---|---|
| $N_1$ | 2 | 1 | 3 | 1 |
| $N_2$ | 3 | 2 | 3 | 2 |
| $N_3$ | 2 | 2 | 1 | 2 |
| $N_4$ | 3 | 1 | 4 | 3 |
| $N_5$ | 1 | 1 | 2 | 3 |

Table 3.1 is firstly converted into a new one presented by binary values as shown in Table 3.2. Here $a_{jp}$ is called a sub-attribute of attribute $a_j$. A nation $N_i$ of the class $k$ is expressed as

$$N_i = (a^i_{11}, a^i_{12}, a^i_{13}; a^i_{21}, a^i_{22}; a^i_{31}, a^i_{32}, a^i_{33}, a^i_{34}), \quad g_i = k \qquad ------------------(3.1)$$

For instance, $N_1$ is expressed as $N_1$=(0,1,0;1,0;0,0,1,0) and $g_1$=1.

Denote $R_l(k)$ as $l^{\text{th}}$ rule of classifying $k^{\text{th}}$ class can be expressed as a binary vector below

$$R_l(k) = (d^l_{11}, d^l_{12}, d^l_{13}; d^l_{21}, d^l_{22}; d^l_{31}, d^l_{32}, d^l_{33}, d^l_{34}) \qquad ------------------(3.2)$$

***where***

$d^l_{jp} = 1$, ***if sub-attribute*** $a_{jp}$ ***is chosen in*** $l^{th}$ ***rule.***

$d^l_{jp} = 0$, ***if sub-attribute*** $a_{jp}$ ***is not chosen in*** $l^{th}$ ***rule.***

Such an expression is very useful in expressing rules in conjunction and disjunction forms.

For a data set containing $n$ nations, $m$ attributes where each attribute $a_j$ having q($j$) levels. Consider the following notations and remarks.

**Notation 1:**

A general form for expressing a nation $N_i$ of group $k$ is written as

$$N_i = (\, a^i_{11}, a^i_{12} \ldots a^i_{1q(1)} \;;\; a^i_{21} \ldots a^i_{2q(2)} \;;\ldots;\, a^i_{m1} \ldots a^i_{mq(m)}), \quad g_i = k,\; a_{jp} \in \{0,1\} \quad -------(3.3)$$

A general form for expressing a nation $N_r$ not in group k is written as $N_r = (a^r_{11}, a^r_{12} \ldots a^r_{1q(1)}\ ;\ a^r_{21} \ldots a^r_{2q(2)}\ ; \ldots ; a^r_{m1}\ \ldots\ a^r_{mq(m)}),\ g_r \neq k,\ a_{jp} \in \{0,1\}$ ------(3.4)

**Notation 2:** A general form of expressing a rule $R_l(k)$, the rule of classifying $k^{\text{th}}$ group, is expressed as

$$R_l(k) = (d^l_{11}, d^l_{12} \ldots d^l_{1q(1)}\ ;\ d^l_{21} \ldots d^l_{2q(2)}\ ; \ldots ; d^l_{m1}\ \ldots\ d^l_{mq(m)}),\ d_{jp} \in \{0,1\} \quad \text{--------(3.5)}$$

**Remark 3.1:**

(i) If $j$ is an ignored attribute for $R_l(k)$, then $d^l_{jp} = 0$ for all $p$

(ii) If $jp$ is an active sub-attribute for $R_l(k)$, then $d^l_{jp} = 1$

Situation (i) is for a case when a rule can be expressed compactly by a fewer number of attributes. Situation (ii) is for a case where the disjunction expression is used for an attribute.

**Table 3.2: Binary values converted from data set of Example 1**

| $N_i$ | $a_1$ | | | $a_2$ | | $a_3$ | | | | $g_i$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | $a_{11}$ | $a_{12}$ | $a_{13}$ | $a_{21}$ | $a_{22}$ | $a_{31}$ | $a_{32}$ | $a_{33}$ | $a_{34}$ | |
| $N_1$ | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 |
| $N_2$ | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 2 |
| $N_3$ | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 2 |
| $N_4$ | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 3 |
| $N_5$ | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 3 |

For a small example in Table 3.2, we can list intuitively related classification rules expressed in Table 3.3 and 3.4, the mathematical model of inducing these rules is described later. For instance, the first rule for group 2 is expressed as $R_1(2) = (0,0,0;0,1;0,0,0,0)$ which means that 'if $a_2 = 2$ then the nation belongs to group 2'. Such a rule is supported by two nations $N_2$ and $N_3$. In Table 3.4, two criteria AR (accurate rate) and CR (coverage rate) are used to measure the quality of a rule. The definitions and meanings of AR and CR will be discussed later.

**Table 3.3: Binary codes of rules of Example 1**

| *Rule* | $d_{11}$ | $d_{12}$ | $d_{13}$ | $d_{21}$ | $d_{22}$ | $d_{31}$ | $d_{32}$ | $d_{33}$ | $d_{34}$ |
|---|---|---|---|---|---|---|---|---|---|
| $R_1(1)$ | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| $R_2(1)$ | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| $\mathrm{R}_1(2)$ | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| $R_2(2)$ | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| $R_3(2)$ | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| $R_1(3)$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| $R_2(3)$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| $R_3(3)$ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |

**Table 3.4: Meaning of rules of Example 1**

| Rules | Meaning | Supporting nations | AR (accurate rate) | CR (coverage rate) |
|---|---|---|---|---|
| $R_1(1)$ | If ($a_1$=2) and ($a_2$=1) then $g$ = 1 | $N_1$ | *1* | *1* |
| $R_2(1)$ | If ($a_1$=2) and ($a_3$=3) then $g$ = 1 | $N_1$ | *1* | *1* |
| $\mathrm{R}_1(2)$ | If ($a_2$ = 2) then g=2 | $N_2$ , $N_3$ | *1* | *1* |
| $R_2(2)$ | If ($a_1$ = 3) then g=2 | $N_2$ | *1* | *0.5* |
| $R_3(2)$ | If ($a_3$ = 1) then g=2 | $N_3$ | *1* | *0.5* |
| $R_1(3)$ | If ($a_3$ = 2) then $g$ = 3 | $N_5$ | *1* | *0.5* |
| $R_2(3)$ | If ($a_3$ = 4) then $g$ = 3 | $N_4$ | *1* | *0.5* |
| $R_3(3)$ | If ($a_3$ = 2 or 4) then $g$ = 3 | $N_4$, $N_5$ | *1* | *1* |

Examining Table 3.4 to know the followings:

(i) There may be more than one classification rule for a specific group. For instance, both $R_1(1)$ and $R_2(1)$ are used to classify the 1st group.

(ii) A rule with more supporting nations is better than the rule with less supporting nations. For instance, $R_1(2)$ is better than $R_2(2)$.

(iii) A rule may be obtained by integrating related rules, thus having more supporting nations. For instance, $R_3(3)$ is the union of $R_1(3)$ and $R_2(3)$, which is supported by more nations than $R_1(3)$ and $R_2(3)$.

(iv) The rules can be expressed in both conjunction and disjunction form. For instance, $R_3(3)$ is expressed in disjunction form while $R_1(3)$ and $R_2(3)$ are in conjunction form.

## 3.2 Propositions

**Proposition 3.1:** For the rule $R_l(k)$,

(i) If nation $i$ in class $k$ supports $R_l(k)$ then

$$\sum_p a^i_{jp} d^l_{jp} = 1 \ \textbf{\textit{for all}}\ j \ \textbf{\textit{where}} \sum_p d^l_{jp} \geq 1 \quad \text{------------------------------------} (3.6)$$

Otherwise the nation $i$ does not support the rule $R_l(k)$.

(ii) If nation $r$ not in class $k$ is not discriminated by $R_l(k)$ then

$$\sum_p a^r_{jp} d^l_{jp} = 1 \ \textbf{\textit{for all}}\ j \ \textbf{\textit{where}} \sum_p d^l_{jp} \geq 1 \quad \text{------------------------------} (3.7)$$

Otherwise the nation $r$ supports the rule $R_l(k)$.

Take Table 3.4 for instance, inducible $R_1(1)$ is supported by $N_1$.

**Proposition 3.2:** For the rule $R_l(k)$, $R_l(k) = (d^l_{11}, \ldots, d^l_{mq(m)})$ described in Proposition 3.1, some attributes can be ignored to simplify the expression. If there are h attributes being ignored in $R_l(k)$ then

$$(\boldsymbol{i})\sum_{j=1}^{m}\sum_{p} a_{jp}^{i} d_{jp}^{l} = m-h \qquad \text{------------------------------}(3.8)$$

$$\textbf{\textit{for some }} i \textbf{\textit{ supporting the rule where }} g_i = k,$$

$$\textbf{\textit{which also means }} i \textbf{\textit{ is covered by the rule}}$$

$$(\boldsymbol{ii})\sum_{j=1}^{m}\sum_{p} a_{jp}^{r} d_{jp}^{l} \le m-h-1 \qquad \text{------------------------------}(3.9)$$

$$\textbf{\textit{for some }} r \textbf{\textit{ supporting the rule where }} g_r \ne k$$

Take the rule $R_1(1)$ in Table 3.3 for instance to check proposition 3.2, here $d_{12} = d_{21} = 1$ and the number of attributes with $\sum_{p} d_{jp}^{l} = 0$ is 1. That means $m$=3 and $h$=1. It is convenient to check that

$$
\begin{aligned}
&(\boldsymbol{i}) \quad a_{12}^{1}d_{12} + a_{21}^{1}d_{21} = 2 \;\; \textbf{\textit{for}} \;\; N_1 \\
&(\boldsymbol{ii}) \quad a_{12}^{2}d_{12} + a_{21}^{2}d_{21} = 0 \le 1 \;\; \textbf{\textit{for}} \;\; N_2 \\
&\qquad a_{12}^{3}d_{12} + a_{21}^{3}d_{21} = 1 \le 1 \;\; \textbf{\textit{for}} \;\; N_3 \\
&\qquad a_{12}^{4}d_{12} + a_{21}^{4}d_{21} = 1 \le 1 \;\; \textbf{\textit{for}} \;\; N_4 \\
&\qquad a_{12}^{5}d_{12} + a_{21}^{5}d_{21} = 1 \le 1 \;\; \textbf{\textit{for}} \;\; N_5
\end{aligned}
$$

Similarly, checking a union rule $R_3(3)$ where $d_{32} = d_{34} = 1$ and the number of attributes with $\sum_{p} d_{jp}^{l} = 0$ is 2, will have the following results :

$$
\begin{aligned}
&(\boldsymbol{i}) \quad a_{32}^{4}d_{32} + a_{34}^{4}d_{34} = 1 \;\; \textbf{\textit{for}} \;\; N_4 \\
&\qquad a_{32}^{5}d_{32} + a_{34}^{5}d_{34} = 1 \;\; \textbf{\textit{for}} \;\; N_5 \\
&(\boldsymbol{ii}) \quad a_{32}^{1}d_{32} + a_{34}^{1}d_{34} \le 0 \;\; \textbf{\textit{for}} \;\; N_1 \\
&\qquad a_{32}^{2}d_{32} + a_{34}^{2}d_{34} \le 0 \;\; \textbf{\textit{for}} \;\; N_2 \\
&\qquad a_{32}^{3}d_{32} + a_{34}^{3}d_{34} \le 0 \;\; \textbf{\textit{for}} \;\; N_3
\end{aligned}
$$

We then have the following remark:

**<u>Remark 3.2</u>:**

A $N_i$ where $g_i = k$ is said to 'support' a rule $R_l(k)$ if $N_i$ fits the condition (i) of proposition 3.2.

A $N_r$ where $g_r \neq k$ is said to 'not support $R_l(k)$' if $N_r$ fits condition (ii) of proposition 3.2.

Here we specify binary variable $u_i$ and $v_r$ defined as below:

- $\boldsymbol{u}_i = 1$ if a nation $N_i$ supports $R_l(k)$, covered by $R_l(k)$, where $g_i = k$; otherwise $u_i = 0$.
- $\boldsymbol{v}_r = 1$ if a nation $N_r$ support $R_l(k)$, not covered by $R_l(k)$, where $g_r \neq k$; otherwise $v_r = 0$.

**Proposition 3.3**

For a rule $R_l(k)$ and $n$ nation $N_1, N_2, N_3, \ldots, N_{\mathrm{n}}$, there exists $u_i$ and $v_r$ for satisfying following inequalities.

$$(i)\ \ n(\boldsymbol{u}_i - 1) + m - \boldsymbol{h} \leq \sum_{j=1}^{m}\sum_{p} a^{i}_{jp} d^{l}_{jp} \leq m - h + n(1 - \boldsymbol{u}_i) \quad --------------(3.10)$$

$$\textbf{\textit{for all}}\ \ i\ \textbf{\textit{where}}\ g_i = k$$

$$(ii)\ \ \sum_{j=1}^{m}\sum_{p} a^{r}_{jp} d^{l}_{jp} \leq m - \boldsymbol{h} - 1 + n(1 - \boldsymbol{v}_r) \quad ---------------(3.11)$$

$$\textbf{\textit{for all}}\ \ r\ \textbf{\textit{where}}\ g_r \neq k$$

$$(iii)\ \ u_i\ ,\ v_r\ \in\ \{0,\ 1\} \quad -----------------(3.12)$$

Proof : If $\boldsymbol{u}_i = 1$ then (i) is equivalent to (i) in Proposition 3.2.

If $\boldsymbol{v}_r = 1$ then (ii) is equivalent to (ii) in Proposition 3.2.

Following are two criteria for evaluating the quality of the rule.

(i) The rule should be supported by most nations of a specific group. That means, the support rate of a good rule should be high.

(ii) The rule should be accurate. That means, the rule should not cover the nations of non-specific groups. In other words, the accuracy rate of a good rule should be high.

**Proposition 3.4**

Considering a data set containing $n$ nations. Denote the number of nations belonging to a specific $k$ group as $n(k)$. By referring to (3.3) and (3.4), the meaning of the accuracy rate and the supporting rate are specified below:

**Accuracy rate:** The accuracy rate of a rule is specified as

$$AR_l(k) = \frac{1}{n-n(k)}(\sum_{g_r \neq k} \boldsymbol{v}_r)$$

That means if none of nation $N_r$ where $g_r \neq k$ is covered by the rule, then the accuracy rate of the rule is 1.

**Coverage rate:** The coverage rate of a rule is specified as

$$CR_l(k) = \frac{1}{n(k)}(\sum_{x_i = k} \boldsymbol{u}_i)$$

That means if all $N_i$ where $g_i = k$ support the rule then the coverage rate of the rule is 1.

*AR* and *CR* value for the rules in Table 3.3 are listed in the last two columns of Table3.4. Explanation is described below.

(i) Considering AR and CR of $R_1(1)$, one nation belongs to group 1 (i.e., g=1) and 4 nations belong to other groups. Therefore, n(1) =1 and n-n(1)=4. Thus,

$$AR = \frac{4}{4} = 1 \quad \text{and} \quad CR = \frac{1}{1} = 1$$

(ii) Considering disjunctive values of the rule $R_3(3)$, two nations belongs to group 3 (i.e., g=3) and 3 nations belong to other groups. Therefore, n(1) =2 and n-n(3)=3. Thus, its AR and CR of $R_3(3)$ is as

$$AR = \frac{3}{3} = 1 \quad \text{and} \quad CR = \frac{2}{2} = 1$$

Take Table 3.1 for instance, inducing the rule for $g$ = 1 is formulated below.

$\boldsymbol{MAX}\ CR(1)$

$$s.t. \quad AR = \frac{1}{5-1}(\boldsymbol{v}_2 + \boldsymbol{v}_3 + \boldsymbol{v}_4 + \boldsymbol{v}_5) \geq a$$

$$CR = \frac{1}{1}\boldsymbol{u}_1$$

$$5(\boldsymbol{u}_1 - 1) + 3 - \boldsymbol{h} \leq d_{12} + d_{21} + d_{33} \leq 3 - \boldsymbol{h} + 5(1-\boldsymbol{u}_1)$$

$$d_{13} + d_{22} + d_{33} \leq 3 - \boldsymbol{h} - 1 + 5(1-\boldsymbol{v}_2)$$

$$d_{12} + d_{22} + d_{31} \leq 3 - \boldsymbol{h} - 1 + 5(1-\boldsymbol{v}_3)$$

$$d_{13} + d_{21} + d_{34} \leq 3 - \boldsymbol{h} - 1 + 5(1-\boldsymbol{v}_4)$$

$$d_{11} + d_{21} + d_{32} \leq 3 - \boldsymbol{h} - 1 + 5(1-\boldsymbol{v}_5)$$

$$\boldsymbol{u}_i, \boldsymbol{v}_r, d_{jp} \in \{0.1\},$$

$$\mathbf{h} \geq \mathrm{b}$$

By specifying $a$ = 1 and b=1, the solution obtained is: CR=1 with $d_{12}=d_{21}=1$ (all other $d_{jp}=0$), $\boldsymbol{h}=1$, $\boldsymbol{u}_1=\boldsymbol{v}_2=\boldsymbol{v}_3=\boldsymbol{v}_4=\boldsymbol{v}_5=1$, AR=1. This rule is exactly $R_1(1)$ in Table 3.3. Another instance of inducing the rule for $g$ = 3 is formulated below

$\boldsymbol{MIN}\ CR(3)$

$$s.t. \quad AR = \frac{1}{5-2}(v_1 + v_2 + v_3 + v_4 + v_5) \geq a$$

$$CR = \frac{1}{2}(u_4 + u_5)$$

$$5(u_4 - 1) + 3 - \boldsymbol{h} \leq d_{13} + d_{21} + d_{34} \leq 3 - \boldsymbol{h} + 5(1-\boldsymbol{u}_4)$$

$$5(u_5 - 1) + 3 - \boldsymbol{h} \leq d_{11} + d_{21} + d_{32} \leq 3 - \boldsymbol{h} + 5(1-\boldsymbol{u}_5)$$

$$d_{12} + d_{21} + d_{33} \leq 3 - \boldsymbol{h} - 1 + 5(1-\boldsymbol{v}_1)$$

$$d_{13} + d_{22} + d_{33} \leq 3 - \boldsymbol{h} - 1 + 5(1-\boldsymbol{v}_2)$$

$$d_{12} + d_{22} + d_{31} \leq 3 - \boldsymbol{h} - 1 + 5(1-\boldsymbol{v}_3)$$

$$\boldsymbol{u}_i, \boldsymbol{v}_r, d_{jp} \in \{0.1\}$$

$$\boldsymbol{h} \geq \mathrm{b}$$

By specifying $a$= 1 and b=1, the solution obtained is

$$CR = 1\ \boldsymbol{with}\ d_{32} = d_{34} = 1,\ \ \boldsymbol{all\ other}\ d_{jp} = 0,\ \boldsymbol{h} = 1,\ \boldsymbol{u}_4 = \boldsymbol{u}_5 = \boldsymbol{v}_1 = \boldsymbol{v}_2 = \boldsymbol{v}_3 = 1,\ AR = 1$$

## 3.3 Models of Inducing Rules

From the basis of the discussion above, two models for inducing the rule are illustrated. Model (I) is designed to obtain rules that at most one attribute has disjunctive sub attribute values. The interval values of an attribute represent proximity of a class. The other attributes show specific characteristics in the class. Users can realize the specific competitiveness based on the proximity. Technically, the optimization is applied to approach the objective of the model.

***Model (I)***

$\boldsymbol{Max}\ \ CR_l(k)$

$s.t.$

$$(i)\ \ AR_l(k) = \frac{1}{n - n(k)}\left(\sum_{g_r \neq k} \boldsymbol{v}_r\right) \geq a$$

$$(ii)\ CR_l(k) = \frac{1}{n(k)}\left(\sum_{g_i = k} \boldsymbol{u}_i\right)$$

$$(iii)\ (3.10), (3,11), (3,12)\ \boldsymbol{of\,proposition\ 3.3}$$

$$(iv)\ \sum_j \boldsymbol{\theta}_j \leq 1,\ \ \sum_p \boldsymbol{d}_{jp} \leq n * \boldsymbol{\theta}_j$$

$$(v)\ \ \sum_p \boldsymbol{d}_{jp} - 1 \leq n * \boldsymbol{\theta}_j,\ \ \boldsymbol{\theta}_j \leq \sum_P \boldsymbol{d}_{jp} * \left(\sum_p \boldsymbol{d}_{jp} - 1\right)\ \boldsymbol{for\ all}\ j$$

$$(iv)\ \boldsymbol{h} \geq b,\ \ \boldsymbol{d}_{jp}, \boldsymbol{\theta}_j \in \{0,1\}$$

Model (II) is designed to generate rules with attribute reduction that approaches optimal performance of coverage and accuracy rates. Two advantages are provided. First, it ignores attributes as possible. Second, it generates a continuous sub attributes in the rule. Step (iv) of Model (II) enforces $d_{j,t}$ to value 1 if both sides of sub attribute $t$ have value 1. This model generates rule presented by attribute intervals. Application of Model (II) on Example 1 is described in Section 6.2 of Chapter 6 (Li 2007).

***Model (II)***

$$\textbf{\textit{Max}} \quad \frac{CR_l(k)+AR_l(k)}{m-h},$$

$m$ ***is the number of attributes***

$h$ ***is the number of ignored attributes***

$s.t.$

$$(i)\ \ AR_l(k)=\frac{1}{n-n(k)}(\sum_{g_r\neq k}\boldsymbol{v}_r)\geq a$$

$$(ii)\ CR_l(k)=\frac{1}{n(k)}(\sum_{g_i=k}\boldsymbol{u}_i)\geq b$$

$(iii)$ (3.10), (3,11), (3,12) ***of proposition 3.3***

$$(iv)\ \boldsymbol{d}_{j,t}\geq\frac{\sum_{p=1}^{t-1}\boldsymbol{d}_{j,p}}{t-1}+\frac{\sum_{p=t+1}^{q(j)-1}\boldsymbol{d}_{j,p}}{q(j)-t}-\max\{\frac{\sum_{p=1}^{t-1}\boldsymbol{d}_{j,p}}{t-1},\frac{\sum_{p=t+1}^{q(j)-1}\boldsymbol{d}_{j,p}}{q(j)-t}\},$$

$2\leq t\leq q(j)-1,\ t$ ***is a sub attribute of*** $j$

$q(j)$ ***is the number of sub attributes of attribute*** $j$

$\boldsymbol{d}_{jp}\in\{0,1\}$

# Chapter 4 Induction Rules

## 4.1 Dynamic Rules of Competitiveness Classes

By utilizing the method proposed in Chapter 3, we can induce the rules of 4 classes for each year. These rules are described as $R_i^{2001}, R_i^{2003}$, and $R_i^{2005}$, where $i$ represents 4 classes $G_1$, $G_2$, $G_3$, and $G_4$. The results are presented in Table 4.1. These rules are the best rules for each class with high AR and CR. Take $R_i^{2001}$ for instance, $R_4^{2001}$ is the best rule for class 4 at year 2001, which is expressed as ($a_3 \geq 3$ ) and ($a_1 = 4$ or $a_2 = 4$) with AR = 0.87 and CR = 0.86. That means: For a nation at year 2001, if its GDP ($a_3$) greater than or equal to level 3, and its Computer ($a_2$) or its Export ($a_1$) is at the highest level (level 4) then this nation belongs to the highly competitive class ($G_4$). 14 of 46 nations fit these conditions (12 in $G_4$, BELGIUM and NORWAY in $G_3$). Therefore the rule covers 12 of the 14 nations in $G$4 (GERMANY, and AUSTRIA are not covered) and the coverage rate is 12/14=0.86. There are 32 nations in other classes ($G_1$, $G_2$, and $G_3$). Therefore, the accuracy rate is 30/32=0.94 due to BELGIUM and NORWAY in the $G_3$ class are covered by the rule.

**Table 4.1: Rules of competitiveness classes**

| | Rule ID | Rules | Supporting Nations | Not supporting Nations | AR | CR |
|---|---|---|---|---|---|---|
| $G_4$ | $R_4^{2001}$ | $(a_3 \geq 3)$ ***and*** $(a_1 = 4$ ***or*** $a_2 = 4)$ | CANADA, DENMARK FINLAND , AUSTRALIA, HONG KONG, ICELAND, IRELAND, NETHERLANDS, SINGAPORE, | GERMANY, AUSTRIA | 0.94 | 0.86 |
| | $R_4^{2003}$ | $(a_3 \geq 3)$ ***and*** $(a_1 = 4$ ***or*** $a_2 = 4)$ | AUSTRALIA, AUSTRIA, CANADA, DENMARK, FINLAND, HONG KONG ICELAND,LUXEMBOURG, NETHERLANDS, SINGAPORE, | | 090 | 1 |
| | $R_4^{2005}$ | $(a_3 \geq 3)$ ***and*** $(a_1 = 4$ ***or*** $a_2 = 4)$ | CANADA, DENMARK FINLAND, HONG KONG ICELAND, IRELAND, LUXEMBOURG, NETHERLANDS, SINGAPORE, SWEDEN, | TAIWAN | 0.90 | 0.92 |
| $G_3$ | $R_3^{2001}$ | $(a_3 \geq 2)$ ***and*** $(a_2 = 3$ ***or*** $a_5 = 3)$ | BELGIUM, TAIWAN, NORWAY, FRANCE, SPAIN, JAPAN, UNITED KINGDOM | ISRAEL, NEW ZEALAND, CHILE | 0.72 | 0.70 |
| | $R_3^{2003}$ | $(a_3 \geq 2)$ ***and*** $(a_2 = 3$ ***or*** $a_5 = 3)$ | NORWAY, BELGIUM, NEW ZEALAND, GERMANY, TAIWAN, UNITED KINGDOM, FRANCE, NEW ZEALAND | MALAYSIA | 0.72 | 0.88 |
| | $R_3^{2005}$ | $(a_3 \geq 2)$***and*** $(a_2 = 3$ ***or*** $a_5 = 3)$ | AUSTRIA, BELGIUM, NEW ZEALAND, GERMANY, ISRAEL, JAPAN, NORWAY, UNITED KINGDOM | CHILE | 0.72 | 0.88 |
| $G_2$ | $R_2^{2001}$ | $(a_1 = 2$ ***or*** $a_{10} = 2)$ | HUNGARY, KOREA, MALAYSIA, ITALY, CZECH REPUBLIC, MEXICO, BRAZIL, GREECE, PORTUGAL, THAILAND | MAINLAND CHINA | 0.72 | 0.90 |
| | $R_2^{2003}$ | $(a_1 = 2$ ***or*** $a_8 = 2)$ | CHILE, SPAIN, JAPAN, HUNGARY, KOREA, ITALY, CZECH REPUBLIC, ISRAEL, SOUTH-AFRICA, THAILAND | COLOMBIA, MAINLAND CHINA | 0.70 | 0.67 |
| | $R_2^{2005}$ | $(a_1 = 2$ ***or*** $a_8 = 2)$ | SPAIN, MALAYSIA, HUNGARY, THAILAND, INDIA, PORTUGAL, KOREA, CZECH REPUBLIC | MAINLAND CHINA, FRANCE | 0.72 | 0.8 |
| $G_1$ | $R_1^{2001}$ | $a_2 = 1$ ***and*** $a_3 \leq 2$ | COLOMBIA, TURKEY, INDIA, PHILIPPINES, RUSSIA, POLAND, SOUTH-AFRICA, ARGENTINA, INDONESIA, VENEZUELA, | | 0.85 | 1 |
| | $R_1^{2003}$ | $a_2 = 1$ ***and*** $a_3 \leq 2$ | INDIA, TURKEY, PHILIPPINES, BRAZIL, MEXICO, RUSSIA, ARGENTINA, INDONESIA, VENEZUELA | PORTUGAL, GREECE, POLAND | 0.88 | 0.75 |
| | $R_1^{2005}$ | $a_2 = 1$ ***and*** $a_3 \leq 2$ | COLOMBIA, TURKEY, PHILIPPINES, BRAZIL, MEXICO, RUSSIA, POLAND, ARGENTINA, INDONESIA, VENEZUELA, SOUTH-AFRICA | ITALY, GREECE | 0.87 | 0.84 |

Table 4.1 shows that 6 most significant attributes in the induced rules. The rules in Table 4.1 can also be expressed graphically in Figure 4.1. Here we use 6 axes to express 6 key attributes included in the induced rules. They are $a_1$ (EXPORT), $a_2$ (COMPUTER), $a_3$ (GDP), $a_5$ (STOCK), $a_8$ (INFLATION), and $a_{10}$ (FDI). Each axis is denoted by 4 segments which express the 4 levels of an attribute. A full dot at the segment of an axis means "necessary conditions" of supporting the rule, while a hollow-dot means "sufficient conditions" of supporting rules. For instance, 3 attributes ($a_1$, $a_2$, $a_3$) are used to describe $R_4^{2001}$ where $a_3$ (GDP) $\geq 3$ is a necessary condition and ($a_1 = 4$ or $a_2 = 4$) is the sufficient condition. Both of them are conjunctively connected to support the rule $R_4^{2001}$. Examining Table 4.1 and Figure 4.1, the induced rules are analyzed below:

(i) GDP ($a$3) plays a critical role in formulating classes. If a nation wants to be highly competitive, it should have GDP $\geq 3$ during 2001-2005. On the other hand, if a nation is at the worst level (GDP=1), then it is very likely to belong to a non-competitive or a least-competitive class. That means GDP is the fundamental attribute of competitiveness.

(ii) Computers ($a_2$), indicating the level of technology infrastructure, is an essential attribute of competitiveness. For example, if a nation's $a_2$ is 4 or 3 then this nation quite possibly belongs to a highly competitive or competitive class. On the contrary, if a nation's computers are restricted to a low level (i.e., $a_2 = 1$) then the nation's competitiveness is limited to the least competitive class (i.e., $G_1$).

(iii) Export ($a_1$), which shows a nation's comparative advantage and its ability to globalize, is another critical attribute of competitiveness. In the same way of $a_2$, $a_1 = 4$ is another sufficient condition for a nation to be highly competitive. From the point of view of enhancing competitiveness, if a least competitive nation wants to upgrade as a non-competitive nation, one potential way is to improve its export volume to level 2 (i.e. $a_1 = 2$).

(iv) Inflation ($a_8$) is important for competitive and non-competitive nations. If a nation does not want to fall into the least competitive, it should prevent its inflation from being at a low level.

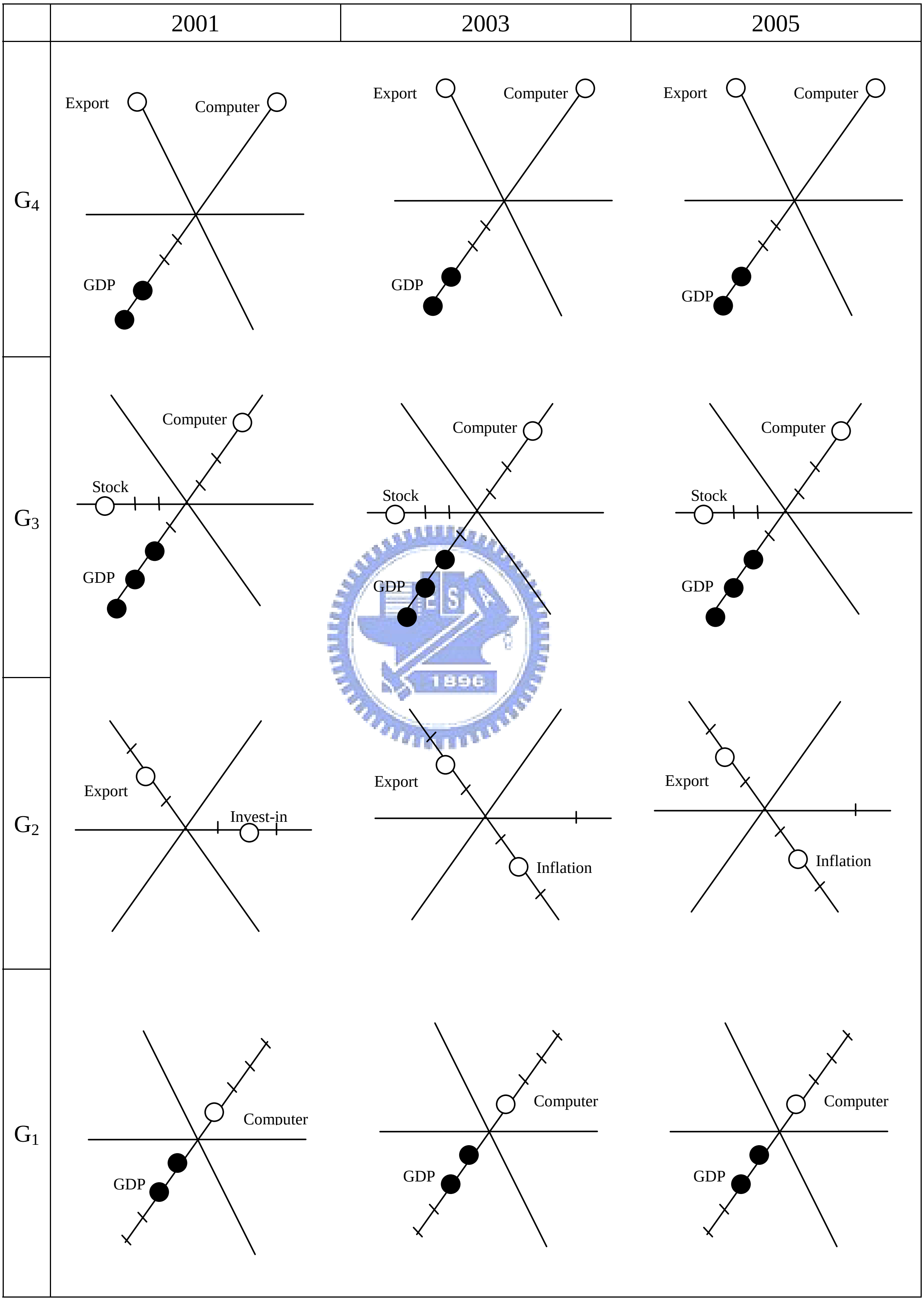
(v) Stock ($a_5$) can reflect business ability and nations' competitiveness from the standpoint of globalization. Foreign capital investment gives rises of international collaboration and globalization. A competitive nation had better to keep its stock market capitalization level higher than or equal to three (i.e. $a_5 \geq 3$).

(vi) FDI ($a_{10}$) carries capital and technology to help nations to promote their competitiveness. For a nation of the least competitive class to move up to a noncompetitive class, it needs to enhance its Foreign Direct Investment or its export volume (i.e. to let $a_{10} = 2$ or $a_1 = 2$).

(vii) All $R_1^{2001}$, $R_1^{2003}$, and $R_1^{2005}$ rules indicate that a nation may stay in the least competitive class due to its lower GDP ($a_3 \leq 2$) and lowest Computer hosts ($a_2 = 1$).

(viii) $R_2^{2001}$, $R_2^{2003}$, and $R_2^{2005}$ rules for the non-competitive class show that inflation ($a_8$) has become more significant than Foreign Direct Investment in recent years.

Figure 4.1: Competitiveness structure of 4 classes during 2001~2005



From the basis of the induced rules of forming 4 classes in Table 4.1, here we induce dynamic rules for forming 18 various competitive groups listed in Table 2.2. There are 4 types of competitive groups: sustaining type, upward type, downward type, and mixed type described in the following.

## 4.2 Dynamic Rules of Sustaining Groups

There are 4 groups in sustaining type. Each group has 3 same classes for 2001, 2003, and 2005. Take $R_{444}$ for instance, $R_{444}$ is the rule for forming $G_4$ class in all 2001, 2003, and 2005, which is expressed as

$$R_{444} = R_1^{2001}(4) \wedge R_1^{2003}(4) \wedge R_1^{2005}(4) = (a_3 \geq 3) \wedge (a_1 = 4 \vee a_2 = 4)$$

Twelve nations are covered by this rule, where $AR$ = 0.94 and $CR$ = 1. Similarly,

$$R_{333} = R_1^{2001}(3) \wedge R_1^{2003}(3) \wedge R_1^{2005}(3) = (a_3 \geq 2 \wedge a_8 \geq 2) \wedge (a_2 = 3 \vee a_5 = 3)$$

The 4 rules for sustaining types are shown in Table 5.1.

**Table 4.2 : Sustaining type**

| groups | Rules | Supporting nations | Not supporting | AR | CR |
|---|---|---|---|---|---|
| $R_{444}$ | $R_4^{2001} \wedge R_4^{2003} \wedge R_4^{2005}$<br>$(a_3 \geq 3)$ and<br>$(a_1 = 4$ or $a_2 = 4)$ | AUSTRALIA , CANADA, DENMARK, FINLAND, HONG KONG, ICELAND, LUXEMBOURG, NETHERLANDS, SINGAPORE, SWEDEN, SWITZERLAND, USA | | 0.94 | 1 |
| $R_{333}$ | $R_3^{2001} \wedge R_3^{2003} \wedge R_3^{2005}$<br>$(a_3 \geq 2)$ and $(a_2 = 3 \wedge a_5 = 3)$ | BELGIUM, NORWAY, UNITED KINGDOM | NEW ZEALAND | 0.80 | 0.75 |
| $R_{222}$ | $R_2^{2001} \wedge R_2^{2003} \wedge R_2^{2005}$ | CZECH REPUBLIC, HUNGARY, KOREA | MAINLAND CHINA | 0.85 | 0.75 |
| $R_{111}$ | $R_1^{2001} \wedge R_1^{2003} \wedge R_1^{2005}$<br>$a_2 = 1$ and $a_3 \leq 2$ | ARGENTINA, INDONESIA, PHILIPPINES, RUSSIA, TURKEY, VENEZUELA | POLAND | 0.92 | 0.85 |

## 4.3 Dynamic Rules of Upward Groups

The rules for the upward groups are described in Table 5.2 and significant attributes are illustrated in Figure 4.2. Only 3 nations are included in this type, where Taiwan belongs to $G_{334}$, THAILAND belongs to $G_{122}$, and INDIA belongs to $G_{112}$. These nations benefit from an increase of GDP growth rate. However, TAIWAN is an exception, which only has growth in the number of incorporated companies. The 14 attributes cannot clearly explain this case.

**Table 4.3: Upward type**

| groups | Nations | Critical attributes | Description |
|---|---|---|---|
| $G_{344}$ | TAIWAN | $a_4$ | ● Its incorporated companies steadily increased from 462 (2001), 584 (2003) to 669 (2005). |
| $G_{122}$ | THAILAND | $a_{12}$ | ● Its GDP growth rate increased from 4.5 (2001) and 5.2 (2003) to 6.1 (2005).<br>● Its exports of goods and services increased from 1275 (2001) to 1252 (2003) and 1741 (2005) billions.<br>● Her GDP per capita also increased from 2001(2001) and 1955 (2003) to 2509 (2005). |
| $G_{112}$ | INDIA | $a_{12}$ | ● Its GDP growth rate increased from 6.0 (2001) and 4.37 (2003) to 6.8 (2005).<br>● Its consumer price inflation decreased from 4.3 (2001) and 4.3 (2003) to 2.6 (2005).<br>● Its GDP per capita also increased from 444 (2001) and 445 (2003) to 578 (2005). |

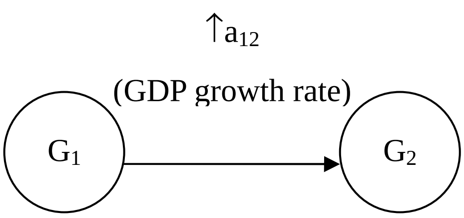



Figure 4.2 Critical attributes of upward type

## 4.4 Dynamic Rules of Downward Groups

The downward type is described in Table 4.4 and significant attributes are illustrated in Figure 4.3. Most nations in the downward type (AUSTRIA, GERMANY, FRANCE, SPAIN, and ITALY) suffered from the increase in the unemployment rate ($a_9$). Some competitive nations (GERMANY, FRANCE, SPAIN, ITALY, and BRAZIL) are affected by a decrease in the GDP growth rate ($a_{12}$). Some nations (SPAIN, ITALY, and GREECE) have lost competitiveness due to continuously borrowing money from foreign nations ($a_{13}$).

**Table 4.4 : Downward type**

| groups | Nations | Critical attributes | Description |
|---|---|---|---|
| $G_{443}$ | AUSTRIA | $a_{12}$ | ● Its GDP growth rate decreased from 3.3 (2001) to 0.5 (2003) and 2 (2005). There are negatives of soft data from Global Competitiveness Report about her most problematic attributes such as tax regulations, corruption, and access to financing, and inefficient government bureaucracy. |
| $G_{433}$ | GERMANY | $a_{12}$ $a_9$ | ● Its GDP growth rate decreased from 3.2 (2001) to 0.1 (2003) and 1.6 (2005).<br>● Its foreign direct investment decreased from 631 (2001) to 381 (2003) and -592 (2005) billions.<br>● Its unemployment rate increased from 7.7 (2001) to 8.2 (2003) and 9.5 (2005). |
| $G_{332}$ | FRANCE | $a_{12}$ $a_9$ | ● Its GDP growth rate decreased from 3.2 (2001) to 0.1 (2003) and 1.6 (2005).<br>● Its er unemployment rate started at 9.7 (2001), 8.7 (2003) and up to 9.6 (2005).<br>● Her current account balance decreased from 373 (2001) and 459 (2003) to -108 (2005) billions. |
| $G_{322}$ | SPAIN | $a_{12}$ $a_9$ $a_{13}$ | ● Its GDP growth rate decreased from 4 (2001) to 2 (2003) and 2.7 (2005).<br>● Its unemployment rate has been keeping high as 14.1 (2001), 11.4 (2003) and 10.8 (2005).<br>● Its current account balance is extremely negative as -380 (2001), -379 (2003) and -1113 (2005) billions. |
| $G_{221}$ | ITALY | $a_{12}$ | ● Its GDP growth rate decreased from 2.8 (2001) to 0.4 (2003) and 1.2 |

| | | | |
|---|---|---|---|
| | | $a_9$ <br> $a_{13}$ | (2005). <br> ● Its unemployment rate has been keeping high as 10.8 (2001), 9 (2003) and 8 (2005). <br> ● Its current account balance has been keeping negative for -75 (2001), -116 (2003) and -189 (2005) billions. |
| $G_{211}$ | BRAZIL | $a_8$ <br> $a_9$ | ● Its unemployment rate has been keeping high as 9.6 (2001), 10.5 (2003) and 11.48 (2005). <br> ● Its consumer price inflation has been keeping high as 5.97 (2001), 12.5 (2003) and 7.6 (2005) |
| | GREECE | $a_{13}$ <br> $a_9$ | ● Its current account balance has been extremely negative as -379 (2001), -775 (2003) and -1001 (2005) billions. <br> ● Its unemployment rate has been keeping high as 11.4 (2001), 10 (2003) and 9.1 (2005). |
| | MEXICO | $a_8$ <br> $a_{13}$ | ● Its consumer price inflation has been keeping high as 9.49 (2001), 5.06 (2003) and 5.2 (2005) <br> ● Its current account balance has been keeping negative -172 (2001), -147 (2003) and -84 (2005) billions. |

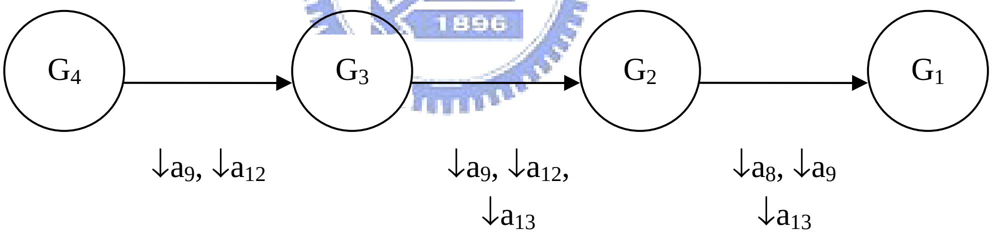



Figure 4.3: Critical attributes of downward type

# Chapter 5 Displaying National Competitiveness on Spheres

Nations covered by rules of Table 4.1 are displayed on spheres in this chapter. A visual differentiation of nations is presented to enhance readability of the induced rules. The displaying method consists of 3 steps, which are data normalization, data conversion, and transformation, as shown in Figure 5.1.

## 5.1 Proposed Displaying Method

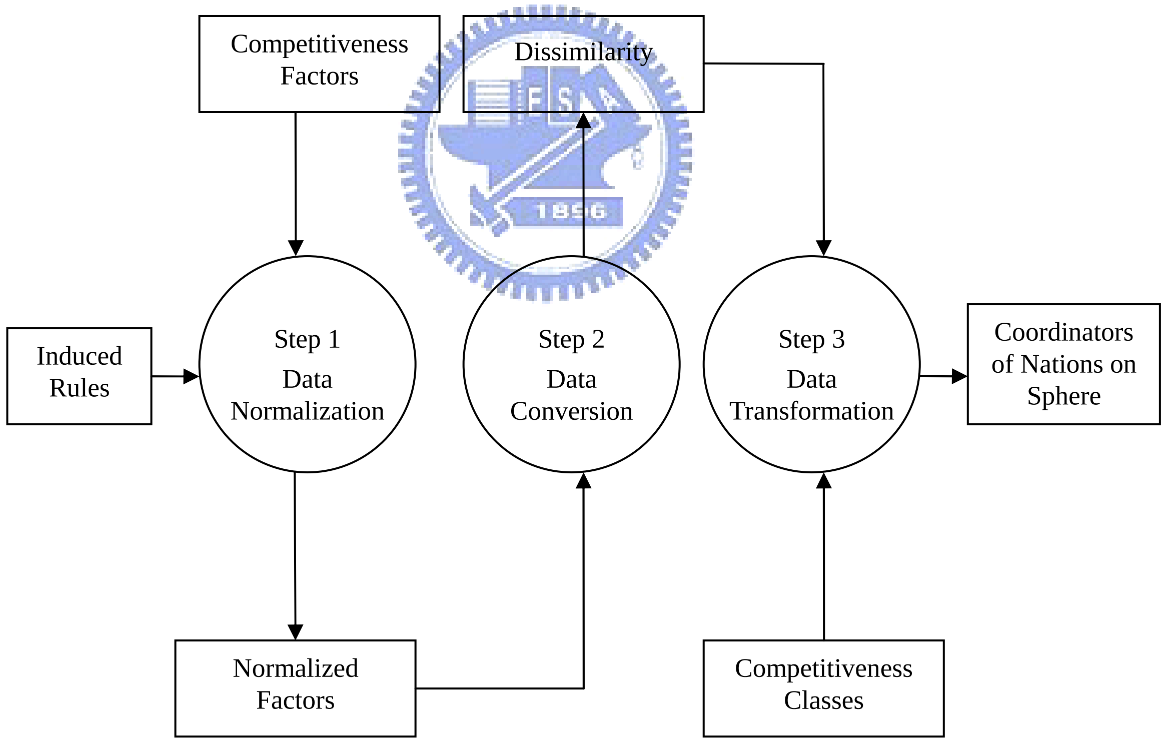



Figure 5.1: The process of displaying method

In our design the first two steps are preprocessing steps that generate dissimilarity between nations. The last step transforms the dissimilarity into coordinates of nations on a sphere. An example (Example 2) is illustrated with data and implementation below.

This example randomly selects 11 nations covered by two induced rules for 2005 from Table 4.1. Consider a data set in Table 5.1 with 11 nations ($N_1$, $N_2$, …, $N_{10}$, $N_{11}$), 4 factors ($f_1$, $f_2$, $f_3$, $f_4$) and 1 class indicator $g$. The domain values of $f_1$, $f_2$, $f_3$, and $f_4$ are continuous numbers, which are retrieved from Table E.1 in Appendix E. The domain value of $g$ is {4, 2}. For instance, $N_{11}$ (USA) is expressed as $N_{11}$= (62.72, 100.00, 84.00, 95.46) and $g_{11}$ = 4.

**Table 5.1: Data set of Example 2**

| | Nations | $f_1$ | $f_2$ | $f_3$ | $f_4$ | $g$ |
|---|---|---|---|---|---|---|
| $N_1$ | Australia | 73.39 | 53.03 | 78.62 | 65.05 | 4 |
| $N_2$ | Canada | 69.97 | 57.92 | 72.50 | 72.37 | 4 |
| $N_3$ | Denmark | 74.34 | 46.97 | 77.07 | 73.99 | 4 |
| $N_4$ | Finland | 75.87 | 46.08 | 75.66 | 75.09 | 4 |
| $N_5$ | France | 38.63 | 58.94 | 37.46 | 63.96 | 2 |
| $N_6$ | India | 42.83 | 56.85 | 53.34 | 25.38 | 2 |
| $N_7$ | Korea | 47.57 | 42.48 | 49.21 | 59.88 | 2 |
| $N_8$ | Malaysia | 51.22 | 59.53 | 51.11 | 43.69 | 2 |
| $N_9$ | Spain | 47.81 | 50.82 | 34.31 | 46.96 | 2 |
| $N_{10}$ | Taiwan | 60.19 | 54.19 | 77.19 | 63.89 | 4 |
| $N_{11}$ | USA | 62.72 | 100.00 | 84.00 | 95.46 | 4 |

Based on the Table 5.1, the steps of display method are illustrated in following sections.

## 5.2 Data Normalization

The normalizing function puts different measures of factors into the same scale [0, 1]. It is formulated as

$$s_{i,f} = w_j * \frac{f_{i,j} - \underline{f_j}}{\overline{f_j} - \underline{f_j}} \ \textit{for} \ \ i = 1,..,45; \ \ j = 1,...,4 \qquad -------------------(5.1)$$

where $i$ is an index for nations, $j$ for factors, i.e. government efficiency, economic performance, business efficiency, and infrastructure, respectively; $w_j$ is 0.25 for each factor defined in WCY-IMD; $f_{i,j}$ is the raw data of the $j$ factor for the $i$ nation in Table E.1, $\overline{f_j} = \max\{f_{1,j}, f_{2,j}, \ldots, f_{46,j})$ and $\underline{f_j} = \min\{f_{1,j}, f_{2,j}, \ldots, f_{46,j})$; $0 \le s_{if} \le 1$.

Example 2 of Table 5.1 can be normalized into Table 5.2 by using (5.1).

**Table 5.2: Normalized data set of Example 2**

| $S_{i,f}$ | Nations | $f_1$ | $f_2$ | $f_3$ | $f_4$ | $g$ |
|---|---|---|---|---|---|---|
| $N_1$ | Australia | 0.220 | 0.087 | 0.198 | 0.161 | 4 |
| $N_2$ | Canada | 0.210 | 0.104 | 0.182 | 0.182 | 4 |
| $N_3$ | Denmark | 0.121 | 0.059 | 0.117 | 0.115 | 4 |
| $N_4$ | Finland | 0.223 | 0.066 | 0.194 | 0.187 | 4 |
| $N_5$ | India | 0.228 | 0.062 | 0.190 | 0.190 | 2 |
| $N_6$ | Korea | 0.116 | 0.107 | 0.090 | 0.158 | 2 |
| $N_7$ | Malaysia | 0.135 | 0.041 | 0.116 | 0.116 | 2 |
| $N_8$ | Portugal | 0.154 | 0.109 | 0.125 | 0.098 | 2 |
| $N_9$ | Spain | 0.144 | 0.079 | 0.081 | 0.108 | 2 |
| $N_{10}$ | Taiwan | 0.218 | 0.090 | 0.170 | 0.197 | 4 |
| $N_{11}$ | USA | 0.188 | 0.250 | 0.212 | 0.250 | 4 |

## 5.3 Data Conversion

The dissimilarity between nations $i$ and $j$, is calculated by the function (5.2), which converts the normalized data of Table 5.2 into Table 5.3.

The dissimilarity function is formulated as

$$\overline{d}_{ij}(w) = \sqrt{\sum_{k=1}^{4} (s_{i,f} - s_{j,f})^2}, \quad 0 \le d_{ij} \le 1, \;\; d_{ij} = d_{ji} \qquad \text{-----------------}(5.2)$$

**Table 5.3: Dissimilarity matrix of Example 2**

| $\bar{d}_{ij}$ | $N_1$ | $N_2$ | $N_3$ | $N_4$ | $N_5$ | $N_6$ | $N_7$ | $N_8$ | $N_9$ | $N_{10}$ | $N_{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_1$ | 0 | 0.031 | 0.030 | 0.035 | 0.156 | 0.115 | 0.117 | 0.189 | 0.154 | 0.037 | 0.149 |
| $N_2$ | | 0 | 0.033 | 0.036 | 0.160 | 0.105 | 0.113 | 0.182 | 0.145 | 0.039 | 0.130 |
| $N_3$ | | | 0 | 0.007 | 0.176 | 0.116 | 0.133 | 0.195 | 0.162 | 0.051 | 0.151 |
| $N_4$ | | | | 0 | 0.179 | 0.117 | 0.135 | 0.195 | 0.162 | 0.057 | 0.154 |
| $N_5$ | | | | | 0 | 0.104 | 0.056 | 0.101 | 0.084 | 0.136 | 0.245 |
| $N_6$ | | | | | | 0 | 0.063 | 0.086 | 0.060 | 0.093 | 0.206 |
| $N_7$ | | | | | | | 0 | 0.090 | 0.055 | 0.098 | 0.202 |
| $N_8$ | | | | | | | | 0 | 0.040 | 0.172 | 0.274 |
| $N_9$ | | | | | | | | | 0 | 0.137 | 0.236 |
| $N_{10}$ | | | | | | | | | | 0 | 0.146 |
| $N_{11}$ | | | | | | | | | | | 0 |

To illustrate visual classes, we select 4 nations from Table 5.3 to represent 2 classes. Apparently, the dissimilarity between nations of the same class is much smaller than those of different classes. For instance, $\bar{d}_{\textit{Finland, Australia}} = 0.035$ (within class 4) is much smaller than $\bar{d}_{\textit{Finland, Spain}} = 0.162$ (between different classes).

Based on the pair dissimilarity provided in Table 5.3, we further display Example 2 through a transformation function, which is described next.

## 5.4 Transformation

This section adopts multidimensional scaling to transform $\bar{d}_{ij}$ to $\hat{d}_{ij}$, the distance between nation *i* and *j*, as shown on the surface of sphere. Following Kruskal (1964), the Stress has the value range from 0 to 1, with 0 indicating a perfect fit and 1 implying the worst possible fit. The rule of thumb for the value of Stress is that anything under 0.1 is excellent and anything over 0.15 is unacceptable. To display nations covered by the induced rules on the sphere we have a function that transforms dissimilarity into distance on the sphere, which is described below.

**Transformation Model:**

$$\text{MIN} \ \sum_i \sum_j | d_{ij}^2 - \bar{d}_{ij}^2 |$$

$$Stress = \frac{\sum_i \sum_j (d_{ij} - \bar{d}_{ij})^2}{\sum_i \sum_j \bar{d}_{ij}} \le 0.15, \ \ (i \ \boldsymbol{and} \ j \ \boldsymbol{belong\ to\ the\ same\ class})$$

$$\sqrt{x_i^2 + y_i^2 + z_i^2} = 1$$

$$x_{USA} = 0, \ \ y_{USA} = r, \ \ z_{USA} = 0$$

$$-1 \le x_i, z_i \le 1; \quad 0 \le y_i \le 1 \ \ (\boldsymbol{nations\ are\ arranged\ on\ the\ up\ half\ sphere})$$

$$d_{ij} \ge \delta \ (\boldsymbol{where\ nation}\ i\ \boldsymbol{belongs\ class}\ k\ \boldsymbol{and}\ j\ \boldsymbol{belongs\ class}\ k+1,$$

$$\boldsymbol{classes\ are\ arranged\ away\ mutually\ by}\ \delta)$$

The optimization technique is applied to restrict the error rate of MDS to less than 0.15. Our model is implemented in Lingo 10. Once users finish the dissimilarity matrix the execution of model will solve $\hat{d}_{ij}$ and get coordinates of nations.

By executing the model above, coordinates (x, y, z) of Australia ($N_1$), Finland ($N_4$), Malaysia ($N_8$), Spain ($N_9$), USA ($N_{11}$) are listed in Table 5.4. They are displayed on the

Figure 5.2.

**Table 5.4: Coordinates of nations on the sphere**

| | x | y | z |
|---|---|---|---|
| $N_1$ | 0.2885919 | 0.8992801 | -0.3286487 |
| $N_2$ | 0.2850063 | 0.9230719 | -0.2582821 |
| $N_3$ | -0.5639094 | 0.7994895 | 0.4131095 |
| $N_4$ | 0.3353658 | 0.8889409 | -0.3119515 |
| $N_{51}$ | 0.344036 | 0.8854371 | -0.3124744 |
| $N_6$ | -0.5771191 | 0.6684961 | 0.5562589 |
| $N_7$ | -0.5752986 | 0.8093132 | 0.3808428 |
| $N_8$ | 0.2632078 | 0.9103639 | -0.3193105 |
| $N_9$ | 0.1036893 | 0.9393901 | -0.3267948 |
| $N_{10}$ | -0.4580393 | 0.8218026 | 0.4999124 |
| $N_{11}$ | -0.5982569 | 0.6455617 | -0.4746987 |

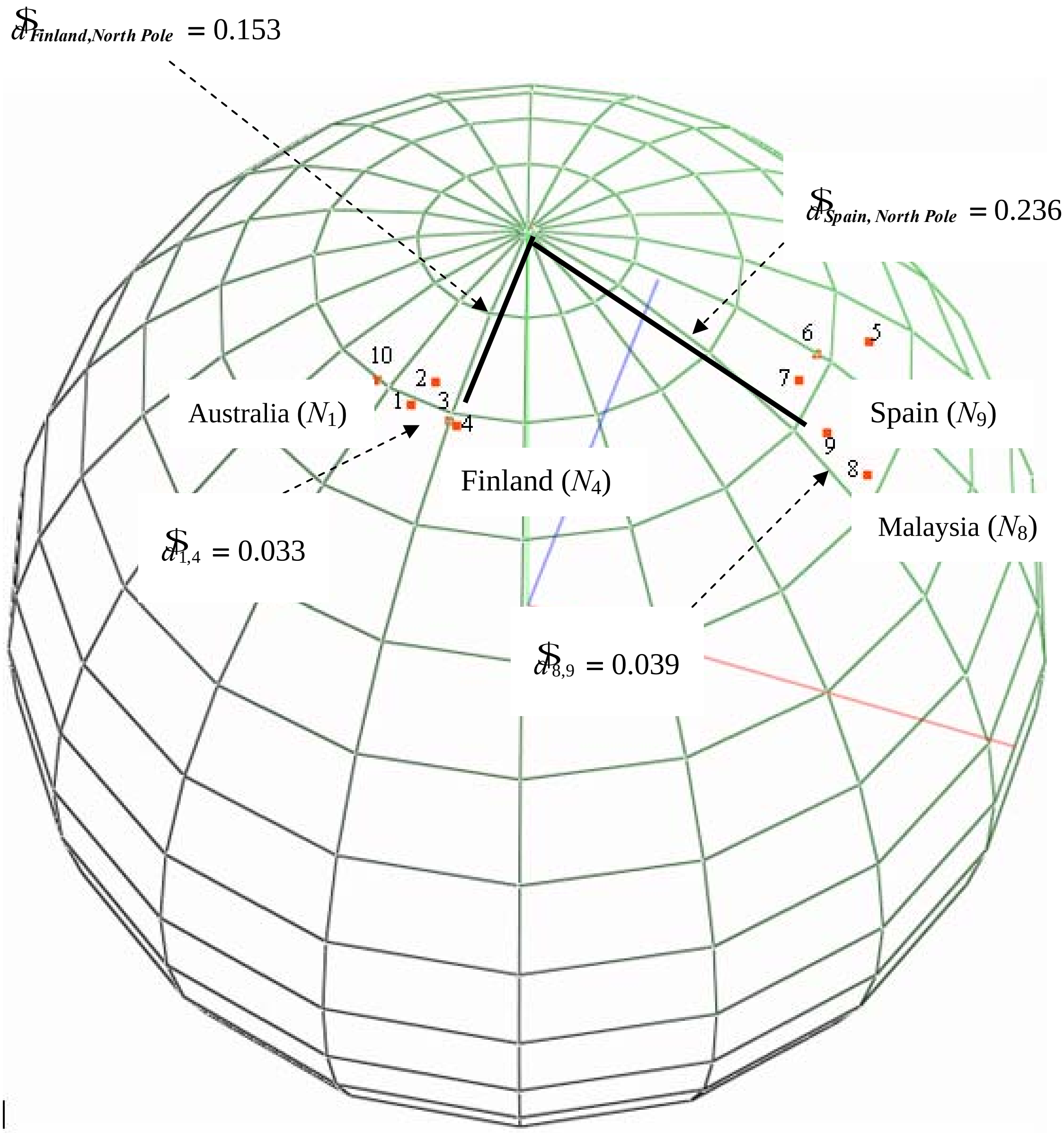



Figure 5.2: A display sphere with competitiveness classes for Example 2

According to values of Table 5.4 and Figure 5.2, users can take visual distance and direction of the North Pole to have enhanced realization of induced rules. The proposed method provides a simple way to understand the approximate differentiation of competitiveness rules, which is described in details next section.

## 5.5 Displaying Induced Rules of 2003 and 2005

In this section induced rules and their covered nations are displayed to give explanation for competitiveness differentiation of Table 4.1. Users can catch competitiveness direction from Figure 5.3 and 5.4 which show the closer to the USA the more competitiveness in computer usage and Gross Domestic Product. For instances, $R_4^{2005}$ ***and*** $R_4^{2003}$, the covered nations have good investment in computers and their citizens have a good standard living. Inversely, nations farther away from USA like those covered by $R_1^{2005}$ ***and*** $R_1^{2003}$ are worse in the previous two indicators. For nations covered by $R_3^{2005}$, they have medium Gross Domestic Product and stock market value. Nations under $R_2^{2005}$ struggle with inflation and have low investment in computers, which means they have weak potential for the future competitiveness.

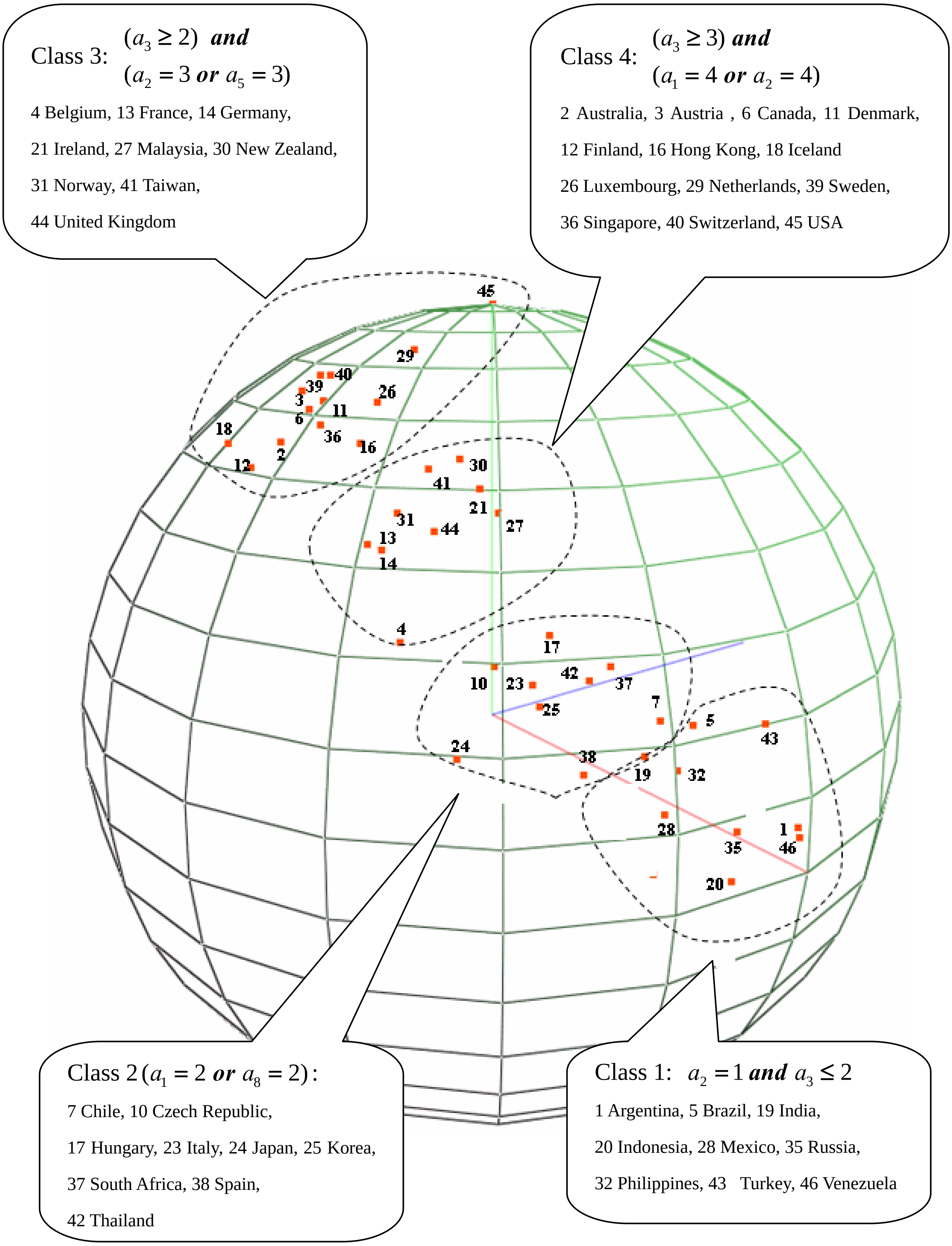



Figure 5.3: Display sphere for 2003

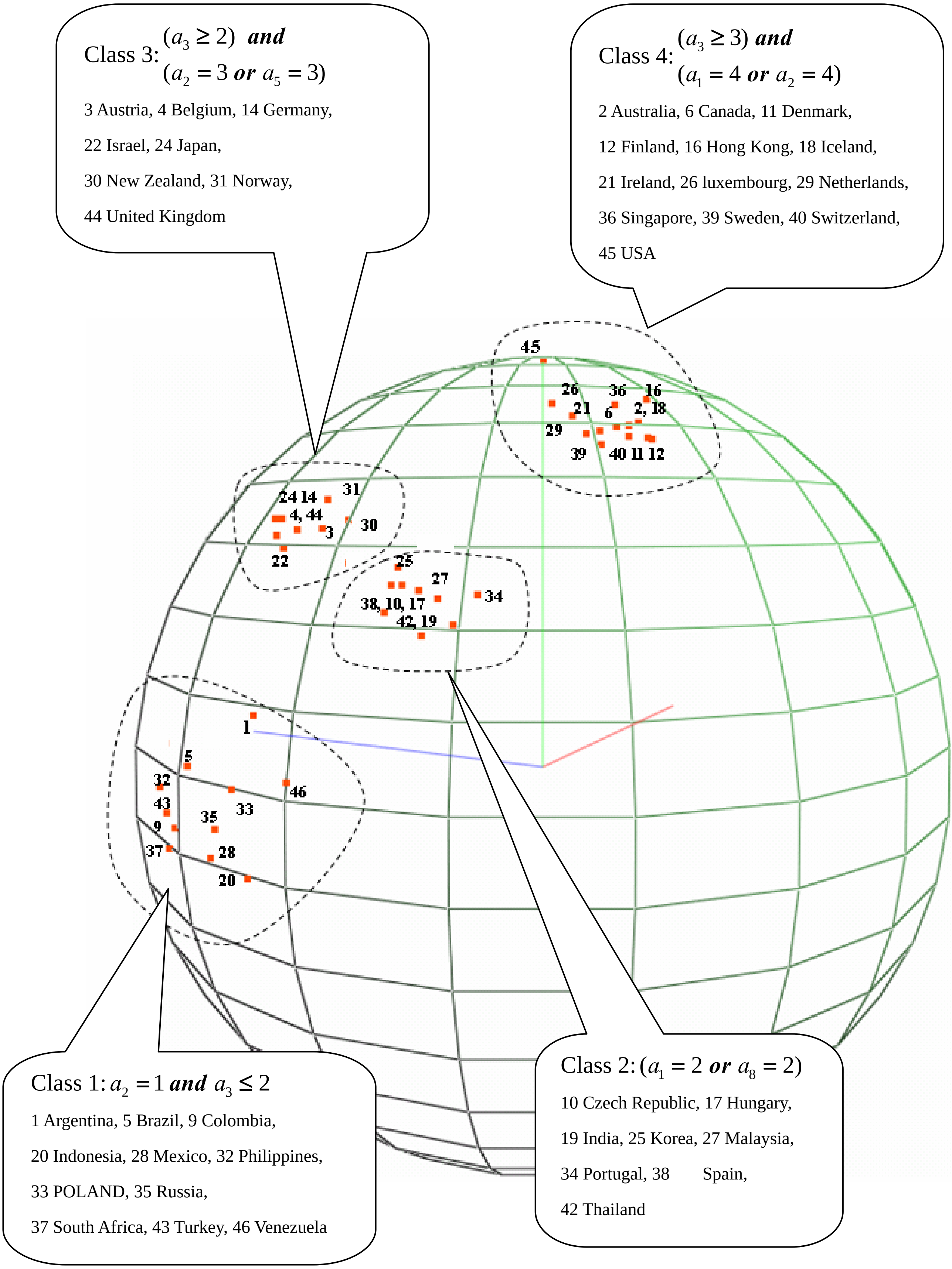



Figure 5.4: Display sphere for 2005

# Chapter 6 Comparison of Decision Tree and the Proposed Method

ID3 is one of the most popular methods in rule induction. In research literature, it is appraised with easy and simple rule expression. It is better in classification accuracy than other methods (Mak 2002; Sikder 2009). However, it is a heuristic method that does not provide optimal solutions. We develop the inducing method based on optimization technology that has good accuracy performance and provides more rules than ID3. This chapter compares ID3 and our proposed method for inducing rules based on class nations for 2008 of WCY-IMD.

There are 3 sections next. Section 6.1 presents ID3 based on Example 1. Section 6.2 applies the proposed method on Example 1. Finally comparison between update ID3 and the proposed method are presented.

## 6.1 ID3

ID3 provides decision trees by recursively partitioning a set, $\boldsymbol{S}$, and presents the classified subsets at leaf level with conjunctive terms of attribute values. Selecting a classifier is the critical issue of the performance, which has been improving for 20 years. We present the ID3 by using Example 1 of Table 3 below. Finally, an update ID3 is also presented to show its improvement.

The algorithm of ID3 is illustrated in Figure 6.1 with 4 steps.

Step 1: Compute the entropy value of information over a set, $\boldsymbol{S}$, by E($\boldsymbol{S}$), which is illustrated in Table 6.1.

Step 2: Compute the entropy value of information over classes for each attribute by PE($\boldsymbol{S}_j$), which is illustrated in Table 6.2. If all samples in $\boldsymbol{S}$ are in the class $k$ then stop and return.

Step 3: Select an attribute with the biggest information gain E($\boldsymbol{S}$) - PE($\boldsymbol{S}$, $j$) then partition the nations of S into subsets like Figure 6.2.

Step 4: Apply the algorithm recursively to subsets $\boldsymbol{S}_1$, $\boldsymbol{S}_2$, …, and $\boldsymbol{S}_x$.

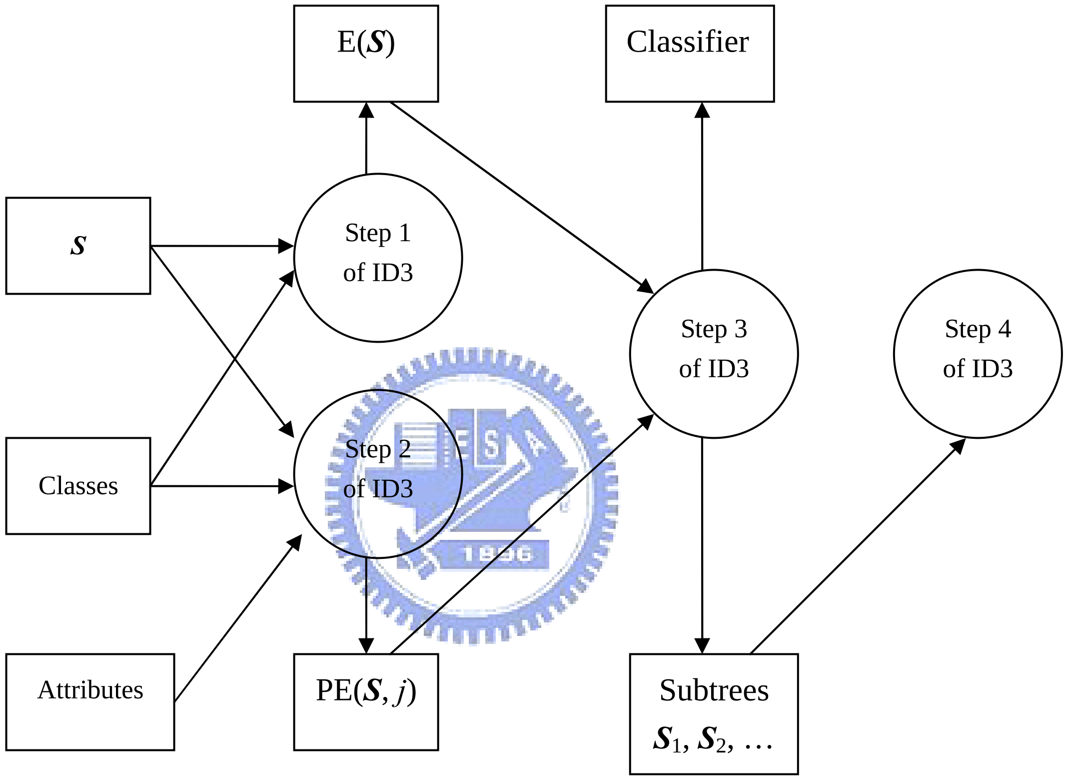



Figure 6.1: The processes of ID3 algorithm

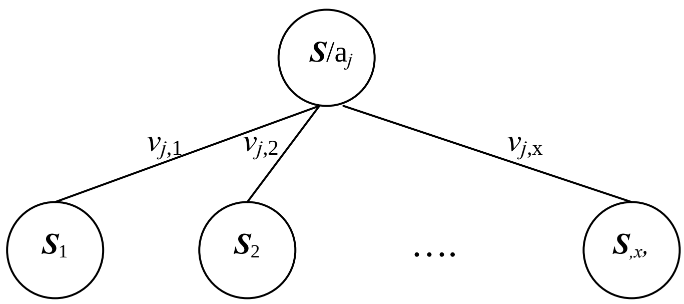



Figure 6.2: A conceptual ID3 tree

Here we take the example in Table 3.1 of this dissertation to illustrate the steps of ID3. The process is calculated as below.

**Step 1: Compute** E($\boldsymbol{S}$)

Consider a data set, *S*, in Table 3.1. The set of sample nations is expressed as $\boldsymbol{S}$. Three classes indicated by g of Example 1 are involved in probability calculation. The expected information to express the classes is measured by E($\boldsymbol{S}$) of (6.1).

**Table 6.1: Step 1 of ID3**

| Set and class sets | Probability | Entropy value of information over S |
|---|---|---|
| $\boldsymbol{S}=\{N_1,N_2,N_3,N_4,N_5\}$ | | $\mathrm{E}(\boldsymbol{S})$ |
| $\boldsymbol{S}(1)=\{N_1\}$ | $\mathrm{P}(1)=\dfrac{\lvert\boldsymbol{S}(1)\rvert}{\lvert\boldsymbol{S}\rvert}=0.2$ | $=\sum_{k=1}^{m}(-1)*\mathrm{P}(k)\log_m(\mathrm{P}(k))$ |
| $\boldsymbol{S}(2)=\{N_2,N_3\}$ | $\mathrm{P}(2)=\dfrac{\lvert\boldsymbol{S}(2)\rvert}{\lvert\boldsymbol{S}\rvert}=0.4$ | $=0.9602$ |
| $\boldsymbol{S}(3)=\{N_4,N_5\}$ | $\mathrm{P}(3)=\dfrac{\lvert\boldsymbol{S}(3)\rvert}{\lvert\boldsymbol{S}\rvert}=0.4$ | |

$$\mathrm{E}(\boldsymbol{S})=\sum_{k=1}^{m}\mathrm{P}(k)*(-1)*\log_m(\mathrm{P}(k)) \qquad ----------(6.1)$$

$m$ ***is the number of classes in the set S,***

$k$ ***is an index for a class***

$$\mathrm{P}(k)=\frac{\textbf{\textit{the number of nations in class }} k}{\textbf{\textit{the number of nations in S}}},$$

***which is the probability distribution for the class*** $k$

$(-1)*\log_m(\mathrm{P}(k))$ ***is a random variable on the class*** $k$

***If*** $\mathrm{P}(k)=0$ ***then*** $\mathrm{P}(k)\log_m(1/\mathrm{P}(k))=0$

**Step 2: Compute PE(*S*,*j*)**

This step measures the entropy of information over classes by PE($\boldsymbol{S}_j$) of (6.2) for each attribute. The computation of attribute, $a_2$, is illustrated in Table 6.2.

$$PE(\boldsymbol{S}, j) = \sum_{av} p_{aj=av} \times \mathrm{E}(\boldsymbol{S}_{aj=av}) \qquad ------------------(6.2)$$

$$av \textbf{\textit{ presents a value of attribute }} a_j$$

$$\boldsymbol{S}_{aj=av} \textbf{\textit{ is a subset composed of nations having }} a_j = av$$

$$\mathrm{p}_{aj=av} = \frac{\textbf{\textit{the number of nations having }} \boldsymbol{S}_{aj=av}}{\textbf{\textit{the number of nations in }} \boldsymbol{S}} = \frac{|\boldsymbol{S}_{aj=av}|}{|\boldsymbol{S}|}$$

$$\mathrm{E}(\boldsymbol{S}_{aj=av}) \textbf{\textit{ is the function }} (6.1) \textbf{\textit{ applied on a subset }} \boldsymbol{S}_{aj=av}$$

**Table 6.2: Step 2 of ID3 by the attribute *a*₂**

| | Set and class sets | Probability | Entropy of information over classes |
|---|---|---|---|
| $a_2=1$ | $\boldsymbol{S}_{a2=1} = \{N_1, N_4, N_5\}$ | $\mathrm{p}_{a2=1} = \frac{\lvert\boldsymbol{S}_{a2=1}\rvert}{\lvert\boldsymbol{S}\rvert} = 0.6$ | $\mathrm{PE}(\boldsymbol{S}, a_2)$ |
| | $\boldsymbol{S}_{a2=1}(1) = \{N_1\}$ | $\mathrm{P}_{a2=1}(1) = \frac{\lvert\boldsymbol{S}_{a2=1}(1)\rvert}{\lvert\boldsymbol{S}_{a2=1}\rvert} = 0.33$ | $= \sum_{av=1}^{2} \mathrm{p}_{a2=av} \times \mathrm{E}(\boldsymbol{S}_{a2=av})$ |
| | $\boldsymbol{S}_{a2=1}(2) = \varnothing$ | $\mathrm{P}_{a2=1}(2) = 0$ | |
| | $\boldsymbol{S}_{a2=2}(3) = \{N_4, N_5\}$ | $\mathrm{P}_{a2=1}(3) = \frac{\lvert\boldsymbol{S}_{a2=1}(3)\rvert}{\lvert\boldsymbol{S}_{a2=1}\rvert} = 0.67$ | $= \mathrm{p}_{a2=1} * \mathrm{E}(\boldsymbol{S}_{a2=1}) + \mathrm{p}_{a2=2} * \mathrm{E}(\boldsymbol{S}_{a2=2})$ |
| $a_2=2$ | $\boldsymbol{S}_{a2=2} = \{N_2, N_3\}$ | $\mathrm{p}_{a2=2} = \frac{\lvert\boldsymbol{S}_{a2=2}\rvert}{\lvert\boldsymbol{S}\rvert} = 0.4$ | $= 0.6 * \mathrm{E}(\boldsymbol{S}_{a2=1}) + 0.4 * \mathrm{E}(\boldsymbol{S}_{a2=2})$ |
| | $\boldsymbol{S}_{a2=2}(1) = \varnothing$ | $\mathrm{P}_{a2=2}(1) = 0$ | $= 0.6 * (-\frac{1}{3} * \log_3 3 - \frac{2}{3} * \log_2 \frac{3}{2}) + 0.4 * (-1 * \log_3 1)$ |
| | $\boldsymbol{S}_{a2=2}(2) = \{N_2, N_3\}$ | $\mathrm{P}_{a2=2}(2) = \frac{\lvert\boldsymbol{S}_{a2=2}(2)\rvert}{\lvert\boldsymbol{S}_{a2=2}\rvert} = 1$ | |
| | $\boldsymbol{S}_{a2=2}(3) = \varnothing$ | $\mathrm{P}_{a2=2}(3) = 0$ | $= 0.29814$ |

**Step 3: Select a classifier and generate subtrees**

The results of PE(**S**, $j$) are listed in Table 6.3. The classifier, $a_3$, is selected due to having the maximum information gain in Table 6.3. Then, $\boldsymbol{S}$ is partitioned into $\boldsymbol{S}_1$, $\boldsymbol{S}_2$, $\boldsymbol{S}_3$, and $\boldsymbol{S}_4$ by $a_3$, as shown in Figure 6.3.

**Table 6.3: Step 3 of ID3**

| | E(**S**) | PE(**S**, $a_1$) | PE(**S**, $a_2$) | PE(**S**, $a_3$) |
|---|---|---|---|---|
| Entropy of information | 0.9602 | 0.6309 | 0.29814 | 0 |
| Information Gain | | 0.3293 | 0.66206 | **0.9602** |
| Selected classifier | | | | $a_3$ |

$$\textbf{\textit{Information Gain}} = E(\boldsymbol{S}) - PE(\boldsymbol{S}, j) \quad ---------------------(6.3)$$

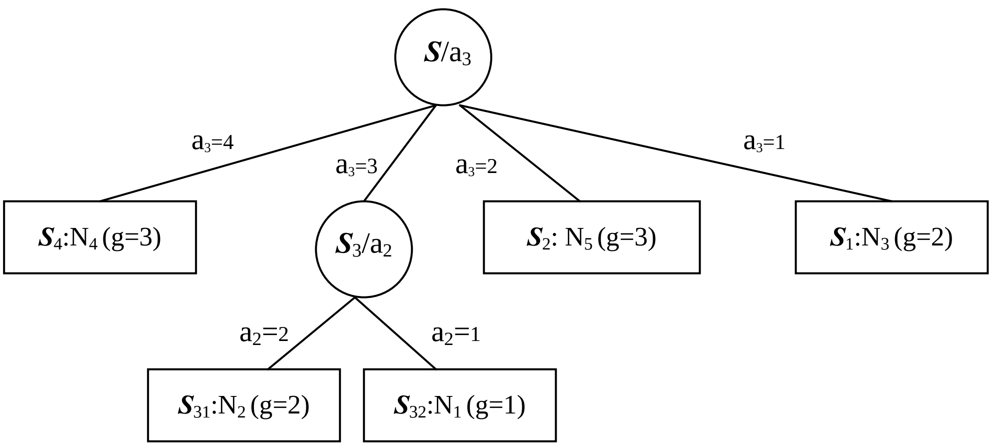



Figure 6.3: The ID3 tree of Example 1 in Table 3.1

**Step 4: Recursively partition subsets with Step 1**

All nations of $\boldsymbol{S}_1$, $\boldsymbol{S}_2$, and $\boldsymbol{S}_4$ in Figure 6.3 are in the same class. The ID3 terminates at these subtrees. $\boldsymbol{S}_3$ has two nations belonging to different classes. Thus, $\boldsymbol{S}_3$ is further partitioned with Step 1.

Decision rules of ID3 are extracted by taking attribute values conjunctively from the root to the leaf in the tree. The class rules with AR and CR are listed in Table 6.4.

**Table 6.4: Induced rules of Example 1 by ID3**

| | Induced Rules | AR | CR |
|---|---|---|---|
| g=1 | $a_3$=3 and $a_2$=1 | 1 | 1 |
| g=2 | $a_3$=1 | 1 | 0.5 |
| g=3 | $a_3$=4 | 1 | 0.5 |

An update ID3 modifying information gain with an average value is formulated below (Wang, 2007).

$$\textbf{\textit{Average Information Gain}} = \frac{\mathrm{E}(\boldsymbol{S}) - \mathrm{PE}(\boldsymbol{S}, j)}{\textbf{\textit{the number of}}\ a_j\ \textbf{\textit{value}}} \quad ---------------(6.4)$$

The update ID3 chooses a classifier by skipping the attribute that has many attribute values. The result of update ID3 is shown in Table 6.5 and Figure 6.4. It enhances coverage rate of rules by choosing $a_2$. Take a look at Table 6.4 and 6.5. The update ID3 has a better coverage rate than ID3 for g=2.

**Table 6.5: Induced rules of Example 1 by update ID3**

| group | Induced Rules | AR | CR |
|---|---|---|---|
| g=1 | $a_2$=1 and $a_1$=2 | 1 | 1 |
| g=2 | $a_2$=2 | 1 | 1 |
| g=3 | $a_2$=1 and $a_1$=1 | 1 | 0.5 |

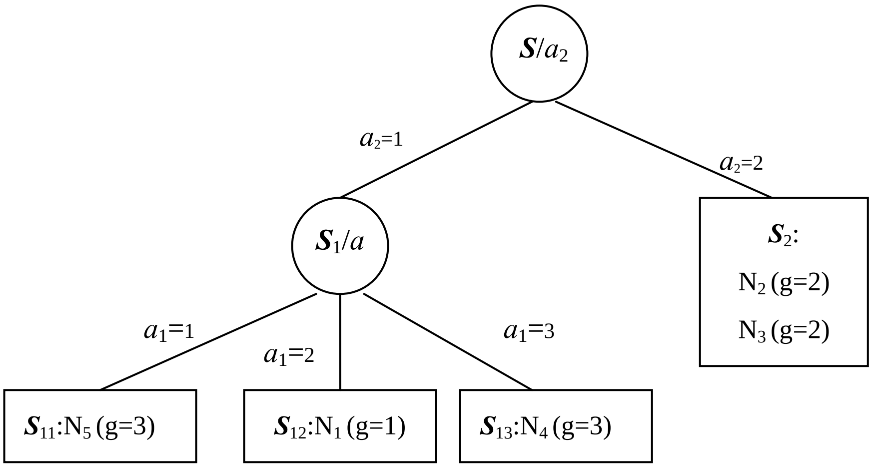



Figure 6.4: The update ID3 tree of Example 1

## 6.2 The Proposed Method

By applying the proposed Model (II) on Example 1, formulation of continuous sub attributes is illustrated below (Li, 2007).

$$\textbf{\textit{Max}} \quad \frac{AR(k)+CR_l(k)}{m-h}$$

$$s.t.$$

$$(i) \quad AR_l(k)=\frac{1}{n-n(k)}\Big(\sum_{g_r\neq k} v_r\Big)$$

$$(ii) \; CR_l(k)=\frac{1}{n(k)}\Big(\sum_{g_i=k} u_i\Big)$$

$$(iii) \; (3.9),(3,10),(3,11) \; \textbf{\textit{of proposition 3.3}}$$

$$(iv) \; d_{1,2} \geq \frac{d_{1,1}}{1}+\frac{d_{1,3}+d_{1,4}}{2}-\max\{\frac{d_{1,1}}{1},\frac{d_{1,3}+d_{1,4}}{2}\}$$

$$(v) \; d_{3,2} \geq \frac{d_{3,1}}{1}+\frac{d_{3,3}+d_{3,4}}{2}-\max\{\frac{d_{3,1}}{1},\frac{d_{3,3}+d_{3,4}}{2}\}$$

$$(vi) \; d_{3,3} \geq \frac{d_{3,4}}{1}+\frac{d_{3,1}+d_{3,2}}{2}-\max\{\frac{d_{3,4}}{1},\frac{d_{3,1}+d_{3,2}}{2}\}$$

Model (II) of inducing the rule for $g$ = 3 is formulated below.

$$5(u_4\ -1)\ +\ 3\ -\ h\ \le\ d_{21}\ +\ d_{34} \le 3\ -\ h\ +\ 5\ (1-u_4)$$

$$5(u_5\ -1)\ +\ 3\ -\ h\ \le\ d_{21}\ +\ d_{32}\ \le 3\ -\ h\ +\ 5\ (1-u_5)$$

$$d_{21}\ +\ d_{33}\ \le\ 3\ -\ h\ -\ 1\ +\ 5\ (1-v_1)$$

$$d_{33}\ \le\ 3\ -\ h\ -\ 1\ +\ 5\ (1-v_2)$$

$$0\ \le\ 3\ -\ h\ -\ 1\ +\ 5\ (1-v_3)$$

$$d_{3,2} \ge \frac{d_{3,3}+d_{3,4}}{2} - \max\{0, \frac{d_{3,3}+d_{3,4}}{2}\}$$

$$d_{3,3} \ge \frac{d_{3,4}}{1} + \frac{d_{3,2}}{2} - \max\{\frac{d_{3,4}}{1}, \frac{d_{3,2}}{2}\}$$

$$u_i,\ v_r,\ d_{jp}\quad \{0.1\}$$

The solution obtained is: CR=1 with AR=0.667 $d_{21}$=1 and $d_{32}$= $d_{33}$= $d_{34}$=1 (all other $d_{jp}$=0), $h$=1, $u_4$= $u_5$=1, $v_1$=0, $v_2$=$v_3$=1. This rule is shown $R_1(3)$ in Table 6.6.

**Table 6.6: Induced rules of Example 1 by the proposed method**

| Rule | $d_{11}$ | $d_{12}$ | $d_{13}$ | $d_{21}$ | $d_{22}$ | $d_{31}$ | $d_{32}$ | $d_{33}$ | $d_{34}$ | AR | CR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $R_1(1)$: $a_2$=1 and $a_1$=2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| $R_1(2)$: $a_2$=2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| $R_1(3)$: $a_2$=1 and $a_3\ge2$ | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0.67 | 1 |

## 6.3 Analysis of Update ID3 and the Proposed Method Based on WCY-IMD for 2008

According to Table 6.1, and 6.2, update ID3 performs better than ID3 for all classes. To discriminate update ID3 and the proposed method, we take a data set from WCY-IMD for 2008 and induce rules for nation classes. The raw data is presented in Table B.4 and discretized data and classes in Table D.4 (nations are partitioned by k-mean of SPSS into 4 classes). The induced results are presented in Table 6.7.

**Table 6.7: Comparison of update ID3 and the proposed method**

| Class | Rules by update ID3 | AR | CR | Rules by the proposed method | AR | CR |
|---|---|---|---|---|---|---|
| $G_4$ | $a_2 = 4$ | 0.78 | 0.5 | $(3\leq a_1 \leq 4) \wedge (3\leq a_2 \leq 4) \wedge (3\leq a_3 \leq 4) \wedge (3\leq a_9 \leq 4) \wedge (3\leq a_{11} \leq 4) \wedge (3\leq a_{14} \leq 4)$ | 0.8 | 1 |
| $G_3$ | $a_2 = 3$ | 0.84 | 0.36 | $(3\leq a_2 \leq 4) \wedge (3\leq a_7 \leq 4)$ | 0.80 | 0.84 |
| $G_2$ | $a_2 = 2$ | 0.82 | 0.45 | $(2\leq a_2 \leq 3) \wedge (2\leq a_3 \leq 3) \wedge (2\leq a_6 \leq 3)$ | 0.72 | 0.78 |
| $G_1$ | $a_2 = 1$ | 0.9 | 0.7 | $a_2 = 1$ | 0.9 | 0.7 |

The comparison of induced rules for nation classes is presented below.

(i) The good rules generated by update ID3 can also be found by the proposed method. For instance, induced rule for $G_1$.

(ii) Some rules generated by the proposed method cannot be found by update ID3 such as $G_4$, $G_3$, and $G_2$. The reason for this is that ID3 suffers from too many branches to give a quality rule. Users can take a look at Figure 6.5 and find 12 sub branches that are too many to cover enough nations to support rule quality.

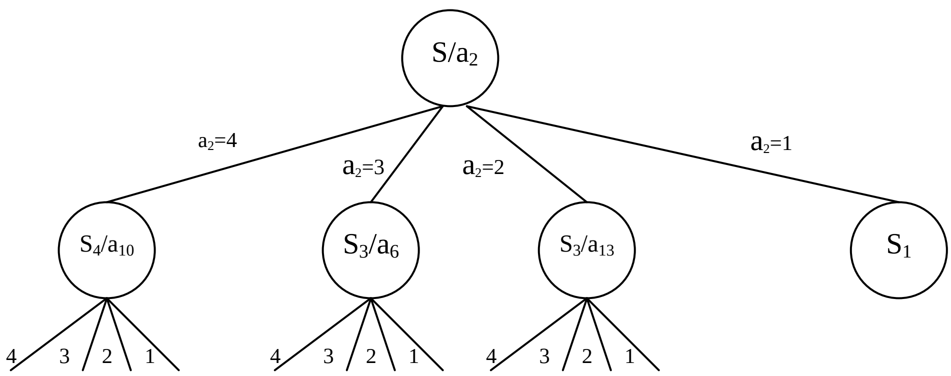



Figure 6.5: The decision tree of nation classes for 2008

In summary, the advantages of the proposed method over the ID3 are listed below:

- The decision tree technique is a widely used method of inducing rules. However, its induced rules may not be optimal, and may not cover all set of rules. That means the accuracy rate and the coverage rate for the rules found by the decision tree may not be the best.

- The greedy algorithm of the decision tree recursively partitions a tree with the most entropy reduction but it cannot guarantee the selected attribute is the best classifier.
- As described in the literature of Zanakis 2005 and Quinlan 1986, the decision tree method may expand many branches due to multiplication of the number of attribute values and those of classes. The more branches, the fewer nations are covered in a branch.

# Chapter 7 Concluding Remarks

This research constructs an optimization model for inducing a nation's dynamic rules based on the MCI-WCY data set. The rules, expressed in 'IF...THEN' forms, are generated with a high coverage rate and accuracy rate. Based on the simple and consistent rules during 2001~2005, policy makers can use them to imply strategic initiatives for global competition or validate their decisions of economic policy.

The integer programming is applied to design models of rule extraction of competitiveness classes. Induced rules are composed of conjunctive and disjunctive terms of attribute values that give high coverage and accuracy rates. A visual displaying sphere is provided to show the dissimilarity of nations on the surface and also gives direction of competitiveness. Users can get a visual understanding of knowledge in WCY over years.

Advantages from two approaches of analyzing national competitiveness, ranks and classes, are combined into our proposed method. Stakeholders can catch competitiveness differentiation of classes and get explanation from induced rules, which directly point how to sustain, improve, or prevent fall in competitiveness. The features of the proposed model are listed below, compared with the other studies of inducing the rules of a nation's competitiveness:

(i) Instead of using the WCY data set with a huge number of attributes, a high quality data set is used in the proposed model. This data set contains 14 most reliable and consistent attributes for 46 nations and three time periods, which help us to induce more reasonable rules.

(ii) Instead of using regression, neural network and decision tree techniques, the proposed model utilizes optimization techniques to induce rules. The rules have higher accuracy rates and coverage rates, and can be expressed in conjunction and disjunction terms.

(iii) Various types of national competitiveness have been found in this study, labeled as upward, downward, and sustaining, which are quite helpful to understand the critical factors affecting national competitiveness.

Some useful suggestions for both nations and investors are as follows:

(i) For nations wanting to move to a highly competitive level, the nations need to have a leading technology infrastructure or high export capacity.

(ii) For nations wanting to move from medium to competitive level, the nations need to have a medium level of GDP and have a high degree of technology infrastructure or stock market value.

(iii) For nations wanting to prevent falling in competitiveness, the nations need to lower unemployment rates and prevent GDP growth rates from declining.

(iv) GDP plays a fundamental role in forming nations' classes.

(v) Computer, which indicates the level of technology infrastructure, is an essential attribute of competitiveness. A nation can enhance significantly its competitiveness by enhancing its computer network.

(vi) Export is another sufficient condition for a nation to be highly competitive.

(vii) A nation should prevent its inflation from being at the low level if it does not want to be the least competitive.

(viii) A nation of the least competitive or non-competitive class should enhance its Foreign Direct Investment and its export volume.

The limitations of this study and validation with data are discussed in the followings.

- A limitation of this study is the classification of nation groups. By applying the k-mean technique based on nations' annual competitiveness scores, this study divides nations into 4 classes. Since k-mean is a heuristic method, the ranges of the 4 groups may not be the optimal.

- The attribute discretization (Appendix C) is determined approximately by equalizing the number of nations in each level. A more precise process of discretization may be studied in the future.
- The competitiveness scores before 2001 are not available, which restricts the time period of our study.

# Appendix A: Classification of Nations

Here we use the algorithm of k-mean (reference) to classify 46 nations into four classes, $G_4$, $G_3$, $G_2$, and $G_1$, based on the score values in TableB.1, Table B.2, and Table B.3. The steps are listed below (Han , 2001).

Step 1: Initialization

To assign initially each nation into a class for a specific year. Two criteria are used in the assignment. Firstly, the number of nations in each group is kept the same as possible. Secondly, the gap of scores for the nearby groups is obvious. Take 2001 for instance, the initial classification is listed below.

$G_1^{2001}$ ={PHILIPPINES, INDIA, SOUTH AFRICA, ARGENTINA, TURKEY, RUSSIA, COLOMBIA, POLAND, VENEZUELA, INDONESIA}

$G_2^{2001}$ ={ JAPAN, HUNGARY, KOREA, MALAYSIA, GREECE, BRAZIL, ITALY, MAINLAND CHINA, PORTUGAL, CZECH REPUBLIC, MEXICO, THAILAND}

$G_3^{2001}$ ={ ICELAND, AUSTRIA, DENMARK, ISRAEL, BELGIUM, TAIWAN, UNITED KINGDOM, NORWAY, NEW ZEALAND, SPAIN, CHILE, FRANCE}

$G_4^{2001}$ ={USA, SINGAPORE, FINLAND, LUXEMBOURG, HONG KONG, NETHERLANDS, IRELAND, SWEDEN, CANADA, SWITZERLAND, AUSTRALIA, GERMANY}

Step 2: Computing the average score, $C_k^y$ for a specific year y and class k, in each class.

Following Step 1 the related $C_k^y$ values are as follows:

$C_1^{2001}$ = 34.5, $C$2001

$C_2^{2001}$ = 48.8, $C$2001

$C_3^{2001}$ = 65.5, $C$2001

$C_4^{2001}$ = 81.4

Step 3: Denote $d^y(i,k)$ as the similarity distance of nation $i$ to the center of the class $k$, defined as $d^y(i,k) = | S_i^y - C_k^y |$ where $S_i^y$ is the score of $i^{\text{th}}$ nation in year $y$

Compute $d^y(i,k)$ for $i$ = 1, 2, 3, ..., 46 and $k$ = 1, 2, 3, 4.

Step 4: If $d^y(i,k) \le d^y(i,k^{'})$ then nation $i$ belongs to class $k$.

Step 5: Recalculate $C_i^y$ and $d^y(i,k)$ until converges to a final solution. The final classification is listed in Table A.

For instance, ARGENTINA belongs to $G1$ (least competitive) in 2001, 2003, and 2005. The group type is $G_{111}$. AUSTRIA belongs to $G4$ for 2001 and 2003, but downward to $G_3$ in 2005. The group type is $G_{443}$.

## Table A: Classified nations

| Nations | 2001 | | 2003 | | 2005 | | Competitiveness groups |
|---|---|---|---|---|---|---|---|
| | score | classes | score | classes | score | classes | |
| ARGENTINA | 37.5 | $G_1$ | 12.5 | $G_1$ | 37.8 | $G_1$ | $G_{111}$ |
| AUSTRALIA | 75.9 | $G_4$ | 86.5 | $G_4$ | 82.0 | $G_4$ | $G_{444}$ |
| AUSTRIA | 72.5 | $G_4$ | 82.6 | $G_4$ | 74.3 | $G_3$ | $G_{443}$ |
| BELGIUM | 66.0 | $G_3$ | 74.6 | $G_3$ | 67.5 | $G_3$ | $G_{333}$ |
| BRAZIL | 49.7 | $G_2$ | 40.7 | $G_1$ | 49.9 | $G_1$ | $G_{211}$ |
| CANADA | 76.9 | $G_4$ | 84.1 | $G_4$ | 82.6 | $G_4$ | $G_{444}$ |
| CHILE | 59.8 | $G_3$ | 61.5 | $G_2$ | 72.2 | $G_3$ | $G_{323}$ |
| MAINLAND-CHINA | 49.5 | $G_2$ | 50.8 | $G_2$ | 63.2 | $G_2$ | $G_{222}$ |
| COLOMBIA | 32.8 | $G_1$ | 44.5 | $G_2$ | 51.4 | $G_1$ | $G_{121}$ |
| CZECH-REPUBLIC | 46.7 | $G_2$ | 45.6 | $G_2$ | 60.1 | $G_2$ | $G_{222}$ |
| DENMARK | 71.8 | $G_4$ | 92.4 | $G_4$ | 82.5 | $G_4$ | $G_{444}$ |
| FINLAND | 83.4 | $G_4$ | 100.0 | $G_4$ | 82.6 | $G_4$ | $G_{444}$ |
| FRANCE | 59.6 | $G_3$ | 66.4 | $G_3$ | 64.2 | $G_2$ | $G_{332}$ |
| GERMANY | 74.0 | $G_4$ | 69.8 | $G_3$ | 67.8 | $G_3$ | $G_{433}$ |
| GREECE | 50.0 | $G_2$ | 34.2 | $G_1$ | 50.3 | $G_1$ | $G_{211}$ |
| HONG-KONG | 79.5 | $G_4$ | 90.3 | $G_4$ | 93.1 | $G_4$ | $G_{444}$ |
| HUNGARY | 55.6 | $G_2$ | 42.5 | $G_2$ | 59.9 | $G_2$ | $G_{222}$ |
| ICELAND | 73.7 | $G_4$ | 83.4 | $G_4$ | 85.3 | $G_4$ | $G_{444}$ |
| INDIA | 40.4 | $G_1$ | 42.2 | $G_1$ | 59.1 | $G_2$ | $G_{112}$ |
| INDONESIA | 28.3 | $G_1$ | 13.2 | $G_1$ | 33.8 | $G_1$ | $G_{111}$ |
| IRELAND | 79.2 | $G_4$ | 79.4 | $G_3$ | 77.8 | $G_4$ | $G_{434}$ |
| ISRAEL | 67.9 | $G_3$ | 43.6 | $G_2$ | 67.3 | $G_3$ | $G_{323}$ |
| ITALY | 49.6 | $G_2$ | 44.3 | $G_2$ | 45.8 | $G_1$ | $G_{221}$ |
| JAPAN | 57.5 | $G_3$ | 56.3 | $G_2$ | 68.7 | $G_3$ | $G_{323}$ |
| KOREA | 51.1 | $G_2$ | 46.5 | $G_2$ | 64.2 | $G_2$ | $G_{222}$ |
| LUXEMBOURG | 82.8 | $G_4$ | 88.7 | $G_4$ | 80.3 | $G_4$ | $G_{444}$ |
| MALAYSIA | 50.0 | $G_2$ | 72.9 | $G_3$ | 65.8 | $G_2$ | $G_{232}$ |
| MEXICO | 43.7 | $G_2$ | 33.3 | $G_1$ | 41.5 | $G_1$ | $G_{211}$ |
| NETHERLANDS | 79.5 | $G_4$ | 86.5 | $G_4$ | 77.4 | $G_4$ | $G_{444}$ |
| NEW-ZEALAND | 61.7 | $G_3$ | 72.2 | $G_3$ | 75.5 | $G_3$ | $G_{333}$ |
| NORWAY | 63.1 | $G_3$ | 75.8 | $G_3$ | 76.2 | $G_3$ | $G_{333}$ |
| PHILIPPINES | 40.6 | $G_1$ | 37.9 | $G_1$ | 51.1 | $G_1$ | $G_{111}$ |
| POLAND | 32.0 | $G_1$ | 21.5 | $G_1$ | 39.0 | $G_1$ | $G_{111}$ |
| PORTUGAL | 48.4 | $G_2$ | 35.2 | $G_1$ | 52.4 | $G_2$ | $G_{212}$ |
| RUSSIA | 34.6 | $G_1$ | 24.6 | $G_1$ | 43.6 | $G_1$ | $G_{111}$ |
| SINGAPORE | 87.7 | $G_4$ | 98.2 | $G_4$ | 89.7 | $G_4$ | $G_{444}$ |
| SOUTH-AFRICA | 38.6 | $G_1$ | 43.9 | $G_2$ | 52.0 | $G_1$ | $G_{121}$ |
| SPAIN | 60.1 | $G_3$ | 59.8 | $G_2$ | 59.4 | $G_2$ | $G_{322}$ |
| SWEDEN | 77.9 | $G_4$ | 87.1 | $G_4$ | 76.3 | $G_4$ | $G_{444}$ |
| SWITZERLAND | 76.8 | $G_4$ | 89.7 | $G_4$ | 82.5 | $G_4$ | $G_{444}$ |
| TAIWAN | 64.8 | $G_3$ | 69.3 | $G_3$ | 78.3 | $G_4$ | $G_{334}$ |
| THAILAND | 42.7 | $G_1$ | 58.4 | $G_2$ | 66.0 | $G_2$ | $G_{122}$ |
| TURKEY | 35.4 | $G_1$ | 29.8 | $G_1$ | 51.3 | $G_1$ | $G_{111}$ |
| UNITED-KINGDOM | 64.8 | $G_3$ | 66.5 | $G_3$ | 68.5 | $G_3$ | $G_{333}$ |
| USA | 100.0 | $G_4$ | 100.0 | $G_4$ | 100.0 | $G_4$ | $G_{444}$ |
| VENEZUELA | 30.7 | $G_1$ | 9.8 | $G_1$ | 30.3 | $G_1$ | $G_{111}$ |

# Appendix B: Data Set of MCI-WCY

**Table B.1: Raw data set for 2001**

| | Nation | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ | $a_7$ | $a_8$ | $a_9$ | $a_{10}$ | $a_{11}$ | $a_{12}$ | $a_{13}$ | $a_{14}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ARGENTINA | 792.7 | 69.9 | 7694 | 129 | 2174.1 | 5.6 | 23643.0 | -0.9 | 14.7 | 611.0 | 31.6 | -0.5 | -256.5 | 5117.9 |
| 2 | AUSTRALIA | 3989.2 | 555.8 | 20495 | 1217 | 21037.9 | 14.3 | 43910.0 | 4.5 | 6.6 | 278.4 | -141.7 | 4.2 | -910.0 | 10836.2 |
| 3 | AUSTRIA | 11593.0 | 401.6 | 22850 | 97 | 4009.7 | 18.9 | 50724.0 | 2.3 | 4.6 | 343.9 | 340.2 | 3.3 | -716.9 | 12891.9 |
| 4 | BELGIUM | 20337.5 | 402.4 | 22384 | 172 | 17727.7 | 19.7 | 57552.0 | 2.6 | 8.2 | 3680.7 | 3246.4 | 3.8 | 776.6 | 11543.6 |
| 5 | BRAZIL | 333.4 | 70.8 | 3523 | 478 | 1228.7 | 6.7 | 7383.0 | 6.0 | 9.6 | 176.0 | 9.1 | 4.2 | -132.6 | 1762.8 |
| 6 | CANADA | 9660.6 | 549.0 | 22379 | 3767 | 24849.5 | 15.6 | 46124.0 | 2.7 | 6.7 | 779.7 | 553.5 | 4.8 | 390.9 | 12171.9 |
| 7 | CHILE | 1187.5 | 80.5 | 4635 | 285 | 4191.8 | 4.9 | 13275.0 | 4.0 | 9.3 | 566.7 | 298.7 | 5.4 | -41.8 | 2667.5 |
| 8 | MAINLAND-CHINA | 263.0 | 14.3 | 845 | 950 | 308.1 | 0.5 | 1518.0 | 0.4 | 3.1 | 37.3 | 1.7 | 8.0 | 15.1 | 458.7 |
| 9 | COLOMBIA | 291.5 | 46.1 | 1948 | 145 | 252.0 | 2.1 | 5105.0 | 8.7 | 20.4 | 24.8 | -0.2 | 3.0 | 3.9 | 1155.5 |
| 10 | CZECH-REPUBLIC | 3513.7 | 164.4 | 4816 | 164 | 1156.9 | 2.1 | 10584.0 | 3.9 | 8.8 | 499.0 | 19.6 | 2.5 | -232.4 | 2578.4 |
| 11 | DENMARK | 11996.3 | 560.5 | 30112 | 233 | 19428.0 | 19.8 | 66491.0 | 2.9 | 5.2 | 1564.6 | 1804.4 | 2.9 | 627.3 | 14262.0 |
| 12 | FINLAND | 9190.5 | 573.3 | 23430 | 147 | 66552.4 | 18.3 | 52527.0 | 3.3 | 9.6 | 636.2 | 906.7 | 5.6 | 1733.3 | 11352.4 |
| 13 | FRANCE | 6271.5 | 369.4 | 21751 | 968 | 24308.1 | 15.6 | 55717.0 | 1.6 | 9.7 | 639.5 | 1760.0 | 3.2 | 374.0 | 11510.7 |
| 14 | GERMANY | 7624.3 | 372.6 | 23098 | 933 | 17307.6 | 22.6 | 51612.0 | 2.0 | 7.7 | 631.2 | 1194.4 | 3.1 | -326.3 | 13062.2 |
| 15 | GREECE | 1913.4 | 130.2 | 10410 | 281 | 18429.6 | 8.6 | 28402.0 | 3.1 | 11.4 | 88.4 | | 4.0 | -379.1 | 7833.9 |
| 16 | HONG-KONG | 34540.3 | 414.0 | 24010 | 708 | 87464.0 | 5.4 | 50727.0 | -3.7 | 5.0 | 3324.2 | 2866.0 | 10.5 | 1524.5 | 13703.2 |
| 17 | HUNGARY | 3612.1 | 178.0 | 4578 | 66 | 1617.1 | 1.8 | 11829.0 | 9.8 | 6.7 | 193.5 | 24.8 | 5.6 | -165.7 | 2777.8 |
| 18 | ICELAND | 9000.0 | 573.0 | 29680 | 56 | 16000.0 | 14.2 | 54999.0 | 5.0 | 1.3 | 500.0 | 233.3 | 4.0 | -2600.0 | 17000.0 |
| 19 | INDIA | 50.8 | 6.5 | 444 | 5863 | 166.6 | 0.6 | 1033.0 | 4.3 | 5.8 | 2.0 | 0.1 | 6.0 | -5.9 | 261.1 |
| 20 | INDONESIA | 304.0 | 14.0 | 654 | 277 | 298.9 | 0.1 | 1541.0 | 8.3 | 16.9 | -12.5 | 0.3 | 4.8 | 26.4 | 424.4 |
| 21 | IRELAND | 22055.7 | 408.6 | 24711 | 84 | 10290.6 | 11.7 | 54903.0 | 5.6 | 3.9 | 4622.3 | 1312.3 | 9.9 | -48.4 | 10581.1 |
| 22 | ISRAEL | 5952.8 | 347.7 | 17710 | 644 | 9127.3 | 12.1 | 46125.0 | 1.2 | 8.8 | 337.6 | 147.4 | 5.3 | -274.7 | 9327.6 |
| 23 | ITALY | 5088.3 | 308.0 | 18730 | 241 | 12528.8 | 14.4 | 51811.0 | 2.6 | 10.8 | 116.6 | 116.1 | 2.8 | -75.7 | 10755.2 |
| 24 | JAPAN | 4223.6 | 389.2 | 37567 | 2470 | 35589.4 | 22.0 | 73825.0 | -0.7 | 4.7 | 96.4 | 174.3 | 1.7 | 916.6 | 20825.8 |
| 25 | KOREA | 4088.2 | 313.0 | 9668 | 725 | 6388.5 | 8.7 | 21709.0 | 2.3 | 4.1 | 193.2 | 87.0 | 8.8 | 228.6 | 5423.5 |
| 26 | LUXEMBOURG | 41565.2 | 300.0 | 43951 | 51 | 78043.5 | 18.1 | 77416.0 | 3.2 | 2.7 | | | 8.5 | 4065.2 | 16739.1 |
| 27 | MALAYSIA | 4217.0 | 114.6 | 3680 | 757 | 5564.5 | 2.0 | 9230.0 | 1.6 | 3.0 | 59.3 | 396.9 | 8.6 | 313.8 | 1446.6 |
| 28 | MEXICO | 1728.7 | 66.2 | 5817 | 188 | 1493.7 | 2.1 | 12386.0 | 9.5 | 2.2 | 114.4 | 129.5 | 7.0 | -172.7 | 3731.3 |
| 29 | NETHERLANDS | 16486.7 | 468.3 | 22819 | 344 | 43099.8 | 18.1 | 46620.0 | 2.6 | 2.8 | 2117.2 | 2696.8 | 3.8 | 843.1 | 11171.7 |
| 30 | NEW-ZEALAND | 4053.4 | 484.6 | 13003 | 114 | 6893.2 | 7.8 | 28136.0 | 2.6 | 6.1 | 182.0 | 182.0 | 3.5 | -922.3 | 7378.6 |
| 31 | NORWAY | 17670.7 | 571.7 | 36147 | 195 | 15312.5 | 22.5 | 72455.0 | 3.0 | 3.4 | 865.4 | 605.8 | 3.1 | 4567.3 | 15865.4 |
| 32 | PHILIPPINES | 526.7 | 23.3 | 998 | 226 | 565.7 | 1.8 | 2739.0 | 4.3 | 11.2 | 6.7 | -0.7 | 3.9 | 79.4 | 621.0 |
| 33 | POLAND | 1088.0 | 108.8 | 4222 | 221 | 774.9 | | 11228.0 | 10.1 | 16.5 | 190.3 | 0.8 | 5.1 | -258.9 | 2586.4 |
| 34 | PORTUGAL | 3047.3 | 183.8 | 10546 | 125 | 6297.3 | 5.3 | 22483.0 | 2.9 | 4.1 | 105.1 | 290.7 | 3.2 | -1022.7 | 6164.8 |
| 35 | RUSSIA | 779.7 | 67.4 | 1697 | 207 | 503.1 | 0.5 | 3799.0 | 20.8 | 13.3 | 23.1 | 14.9 | 7.7 | 173.9 | 781.2 |
| 36 | SINGAPORE | 37455.2 | 439.8 | 22949 | 355 | 45609.2 | 7.1 | 44041.0 | 1.3 | 3.1 | 1604.6 | 905.7 | 9.9 | 5011.5 | 8482.8 |
| 37 | SOUTH-AFRICA | 741.7 | 69.8 | 2864 | 668 | 5638.7 | 5.3 | 17058.0 | 5.3 | 36.2 | 29.4 | 23.9 | 3.1 | -14.5 | 1708.3 |
| 38 | SPAIN | 3779.2 | 205.9 | 14077 | 718 | 9786.9 | 10.5 | 38766.0 | 3.5 | 14.1 | 211.3 | 799.1 | 4.0 | -380.9 | 7383.8 |
| 39 | SWEDEN | 11614.4 | 576.1 | 25705 | 277 | 41248.6 | 19.5 | 54957.0 | 1.0 | 4.7 | 6562.4 | 2160.2 | 3.6 | 939.2 | 12585.6 |
| 40 | SWITZERLAND | 14357.5 | 488.4 | 33608 | 239 | 93158.6 | 21.0 | 61663.0 | 1.6 | 2.0 | 1336.0 | 4638.4 | 3.4 | 4072.6 | 19193.6 |
| 41 | TAIWAN | 7155.0 | 336.0 | 13921 | 462 | 16513.0 | 6.2 | 32673.0 | 1.3 | 3.0 | 128.7 | 194.1 | 6.0 | 409.3 | 8467.3 |
| 42 | THAILAND | 1275.8 | 48.4 | 2001 | 392 | 897.2 | | 3784.0 | 1.6 | 2.3 | 95.4 | 5.4 | 4.5 | 142.9 | 1073.9 |
| 43 | TURKEY | 601.2 | 34.6 | 3045 | 285 | 1558.2 | 3.5 | 9398.0 | 54.9 | 6.3 | 10.8 | 9.0 | 7.2 | -135.6 | 1594.3 |
| 44 | UNITED-KINGDOM | 6356.1 | 442.4 | 23688 | 1945 | 48855.8 | 15.5 | 51038.0 | 2.9 | 5.5 | 1412.6 | 3365.6 | 2.9 | -374.8 | 15268.2 |
| 45 | USA | 3493.1 | 580.5 | 36144 | 7651 | 56101.1 | 19.2 | 73888.0 | 3.4 | 4.0 | 929.2 | 508.9 | 5.0 | -1459.6 | 22793.1 |
| 46 | VENEZUELA | 795.7 | 63.3 | 4981 | 87 | 282.2 | 2.5 | 12778.0 | 16.2 | 10.2 | 120.0 | 19.6 | 3.2 | 503.0 | 2859.3 |

| Table B.2: Raw data set for 2003 | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nation | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ | $a_7$ | $a_8$ | $a_9$ | $a_{10}$ | $a_{11}$ | $a_{12}$ | $a_{13}$ | $a_{14}$ |
| 1 | ARGENTINA | 758.0 | 68 | 2875 | 111 | 4988.3 | 1.8 | 9496.0 | 25.9 | 17.8 | 83.2 | -3.1 | -11.2 | 241.2 | 1648.1 |
| 2 | AUSTRALIA | 3970.5 | 630 | 19965 | 1334 | 18411.2 | 13.8 | 42471.0 | 3.0 | 6.3 | 215.9 | 571.1 | 3.8 | -873.6 | 11603.5 |
| 3 | AUSTRIA | 13566.2 | 476 | 25002 | 114 | 2976.9 | 20.4 | 53573.0 | 1.8 | 4.1 | 716.9 | 370.6 | 0.5 | -201.7 | 14167.7 |
| 4 | BELGIUM | 22698.0 | 509 | 23981 | 156 | 15896.5 | 22.2 | 59553.0 | 1.7 | 7.3 | 4838.0 | 6364.3 | 0.7 | 1112.2 | 12838.0 |
| 5 | BRAZIL | 372.3 | 83 | 2591 | 428 | 1003.4 | 2.4 | 5870.0 | 12.5 | 10.5 | 122.0 | 12.2 | 1.5 | -41.3 | 1445.4 |
| 6 | CANADA | 8941.0 | 647 | 23262 | 4004 | 21743.7 | 15.5 | 47714.0 | 2.2 | 7.7 | 851.4 | 1103.6 | 3.4 | 342.1 | 12901.0 |
| 7 | CHILE | 1339.9 | 120 | 3878 | 249 | 3460.4 | 2.1 | 10986.0 | 1.5 | 9.0 | 275.4 | 87.9 | 1.9 | -34.0 | 2636.8 |
| 8 | MAINLAND-CHINA | 345.5 | 27 | 963 | 1160 | 505.0 | 0.6 | 1678.0 | -0.8 | 4.0 | 42.6 | 6.6 | 8.0 | 16.8 | 534.7 |
| 9 | COLOMBIA | 312.6 | 59 | 1878 | 123 | 286.7 | 2.2 | 4980.0 | 7.0 | 16.9 | 50.6 | 0.9 | 2.5 | -46.2 | 1129.5 |
| 10 | CZECH-REPUBLIC | 3950.0 | 211 | 6767 | 94 | 911.8 | 2.9 | 14410.0 | 1.8 | 7.2 | 482.4 | 9.8 | 2.0 | -363.5 | 3598.0 |
| 11 | DENMARK | 15444.7 | 658 | 32183 | 208 | 17527.7 | 23.2 | 63396.0 | 2.4 | 4.5 | 1335.8 | 1776.8 | 1.6 | 907.7 | 15332.1 |
| 12 | FINLAND | 9270.5 | 662 | 25303 | 152 | 36285.7 | 21.0 | 55523.0 | 1.6 | 9.1 | 653.3 | 1592.4 | 1.6 | 1791.0 | 12628.6 |
| 13 | FRANCE | 6743.8 | 419 | 23939 | 791 | 19347.6 | 16.7 | 58822.0 | 1.9 | 8.7 | 864.9 | 1370.5 | 1.0 | 459.8 | 12828.7 |
| 14 | GERMANY | 8361.2 | 480 | 24123 | 988 | 12951.1 | 24.1 | 51359.0 | 1.4 | 8.2 | 381.0 | 516.6 | 0.2 | 556.7 | 14145.0 |
| 15 | GREECE | 2531.6 | 130 | 13365 | 338 | 7806.9 | 7.0 | 33462.0 | 3.6 | 10.0 | 143.5 | 55.1 | 4.0 | -775.3 | 8113.7 |
| 16 | HONG-KONG | 35021.6 | 434 | 24003 | 857 | 72925.1 | 5.2 | 50541.0 | -3.0 | 7.3 | 3426.5 | 1634.0 | 2.3 | 2519.2 | 13098.0 |
| 17 | HUNGARY | 4163.7 | 153 | 6186 | 57 | 1031.7 | 2.1 | 16515.0 | 5.3 | 5.6 | 242.1 | 33.7 | 3.3 | -257.9 | 4156.7 |
| 18 | ICELAND | 9900.0 | 649 | 29156 | 61 | 12000.0 | 14.0 | 53958.0 | 5.2 | 2.5 | 500.0 | 1233.3 | -0.5 | 26.7 | 15333.3 |
| 19 | INDIA | 63.6 | 9 | 445 | 5795 | 99.6 | 0.4 | 1103.0 | 4.3 | 10.3 | 2.1 | 0.3 | 4.4 | 2.3 | 285.5 |
| 20 | INDONESIA | 260.6 | 13 | 802 | 316 | 105.0 | 0.4 | 1556.0 | 10.0 | 9.0 | -15.0 | 0.7 | 3.7 | 34.9 | 557.6 |
| 21 | IRELAND | 26295.4 | 516 | 30514 | 68 | 18232.5 | 14.0 | 67213.0 | 4.6 | 4.4 | 2389.8 | 1309.9 | 5.1 | -41.2 | 13268.8 |
| 22 | ISRAEL | 5765.4 | 387 | 15541 | 636 | 10057.2 | 12.0 | 44873.0 | 5.7 | 10.4 | 460.7 | 163.1 | -1.1 | -972.4 | 8555.1 |
| 23 | ITALY | 5315.2 | 310 | 20447 | 288 | 9072.8 | 14.5 | 54332.0 | 2.5 | 9.0 | 255.8 | 374.3 | 0.4 | -116.5 | 12196.8 |
| 24 | JAPAN | 3754.4 | 477 | 31368 | 2471 | 17625.2 | 19.0 | 63132.0 | -1.0 | 5.4 | 48.5 | 301.3 | 0.3 | 890.4 | 17881.2 |
| 25 | KOREA | 3977.4 | 342 | 9797 | 1409 | 4555.8 | 8.4 | 21499.0 | 2.8 | 3.1 | 66.3 | 53.8 | 6.3 | 126.1 | 5939.1 |
| 26 | LUXEMBOURG | 59891.3 | 460 | 45972 | 52 | 51739.1 | 18.3 | 76964.0 | 2.1 | 2.4 | | 18760.9 | 1.0 | 3869.6 | 19130.4 |
| 27 | MALAYSIA | 4197.9 | 137 | 3814 | 809 | 4592.4 | 2.8 | 9900.0 | 1.8 | 3.5 | 21.0 | 10.3 | 4.2 | 275.9 | 1603.5 |
| 28 | MEXICO | 1681.3 | 88 | 6161 | 168 | 1225.0 | 2.3 | 15091.0 | 5.1 | 2.7 | 239.9 | 217.0 | 0.9 | -147.8 | 4260.9 |
| 29 | NETHERLANDS | 18290.8 | 605 | 25963 | 180 | 28406.7 | 20.3 | 52827.0 | 3.4 | 2.7 | 3176.7 | 2458.8 | 0.3 | 552.4 | 12851.8 |
| 30 | NEW-ZEALAND | 4344.7 | 571 | 14583 | 145 | 4320.4 | 8.5 | 30107.0 | 2.7 | 5.2 | 419.9 | 72.8 | 3.2 | -419.9 | 8058.3 |
| 31 | NORWAY | 18516.8 | 657 | 42241 | 186 | 16610.6 | 26.1 | 84407.0 | 1.3 | 3.9 | 521.6 | -262.0 | 1.0 | 6358.2 | 20576.9 |
| 32 | PHILIPPINES | 414.6 | 25 | 977 | 232 | 488.1 | 0.9 | 2548.0 | 3.2 | 10.2 | 21.1 | -1.9 | 5.2 | 29.2 | 625.7 |
| 33 | POLAND | 1255.0 | 114 | 4801 | 230 | 680.6 | 2.5 | 13295.0 | 1.9 | 19.9 | 149.5 | -2.4 | 1.0 | -176.3 | 3196.3 |
| 34 | PORTUGAL | 3086.2 | 201 | 12014 | 97 | 4384.5 | 4.9 | 23882.0 | 3.6 | 5.0 | 563.4 | 745.3 | 0.4 | -883.5 | 6354.2 |
| 35 | RUSSIA | 820.6 | 77 | 2408 | 236 | 531.0 | 0.7 | 5219.0 | 15.1 | 7.1 | 17.2 | 17.6 | 4.1 | 240.9 | 1073.9 |
| 36 | SINGAPORE | 34931.0 | 596 | 20906 | 386 | 26965.5 | 7.8 | 43109.0 | -0.4 | 4.4 | 2517.2 | 2195.4 | 2.2 | 4299.8 | 8597.7 |
| 37 | SOUTH-AFRICA | 721.3 | 84 | 2293 | 542 | 2981.4 | 5.3 | 7897.0 | 10.1 | 29.4 | 152.7 | -78.7 | 3.0 | 6.7 | 1379.8 |
| 38 | SPAIN | 3997.7 | 224 | 16282 | 1458 | 10614.4 | 11.5 | 40229.0 | 3.5 | 11.4 | 488.3 | 628.0 | 2.0 | -379.7 | 8589.9 |
| 39 | SWEDEN | 11327.1 | 687 | 26921 | 285 | 25701.7 | 19.5 | 56143.0 | 0.5 | 4.9 | 1446.4 | 769.1 | 1.6 | 1106.1 | 12817.7 |
| 40 | SWITZERLAND | 15157.3 | 641 | 36937 | 263 | 70053.8 | 23.7 | 64151.0 | 0.7 | 3.0 | 1159.9 | 1485.2 | 0.1 | 4279.6 | 21814.5 |
| 41 | TAIWAN | 6612.2 | 314 | 12500 | 584 | 12850.2 | 6.1 | 29777.0 | -0.2 | 5.2 | 180.5 | 240.7 | 3.5 | 1130.0 | 7804.1 |
| 42 | THAILAND | 1252.9 | 43 | 1955 | 449 | 557.7 | 0.9 | 3759.0 | 0.7 | 2.2 | 58.7 | 2.5 | 5.2 | 117.2 | 1096.9 |
| 43 | TURKEY | 709.2 | 52 | 2631 | 310 | 654.9 | 3.5 | 9045.0 | 45.0 | 10.6 | 45.4 | 6.9 | 7.8 | -24.8 | 1698.3 |
| 44 | UNITED-KINGDOM | 6400.7 | 526 | 25894 | 1923 | 36930.4 | 16.8 | 54775.0 | 1.6 | 5.1 | 1051.1 | 570.3 | 1.6 | -217.0 | 16892.1 |
| 45 | USA | 3227.1 | 739 | 36552 | 6355 | 46574.9 | 20.3 | 77812.0 | 1.6 | 5.8 | 441.1 | 431.1 | 2.3 | -1697.7 | 24622.0 |
| 46 | VENEZUELA | 1071.1 | 76 | 5137 | 63 | 233.3 | 2.5 | 14151.0 | 31.2 | 18.3 | 129.8 | 7.9 | -9.6 | 287.5 | 3186.6 |

**Table B.3: Raw data set for 2005**

| | Nation | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ | $a_7$ | $a_8$ | $a_9$ | $a_{10}$ | $a_{11}$ | $a_{12}$ | $a_{13}$ | $a_{14}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ARGENTINA | 987.6 | 77 | 3833 | 107 | 1008.0 | 1.8 | 11581.0 | 6.1 | 13.5 | 27.2 | 20.5 | 8.5 | 80.3 | 2500.6 |
| 2 | AUSTRALIA | 5276.9 | 689 | 30679 | 1405 | 28799.8 | 22.6 | 63758.0 | 2.4 | 5.5 | 245.9 | 763.4 | 3.6 | -1923.3 | 17732.4 |
| 3 | AUSTRIA | 19279.5 | 547 | 36026 | 86 | 6622.1 | 27.9 | 78202.0 | 2.1 | 4.5 | 884.6 | 857.8 | 2.0 | -158.0 | 19829.9 |
| 4 | BELGIUM | 33681.7 | 575 | 33840 | 152 | 17123.7 | 30.5 | 84466.0 | 2.1 | 7.8 | 671.1 | 2290.5 | 2.7 | 1140.9 | 18283.8 |
| 5 | BRAZIL | 571.8 | 105 | 3330 | 367 | 1264.3 | 2.8 | 7451.0 | 7.6 | 11.5 | 97.9 | 51.0 | 5.2 | 63.1 | 1801.6 |
| 6 | CANADA | 11292.3 | 689 | 31153 | 3578 | 27738.1 | 20.8 | 62317.0 | 1.8 | 7.2 | 204.2 | 1372.6 | 2.8 | 806.7 | 17232.4 |
| 7 | CHILE | 2257.5 | 159 | 5896 | 240 | 5304.2 | 2.1 | 16645.0 | 2.4 | 8.8 | 467.1 | 57.8 | 6.1 | -86.0 | 3337.4 |
| 8 | MAINLAND-CHINA | 616.6 | 41 | 1269 | 1296 | 656.5 | 0.8 | 2187.0 | 3.9 | 4.2 | 59.8 | -0.1 | 9.5 | 44.2 | 613.4 |
| 9 | COLOMBIA | 312.6 | 70 | 2082 | 114 | 310.6 | 2.2 | 5369.0 | 5.9 | 13.6 | 53.6 | 20.4 | 3.6 | -23.9 | 1288.0 |
| 10 | CZECH-REPUBLIC | 5539.2 | 272 | 10535 | 63 | 1735.3 | 5.2 | 22750.0 | 2.8 | 8.3 | 490.2 | 23.5 | 4.0 | -539.2 | 5215.7 |
| 11 | DENMARK | 19870.9 | 721 | 44725 | 187 | 23616.2 | 35.4 | 88720.0 | 1.2 | 5.4 | 219.6 | 158.7 | 2.4 | 1107.0 | 21420.7 |
| 12 | FINLAND | 13053.3 | 719 | 35526 | 142 | 32438.1 | 29.8 | 78653.0 | 0.2 | 8.9 | 872.4 | -224.8 | 3.7 | 1600.0 | 18323.8 |
| 13 | FRANCE | 9059.8 | 487 | 33617 | 723 | 22332.8 | 23.2 | 83111.0 | 2.1 | 9.6 | 576.6 | 972.8 | 2.1 | -108.7 | 18192.8 |
| 14 | GERMANY | 12452.0 | 562 | 32716 | 684 | 13039.3 | 32.8 | 70349.0 | 1.7 | 9.5 | -592.1 | 30.9 | 1.6 | 1169.8 | 19076.7 |
| 15 | GREECE | 3436.8 | 166 | 18337 | 339 | 9639.0 | 7.0 | 47520.0 | 3.1 | 9.1 | 65.0 | 0.9 | 3.9 | -1001.8 | 12355.6 |
| 16 | HONG-KONG | 43786.7 | 503 | 23926 | 1029 | 102968.3 | 5.5 | 50023.0 | -0.4 | 6.8 | 4903.5 | 5727.7 | 8.1 | 2305.5 | 13876.1 |
| 17 | HUNGARY | 6251.0 | 191 | 9879 | 49 | 1617.1 | 2.1 | 25585.0 | 6.8 | 5.9 | 436.5 | 59.5 | 4.0 | -873.0 | 6756.0 |
| 18 | ICELAND | 12266.7 | 726 | 41765 | 48 | 31000.0 | 19.1 | 78342.0 | 3.2 | 3.1 | 1466.7 | 8433.3 | 5.2 | -3333.3 | 23666.7 |
| 19 | INDIA | 88.0 | 12 | 578 | 5644 | 251.9 | 0.6 | 1296.0 | 2.6 | 10.3 | 5.4 | 0.4 | 6.8 | 9.6 | 346.8 |
| 20 | INDONESIA | 347.8 | 16 | 1191 | 333 | 249.6 | 0.3 | 2681.0 | 6.0 | 9.5 | 4.8 | 0.0 | 5.1 | 23.7 | 782.6 |
| 21 | IRELAND | 33840.2 | 560 | 44923 | 55 | 20605.3 | 21.0 | 98851.0 | 2.2 | 4.5 | 6295.4 | 854.7 | 5.6 | -435.8 | 19878.9 |
| 22 | ISRAEL | 7038.6 | 495 | 17100 | 576 | 10829.8 | 11.9 | 48861.0 | 1.2 | 10.4 | 78.7 | 364.8 | 4.3 | 0.0 | 9914.2 |
| 23 | ITALY | 7204.4 | 390 | 29167 | 271 | 10576.3 | 20.2 | 74927.0 | 2.2 | 8.0 | 258.0 | 154.7 | 1.2 | -189.2 | 17235.5 |
| 24 | JAPAN | 4979.0 | 543 | 36559 | 3116 | 23800.1 | 21.5 | 73757.0 | 0.0 | 4.7 | 54.8 | 225.2 | 2.6 | 1212.4 | 20666.9 |
| 25 | KOREA | 6020.1 | 539 | 14105 | 1563 | 6825.4 | 10.7 | 30140.0 | 3.6 | 3.6 | 173.1 | 99.2 | 4.6 | 571.5 | 7247.9 |
| 26 | LUXEMBOURG | 83804.3 | 692 | 70744 | 44 | 81087.0 | 25.4 | 105588.0 | 2.2 | 4.2 | | | 4.2 | 5000.0 | 27608.7 |
| 27 | MALAYSIA | 5356.3 | 192 | 4604 | 897 | 6444.7 | 2.4 | 12106.0 | 1.4 | 3.5 | 180.6 | 71.6 | 7.1 | 570.2 | 1932.6 |
| 28 | MEXICO | 1951.2 | 105 | 6415 | 159 | 1188.2 | 2.4 | 16101.0 | 5.2 | 3.8 | 174.6 | 17.3 | 4.4 | -84.4 | 4532.5 |
| 29 | NETHERLANDS | 26149.4 | 685 | 35629 | 183 | 30291.4 | 29.5 | 73074.0 | 1.2 | 4.7 | 973.3 | 2182.3 | 1.4 | 1475.5 | 17569.8 |
| 30 | NEW-ZEALAND | 5502.4 | 604 | 22369 | 157 | 8034.0 | 12.7 | 45358.0 | 2.7 | 3.9 | 623.8 | 118.9 | 4.6 | -728.2 | 13155.3 |
| 31 | NORWAY | 24901.4 | 717 | 54433 | 156 | 22764.4 | 33.2 | 110942.0 | 0.5 | 4.5 | 495.2 | 555.3 | 2.9 | 8197.1 | 26947.1 |
| 32 | PHILIPPINES | 500.5 | 30 | 1026 | 234 | 277.6 | 0.7 | 2737.0 | 5.6 | 12.2 | 3.8 | 1.9 | 6.1 | 38.8 | 702.2 |
| 33 | POLAND | 2262.8 | 138 | 6205 | 203 | 973.8 | 2.5 | 17350.0 | 3.5 | 18.8 | 130.9 | 5.2 | 5.4 | -107.3 | 3568.1 |
| 34 | PORTUGAL | 4078.6 | 252 | 15719 | 59 | 5520.8 | 6.8 | 32525.0 | 2.3 | 6.7 | 568.2 | 12.3 | 1.5 | -1259.5 | 8608.0 |
| 35 | RUSSIA | 1387.4 | 132 | 4083 | 214 | 1608.4 | 0.9 | 8827.0 | 11.0 | 8.9 | 69.7 | 67.8 | 7.1 | 249.5 | 1958.9 |
| 36 | SINGAPORE | 48312.6 | 573 | 25191 | 475 | 33356.3 | 7.6 | 51680.0 | 1.7 | 4.0 | 3692.0 | 2452.9 | 8.4 | 6413.8 | 10367.8 |
| 37 | SOUTH-AFRICA | 1115.6 | 104 | 4574 | 426 | 5709.1 | 4.9 | 17782.0 | 1.4 | 27.8 | 12.4 | 34.3 | 3.7 | -147.2 | 2874.8 |
| 38 | SPAIN | 5786.7 | 257 | 22968 | 3191 | 16463.4 | 16.4 | 57964.0 | 3.0 | 10.8 | 223.3 | 952.2 | 2.7 | -1113.1 | 12931.3 |
| 39 | SWEDEN | 16722.7 | 741 | 38063 | 264 | 31768.0 | 27.7 | 79315.0 | 0.5 | 6.3 | 0.0 | 1319.3 | 3.3 | 3038.7 | 16254.1 |
| 40 | SWITZERLAND | 20215.1 | 712 | 48389 | 289 | 97540.3 | 30.2 | 85425.0 | 0.8 | 4.4 | 1918.0 | 3778.2 | 1.9 | 6733.9 | 28951.6 |
| 41 | TAIWAN | 8975.0 | 375 | 13459 | 669 | 16644.7 | 6.0 | 31204.0 | 1.6 | 4.4 | 83.4 | 311.4 | 5.7 | 834.4 | 8445.3 |
| 42 | THAILAND | 1741.7 | 57 | 2509 | 405 | 1823.6 | 0.9 | 4686.0 | 2.7 | 2.0 | 15.4 | 5.2 | 6.1 | 112.2 | 1396.5 |
| 43 | TURKEY | 1134.0 | 58 | 4190 | 284 | 949.1 | 3.5 | 13667.0 | 10.6 | 10.0 | 35.7 | 11.9 | 9.6 | -215.1 | 2762.6 |
| 44 | UNITED-KINGDOM | 8144.7 | 595 | 35566 | 2311 | 40179.9 | 22.8 | 75779.0 | 3.0 | 5.0 | 916.1 | 1089.9 | 3.2 | -504.7 | 19623.6 |
| 45 | USA | 3732.3 | 763 | 39468 | 5295 | 48112.4 | 22.0 | 84261.0 | 2.7 | 5.5 | 408.1 | 684.3 | 4.4 | -2037.6 | 27759.3 |
| 46 | VENEZUELA | 919.5 | 90 | 4184 | 54 | 143.0 | 2.5 | 10667.0 | 19.2 | 16.6 | 42.9 | -6.0 | 17.3 | 549.3 | 2061.7 |

## Table B.4: Raw data set for 2008

| | Nation | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ | $a_7$ | $a_8$ | $a_9$ | $a_{10}$ | $a_{11}$ | $a_{12}$ | $a_{13}$ | $a_{14}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ARGENTINA | 31 | 104 | 6616 | 103 | 80 | | 17593 | 8.50 | 7.50 | 5 | 1 | 8.50 | 6 | 3875 |
| 2 | AUSTRALIA | 73 | 796 | 43251 | 1751 | 1096 | 26.12 | 86821 | 2.33 | 4.40 | 24 | 26 | 4.13 | -57 | 24051 |
| 3 | AUSTRIA | 93 | 691 | 44891 | 96 | 191 | 30.42 | 92955 | 2.20 | 4.40 | 22 | 24 | 3.40 | 11 | 24342 |
| 4 | BELGIUM | | 705 | 42741 | 153 | 396 | 31.80 | 104064 | 1.82 | 7.50 | 8 | 34 | 2.80 | 3 | 22412 |
| 5 | BRAZIL | 58 | 156 | 6941 | 392 | 711 | 4.90 | | 3.64 | 9.30 | 35 | 7 | 5.40 | 14 | 4225 |
| 6 | CANADA | 247 | 790 | 43300 | 3790 | 1701 | 25.74 | 84540 | 2.14 | 6.03 | 110 | 49 | 2.70 | 13 | 24147 |
| 7 | CHILE | 20 | 239 | 9880 | 244 | 175 | | 24644 | 7.57 | 7.20 | 12 | 4 | 5.10 | 7 | 5403 |
| 8 | CHINA MAINLAND | 208 | 65 | 2454 | 1440 | 2426 | 1.14 | 4211 | 4.80 | 4.00 | | 19 | 11.90 | 363 | |
| 9 | COLOMBIA | 13 | 94 | 3915 | 114 | 58 | | 9475 | 5.54 | 10.87 | 9 | 0 | 7.52 | -6 | 2429 |
| 10 | CZECH REPUBLIC | 33 | 375 | 16991 | 29 | 49 | 6.78 | 35405 | 2.80 | 5.30 | 9 | 1 | 6.50 | -5 | 8066 |
| 11 | DENMARK | 64 | 825 | 57204 | 201 | 231 | 35.44 | 110848 | 1.70 | 3.80 | 11 | 18 | 1.80 | 3 | 28417 |
| 12 | FINLAND | 50 | 788 | 46322 | 134 | 265 | 29.86 | 98184 | 2.50 | 6.90 | 8 | 9 | 4.40 | 11 | 23440 |
| 13 | FRANCE | 405 | 645 | 41449 | 717 | 2429 | 24.87 | 99693 | 1.49 | 8.30 | 124 | 195 | 2.20 | -33 | 23400 |
| 14 | GERMANY | 624 | 706 | 40316 | 656 | 1638 | 34.16 | 83460 | 2.30 | 8.30 | 62 | 108 | 2.50 | 252 | 22868 |
| 15 | GREECE | 21 | 232 | 27973 | 318 | 208 | 16.08 | 69295 | 2.89 | 8.30 | | | 4.00 | -44 | 19800 |
| 16 | HONG KONG | 209 | 636 | 29847 | 1165 | 1715 | 5.16 | 59121 | 2.00 | 4.00 | 60 | 53 | 6.30 | 27 | 17888 |
| 17 | HUNGARY | 28 | 306 | 13707 | 41 | 42 | 6.29 | 35156 | 7.90 | 7.40 | 23 | 23 | 1.30 | -7 | 8915 |
| 18 | INDIA | 45 | 24 | 988 | 4796 | 819 | | 2729 | 6.78 | 8.92 | | | 9.00 | 0 | 548 |
| 19 | INDONESIA | 55 | 25 | 1923 | 344 | 139 | | 4432 | 6.59 | 9.75 | 6 | 2 | 6.32 | 11 | 1221 |
| 20 | IRELAND | 81 | 677 | 58926 | 57 | 163 | 25.92 | 121753 | 4.90 | 4.60 | 11 | 22 | 5.30 | -14 | 28815 |
| 21 | ISRAEL | 33 | 677 | 22347 | 612 | 173 | 12.98 | 60326 | 0.52 | 7.30 | 10 | 7 | 5.32 | 5 | 12429 |
| 22 | ITALY | 312 | 559 | 35696 | 284 | 1027 | 25.04 | 90538 | 1.82 | 6.10 | 32 | 60 | 1.50 | -48 | 20928 |
| 23 | JAPAN | 455 | 642 | 34274 | 3362 | 4726 | 20.19 | 68308 | 0.06 | 3.90 | 22 | 73 | 2.10 | 213 | 19044 |
| 24 | KOREA | 157 | 673 | 20015 | 1694 | 835 | 14.70 | 41388 | 2.50 | 3.20 | 2 | 15 | 5.00 | 6 | 10825 |
| 25 | LUXEMBOURG | | 719 | 105243 | 36 | 80 | 27.70 | 150438 | 2.30 | 4.70 | | | 4.50 | 5 | |
| 26 | MALAYSIA | 85 | 262 | 6864 | 1027 | 235 | 2.74 | 16369 | 2.03 | 3.26 | 7 | 8 | 6.30 | 29 | 3164 |
| 27 | MEXICO | 129 | 152 | 8886 | 131 | 348 | 2.75 | 21542 | 3.80 | 4.06 | 22 | 10 | 3.30 | -7 | 5811 |
| 28 | NETHERLANDS | 263 | 802 | 46772 | 226 | 780 | 32.29 | 91336 | 1.60 | 3.20 | 2 | 57 | 3.50 | 50 | 21991 |
| 29 | NEW ZEALAND | 16 | 718 | 30109 | 154 | 45 | 14.45 | 59525 | 2.38 | 3.60 | 4 | 0 | 3.10 | -10 | 17002 |
| 30 | NORWAY | 56 | 816 | 83482 | 195 | 281 | 41.03 | 154670 | 0.80 | 2.60 | 3 | 17 | 3.70 | 67 | 34520 |
| 31 | PHILIPPINES | 29 | 56 | 1593 | 238 | 69 | 0.85 | 4281 | 2.77 | 6.30 | 3 | 3 | 7.30 | 4 | 1105 |
| 32 | POLAND | 39 | 260 | 11027 | 267 | 149 | 4.99 | 27580 | 2.50 | 9.60 | 24 | 9 | 6.50 | -16 | 6623 |
| 33 | PORTUGAL | 34 | 351 | 21035 | 47 | 104 | 7.64 | 43135 | 2.50 | 8.00 | 6 | 6 | 1.80 | -22 | 13588 |
| 34 | RUSSIA | 87 | 221 | 9069 | 309 | 1057 | 2.18 | 18292 | 9.10 | 6.10 | 40 | 44 | 8.10 | 70 | 4345 |
| 35 | SINGAPORE | 132 | 651 | 35163 | 461 | 276 | 8.54 | 59085 | 2.10 | 2.10 | 24 | 12 | 7.70 | 39 | 13922 |
| 36 | SOUTH AFRICA | 32 | 135 | 5907 | 401 | 715 | 7.39 | 21358 | 7.20 | 23.00 | 2 | 1 | 5.10 | -21 | 3656 |
| 37 | SPAIN | 160 | 370 | 31791 | 3339 | 1323 | 18.81 | 70592 | 2.80 | 8.30 | 59 | 115 | 3.80 | -146 | 18081 |
| 38 | SWEDEN | 102 | 847 | 49509 | 321 | 573 | 31.77 | 102281 | 2.20 | 6.10 | | | 2.70 | 38 | 23118 |
| 39 | SWITZERLAND | 105 | 817 | 56224 | 256 | 1213 | 30.67 | 96003 | 0.73 | 3.60 | 53 | 42 | 3.10 | 71 | 32798 |
| 40 | TAIWAN | 129 | 488 | 16201 | 1222 | 655 | 6.43 | 36133 | 1.80 | 3.91 | 7 | 11 | 5.70 | 32 | 9590 |
| 41 | THAILAND | 68 | 86 | 3734 | 518 | 141 | | 6772 | 2.27 | 1.38 | 10 | 2 | 4.80 | 15 | 1997 |
| 42 | TURKEY | 50 | 83 | 9552 | 314 | 162 | 2.50 | 31060 | 8.76 | 9.90 | 22 | 2 | 4.45 | -38 | 6751 |
| 43 | UNITED KINGDOM | 385 | 729 | 45511 | 2913 | 3794 | 27.05 | 94849 | 2.32 | 5.30 | 121 | 128 | 3.00 | -116 | 28793 |
| 44 | USA | 921 | 836 | 45256 | 5133 | 19426 | 23.82 | 94774 | 2.85 | 4.60 | 191 | 285 | 2.20 | -739 | 31822 |
| 45 | VENEZUELA | 19 | 119 | 7837 | 53 | 9 | | 18723 | 18.70 | 7.50 | 1 | 4 | 8.40 | 20 | 4409 |

# Appendix C: Attribute Segments

Each attribute a$_i$ is divided into four levels with three cutting points $P_1$, $P_2$, and $P_3$. $a_i$ belongs to 1st, 2nd, 3rd, and 4th level respectively if $a_i \le P_1$, $P_1 \le a_i \le P_2$, $P_2 \le a_i \le P_3$, and $P_3 \le a_i$. The values of $P_1$, $P_2$, and $P_3$ are determined by the approximate equal number of nations in each level. Take $a_1$ for instance, by specifying $P_1$=1645, $P_2$=6537, and $P_3$=13024, the number of nations at 1st, 2nd, 3rd, and 4th is 12, 12, 11, and 11. The cutting point of each attribute is listed in Table C.

**Table C: Cutting point of indicator value**

| year | | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ | $a_7$ | $a_8$ | $a_9$ | $a_{10}$ | $a_{11}$ | $a_{12}$ | $a_{13}$ | $a_{14}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | $p_1$ | 2.645 | 179 | 6970 | 330 | 4.782 | 3 | 16310 | 3.3 | 8.3 | 0.316 | 0.157 | 3.9 | 0.064 | 4.486 |
| | $p_2$ | 6.537 | 408 | 20022 | 483 | 11.759 | 9 | 35405 | 4.5 | 11.8 | 0.645 | .306 | 5.0 | 0.445 | 11.527 |
| | $p_3$ | 13.024 | 523 | 26548 | 940 | 28.039 | 17 | 58320 | 8.0 | 15.3 | 1.467 | 1.053 | 7.2 | 1.206 | 14.344 |
| 2003 | $p_1$ | 2.457 | 126 | 4087 | 271 | 3.013 | 5 | 17764 | 4.2 | 5.0 | 0.228 | 0.469 | 2.2 | -0.087 | 4.846 |
| | $p_2$ | 6.046 | 330 | 14103 | 397 | 10.295 | 10 | 38590 | 6.6 | 7.7 | 0.470 | 1.260 | 3.2 | 0.236 | 10.933 |
| | $p_3$ | 10.833 | 593 | 25940 | 904 | 20.461 | 20 | 59416 | 11.4 | 10.9 | 0.956 | 2.021 | 5.1 | 1.041 | 15.466 |
| 2005 | $p_1$ | 3.437 | 237 | 6191 | 239 | 4.256 | 4 | 17743 | 2.5 | 5.1 | 0.269 | 0.295 | 3.6 | -0.105 | 5.710 |
| | $p_2$ | 8.460 | 538 | 21628 | 352 | 12.482 | 9 | 45154 | 3.5 | 8.2 | 0.441 | 0.641 | 5.2 | 0.356 | 11.074 |
| | $p_3$ | 15.157 | 688 | 37064 | 690 | 28.934 | 24 | 83531 | 5.2 | 10.2 | 0.785 | 1.161 | 6.8 | 1.509 | 20.013 |
| 2008 | $p_1$ | 82.4 | 232.4 | 9552 | 153 | 162 | 3.5 | 24643 | 2.03 | 4 | 3.1 | 2.2 | 3.1 | -7.4 | 5811 |
| | $p_2$ | 216 | 558.8 | 27973 | 314 | 348.3 | 13 | 59121 | 2.76 | 6.1 | 10 | 12.3 | 5 | 5 | 13922 |
| | $p_3$ | 435.8 | 717.5 | 43300 | 1165 | 1095.8 | 26 | 92955 | 4.9 | 8 | 32 | 43.9 | 6.5 | 28.9 | 23400 |

# Appendix D: Discretized Codes of MCI-WCY

**Table D.1: Discritized codes for 2001**

| | Nation | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ | $a_7$ | $a_8$ | $a_9$ | $a_{10}$ | $a_{11}$ | $a_{12}$ | $a_{13}$ | $a_{14}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ARGENTINA | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 4 | 1 | 3 | 2 | 1 | 2 | 2 |
| 2 | AUSTRALIA | 2 | 4 | 3 | 4 | 3 | 3 | 3 | 2 | 3 | 2 | 1 | 2 | 1 | 3 |
| 3 | AUSTRIA | 3 | 3 | 3 | 1 | 2 | 4 | 3 | 3 | 4 | 2 | 3 | 1 | 1 | 3 |
| 4 | BELGIUM | 4 | 3 | 3 | 1 | 3 | 4 | 4 | 3 | 3 | 4 | 4 | 2 | 3 | 3 |
| 5 | BRAZIL | 1 | 1 | 1 | 3 | 1 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 1 |
| 6 | CANADA | 3 | 4 | 3 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| 7 | CHILE | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 2 | 1 |
| 8 | MAINLAND-CHINA | 1 | 1 | 1 | 4 | 1 | 1 | 1 | 4 | 4 | 1 | 1 | 4 | 2 | 1 |
| 9 | COLOMBIA | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 |
| 10 | CZECH-REPUBLIC | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 2 | 1 | 2 | 1 |
| 11 | DENMARK | 4 | 4 | 4 | 2 | 3 | 4 | 4 | 3 | 3 | 4 | 4 | 1 | 3 | 4 |
| 12 | FINLAND | 3 | 4 | 3 | 1 | 4 | 4 | 3 | 2 | 2 | 3 | 4 | 3 | 4 | 3 |
| 13 | FRANCE | 3 | 3 | 3 | 4 | 3 | 3 | 4 | 4 | 2 | 3 | 4 | 1 | 3 | 3 |
| 14 | GERMANY | 3 | 3 | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 3 | 4 | 1 | 1 | 4 |
| 15 | GREECE | 2 | 2 | 2 | 2 | 3 | 3 | 2 | 3 | 2 | 1 | 1 | 2 | 1 | 2 |
| 16 | HONG-KONG | 4 | 3 | 3 | 3 | 4 | 2 | 3 | 4 | 3 | 4 | 4 | 4 | 4 | 4 |
| 17 | HUNGARY | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 2 | 2 | 3 | 2 | 1 |
| 18 | ICELAND | 3 | 4 | 4 | 1 | 3 | 3 | 4 | 2 | 4 | 3 | 3 | 2 | 1 | 4 |
| 19 | INDIA | 1 | 1 | 1 | 4 | 1 | 1 | 1 | 2 | 3 | 1 | 1 | 3 | 2 | 1 |
| 20 | INDONESIA | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 2 | 1 |
| 21 | IRELAND | 4 | 3 | 4 | 1 | 3 | 3 | 4 | 2 | 4 | 4 | 4 | 4 | 2 | 3 |
| 22 | ISRAEL | 3 | 2 | 2 | 3 | 2 | 3 | 3 | 4 | 2 | 2 | 2 | 3 | 2 | 2 |
| 23 | ITALY | 2 | 2 | 3 | 2 | 3 | 3 | 3 | 3 | 2 | 1 | 2 | 1 | 2 | 3 |
| 24 | JAPAN | 2 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 1 | 3 | 1 | 4 | 4 |
| 25 | KOREA | 2 | 2 | 2 | 3 | 2 | 3 | 2 | 3 | 4 | 2 | 2 | 4 | 3 | 2 |
| 26 | LUXEMBOURG | 4 | 2 | 4 | 1 | 4 | 4 | 4 | 3 | 4 | 1 | 1 | 4 | 4 | 4 |
| 27 | MALAYSIA | 2 | 1 | 1 | 3 | 2 | 1 | 1 | 4 | 4 | 1 | 3 | 4 | 3 | 1 |
| 28 | MEXICO | 2 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 4 | 1 | 2 | 4 | 2 | 2 |
| 29 | NETHERLANDS | 4 | 4 | 3 | 3 | 4 | 4 | 3 | 3 | 4 | 4 | 4 | 2 | 4 | 3 |
| 30 | NEW-ZEALAND | 2 | 4 | 2 | 1 | 2 | 2 | 2 | 3 | 3 | 2 | 3 | 2 | 1 | 2 |
| 31 | NORWAY | 4 | 4 | 4 | 2 | 3 | 4 | 4 | 3 | 4 | 3 | 3 | 1 | 4 | 4 |
| 32 | PHILIPPINES | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 3 | 1 |
| 33 | POLAND | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 3 | 2 | 1 |
| 34 | PORTUGAL | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 3 | 4 | 1 | 3 | 1 | 1 | 2 |
| 35 | RUSSIA | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 4 | 3 | 1 |
| 36 | SINGAPORE | 4 | 3 | 3 | 3 | 4 | 2 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 2 |
| 37 | SOUTH-AFRICA | 1 | 1 | 1 | 3 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 1 | 2 | 1 |
| 38 | SPAIN | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 1 | 2 | 3 | 2 | 1 | 2 |
| 39 | SWEDEN | 3 | 4 | 4 | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 3 |
| 40 | SWITZERLAND | 4 | 4 | 4 | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 4 |
| 41 | TAIWAN | 3 | 2 | 2 | 3 | 3 | 2 | 3 | 4 | 4 | 1 | 3 | 3 | 3 | 2 |
| 42 | THAILAND | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 4 | 4 | 1 | 1 | 3 | 3 | 1 |
| 43 | TURKEY | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 3 | 1 | 2 | 4 | 2 | 1 |
| 44 | UNITED-KINGDOM | 3 | 3 | 3 | 4 | 4 | 3 | 3 | 3 | 3 | 4 | 4 | 1 | 1 | 4 |
| 45 | USA | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 3 | 3 | 3 | 1 | 4 |
| 46 | VENEZUELA | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 1 | 2 | 1 | 2 | 1 | 3 | 1 |

**Table D.2: Discretized codes for 2003**

| | Nation | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ | $a_7$ | $a_8$ | $a_9$ | $a_{10}$ | $a_{11}$ | $a_{12}$ | $a_{13}$ | $a_{14}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ARGENTINA | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 1 |
| 2 | AUSTRALIA | 2 | 4 | 3 | 4 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 3 | 1 | 3 |
| 3 | AUSTRIA | 4 | 3 | 3 | 1 | 2 | 4 | 3 | 4 | 4 | 3 | 2 | 1 | 2 | 4 |
| 4 | BELGIUM | 4 | 3 | 3 | 2 | 3 | 4 | 4 | 4 | 2 | 4 | 4 | 1 | 4 | 3 |
| 5 | BRAZIL | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 2 | 1 |
| 6 | CANADA | 3 | 4 | 3 | 4 | 4 | 3 | 3 | 3 | 2 | 4 | 3 | 3 | 3 | 3 |
| 7 | CHILE | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 4 | 2 | 2 | 1 | 2 | 2 | 1 |
| 8 | MAINLAND-CHINA | 1 | 1 | 1 | 4 | 1 | 1 | 1 | 4 | 4 | 1 | 1 | 4 | 2 | 1 |
| 9 | COLOMBIA | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 3 | 2 | 1 |
| 10 | CZECH-REPUBLIC | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 4 | 2 | 3 | 1 | 2 | 1 | 2 |
| 11 | DENMARK | 4 | 4 | 4 | 2 | 3 | 4 | 4 | 3 | 3 | 4 | 4 | 2 | 4 | 4 |
| 12 | FINLAND | 3 | 4 | 4 | 2 | 4 | 4 | 4 | 4 | 2 | 3 | 3 | 2 | 4 | 3 |
| 13 | FRANCE | 3 | 3 | 3 | 4 | 4 | 3 | 4 | 3 | 2 | 4 | 3 | 1 | 3 | 3 |
| 14 | GERMANY | 3 | 3 | 3 | 4 | 3 | 4 | 3 | 4 | 2 | 3 | 2 | 1 | 3 | 4 |
| 15 | GREECE | 2 | 2 | 3 | 3 | 2 | 2 | 2 | 3 | 2 | 2 | 1 | 3 | 1 | 2 |
| 16 | HONG-KONG | 4 | 3 | 3 | 4 | 4 | 2 | 3 | 4 | 2 | 4 | 3 | 3 | 4 | 3 |
| 17 | HUNGARY | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 3 | 2 | 1 | 3 | 1 | 2 |
| 18 | ICELAND | 4 | 4 | 4 | 1 | 3 | 3 | 3 | 2 | 4 | 3 | 3 | 1 | 2 | 4 |
| 19 | INDIA | 1 | 1 | 1 | 4 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 4 | 2 | 1 |
| 20 | INDONESIA | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 3 | 2 | 1 |
| 21 | IRELAND | 4 | 3 | 4 | 1 | 3 | 3 | 4 | 2 | 4 | 4 | 3 | 4 | 2 | 3 |
| 22 | ISRAEL | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 1 | 3 | 2 | 1 | 1 | 2 |
| 23 | ITALY | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 1 | 2 | 3 |
| 24 | JAPAN | 2 | 3 | 4 | 4 | 3 | 4 | 4 | 4 | 3 | 1 | 2 | 1 | 4 | 4 |
| 25 | KOREA | 2 | 3 | 2 | 4 | 2 | 2 | 2 | 3 | 4 | 1 | 1 | 4 | 3 | 2 |
| 26 | LUXEMBOURG | 4 | 3 | 4 | 1 | 4 | 3 | 4 | 3 | 4 | 1 | 4 | 1 | 4 | 4 |
| 27 | MALAYSIA | 2 | 2 | 2 | 4 | 2 | 1 | 1 | 4 | 4 | 1 | 1 | 4 | 3 | 1 |
| 28 | MEXICO | 2 | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 4 | 2 | 2 | 1 | 2 | 2 |
| 29 | NETHERLANDS | 4 | 4 | 4 | 2 | 4 | 4 | 3 | 3 | 4 | 4 | 4 | 1 | 3 | 3 |
| 30 | NEW-ZEALAND | 2 | 3 | 3 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 1 | 3 | 1 | 2 |
| 31 | NORWAY | 4 | 4 | 4 | 2 | 3 | 4 | 4 | 4 | 4 | 3 | 1 | 1 | 4 | 4 |
| 32 | PHILIPPINES | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 3 | 2 | 1 | 1 | 4 | 2 | 1 |
| 33 | POLAND | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 3 | 1 | 2 | 1 | 1 | 2 | 1 |
| 34 | PORTUGAL | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 3 | 3 | 3 | 2 | 1 | 1 | 2 |
| 35 | RUSSIA | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 3 | 3 | 1 |
| 36 | SINGAPORE | 4 | 4 | 3 | 3 | 4 | 2 | 3 | 4 | 4 | 4 | 4 | 2 | 4 | 2 |
| 37 | SOUTH-AFRICA | 1 | 1 | 1 | 3 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 3 | 2 | 1 |
| 38 | SPAIN | 2 | 2 | 3 | 4 | 3 | 3 | 3 | 3 | 1 | 3 | 2 | 2 | 1 | 2 |
| 39 | SWEDEN | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 3 | 4 | 2 | 2 | 4 | 3 |
| 40 | SWITZERLAND | 4 | 4 | 4 | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 1 | 4 | 4 |
| 41 | TAIWAN | 3 | 2 | 2 | 3 | 3 | 2 | 2 | 4 | 3 | 2 | 2 | 3 | 4 | 2 |
| 42 | THAILAND | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 4 | 4 | 1 | 1 | 4 | 3 | 1 |
| 43 | TURKEY | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 2 | 1 |
| 44 | UNITED-KINGDOM | 3 | 3 | 4 | 4 | 4 | 3 | 3 | 4 | 3 | 4 | 2 | 2 | 2 | 4 |
| 45 | USA | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 2 | 3 | 1 | 4 |
| 46 | VENEZUELA | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 1 | 1 | 3 | 1 |

## Table D.3: Discretized codes for 2005

| | Nation | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ | $a_7$ | $a_8$ | $a_9$ | $a_{10}$ | $a_{11}$ | $a_{12}$ | $a_{13}$ | $a_{14}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ARGENTINA | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 2 | 1 |
| 2 | AUSTRALIA | 2 | 4 | 3 | 4 | 4 | 3 | 3 | 3 | 3 | 2 | 3 | 2 | 1 | 3 |
| 3 | AUSTRIA | 4 | 3 | 4 | 1 | 2 | 4 | 4 | 3 | 4 | 4 | 3 | 1 | 2 | 4 |
| 4 | BELGIUM | 4 | 3 | 3 | 2 | 3 | 4 | 4 | 3 | 2 | 4 | 4 | 1 | 3 | 4 |
| 5 | BRAZIL | 1 | 1 | 1 | 3 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 3 | 2 | 1 |
| 6 | CANADA | 3 | 4 | 3 | 4 | 4 | 3 | 3 | 3 | 3 | 2 | 4 | 1 | 3 | 3 |
| 7 | CHILE | 2 | 1 | 2 | 3 | 2 | 1 | 2 | 3 | 2 | 3 | 1 | 4 | 2 | 1 |
| 8 | MAINLAND-CHINA | 1 | 1 | 1 | 4 | 1 | 1 | 1 | 2 | 4 | 1 | 1 | 4 | 2 | 1 |
| 9 | COLOMBIA | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 |
| 10 | CZECH-REPUBLIC | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 3 | 1 | 2 | 1 | 2 |
| 11 | DENMARK | 4 | 4 | 4 | 2 | 3 | 4 | 4 | 4 | 3 | 2 | 2 | 1 | 3 | 4 |
| 12 | FINLAND | 3 | 4 | 3 | 2 | 4 | 4 | 4 | 4 | 2 | 4 | 1 | 2 | 4 | 4 |
| 13 | FRANCE | 3 | 3 | 3 | 4 | 3 | 3 | 4 | 3 | 2 | 3 | 3 | 1 | 2 | 3 |
| 14 | GERMANY | 3 | 3 | 3 | 4 | 3 | 4 | 3 | 3 | 2 | 1 | 1 | 1 | 3 | 4 |
| 15 | GREECE | 2 | 2 | 2 | 3 | 2 | 2 | 3 | 2 | 2 | 1 | 1 | 2 | 1 | 3 |
| 16 | HONG-KONG | 4 | 3 | 3 | 4 | 4 | 2 | 3 | 4 | 3 | 4 | 4 | 4 | 4 | 3 |
| 17 | HUNGARY | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 3 | 3 | 1 | 2 | 1 | 2 |
| 18 | ICELAND | 3 | 4 | 4 | 1 | 4 | 3 | 4 | 2 | 4 | 4 | 4 | 3 | 1 | 4 |
| 19 | INDIA | 1 | 1 | 1 | 4 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 4 | 2 | 1 |
| 20 | INDONESIA | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 3 | 2 | 1 |
| 21 | IRELAND | 4 | 3 | 4 | 1 | 3 | 3 | 4 | 3 | 4 | 4 | 3 | 3 | 1 | 4 |
| 22 | ISRAEL | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 4 | 1 | 1 | 2 | 2 | 2 | 3 |
| 23 | ITALY | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 1 | 2 | 3 |
| 24 | JAPAN | 2 | 3 | 4 | 4 | 3 | 3 | 3 | 4 | 3 | 1 | 2 | 1 | 3 | 4 |
| 25 | KOREA | 2 | 3 | 2 | 4 | 2 | 3 | 2 | 2 | 4 | 2 | 1 | 3 | 3 | 2 |
| 26 | LUXEMBOURG | 4 | 4 | 4 | 1 | 4 | 4 | 4 | 3 | 4 | 1 | 1 | 2 | 4 | 4 |
| 27 | MALAYSIA | 2 | 2 | 1 | 4 | 2 | 1 | 1 | 4 | 4 | 2 | 1 | 4 | 3 | 1 |
| 28 | MEXICO | 2 | 1 | 2 | 2 | 1 | 1 | 2 | 1 | 4 | 2 | 1 | 2 | 2 | 2 |
| 29 | NETHERLANDS | 4 | 4 | 3 | 2 | 4 | 4 | 3 | 4 | 3 | 4 | 4 | 1 | 4 | 3 |
| 30 | NEW-ZEALAND | 2 | 3 | 3 | 2 | 2 | 3 | 3 | 2 | 4 | 4 | 1 | 3 | 1 | 3 |
| 31 | NORWAY | 4 | 4 | 4 | 2 | 3 | 4 | 4 | 4 | 4 | 3 | 3 | 2 | 4 | 4 |
| 32 | PHILIPPINES | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 2 | 1 |
| 33 | POLAND | 2 | 1 | 2 | 2 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 3 | 2 | 1 |
| 34 | PORTUGAL | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 3 | 3 | 3 | 1 | 1 | 1 | 2 |
| 35 | RUSSIA | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 4 | 3 | 1 |
| 36 | SINGAPORE | 4 | 3 | 3 | 3 | 4 | 2 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 3 |
| 37 | SOUTH-AFRICA | 1 | 1 | 1 | 3 | 2 | 2 | 2 | 4 | 1 | 1 | 1 | 2 | 2 | 1 |
| 38 | SPAIN | 2 | 2 | 3 | 4 | 3 | 3 | 3 | 2 | 1 | 2 | 3 | 1 | 1 | 3 |
| 39 | SWEDEN | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 3 | 1 | 4 | 2 | 4 | 3 |
| 40 | SWITZERLAND | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 1 | 4 | 4 |
| 41 | TAIWAN | 3 | 2 | 2 | 4 | 3 | 2 | 2 | 3 | 4 | 1 | 2 | 3 | 3 | 2 |
| 42 | THAILAND | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 2 | 4 | 1 | 1 | 4 | 2 | 1 |
| 43 | TURKEY | 1 | 1 | 1 | 3 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 4 | 2 | 1 |
| 44 | UNITED-KINGDOM | 3 | 3 | 3 | 4 | 4 | 3 | 3 | 2 | 3 | 4 | 4 | 2 | 1 | 4 |
| 45 | USA | 2 | 4 | 4 | 4 | 4 | 3 | 4 | 2 | 3 | 3 | 3 | 2 | 1 | 4 |
| 46 | VENEZUELA | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 3 | 1 |

**Table D.4: Discretized codes for 2008**

| | Nation | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ | $a_7$ | $a_8$ | $a_9$ | $a_{10}$ | $a_{11}$ | $a_{12}$ | $a_{13}$ | $a_{14}$ | g |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ARGENTINA | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 4 | 3 | 1 | $G_1$ |
| 2 | AUSTRALIA | 3 | 4 | 3 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 1 | 4 | $G_3$ |
| 3 | AUSTRIA | 3 | 3 | 4 | 1 | 2 | 4 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 4 | $G_3$ |
| 4 | BELGIUM | 3 | 3 | 3 | 1 | 3 | 4 | 4 | 4 | 2 | 2 | 3 | 1 | 2 | 3 | $G_3$ |
| 5 | BRAZIL | 2 | 1 | 1 | 3 | 3 | 2 | 1 | 2 | 1 | 4 | 2 | 3 | 3 | 1 | $G_1$ |
| 6 | CANADA | 4 | 4 | 3 | 4 | 4 | 3 | 3 | 3 | 3 | 4 | 4 | 1 | 3 | 4 | $G_3$ |
| 7 | CHILE | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 3 | 2 | 3 | 3 | 2 | $G_2$ |
| 8 | CHINA | 4 | 1 | 1 | 4 | 4 | 1 | 1 | 1 | 4 | 3 | 3 | 4 | 4 | 3 | $G_3$ |
| 9 | COLOMBIA | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 4 | 2 | 1 | $G_1$ |
| 10 | CZECH REPUBLIC | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 3 | 2 | 1 | 4 | 2 | 2 | $G_2$ |
| 11 | DENMARK | 2 | 4 | 4 | 2 | 2 | 4 | 4 | 4 | 4 | 3 | 3 | 1 | 2 | 4 | $G_3$ |
| 12 | FINLAND | 2 | 4 | 4 | 1 | 2 | 4 | 4 | 2 | 2 | 2 | 2 | 2 | 3 | 4 | $G_3$ |
| 13 | FRANCE | 4 | 3 | 3 | 3 | 4 | 3 | 4 | 4 | 1 | 4 | 4 | 1 | 1 | 4 | $G_2$ |
| 14 | GERMANY | 4 | 3 | 3 | 3 | 4 | 4 | 3 | 3 | 1 | 4 | 4 | 1 | 4 | 3 | $G_3$ |
| 15 | GREECE | 1 | 2 | 2 | 3 | 2 | 3 | 3 | 2 | 1 | 1 | 1 | 2 | 1 | 3 | $G_1$ |
| 16 | HONG KONG | 4 | 3 | 3 | 4 | 4 | 2 | 2 | 4 | 3 | 4 | 4 | 3 | 3 | 3 | $G_4$ |
| 17 | HUNGARY | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 2 | 3 | 3 | 1 | 2 | 2 | $G_2$ |
| 18 | INDIA | 2 | 1 | 1 | 4 | 3 | 2 | 1 | 1 | 1 | 2 | 2 | 4 | 2 | 1 | $G_2$ |
| 19 | INDONESIA | 2 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 4 | 3 | 1 | $G_1$ |
| 20 | IRELAND | 3 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 3 | 3 | 3 | 3 | 1 | 4 | $G_3$ |
| 21 | ISRAEL | 1 | 3 | 2 | 3 | 2 | 2 | 3 | 4 | 2 | 2 | 2 | 3 | 2 | 2 | $G_3$ |
| 22 | ITALY | 4 | 2 | 3 | 2 | 3 | 3 | 3 | 4 | 2 | 4 | 4 | 1 | 1 | 3 | $G_1$ |
| 23 | JAPAN | 4 | 3 | 3 | 4 | 4 | 3 | 3 | 4 | 4 | 3 | 4 | 1 | 4 | 3 | $G_3$ |
| 24 | KOREA | 3 | 3 | 2 | 4 | 3 | 3 | 2 | 2 | 4 | 1 | 3 | 3 | 3 | 2 | $G_2$ |
| 25 | LUXEMBOURG | 3 | 4 | 4 | 1 | 1 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | $G_3$ |
| 26 | MALAYSIA | 3 | 2 | 1 | 3 | 2 | 1 | 1 | 3 | 4 | 2 | 2 | 3 | 4 | 1 | $G_3$ |
| 27 | MEXICO | 3 | 1 | 1 | 1 | 3 | 2 | 2 | 2 | 3 | 3 | 2 | 2 | 2 | 2 | $G_1$ |
| 28 | NETHERLANDS | 4 | 4 | 4 | 2 | 3 | 4 | 3 | 4 | 4 | 1 | 4 | 2 | 4 | 3 | $G_3$ |
| 29 | NEW ZEALAND | 1 | 3 | 3 | 2 | 1 | 3 | 3 | 3 | 4 | 1 | 1 | 2 | 2 | 3 | $G_3$ |
| 30 | NORWAY | 2 | 4 | 4 | 2 | 2 | 4 | 4 | 4 | 4 | 1 | 3 | 2 | 4 | 4 | $G_3$ |
| 31 | PHILIPPINES | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 4 | 2 | 1 | $G_1$ |
| 32 | POLAND | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 1 | 3 | 2 | 4 | 1 | 2 | $G_1$ |
| 33 | PORTUGAL | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 1 | 1 | 2 | $G_2$ |
| 34 | RUSSIA | 3 | 2 | 2 | 2 | 3 | 1 | 1 | 1 | 2 | 4 | 4 | 4 | 4 | 1 | $G_1$ |
| 35 | SINGAPORE | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 3 | 4 | 3 | 3 | 4 | 4 | 3 | $G_4$ |
| 36 | SOUTH AFRICA | 1 | 1 | 1 | 3 | 3 | 2 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | $G_1$ |
| 37 | SPAIN | 4 | 2 | 3 | 4 | 4 | 3 | 3 | 2 | 1 | 4 | 4 | 2 | 1 | 3 | $G_2$ |
| 38 | SWEDEN | 3 | 4 | 4 | 3 | 3 | 4 | 4 | 3 | 2 | 3 | 3 | 1 | 4 | 3 | $G_3$ |
| 39 | SWITZERLAND | 3 | 4 | 4 | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 2 | 4 | 4 | $G_4$ |
| 40 | TAIWAN | 3 | 2 | 2 | 4 | 3 | 2 | 2 | 4 | 4 | 3 | 2 | 3 | 4 | 2 | $G_3$ |
| 41 | THAILAND | 2 | 1 | 1 | 3 | 1 | 2 | 1 | 3 | 4 | 2 | 1 | 3 | 3 | 1 | $G_2$ |
| 42 | TURKEY | 2 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 3 | 1 | 2 | 1 | 2 | $G_1$ |
| 43 | UNITED | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 4 | 4 | 1 | 1 | 4 | $G_3$ |
| 44 | USA | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 2 | 3 | 4 | 4 | 1 | 1 | 4 | $G_4$ |
| 45 | VENEZUELA | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 4 | 3 | 2 | $G_1$ |

# Appendix E: Data Set of Consolidated Competitiveness Factors

The data set of competitiveness factors is available for 2003 and 2005 but not for 2001. Its definition is described in Table 2.2. There are a few cells being empty which means no data available. Nations with empty cells are ignored on the displaying sphere.

| Table E.1: Data Set of Competitiveness Factors | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Nation | 2003 | | | | 2005 | | | |
| | | $f_1$ | $f_2$ | $f_3$ | $f_4$ | $f_1$ | $f_2$ | $f_3$ | $f_4$ |
| 1 | ARGENTINA | 4.39 | 6.47 | 6.62 | 32.14 | 9.64 | 49.30 | 3.24 | 31.30 |
| 2 | AUSTRALIA | 89.91 | 57.16 | 85.79 | 82.48 | 73.39 | 53.03 | 78.62 | 65.05 |
| 3 | AUSTRIA | 64.91 | 59.19 | 68.67 | 73.47 | 58.89 | 50.79 | 68.94 | 60.87 |
| 4 | BELGIUM | 34.54 | 100.00 | 54.87 | 64.25 | 41.89 | 54.06 | 51.28 | 64.78 |
| 5 | BRAZIL | 36.45 | 34.00 | 49.67 | 33.35 | 19.96 | 45.64 | 48.87 | 27.13 |
| 6 | CANADA | 76.83 | 68.45 | 82.16 | 81.99 | 69.97 | 57.92 | 72.50 | 72.37 |
| 7 | CHILE | 66.38 | 44.59 | 63.50 | 26.60 | 68.22 | 52.13 | 76.96 | 33.60 |
| 8 | MAINLAND-CHINA | 56.57 | 73.86 | 36.98 | 33.93 | 58.57 | 70.94 | 28.59 | 36.95 |
| 9 | COLOMBIA | 52.35 | 32.29 | 43.76 | 38.86 | 41.88 | 36.46 | 39.18 | 30.29 |
| 10 | CZECH-REPUBLIC | 39.69 | 50.55 | 22.45 | 38.29 | 40.34 | 45.21 | 47.70 | 49.46 |
| 11 | DENMARK | 75.92 | 69.30 | 77.40 | 76.25 | 74.34 | 46.97 | 77.07 | 73.99 |
| 12 | FINLAND | 92.36 | 44.90 | 91.75 | 86.03 | 75.87 | 46.08 | 75.66 | 75.09 |
| 13 | FRANCE | 50.14 | 72.22 | 51.51 | 76.19 | 38.63 | 58.94 | 37.46 | 63.96 |
| 14 | GERMANY | 51.03 | 72.65 | 59.38 | 78.09 | 45.91 | 52.45 | 44.74 | 70.45 |
| 15 | GREECE | 17.59 | 31.22 | 34.63 | 27.00 | 31.12 | 40.18 | 31.08 | 41.13 |
| 16 | HONG-KONG | 85.14 | 69.46 | 89.18 | 48.19 | 83.29 | 70.11 | 98.60 | 62.47 |
| 17 | HUNGARY | 33.32 | 40.31 | 36.58 | 28.05 | 44.84 | 39.83 | 47.37 | 49.61 |
| 18 | ICELAND | 73.33 | 27.94 | 81.03 | 77.26 | 72.91 | 54.22 | 86.46 | 69.98 |
| 19 | INDIA | 41.48 | 52.68 | 43.53 | 27.24 | 42.83 | 56.85 | 53.34 | 25.38 |
| 20 | INDONESIA | 16.90 | 28.00 | 6.11 | 9.58 | 29.96 | 28.11 | 9.32 | 10.04 |
| 21 | IRELAND | 67.38 | 67.06 | 75.61 | 48.08 | 68.92 | 61.82 | 73.44 | 49.39 |
| 22 | ISRAEL | 21.68 | | 48.33 | 60.47 | 47.86 | 43.93 | 55.74 | 63.87 |
| 23 | ITALY | 33.85 | 46.89 | 44.25 | 43.90 | 18.06 | 44.16 | 21.64 | 41.60 |
| 24 | JAPAN | 43.69 | 47.07 | 41.48 | 76.42 | 42.22 | 53.24 | 46.10 | 75.23 |
| 25 | KOREA | 43.24 | 39.32 | 42.07 | 50.00 | 47.57 | 42.48 | 49.21 | 59.88 |
| 26 | LUXEMBOURG | 80.20 | 80.43 | 74.01 | 55.88 | 66.5 | 77.22 | 60.84 | 58.87 |
| 27 | MALAYSIA | 78.02 | 63.51 | 69.79 | 60.51 | 51.22 | 59.53 | 51.11 | 43.69 |
| 28 | MEXICO | 43.72 | 42.23 | 26.11 | 21.32 | 33.70 | 41.11 | 17.98 | 15.32 |
| 29 | NETHERLANDS | 53.32 | 99.68 | 67.28 | 69.48 | 56.22 | 58.40 | 67.93 | 69.22 |
| 30 | NEW-ZEALAND | 69.07 | 47.27 | 61.44 | 52.53 | 72.61 | 54.61 | 63.44 | 53.36 |
| 31 | NORWAY | 59.14 | 62.32 | 54.95 | 70.10 | 64.17 | 50.26 | 60.50 | 71.88 |
| 32 | PHILIPPINES | 41.12 | 38.83 | 37.24 | 29.32 | 36.99 | 43.07 | 43.42 | 23.11 |
| 33 | POLAND | 15.00 | 23.37 | 17.09 | 30.13 | 21.22 | 35.49 | 11.47 | 30.06 |
| 34 | PORTUGAL | 46.77 | 43.92 | 6.47 | 20.14 | 42.20 | 42.40 | 25.12 | 42.16 |
| 35 | RUSSIA | 23.23 | 27.67 | 13.19 | 33.73 | 37.29 | 32.33 | 15.33 | 31.60 |
| 36 | SINGAPORE | 90.78 | 71.80 | 79.58 | 75.00 | 79.25 | 69.15 | 78.61 | 73.88 |
| 37 | SOUTH-AFRICA | 49.30 | 30.40 | 52.33 | 32.30 | 46.00 | 42.58 | 41.77 | 19.63 |
| 38 | SPAIN | 63.21 | 59.54 | 50.97 | 52.61 | 47.81 | 50.82 | 34.31 | 46.96 |
| 39 | SWEDEN | 62.84 | 68.21 | 67.36 | 84.56 | 57.95 | 49.21 | 67.61 | 72.46 |
| 40 | SWITZERLAND | 74.43 | 70.15 | 60.52 | 86.40 | 72.75 | 54.07 | 68.04 | 77.46 |
| 41 | TAIWAN | 63.32 | 52.71 | 74.77 | 64.17 | 60.19 | 54.19 | 77.19 | 63.89 |
| 42 | THAILAND | 70.86 | 66.85 | 53.49 | 34.29 | 64.51 | 59.69 | 50.58 | 31.45 |
| 43 | TURKEY | 16.96 | 11.96 | 45.19 | 34.86 | 31.70 | 37.10 | 50.91 | 27.64 |
| 44 | UNITED-KINGDOM | 61.53 | 71.39 | 58.17 | 60.54 | 51.03 | 56.50 | 51.01 | 57.72 |
| 45 | USA | 78.20 | 99.78 | 92.66 | 100.00 | 62.72 | 100.00 | 84.00 | 95.46 |
| 46 | VENEZUELA | 1.00 | 5.15 | 8.11 | 26.87 | 0.00 | 29.08 | 12.07 | 22.16 |

## Table E.2: Coordinators of nations

| | Nations | 2003 | | | 2005 | | |
|---|---|---|---|---|---|---|---|
| | | x | y | z | x | y | z |
| 1 | ARGENTINA | -0.6572305 | 0.5637897 | -0.5001892 | -0.5261705 | 0.7468129 | -0.4067125 |
| 2 | AUSTRALIA | 0.09157093 | 0.9610521 | -0.2607557 | 0.2885919 | 0.8992801 | -0.3286487 |
| 3 | AUSTRIA | 0.2462744 | 0.9452799 | -0.2139973 | 0.1862301 | 0.8246496 | 0.3863444 |
| 4 | BELGIUM | 0.2585903 | 0.7992823 | 0.5424749 | 0.3443919 | 0.78848 | 0.3679042 |
| 5 | BRAZIL | -0.3454365 | 0.6381996 | -0.6880224 | -0.745025 | 0.60707 | -0.2764125 |
| 6 | CANADA | 0.1367149 | 0.9758315 | -0.1704756 | 0.2850063 | 0.9230719 | -0.2582821 |
| 7 | CHILE | -0.3704571 | 0.9258821 | 0.07418797 | 0.08464952 | 0.7568797 | 0.5526248 |
| 8 | MAINLAND CHINA | -0.3906579 | 0.8974119 | 0.2050323 | -0.3894844 | 0.7528272 | 0.628413 |
| 9 | COLOMBIA | -0.5311116 | 0.8403087 | 0.1086365 | -0.7578207 | 0.5074652 | -0.410106 |
| 10 | CZECH-REPUBLIC | -0.56091 | 0.7881293 | 0.2534406 | -0.5639094 | 0.7994895 | 0.4131095 |
| 11 | DENMARK | 0.1736907 | 0.9697886 | -0.1712944 | 0.3353658 | 0.8889409 | -0.3119515 |
| 12 | FINLAND | 0.05729335 | 0.9429484 | -0.3279722 | 0.344036 | 0.8854371 | -0.3124744 |
| 13 | FRANCE | 0.3319612 | 0.8722968 | 0.3590266 | -0.5771191 | 0.6684961 | 0.5562589 |
| 14 | GERMANY | 0.3044131 | 0.8762769 | 0.3734588 | 0.3517075 | 0.8028373 | 0.3206938 |
| 15 | GREECE | -0.4685574 | 0.6281605 | -0.621183 | -0.6937431 | 0.6205844 | -0.3655073 |
| 16 | HONG KONG | 0.3415583 | 0.9346637 | -0.09870023 | 0.06999692 | 0.9285804 | -0.3644706 |
| 17 | HUNGARY | -0.5980036 | 0.7744642 | 0.2063899 | -0.5752986 | 0.8093132 | 0.3808428 |
| 18 | ICELAND | 0.1899344 | 0.9016449 | -0.3885373 | 0.2632078 | 0.9103639 | -0.3193105 |
| 19 | INDIA | -0.2823032 | 0.719731 | -0.6342651 | -0.4130363 | 0.9013866 | 0.4235596 |
| 20 | INDONESIA | -0.5595774 | 0.7134025 | -0.4218175 | -0.6041083 | 0.5303078 | -0.5948334 |
| 21 | IRELAND | 0.08414 | 0.9440161 | 0.3189891 | 0.2042338 | 0.8962 | -0.3938453 |
| 22 | ISRAEL | | | | 0.2757363 | 0.8296223 | 0.3131161 |
| 23 | ITALY | -0.6104489 | 0.782709 | 0.121321 | -0.6258356 | 0.6896589 | -0.3642805 |
| 24 | JAPAN | -0.6535853 | 0.7542793 | -0.06236187 | 0.3751869 | 0.8018456 | 0.2961202 |
| 25 | KOREA | -0.593876 | 0.8013543 | 0.07171204 | -0.6129484 | 0.7803701 | 0.3702867 |
| 26 | LUXEMBOURG | 0.301206 | 0.9513805 | -0.06442118 | 0.1036893 | 0.9393901 | -0.3267948 |
| 27 | MALAYSIA | 0.1230456 | 0.9562889 | 0.2652759 | -0.4580393 | 0.8218026 | 0.4999124 |
| 28 | MEXICO | -0.3645716 | 0.7534457 | -0.547181 | -0.6763596 | 0.5226432 | -0.51902 |
| 29 | NETHERLANDS | 0.2703884 | 0.9592568 | 0.08195455 | 0.3473483 | 0.9185222 | -0.1888549 |
| 30 | NEW-ZEALAND | 0.1634185 | 0.9676746 | 0.1920947 | 0.1078082 | 0.8233171 | 0.4182776 |
| 31 | NORWAY | 0.277824 | 0.9115898 | 0.3030146 | 0.1856751 | 0.8533636 | 0.3027366 |
| 32 | PHILIPPINES | -0.3537547 | 0.7016286 | -0.6185265 | -0.7729034 | 0.5138644 | -0.3722415 |
| 33 | POLAND | -0.5519935 | 0.6357766 | -0.5395287 | -0.5982569 | 0.6455617 | -0.4746987 |
| 34 | PORTUGAL | -0.3958973 | 0.80583 | -0.4403446 | -0.6225334 | 0.7062649 | 0.4619567 |
| 35 | RUSSIA | -0.5235797 | 0.6771713 | -0.5170138 | -0.6520786 | 0.5734609 | -0.4959194 |
| 36 | SINGAPORE | 0.1249795 | 0.9695915 | -0.2104101 | 0.1797798 | 0.9489459 | -0.2591929 |
| 37 | SOUTH AFRICA | -0.5004563 | 0.8540775 | 0.1417572 | -0.7885693 | 0.4557103 | -0.4129003 |
| 38 | SPAIN | -0.4844516 | 0.8742718 | -0.03091253 | -0.5411012 | 0.7619742 | 0.4926721 |
| 39 | SWEDEN | 0.235003 | 0.9623271 | -0.1367481 | 0.3919433 | 0.8937901 | -0.2179902 |
| 40 | SWITZERLAND | 0.226548 | 0.9614085 | -0.1561079 | 0.3176676 | 0.9130052 | -0.255947 |
| 41 | TAIWAN | 0.2232414 | 0.951489 | 0.2117355 | 0.3527142 | 0.9035925 | -0.2431321 |
| 42 | THAILAND | -0.3830562 | 0.9237239 | -0.00144001 | -0.3656246 | 0.8588725 | 0.5255369 |
| 43 | TURKEY | -0.4913716 | 0.5350697 | -0.6872076 | -0.7805634 | 0.5361609 | -0.321329 |
| 44 | UNITED KINGDOM | 0.206657 | 0.9137979 | 0.3496659 | 0.2889694 | 0.7896665 | 0.4101328 |
| 45 | USA | 0 | 1 | 0 | 0 | 1 | 0 |
| 46 | VENEZUELA | -0.6679537 | 0.5680158 | -0.4808283 | -0.4843282 | 0.6940127 | -0.5327049 |

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