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Combined DEMATEL technique with a novel MCDM model for exploring portfolio selection based on CAPM

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ABSTRACT

This research proposes a novel MCDM model, including DEMATEL, ANP, and VIKOR for exploring portfolio selection based on CAPM. We probe into the influential factors and relative weights of risk-free rate, expected market return, and beta of the security. The purpose of this research is to establish an investment decision model and provides investors with a reference of portfolio selection most suitable for investing effects to achieve the greatest returns. Taking full consideration of the interrelation effects among criteria/variables of the decision model, this paper examined leading semiconductor companies spanning the hottest sectors of integrated circuit (IC) design, wafer foundry, and IC packaging by experts. Empirical findings revealed that risk-free rate was affected by budget deficit, discount rate, and exchange rate; expected market return was affected by country risk, industrial structure, and macroeconomic factors; and beta of the security was affected by firm-specific risk and financial risk. Also, the factors of the CAPM possessed a self-effect relationship according to the DEMATEL technique. In the eight evaluation criteria, macroeconomic criterion was the most important factor affecting investment decisions, followed by exchange rate and firm-specific risk. In portfolio selection, leading companies in the wafer foundry industry outperformed those in IC design and IC packaging, becoming the optimal portfolio of investors during the time that this study was conducted.

1. Introduction

Markowitz (1952) introduced Mean–Variance Portfolio Model; moreover, Sharpe (1964), Lintner (1965), and Mossin (1966) subsequently referenced his model to propose the CAPM[1] noting that expected return on a security is impacted by risk-free rate, expected market return, and beta of the security. Coupled with the model's ability to predict expected stock return and formally link together the notions of risk and return, it is widely applied to help investors make investment decisions. However, investors care about how much return that they expect to earn. In other words, they are more interested in determining what factors influence the CAPM's three fixed variables, and the level of importance of each individual factor. The CAPM only explained that three important factors impact expected stock return but a description of more detailed factors was not available. Therefore, through extensive literature review, this study identified the factors that were to be influenced by risk-free rate, expected market return, and beta of the security, and examined the level of importance of these factors in an effort to make up for the inadequacy of the CAPM.

Preceding studies on expected stock return were mostly focused on exploring the relationship between expected stock return and macroeconomic factors such as money supply (Bilson, Brailsford, & Hooper, 2001; Kwon & Shin, 1999; Mandelker & Tandon, 1985; Robichek & Cohn, 1974; Rogalski & Vinso, 1977), inflation (Balduzzi, 1995; Fama, 1981; Gultekin, 1983; Kim & In, 2005; Park & Ratti, 2000), and interest rates (Abugri, 2008; Domian, Gilster, & Louton, 1996; Geske & Roll, 1983; Kim & Wu, 1987). Yet, the results of these researches were not consistent in that the studies were conducted on unidirectional relationships. For investors, the message conveyed was simply what factors influence expected stock return and whether the influence was positive or negative. Consequently, these findings contribute little to the goal of constructing a complete set of expected stock return pricing model, and particularly a comprehensive analysis of factors and interactive relationships. In addition, studies on the relative weights among variables were insufficient, and MCDM was seldom used by researches for portfolio selection such as Ehrgott, Klamroth, and Schwehm (2004) and Lee, Tzeng, Guan, Chien, and Huang (2009).

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[1] The CAPM refers to $E(R_i) = R_f + [E(R_m) - R_f] \times \beta$, where $E(R_i)$ denotes expected return on a security; R_f denotes risk-free rate; $E(R_m)$ denotes expected market return; β denotes beta of the security.

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Hence, the purpose of this study is to supplement the CAPM and that of previous findings on expected stock return in establishing an investment decision model by experts to provide investors with a reference of portfolio selection most suitable for investing effects to achieve the greatest returns. This research adopted the CAPM and a novel hybrid MCDM model consisting of combined DEMATEL with ANP and VIKOR. By reviewing literatures, we identified the sub-factors of risk-free rate, expected market return, and beta of the security in order to establish the investment decision model. Through a survey of experts, we employed DEMATEL technique to analyze the causal relationships between complex factors and then to build a network relation map (NRM) among criteria for portfolio evaluation. The weights of each factor of MCDM problem for selecting the best portfolio will then be derived by utilizing the Analytic Network Process (ANP) based on the NRM. Afterward, we ranked the data to recognize cardinal factors. Evaluation objects were taken from leadership companies of the hottest stocks in the semiconductor sectors: IC design, wafer foundry, and IC packaging. We then identified the most suitable investment by VIKOR and offered a complete depiction and testing of the decision model for the reference of investors.

The rest of this paper is organized as follows: in Section 2, we identify the sub-factors influencing risk-free rate, expected market return, and beta of the security on expected stock return pricing model in order to construct the evaluation criteria based on literature review. In Section 3, the depiction and application of the novel MCDM are included. Section 4 shows an empirical study of selecting the optimal portfolio by using the proposed evaluation model, and the results are discussed. The conclusions and remarks are provided in the final section.

2. Expected stock return pricing model

The purpose of this section is to identify the influential factors of expected stock return based on past literatures and discuss the regions of scarcity in these studies. To make up for such a gap, this study conducted a literature review of the CAPM's three main factors – risk-free rate, expected market return, and beta of the security – for the sake of more accurately identifying the evaluation criteria affecting expected stock return.

2.1. Related literature on factors influencing expected stock return

Expected stock return is the basis of comparison of required rate of return of investors in the whole stock market. Investors will not invest in a portfolio unless the required rate of return is higher than expected stock return. Therefore, what investors emphasize would be to estimate the expected stock return to provide them with a reference of portfolio selection for decision making and to make profits in the stock market. The factors influencing expected stock return are diverse, and can be classified into financial and macroeconomic factors. According to Chen, Roll, and Ross (1986), macroeconomic variables were found to be significant in explaining expected stock returns. Moreover, because macroeconomic variables can be quantifiably analyzed, much empirical research, in recent years, has been done by using macroeconomic status's proxy variables to investigate the relationship between macroeconomic variables and expected stock return.

Macroeconomic factors that were detected to be influential of expected stock return contained money supply (Bilson et al., 2001; Kwon & Shin, 1999; Mandelker & Tandon, 1985; Robichek & Cohn, 1974; Rogalski & Vinso, 1977), inflation (Balduzzi, 1995; Fama, 1981; Gultekin, 1983; Kim & In, 2005; Park & Ratti, 2000), interest rates (Abugri, 2008; Domian et al., 1996; Geske & Roll, 1983; Kim & Wu, 1987), and industrial production (Chen et al., 1986; Fama, 1990; Ferson & Harvey, 1998). These literatures are thoroughly discussed as follows.

In the related studies of money supply, Robichek and Cohn (1974) analyzed the data, current money supply and inflation, between January 1963 and October 1970 revealing that the relationship between contemporaneous amount of money supply and stock price was negligible. However, Rogalski and Vinso (1977) concluded that changes in money supply may have influences on real economic activity, thereby having a lagged influence on stock returns, which implied a positive relationship between changes in money supply and stock returns. Whereas, Mandelker and Tandon (1985) found that under situations where monetary policy is not credible, money supply innovations may affect stock returns negatively through its effects on inflation uncertainty. In recent studies, Kwon and Shin (1999) investigated whether macroeconomic variables such as foreign exchange rate, money supply and oil price are significant explanatory factors of stock market returns. Monthly data from Korea between 1980 and 1992 were used to carry out the empirical study. Results indicated that stock price indices are correlated with the production index, exchange rate, trade balance, and money supply which provide a direct long-run equilibrium relation with each stock price index. Bilson et al. (2001) used a least squares procedure to test whether macroeconomic variables have explanatory power over stock returns in twenty emerging markets. The results indicated that the money supply variable is positively significant in six markets.

On the topic of inflation, Fama (1981) employed a simple rational expectations version of the quantity theory of money finding that the results had statistically reliable negative relations between real stock returns and measures of expected and unexpected inflation. Gultekin (1983), on the contrary, conducted an empirical research to investigate the relation between stock returns and inflation in 26 countries observing that countries with bigger rates of inflation generally have bigger nominal stock returns, thus leading to a positive correlation between inflation and stock returns. Balduzzi (1995) reexamined the proxy hypothesis of Fama (1981) as the main explanation for the negative correlation between stock returns and inflation. This paper used quarterly data on industrial-production growth, monetary-base growth, CPI inflation, three-month Treasury-bill rates, and returns on the equally-weighted NYSE portfolio, for the 1954–1976 and 1977–1990 periods. Using time-series techniques, he found that production growth induced only a weak negative correlation between inflation and stock returns, and explained less of the covariance between the two series than inflation and interest-rate innovations. However, Park and Ratti (2000) found that monetary policy tightens shocks generated statistically significant movements in inflation and expected real stock returns, and that these movements go in opposite directions, even though Kim and In (2005) in their empirical results showed that there is a positive relationship between stock returns and inflation at the shortest scale (1-month period) and at the longest scale (128-month period), while a negative relationship is shown at the intermediate scales.

In the related literatures of interest rate, Geske and Roll (1983), according to their empirical research, declared that stock market returns are negatively associated with nominal interest rates. Kim and Wu (1987) discovered that a factor characterized by interest rate and money supply was one of three very significant factors to explain stock returns. Furthermore, based on the empirical findings of Domian et al. (1996), drops in interest rates are followed by twelve months of excessive stock returns, while increases in interest rates have little effect. Abugri (2008) observed that interest rates and exchange rates are significant in three out of the four markets examined to explain market returns. As for the literatures of industrial production, Chen et al. (1986) found that several macro-variables were significant in explaining expected stock returns, which included industrial production. Besides, growth in expected real activity, such as industrial productivity has been found by Fama (1990) as well as Ferson and Harvey (1998) to be positively related to stock returns.

By reviewing the above literatures, we observe that previous literatures mostly discussed changes in stock returns through macroeconomic factors such as money supply, inflation, interest rate, and industrial production. Besides, the conclusions are inconsistent in that the direction of these researches generally concentrates on the exploration between the correlation of variables and stock returns as well as unidirectional explanatory power. Furthermore, in terms of the above macroeconomic variables, the message to investors is vague, since we only comprehend the influence of a macroeconomic variable on stock returns as positive or negative, but not the impact on separate stock returns and relative weight, which is very important for investors to make the optimal decision.

2.2. Criteria of expected stock return for portfolio selection

Sharpe (1964), Lintner (1965), and Mossin (1966) proposed the CAPM revealing that risk-free rate, expected market return, and beta of the security have an influence on expected stock return, and a reasonable expectation of stock return could be obtained by the summation of risk-free rate and the return of bearing systematic risk. Fama and MacBeth (1973) showed that the average return on a portfolio of stocks was positively related to the beta of the portfolio; namely, expected stock return was affected by risk-free rate, expected market return, and beta of the security, a finding consistent with the CAPM. However, the model only noted that three critical factors impacting expected stock return but not the detailed ingredients. Consequently, this research tried to point out the sub-factors of the three factors and set up a pricing scale for portfolio selection.

The so-called risk-free rate is the assumption that all investors can have unlimited lending and borrowing under the risk-free rate of interest in a financial market. We, therefore, identify the sub-factors of risk-free rates by exploring the related literature of interest rate. Cebula, Hung, and Manage (1992) investigated the impact of federal budget deficits on nominal long-term interest rates in the United States. It was found that the federal deficits had positive and significant impact on the long-term rates of interest during the period 1955–1985. Hence, budget deficit is one of the important factors of risk-free rate (Cebula, 1998; Knot & de Haan, 1999). In addition, Thornton (1986) intended to clarify the relationship between the Federal Reserve's discount rate and market interest rates. The evidence showed that a statistically significant effect of a change in the discount rate on both the federal funds and Treasury bill rates immediately following the discount rate change (Rai, Seth, & Mohanty, 2007; Thornton, 1998). Besides, Pi-Anguita (1998) measured capital mobility in France by analyzing the direction of causality between the real exchange rate and the interest rate. Cointegration and Granger causality tests showed that the direction of causality between the two variables reversed in 1987, the date at which capital controls started to be lifted in France (Chow & Kim, 2006; Nakagawa, 2002).

On the other hand, Madura, Tucker, and Wiley (1997) reported the results of an investigation of factors hypothesized to explain differences in mean returns across entire national stock markets. Unlike most studies focused solely on US stocks, the study did not find a beta or size effect in the assessment of national stock market movements. The most relevant factor for explaining disparate returns across markets is country risk (Rouwenhorst, 1999; Serra, 2000). Moreover, Stock Price Indices, according to Roll (1992), were compared across countries in an attempt to explain why they exhibited such disparate behavior. Each country's industrial structure was empirically documented as one of the explanatory influences and played a major role in explaining market return (Hong, Torous, & Valkanov, 2007; Serra, 2000). And then, Hooker (2004) investigated the predictive power of several candidate macroeconomic factors for emerging market equity returns. The results provided strong support for several financial factors as significant predictors of excess returns (Abugri, 2008; Nikkinen, Omran, Sahlström, & Äijö, 2006).

Beta of a security is the instrument of measurement of systematic risk. Therefore, by reviewing the associated literatures of systematic risk, we point out the sub-factors of beta of a security. Rosenberg and McKibben (1973) tried to combine both accounting data for the firm and the previous history of stock prices to provide efficient predictions of the probability distribution of returns. They predicted two parameters of the distribution of returns for each security in each year: the response to the overall market return (β), and the variance of the part of risk, specific to the security, that was uncorrelated with the market return. Results showed that the method proposed for the analysis of specific risk seemed to have been highly successful. The estimated relationships were significant, and the signs of all significant coefficients corresponded with a prior intuition. That is to say, beta of a security is influenced by firm-specific risk (Cai, Faff, Hillier, & Mohamed, 2007; Lee & Jang, 2007). Besides, Hamada (1972) attempted to tie together some of the notions associated with the field of corporation finance with those associated with security and portfolio analyses. The outcome presented that approximately 21–24% of the observed systematic risk of common stocks can be explained merely by the added financial risk taken on by the underlying firm with its use of debt and preferred stock. Corporate leverage did count considerably. Consequently, financial risk is one of the sub-factors of beta of a security (Faff, Brooks, & Kee, 2002; Patel & Olsen, 1984).

Based on the CAPM, three factors (dimensions) impact on expected stock return: (1) risk-free rate, (2) expected market return, and (3) beta of the security. In addition, reviewing literature shows that risk-free rate is affected by three criteria: budget deficit, discount rate, and exchange rate; expected market return is affected by three criteria: country risk, industrial structure, and macroeconomic factors; and beta of the security is affected by two criteria: firm-specific risk and financial risk which are interpreted in Table 1.

3. A novel MCDM model with DEMATEL technique

As any criterion may impact each other, this study used the DEMATEL technique to acquire the structure of the MCDM problems. The weights of each criterion from the structure are obtained by utilizing the ANP. The VIKOR technique will be leveraged for calculating compromise ranking and gap of the alternatives. In short, the framework of evaluation contains three main phases: (1) constructing the network relation map (NRM) among criteria by the DEMATEL technique, (2) calculating the weights of each criterion by the ANP based on the NRM, and (3) ranking or improving the priorities of alternatives of portfolios through the VIKOR.

3.1. The DEMATEL for constructing a NRM

The DEMATEL method (Gabus & Fontela, 1972; Ou Yang, Shieh, Leu, & Tzeng, 2008) was utilized to investigate the interrelations among criteria to build a NRM. The technique has been successfully applied in many situations, such as vehicle telematics system, development strategies, management systems, e-learning evaluations, and knowledge management (Lin, Hsieh, & Tzeng, (2010); Lin & Tzeng, 2009; Tsai & Chou, 2009; Tzeng, Chiang, & Li, 2007; Wu, 2008). The method can be arranged as follows:

Step 1: *Obtain the direct-influence matrix by scores*. Respondents are required to point out the degree of direct influence among

Table 1
Explanation of criteria.

Dimensions	Evaluation criteria	Descriptions	Proposed scholars
Risk-free rate (D_1)	Budget deficit (C_1)	It occurs when a government intends to spend more money than it takes in	Cebula et al. (1992), Cebula (1998), and Knot and Haan (1999)
	Discount rate (C_2)	An interest rate that a central bank charges depository institutions that borrow reserves from it	Thornton (1986, 1998), and Rai et al. (2007)
	Exchange rate (C_3)	Between two currencies indicates how much one currency is worth in terms of the other	Pi-Anguita (1998), Nakagawa (2002), and Chow and Kim (2006)
Expected market return (D_2)	Country risk (C_4)	The probability that changes in the business environment adversely affect the value of assets in a specific country	Madura et al. (1997), Rouwenhorst (1999), and Serra (2000)
	Industrial structure (C_5)	Different financial markets have various industrial structures	Roll (1992), Serra (2000), and Hong et al. (2007)
	Macroeconomic factors (C_6)	It deals with the performance, structure, and behavior of a national economy as a whole	Hooker (2004), Nikkinen et al. (2006), and Abugri (2008)
Beta of the security (D_3)	Firm-specific risk (C_7)	A risk that affects a very small number of assets	Rosenberg and McKibben (1973), Cai et al. (2007), and Lee and Jang (2007)
	Financial risk (C_8)	Any risk associated with any form of financing	Hamada (1972), Patel and Olsen (1984), and Faff et al. (2002)

each criterion. We suppose that the comparison scales, 0, 1, 2, 3 and 4, stand for the levels from "no influence" to "very high influence". Then, the graph which can describe the interrelationships between the criteria of the system is shown in Fig. 1. For instance, an arrow from w to y symbolizes that w impacts on y, and the score of influence is 1. The direct-influence matrix, $\boldsymbol{A}$, can be derived by indicated one criterion i impact on another criterion j as a_{ij}.

Step 2: *Calculate the normalized direct-influence matrix* $\boldsymbol{S}$. $\boldsymbol{S}$ can be calculated by normalizing $\boldsymbol{A}$ through Eqs. (1) and (2).

$$\boldsymbol{S} = m \cdot \boldsymbol{A} \tag{1}$$

$$m = \min\left[\frac{1}{\max\limits_i \sum_{j=1}^{n}|a_{ij}|}, \frac{1}{\max\limits_j \sum_{i=1}^{n}|a_{ij}|}\right] \tag{2}$$

Step 3: *Derive the total direct-influence matrix* $\boldsymbol{T}$. $\boldsymbol{T}$ of NRM can be derived by using a formula (3), where $\boldsymbol{I}$ denotes the identity matrix; i.e., a continuous decrease of the indirect effects of problems along the powers of S, e.g., $S^2, S^3, \ldots, S^q$ and $\lim_{q\to\infty} S^q = [0]_{n\times n}$, where $S = [s_{ij}]_{n\times n}$, $0 \leqslant s_{ij} < 1$ and $0 \leqslant \sum_i s_{ij}$ or $\sum_j s_{ij} < 1$ only one column or one row sum equals 1, but not all. The total-influence matrix is listed as follows:

$$\begin{aligned} T &= \boldsymbol{S} + \boldsymbol{S}^2 + \cdots + \boldsymbol{S}^q \\ &= \boldsymbol{S}(I + \boldsymbol{S} + \boldsymbol{S}^2 + \cdots + \boldsymbol{S}^{k-1})(I - \boldsymbol{S})(I - \boldsymbol{S})^{-1} \\ &= \boldsymbol{S}(I - \boldsymbol{S}^q)(I - \boldsymbol{S})^{-1} \end{aligned}$$

when $q \to \infty$, $\boldsymbol{S}^q = [0]_{n\times n}$, then

$$T = \boldsymbol{S}(I - \boldsymbol{S})^{-1} \tag{3}$$

where $T = [t_{ij}]_{n\times n}$, $i, j = 1, 2, \ldots, n$.

Step 4: Construct the NRM based on the vectors $\boldsymbol{r}$ and $\boldsymbol{c}$. The vectors $\boldsymbol{r}$ and $\boldsymbol{c}$ of matrix $\boldsymbol{T}$ represent the sums of rows and columns respectively, which are shown as Eqs. (4) and (5).

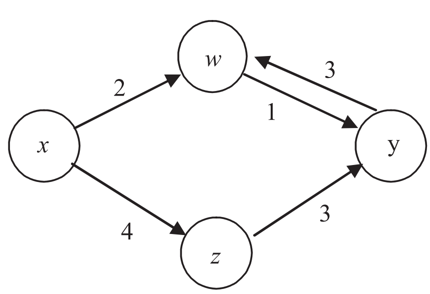
$$\boldsymbol{r} = [r_i]_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} \tag{4}$$

$$\boldsymbol{d} = [d_j]_{n\times 1} = \left[\sum_{i=1}^{n} t_{ij}\right]'_{1\times n} \tag{5}$$

where r_i denotes the sum of the ith row of matrix $\boldsymbol{T}$ and displays the sum of direct and indirect effects of criterion i on another criteria. Also, d_j denotes the sum of the jth column of matrix $\boldsymbol{T}$ and represents the sum of direct and indirect effects that criterion j has received from another criteria. Moreover, when $i = j(r_i + d_i)$, it presents the index of the degree of influences given and received; i.e. $(r_i + d_i)$ reveals the strength of the central role that factor i plays in the problem. If $(r_i - d_i)$ is positive representing that other factors are impacted by factor i. On the contrary, if $(r_i - d_i)$ is negative, other factors has influences on factor i and thus the NRM can be constructed (Huang, Shyu, & Tzeng, 2007; Liou, Tzeng, & Chang, 2007; Tzeng et al., 2007).

3.2. The ANP for calculating weights of criteria based on the NRM

The analytic hierarchy process (AHP) supposes independence among criteria, which is not reasonable in the real world. Saaty (1996) thus extended AHP to ANP to resolve problems with dependence or feedback between criteria, which primarily divides problems into numerous different clusters and every cluster includes multiple criteria. Moreover, there is outer dependence among clusters and inner dependence within the criteria of clusters as illustrated in Fig. 2. In addition, we figured the relative weights of



$$\boldsymbol{A} = \begin{bmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & & \vdots & & \vdots \\ a_{i1} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & & \vdots & & \vdots \\ a_{n1} & \cdots & a_{nj} & \cdots & a_{nn} \end{bmatrix}$$

Fig. 1. The directed graph.

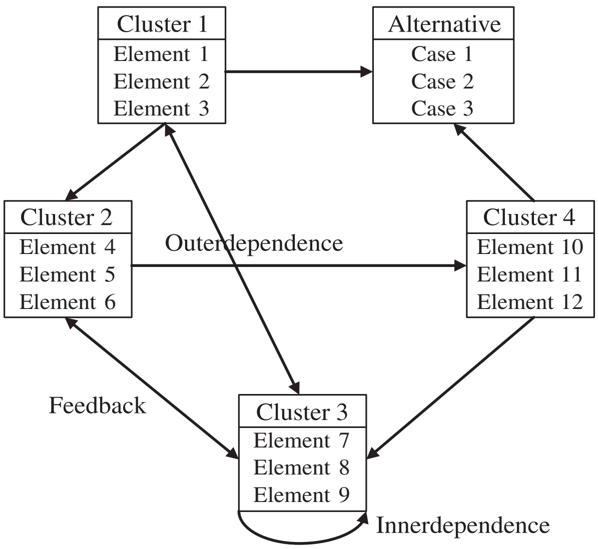


Fig. 2. Relation network structure.

criteria of respective matrices by pair-wise comparison and modifying the weights as eigenvectors. Then we integrated multiple matrices into a supermatrix, because the capacity to examine the inner and outer dependence of clusters is the largest benefit of a supermatrix as Eq. (6).

$$\mathbf{W} = \begin{array}{c} \\ \\ C_1 \\ \\ \\ C_2 \\ \\ \vdots \\ C_n \\ \\ \end{array}\begin{array}{c} \\ e_{11} \\ e_{12} \\ \vdots \\ e_{1n} \\ e_{21} \\ e_{22} \\ \vdots \\ e_{2n} \\ \vdots \\ e_{N1} \\ e_{N2} \\ \vdots \\ e_{Nn} \end{array} \overset{\begin{array}{ccccc} C_1 & & C_2 & \cdots & C_n \\ e_{11}e_{12}\cdots e_{1n} & & e_{21}e_{22}\cdots e_{2n} & \cdots & e_{N1}e_{N2}\cdots e_{Nn} \end{array}}{\begin{bmatrix} \mathbf{W}_{11} & \cdots & \mathbf{W}_{12} & \cdots & \mathbf{W}_{1N} \\ \mathbf{W}_{21} & \cdots & \mathbf{W}_{22} & \cdots & \mathbf{W}_{2N} \\ \vdots & & \vdots & & \vdots \\ \mathbf{W}_{N1} & \cdots & \mathbf{W}_{N2} & \cdots & \mathbf{W}_{NN} \end{bmatrix}} \quad (6)$$

There are three steps for the decision process of ANP. First, the decision problem and the structure of problem were built to offer an evident depiction of the problem and separate it into a relation network structure as shown in Fig. 1. Second, not only is pair-wise comparison matrix established, but also eigenvalue and eigenvector were figured. Pair-wise comparison is composed of clusters and criteria. Furthermore, the pair-wise comparison of clusters was separated into comparison of criteria within and between clusters. We utilize ratio scale (1–9) to determine the level of importance of the comparison. In addition, the data deriving from the survey of ANP were combined and transferred into pair-wise comparison matrix by geometric average. After building the matrix, we received the eigenvector $\mathbf{W}_{ii}$ through an equation: $\mathbf{A}\mathbf{w} = \lambda_{\max}\mathbf{w}$, where A is pair-wise comparison matrix, $\mathbf{w} = (w_1, \ldots, w_i, \ldots, w_n)'$ is the eigenvector, w_i is the eigenvalue, then

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(Aw)_i}{w_i}$$

where $(\mathbf{A}\mathbf{w})_i = \sum_{j=1}^{n} a_{ij}w_j$ and n equals the number of comparative criteria. Third, the supermatrix, tagged $\mathbf{W}$ (as shown in Eq. (6)), was formed. It was constructed by the dependence table obtained from the interrelations among criteria, and the eigenvectors received from the pair-wise comparison matrix served as the weights of it. No inner dependence among criteria or clusters was shown by a blank or zero. By Wu and Lee (2007), the usage of power matrix by $\mathbf{W}^h$ (multiplication) and $\lim_{h\to\infty}\mathbf{W}^h$ is a fixed convergence value; therefore, we can acquire weights in every criterion.

3.3. The VIKOR for ranking and improving the alternatives

Opricovic (1998) proposed the compromise ranking method (VIKOR) as one applicable technique to implement within MCDM. Suppose the feasible alternatives are represented by $A_1, A_2, \ldots, A_k, \ldots, A_m$. The performance score of alternative A_k and the jth criterion is denoted by f_{kj}; w_j is the weight (relative importance) of the jth criterion, where $j = 1, 2, \ldots, n$, and n is the number of criteria. Development of the VIKOR method began with the following form of *L_p-metric*:

$$L_k^p = \left\{\sum_{j=1}^{n}[w_j(|f_j^* - f_{kj}|)/(|f_j^* - f_j^-|)]^p\right\}^{1/p}$$

where $1 \leqslant p \leqslant \infty$; $k = 1, 2, \ldots, m$; weight w_j is derived from the ANP. To formulate the ranking and gap measure $L_k^{p=1}$ (as S_k) and $L_k^{p=\infty}$ (as Q_k) are used by VIKOR (Opricovic, 1998; Opricovic & Tzeng, 2002, 2004, 2007; Tzeng, Lin, & Opricovic, 2005; Tzeng, Teng, Chen, & Opricovic, 2002).

$$S_k = L_k^{p=1} = \sum_{j=1}^{n}[w_j(|f_j^* - f_{kj}|)/(|f_j^* - f_j^-|)]$$

$$Q_k = L_k^{p=\infty} = \max_j\{(|f_j^* - f_{kj}|)/(|f_j^* - f_j^-|)|j = 1, 2, \ldots, n\}$$

The compromise solution $\min_k L_k^p$ shows the synthesized gap to be the minimum and will be selected for its value to be the closest to the aspired level. Besides, the group utility is emphasized when p is small (such as $p = 1$); on the contrary, if p tends to become infinite, the individual maximal regrets/gaps obtain more importance in prior improvement (Freimer & Yu, 1976; Yu, 1973) in each dimension/criterion. Consequently, $\min_k S_k$ stresses the maximum group utility; however, $\min_k Q_k$ accents on the selecting the minimum from the maximum individual regrets/gaps. The compromise ranking algorithm VIKOR has four steps according to the above-mentioned ideas.

Step 1: *Obtain an aspired or tolerable level.* We calculate the best f_j^* values (aspired level) and the worst f_j^- values (tolerable level) of all criterion functions, $j = 1, 2, \ldots, n$. Suppose the jth function denotes benefits: $f_j^* = \max_k f_{kj}$ and $f_j^- = \min_k f_{kj}$ or these values can be set by decision makers, i.e., f_j^* is the aspired level and f_j^- is the worst value. Further, an original rating matrix can be converted into a normalized weight-rating matrix by using the equation: $r_{kj} = (|f_j^* - f_{kj}|)/(|f_j^* - f_j^-|)$.
Step 2: *Calculate mean of group utility and maximal regret.* The values can be computed respectively by $S_k = \sum_{j=1}^{n} w_j r_{kj}$ (the synthesized gap for all criteria) and $Q_k = \max_j\{r_{kj}|j = 1, 2, \ldots, n\}$ (the maximal gap in k criterion for prior improvement).
Step 3: *Calculate the index value.* The value can be counted by $R_i = v(S_k - S^*)/(S^- - S^*) + (1 - v)(Q_k - Q^*)/(Q^- - Q^*)$, where $k = 1, 2, \ldots, m$. $S^* = \min_i S_i$ or setting $S^* = 0$ and $S^- = \max_i S_i$ or setting $S^- = 1$; $Q^* = \min_i Q_i$ or setting $Q^* = 0$ and $Q^- = \max_i Q_i$ or setting $Q^- = 1$; and $\boldsymbol{v}$ is presented as the weight of the strategy of the maximum group utility.
Step 4: *Rank or improve the alternatives for a compromise solution.* Order them decreasingly by the value of S_k, Q_k and R_k. Propose as a compromise solution the alternative $(A^{(1)})$ which is arranged by the measure $\min\{R_k|k = 1, 2, \ldots, m\}$ when the two

conditions are satisfied: **C1**. *Acceptable advantage*: $R(A^{(2)}) - R(A^{(1)}) \geqslant 1/(m-1)$, where $A^{(2)}$ is the second position in the alternatives ranked by R. **C2**. *Acceptable stability in decision making*: Alternative $A^{(1)}$ must also be the best ranked by S_k or/and Q_k. When one of the conditions is not satisfied, a set of compromise solutions is selected. The compromise solutions are composed of: (1) Alternatives $A^{(1)}$ and $A^{(2)}$ if only condition **C2** is not satisfied, or (2) Alternatives $A^{(1)}, A^{(2)}, \ldots, A^{(M)}$ if condition **C1** is not satisfied. $A^{(M)}$ is calculated by the relation $R(A^{(M)}) - R(A^{(1)}) < 1/(m-1)$ for maximum M (the positions of these alternatives are close).

The compromise-ranking method (VIKOR) is applied to determine the compromise solution and the solution is adoptable for decision-makers in that it offers a maximum group utility of the majority (shown by min S), and a maximal regret of minimum individuals of the opponent (shown by min Q). This model utilizes the DEMATEL and ANP processes in Sections 3.1 and 3.2 to get the weights of criteria with dependence and feedback and employs the VIKOR method to acquire the compromise solution.

4. Empirical case – using semiconductor portfolio as an example

In this section, an empirical study is displayed to illustrate the application of the proposed model for evaluating and selecting the best portfolio.

4.1. Background and problem descriptions

Stock markets have significant impact on most of the people in the world. Taiwan especially, there are around eight million accounts of security meaning that one invests in the stock market among three people; investment of stocks thus becomes an important tool when managing one's capital (Taiwan Stock Exchange Corporation). However, choosing portfolios with stable growth and booming prospects in the gradually larger stock market is like fishing for a needle in the ocean. Moreover, there are many factors that investors concern the most affecting stock returns; consequently, it is a tough problem for investors to evaluate and select

Table 2
The initial influence matrix ***A*** for criteria.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	0.000	2.267	2.133	2.933	2.000	3.800	1.800	1.533
C_2	1.733	0.000	2.867	1.933	2.467	2.733	1.067	2.867
C_3	2.000	2.333	0.000	2.200	2.467	2.933	2.467	2.467
C_4	3.067	2.400	2.800	0.000	2.467	2.600	1.667	1.933
C_5	1.267	1.467	1.933	1.867	0.000	3.067	2.267	2.200
C_6	2.933	3.267	3.267	2.667	3.000	0.000	2.400	3.067
C_7	1.000	1.067	1.067	1.067	1.267	1.133	0.000	2.867
C_8	1.067	1.467	1.200	1.200	1.333	1.533	2.533	0.000

Table 3
The normalized direct-influence matrix ***S*** for criteria.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	0.000	0.110	0.104	0.142	0.097	0.184	0.087	0.074
C_2	0.084	0.000	0.139	0.094	0.120	0.133	0.052	0.139
C_3	0.097	0.113	0.000	0.107	0.120	0.142	0.120	0.120
C_4	0.149	0.117	0.136	0.000	0.120	0.126	0.081	0.094
C_5	0.061	0.071	0.094	0.091	0.000	0.149	0.110	0.107
C_6	0.142	0.159	0.159	0.129	0.146	0.000	0.117	0.149
C_7	0.049	0.052	0.052	0.052	0.061	0.055	0.000	0.139
C_8	0.052	0.071	0.058	0.058	0.065	0.074	0.123	0.000

Table 4
The total-influence matrix ***T*** for criteria.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	0.262	0.383	0.394	0.398	0.383	0.496	0.358	0.396
C_2	0.317	0.261	0.399	0.337	0.380	0.431	0.313	0.427
C_3	0.340	0.375	0.290	0.360	0.393	0.453	0.381	0.428
C_4	0.391	0.388	0.420	0.275	0.402	0.454	0.356	0.413
C_5	0.273	0.300	0.332	0.306	0.243	0.407	0.334	0.370
C_6	0.426	0.466	0.485	0.432	0.470	0.396	0.432	0.513
C_7	0.184	0.200	0.208	0.194	0.214	0.232	0.155	0.303
C_8	0.202	0.233	0.232	0.216	0.235	0.268	0.279	0.199

Table 5
The total-influence matrix ***T*** for dimensions.

Dimensions	D_1	D_2	D_3
D_1	3.022	3.631	2.304
D_2	3.480	3.385	2.418
D_3	1.258	1.360	0.936

Table 6
The sum of influences given and received on dimensions.

	r_i	d_i	$r_i + d_i$	$r_i - d_i$
D_1	8.956	7.760	16.716	1.197
D_2	9.282	8.376	17.658	0.907
D_3	3.554	5.658	9.212	−2.103

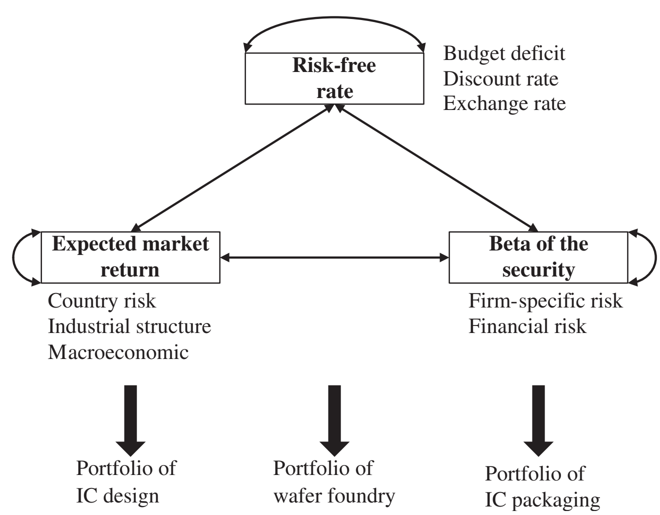


Fig. 3. The impact NRM of investment decision.

Table 7
The novel unweighted supermatrix.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	0.252	0.324	0.338	0.482	0.216	0.235	0.212	0.147
C_2	0.368	0.267	0.374	0.195	0.193	0.229	0.209	0.317
C_3	0.38	0.408	0.288	0.323	0.59	0.536	0.579	0.536
C_4	0.201	0.158	0.162	0.243	0.321	0.333	0.117	0.138
C_5	0.368	0.182	0.137	0.355	0.254	0.362	0.316	0.219
C_6	0.431	0.661	0.701	0.402	0.426	0.305	0.567	0.643
C_7	0.61	0.268	0.592	0.468	0.514	0.471	0.338	0.584
C_8	0.39	0.732	0.408	0.532	0.486	0.529	0.662	0.416

Note: the novel ANP has the relationship of feedback, so the diagonal matrix was derived by normalizing the diagonal matrix of the total-influence matrix from DEMATEL.

Table 8
Weighting the unweighted supermatrix based on total-influence normalized matrix.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	0.085	0.109	0.114	0.181	0.081	0.088	0.075	0.052
C_2	0.124	0.090	0.126	0.072	0.072	0.086	0.074	0.111
C_3	0.128	0.138	0.097	0.121	0.221	0.201	0.205	0.190
C_4	0.082	0.064	0.066	0.089	0.117	0.121	0.045	0.053
C_5	0.149	0.074	0.056	0.130	0.093	0.132	0.121	0.084
C_6	0.175	0.268	0.284	0.146	0.155	0.111	0.217	0.246
C_7	0.157	0.069	0.152	0.122	0.134	0.123	0.089	0.154
C_8	0.100	0.188	0.105	0.139	0.127	0.138	0.174	0.110

Table 9
The stable matrix of ANP when power limit $h \to \infty$ (ANP).

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
C_2	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096
C_3	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165
C_4	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081
C_5	0.103	0.103	0.103	0.103	0.103	0.103	0.103	0.103
C_6	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
C_7	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127
C_8	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134

portfolios to maximize their returns. In order to make investors know what the criteria of portfolio selection are, this study thus explores the criteria in the experts' point of view and constructs an investment decision model. In addition, because Taiwan is a leading country in the industry of semiconductor in the world, this research picked the most suitable portfolio from semiconductor companies spanning the hottest sectors of (IC) design, wafer foundry, and IC packaging to offer investors with a reference of portfolio selection.

4.2. Data collection

The experts with professional knowledge of finance and specialty of investment were the objects of this research, comprising consultants of investment, scholars of finance, and managers of mutual funds. Furthermore, the background of experts are described as follows: consultants of investment are good at security analysis in financial holding companies and institutions of investment, scholars of finance are those who have the specialty of management of investment and the experience of teaching financial courses in a university, and managers of mutual funds are in charge of managing and investing the capital of customers in a mutual fund management company. Experts' perspectives on the diverse criteria and the performance of every portfolio within the criteria were received by personal interviews and filling out the questionnaires. A total of 15 objects were divided into five consultants of investment, five scholars of finance, and five managers of mutual funds. This investigation was carried out in April 2009, and it took 40–80 min for every expert to fill out the questionnaire and to be interviewed.

4.3. Constructing the NRM by DEMATEL

To analyze the interrelationships between the eight determinants summarized through literatures, the DEMATEL method introduced in Section 3.1 will be utilized in the decision problem structure. First, the direct-influence matrix **A** for criteria was presented (see Table 2). Then, the normalized direct-influence matrix ***S*** for criteria can be calculated by Eq. (1) (see Table 3). Third, the total direct-influence matrix ***T*** for criteria/dimensions was derived based on Eq. (3) (see Tables 4 and 5). Finally, the NRM was constructed by the ***r*** and ***d*** in the total direct-influence matrix ***T*** (see Table 6) as shown in Fig. 3.

4.4. Calculating weights of each criterion by ANP

The primary survey targets included investment consultants, financial scholars, and managers of mutual funds. The level of importance (global weights) of eight criteria can be calculated by ANP shown as Tables 7–10. Results showed that experts were most concerned with macroeconomic factors and exchange rate, and least concerned with budget deficit and country risk. Research findings indicated that the level of importance was higher in macroeconomic factors, exchange rate, and firm-specific risk. Specifically, macroeconomic factors scored the highest at 0.200, followed by exchange rate at 0.165, and firm-specific risk at 0.127. The level of importance assessed for budget deficit and country risk was relatively lower, and the two criteria averaged 0.088. From the standpoint of dimensions, experts considered exchange rate relatively most important among the three criteria of "risk-free rate". Among the three criteria of the "expected market return" dimension, experts found "macroeconomic factors" as important. As for the "beta of the security" dimension, experts considered "financial risk" as important. In contrast, experts considered "firm-specific risk" as less important. This finding revealed that the experts believed macroeconomic factors could not be overlooked by investors when

Table 10
The weights of criteria for evaluating portfolio and total performance (SAW method).

Dimensions/criteria	Local weight	Global weight (by ANP)	Portfolio of IC design (A_1)	Portfolio of wafer foundry (A_2)	Portfolio of IC packaging (A_3)
Risk-free rate (D_1)	**0.355**		**7.437**	**8.457**	**8.443**
Budget deficit	0.265	0.094(7)	6.933	6.467	6.667
Discount rate	0.270	0.096(6)	6.867	7.867	7.733
Exchange rate	0.465	0.165(2)	8.133	9.933	9.867
Expected market return (D_2)	**0.384**		**6.270**	**7.197**	**6.714**
Country risk	0.211	0.081(8)	5.733	5.933	5.867
Industrial structure	0.268	0.103(5)	7.867	7.667	7.733
Macroeconomic factors	0.521	0.200(1)	5.667	7.467	6.533
Beta of the security (D_3)	**0.261**		**7.555**	**7.188**	**7.569**
Firm-specific risk	0.487	0.127(4)	9.333	7.667	7.467
Financial risk	0.513	0.134(3)	5.867	6.733	7.667
Total performance			7.032(3)	7.642(1)	7.551(2)

Example:
Calculating total performance by global weights:
$0.094 * 6.933 + 0.096 * 6.867 + 0.165 * 8.133 + 0.081 * 5.733 + 0.103 * 7.867 + 0.200 * 5.667 + 0.127 * 9.333 + 0.134 * 5.867 = \mathbf{7.032}$.
Calculating total performance by local weights:
$0.355 * 7.437 + 0.384 * 6.270 + 0.261 * 7.555 = \mathbf{7.032}$.

Table 11
The weights of criteria for evaluating portfolio and total performance (VIKOR method).

Dimensions/criteria	Local weight	Global weight (by ANP)	Portfolio of IC design (A_1)	Portfolio of wafer foundry (A_2)	Portfolio of IC packaging (A_3)
Risk-free rate (D_1)	**0.355**		**0.253**	**0.154**	**0.156**
Budget deficit	0.265	0.094(7)	0.307	0.353	0.333
Discount rate	0.270	0.096(6)	0.313	0.213	0.227
Exchange rate	0.465	0.165(2)	0.187	0.007	0.013
Expected market return (D_2)	**0.384**		**0.373**	**0.280**	**0.329**
Country risk	0.211	0.081(8)	0.427	0.407	0.413
Industrial structure	0.268	0.103(5)	0.213	0.233	0.227
Macroeconomic factors	0.521	0.200(1)	0.433	0.253	0.347
Beta of the security (D_3)	**0.261**		**0.245**	**0.281**	**0.243**
Firm-specific risk	0.487	0.127(4)	0.067	0.233	0.253
Financial risk	0.513	0.134(3)	0.413	0.327	0.233
S_{A_1}	Total gaps		0.297(3)	0.236(1)	0.245(2)
Q_{A_1}	Maximal gaps		0.433(3)	0.407(1)	0.413(2)

Example:
Calculating dimension gap by dimensions of local weights:
$S_{D_1} = d_{D_1}^{p=1} = \sum_{j=1}^{3} w_j^{D_1}\left(\frac{f_j^{*D_1} - f_{kj}^{D_1}}{f_j^{*D_1} - f_j^{-D_1}}\right) = 0.265 \times \left(\frac{10-6.933}{10-0}\right) + 0.270 \times \left(\frac{10-6.867}{10-0}\right) + 0.465 \times \left(\frac{10-8.133}{10-0}\right) = 0.253.$
$Q_{D_1} = d_{D_1}^{p=\infty} = 0.313.$
Calculating total gap by criteria of global weights:
$S_{A_1} = d_{A_1}^{p=1} = \sum_{j=1}^{8} w_j\left(\frac{f_j^{*} - f_{A_1 j}}{f_j^{*} - f_j^{-}}\right) = 0.094 \times \left(\frac{10-6.933}{10-0}\right) + 0.096 \times \left(\frac{10-6.867}{10-0}\right) + 0.165 \times \left(\frac{10-8.133}{10-0}\right) + 0.081 \times \left(\frac{10-5.733}{10-0}\right) + 0.103 \times \left(\frac{10-7.867}{10-0}\right) + 0.200 \times \left(\frac{10-5.667}{10-0}\right) + 0.127 \times \left(\frac{10-9.333}{10-0}\right) + 0.134 \times \left(\frac{10-5.867}{10-0}\right) = 0.297.$
$Q_{A_1} = d_{A_1}^{p=\infty} = \max\left\{\frac{f_j^{*} - f_{A_1 j}}{f_j^{*} - f_j^{-}} | j = 1, \ldots, n\right\} = 0.433.$

picking portfolios. Also, relative to the dimension of beta of the security, experts were less concerned because the mean of the dimension was substantially lower than others. Besides, the synthesized scores were then calculated to derive the total performance as illustrated in Table 10. Results showed that the total performance was highest in portfolio of wafer foundries, followed by portfolio of IC packaging and IC design. Therefore, the investment decision model provided by this study indicated that investors are suggested to invest in a portfolio of wafer foundries.

4.5. Compromise ranking by VIKOR

The VIKOR technique was applied for compromise ranking after the weights of determinants was calculated by ANP in Section 4.4. Calculation results (Table 11) demonstrated that the total gaps were highest in portfolio of IC design, followed by portfolio of IC packaging and IC design. Therefore, both VIKOR and ANP came to the same conclusions that the investment decision model provided by this study indicated that investors are suggested to invest in a portfolio of wafer foundries.

4.6. Implications and discussion

The empirical results were discussed as follows. In the first place, the most important criterion calculated by ANP when making investment decisions was macroeconomic factors weighting 0.200. If the macroeconomic condition is bad, the demand of most industries will decrease, not to mention the semiconductor

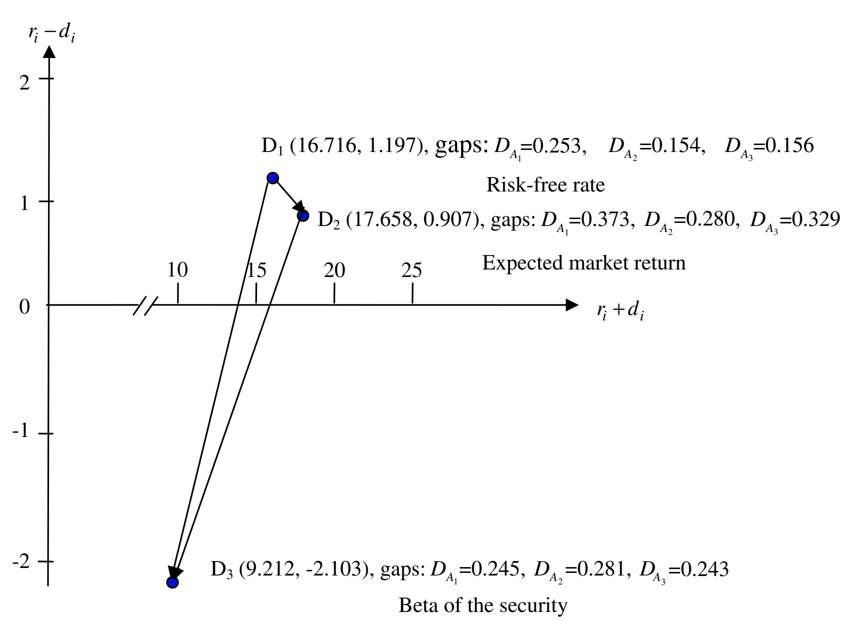


Fig. 4. The impact-direction map for improving gaps in performance values.

industry. Therefore, an economic recession will lead to the returns of portfolios of semiconductor to be lower than during prosperous macroeconomic conditions. On the contrary, the returns of portfolios of semiconductor will be higher when the macroeconomic condition thrives. The macroeconomic criterion was the most significant factor when considering portfolio selection. Secondly, an exchange rate weighting 0.165 was ranked number 2 of the eight criteria. It is a critical criterion of returns of portfolio especially in an island country, such as Taiwan, because exports play a very crucial role in the Gross National Product (GNP) in this kind of country. The returns of portfolio, whose products are for export, will become higher when the currency of the country depreciates. However, the returns of portfolio of exports will go down when the money of the country appreciates. Thirdly, the compromise ranking by VIKOR showed that the portfolio of wafer foundries is the best investment target among the industry of semiconductor followed by IC packaging and design. It is very sensible in that the output value of wafer foundries and IC packaging of Taiwan is one of the largest in the whole world. The wafer foundry industry in particular has been anchoring the economy of Taiwan. Fourthly, Fig. 4 showed that the dimension of risk-free rate was the primary factor that people should improve first when the returns of portfolios became bad. That was why the central banks of most countries adjusted their risk-free rate immediately when a financial crisis broke out.

The portfolio selection model provided by this study can be used in most of the countries of the world. There are some differences that investors should keep in mind when applying this model: the level of importance of the eight criteria could be varied according to the situations of the country and investors can select the portfolios that they want to invest in and compare them and then make the optimal investment decision.

5. Conclusions and remarks

The CAPM is used all over in the financial field as an important reference in evaluating stock returns. Mathematical models have demonstrated that risk-free rate, expected market return, and beta of the security are influential of stock returns. However, it is uncertain how the sub-factors impact these three factors. Moreover, the level of importance of these three factors for estimating stock returns is also not mentioned, even though the understanding of the importance of these factors and sub-factors can be beneficial for investors when selecting their portfolios.

Because the factors possessed interrelations and self-feedback relationships proven by the DEMATEL technique, ANP was then utilized to calculate each weight of the eight criteria. Empirical results presented that macroeconomic factors were rated number 1, followed by exchange rate, firm-specific risk, financial risk, industrial structure, discount rate, budget deficit, and country risk. Though investors have to take into account the effect of all factors when making decisions of portfolio selection, experts noted that macroeconomic factors should be given the most important weight. Therefore, when considering portfolios selection, investors can look more closely in this direction. In the standpoint of portfolio selection, the consolidated score of the eight criteria for evaluation was the highest for portfolio of wafer foundries, followed by portfolio of IC packaging as well as IC design, and the result was consistent with the VIKOR method. As a consequence, experts found that a portfolio of wafer foundries in the semiconductor industry was the most suitable for investment, and this result was coherent with the real-world situations of the samples in this study.

Previous models that studied stock returns were mainly focused on macroeconomic variables and the identification of factors that influenced stock returns. However, few theoretical models were derived from mathematical equations and a description of more detailed factors was not accessible. This study identified the factors and sub-factors that were found to be influential in stock returns by reviewing literature to construct a theoretical model based on the CAPM, using the novel MCDM to explore the relationships between factors and sub-factors, and surveying the views of experts for optimal portfolio selection. Combining the practical experience of experts with the mathematic model assists the CAPM becoming a more helpful model for investors to make investment decisions. Furthermore, these features are not provided by preceding studies. To sum up, this study has integrated the CAPM and novel MCDM to discuss the issues of stock returns and portfolio selection, and further studies can utilize the framework to solve the problems with multiple criteria.

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