

## Article

# Evaluation of Decision-Making for the Optimal Value of Sustainable Enterprise Development under Global 100 Index Thinking

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**Abstract:** This study seeks the best economic returns of a company's sustainable business process, employs the Triple Bottom Line Model using the Global 100 Index as the decision variable, and follows the Geometric Brownian Motion, so as to determine the optimal timing for the input of environmental and social costs. The results of the sensitivity analysis show that when the average growth rate of the Global 100 Index is low, the optimal timing for the company's input of environmental costs and social costs can be obtained. Analysis of the numerical example shows that, based on the financial value of the economic factor, companies should invest in environmental costs as soon as possible. This study replaces the conventional net present value model with the options evaluation model, uses the Global 100 Index as the threshold for decision-making evaluation to provide a more complete decision-making evaluation reference for enterprises, and makes up for the gap in recent research regarding investment time and decision variables. The study results introduce potential strategic value evaluations into the evaluation model of long-term uncertain sustainable operation value, which is more appropriate for the evaluation of the real sustainable operation value. It also provides implementation strategies for decision-makers to mitigate risks under uncertain environments and is the major difference and value of the Real Options Approach (ROA) to supplement Net Present Value (NPV) principles. The results of this study provide a reference for the sustainable development decision-making of corporate sustainability and feasibility and offer an important link in the value chain of food industry operations and management.

**Keywords:** triple bottom line; corporate social responsibility; environmental protection; corporate sustainability

## 1. Introduction

When companies pursue sustainable operations to gain financial benefits, environmental protection and corporate social responsibility (CSR) are also necessary conditions for the company to undertake. Environmental policies, such as social and regulatory responsibilities, are the basic principles of CSR that link environmental performance [1]. The recent Sustainable Development Goals (SDGs) of the United Nations include the CSR reports of cross-industry listed companies [2]. Domestic companies and multinational corporations have paid increasing attention to their CSR and their promotion of social and environmental welfare practices [3]. CSR is not just for disadvantaged groups or for charity institutions and environmental protection; the responsibilities include regulation compliance, the protection of employees', consumers', suppliers', and investors' interests, as well as

energy savings and carbon reduction. Many corporations have instituted plans for the reduction of their product carbon footprints. Global and sustainable packaging trends in 2016 included the use of 100% bio-based plastics, PET, the reduction of carbon footprints, using a green supply chain, reducing packaging waste, using edible packaging materials, and the development of bio-plastics. According to a survey from the Natural Resources Defense Council (NRDC), the implementation of food package recycling can reduce global waste by US\$11.4 billion annually. The environmental impact of reducing product packaging has become the first requirement for corporations' sustainable business [4].

As the food industry faces the issues of food safety, animal welfare, and pollution of environmental soil by chemical fertilizers and herbicides, the food industry has received widespread attention regarding sustainability issues [5]. As profit and food safety are the two main business objectives for food companies, even when profit means a financial reporting index and food safety means a sustainable development report, both lead to the successful operations of these companies [6]. However, a number of large and publicly listed food companies have recently had food safety incidents in Taiwan. Therefore, the Financial Supervisory Commission R.O.C. (Taiwan) made a mandatory rule that, beginning from January 2016, all publicly-held companies with capital of NT\$10 billion shares and those that receive 50% or more of their revenues from food and beverages must prepare CSR reports containing Confident Opinions Reports from CPAs. Before 2015, there were only four corporations compiling CSR reports in Taiwan's food industry. In 2015, the CSR reports in Taiwan, the number of companies that published CSR reports for the first time was 168 corporations, which was more than a 250% increase from 2014, especially in the food industry [7]. The business sustainability index is collected through CSR reports, which is now a competitive indicator of sustainable business [8].

CSR often facilitates potential business sustainability value, as a company's interests are not completely in opposition to consumer surplus or social welfare. While those companies that have implemented CSR have seen a drop in their maximum profit, the quality and quantity of food products have improved and consumer surplus and social welfare have increased [9]. Companies can strengthen their product quality and environmental protection through the implementation of CSR and achieve employee value and social value by protecting the interests of stakeholders. In the past, many studies related to CSR and sustainable development, such as Reference [10], established a conceptual link among groundbreaking thinking, triple bottom line value creation, and organizational capabilities to discuss how companies pursue innovative activities that create economic, social, and environmental values under time-sensitive backgrounds. As discussed in Reference [11], the contributions of the sustainable development of enterprises to enhance corporate business value include social value and natural value in terms of strategic processes, strategic content, and strategic background, as well as 16 propositions.

Due to interested parties' increasing focus on low carbon, CSR, and the importance of sustainable behavior to enhance the enterprise supply chain [12], many scholars in recent years have researched corporate sustainable business issues using the triple bottom line (TBL) model [13–15]. The spirit of the TBL model relies on the fact that a corporation's sustainable business value must consider that sustainable business effectiveness is produced in the economic, environmental, and social dimensions [16]. Normally, the economic dimension's financial value provides the most principle support for business maintenance. Both environmental and social costs can eliminate environmental damage and boost social welfare, which are affected by the economic dimension during sustainable business processes, provide compensatory measures, and fundamentally increase the sustainable business value. The Global 100 Index is recognized as the leader in corporate sustainable development ranking. Corporate Knights, a Canadian media company, targets companies with a global market capitalization of US\$2 billion and above and assesses them according to 12 key indicators: Energy Productivity, Carbon Productivity, Water Productivity, Waste Productivity, Innovation Capacity, Percentage Tax Paid, CEO to Average Worker Pay Ratio, Pension Fund Status, Safety Performance, Employee Turnover, Leadership Diversity, and Clean Capitalism Pay Link, in order to evaluate the world's top 100 leading companies for sustainable development [17]. The Global 100 Index can

strengthen the sustainability value of a company's environmental performance, social performance, and economic performance.

According to the above literature, while many scholars have discussed and studied the TBL model and corporate sustainability issues [3–5,10–16], the factors that affect the enterprises' input of environmental and social costs, as well as the best time points for such input, have been less discussed; thus, the questions of this research are constructed with reference to Reference [18], as follows:

1. What is the impact of the changes in the Global Sustainability Index on an enterprise's sustainable operating costs?
2. From the financial aspects of the enterprise, when should environmental and social costs be invested, while still maintaining the financial income of the enterprise?
3. Does the fixed income of the enterprise affect the time it takes for the enterprise to invest in environmental and social costs?

As Reference [19] pointed out that, conventionally, managers use NPV to evaluate whether a certain capital investment is beneficial to the company, but that using the Real Options Approach (ROA) as an evaluation tool for investment decisions will provide a more flexible decision-making scheme for the enterprise when it purchases or sells assets. Traditional evaluation methods and strategies cannot achieve good results in uncertain environments. The ROA originates from the financial field and is applied to the evaluation of various non-financial or physical assets [20]. The ROA provides a dynamic management model and a new perspective based on the principle of financial options [21]. Sustainable operation is a long-term evaluation model, which is affected by many uncertain external factors. Therefore, ROA is more appropriate than NPV for sustainable operation value. The options evaluation model is adopted as the basis for this present study. Although the issue of sustainable development is less frequently discussed using the options evaluation model, this model can measure the potential value, especially the value of a project, which cannot be measured by the traditional NPV method. The research methods and sustainable management value evaluation process comparison between NPV and ROA are shown in Table 1.

The options evaluation model has the characteristics of risk avoidance [22]. Therefore, this paper employs the TBL model, which takes the Global 100 Index as the threshold values, to provide companies with prudent considerations regarding their investment in environmental costs, whether or not they should engage in social cost investments, and the timing for a company to expand its financial value under the economic aspect. This study's TBL model takes the expected value of the Global 100 Index as the threshold values and assumes that the Global 100 Index follows the geometric Brownian motion and that the variation follows the Standard Wiener Process thereby establishing a mathematical model with  $\alpha$  as the mean and  $\sigma$  as the variance. Through value matching and smooth pasting conditions, this study attempts to determine the optimal time point for a company to invest in environmental costs, social costs, and the corresponding expected value of the Global 100 Index, and further suggests that the development of a viable strategy for sustainable business value is important decision-making behavior for companies in the process of sustainable operations.

**Table 1.** Comparison of the Research Methods and Sustainable Management Value Evaluation Process Analysis between Net Present Value (NPV) and Real Options Approach (ROA).

NPV		ROA	
Theoretical principle	Net present value of cash flows	Options theory	
Judgment criteria for general decision-making evaluation	1. NPV > 0 implement strategy for each stage.	1.	Max project value.
	2. NPV < 0 abandon strategy implementation.	2.	Search for the most appropriate threshold values with Value Matching Condition and Smooth Pasting condition [23].

Table 1. Cont.

	NPV	ROA
Comparison of the advantages for the approaches	<ol style="list-style-type: none"> <li>1. The static discounted cash flows method considers the time value of the capital; the discount rate directly affects the selection of projects.</li> <li>2. It can evaluate multiple investment opportunities of a project, reflects the investment effect and is applicable to the evaluation of mutually exclusive schemes with equal years.</li> <li>3. If there are different risks in different stages of the investment project, it is more appropriate to adopt different discount rates in stages to reflect risks in time [24,25].</li> </ol>	<ol style="list-style-type: none"> <li>1. It is a decision-making method for capital investment under uncertainty and provides a more flexible decision-making evaluation according to the basic characteristics of the options.</li> <li>2. It is suitable for the decision-making on the time to implement strategy evaluation in dynamic and uncertain environments as well as the threshold values of the decision variables [26,27].</li> <li>3. It is also one of the effective tools for risk aversion [28].</li> </ol>
Differences in study results	Determine whether to implement the strategies at the starting point.	Look for the timing for imputing the implementation strategies at each stage and decision-making threshold values.
Objective function	The project value function at the starting point (a fixed point) of the specific period of each stage.	Evaluation of the project value in the whole period under uncertainty during the conversion period of each stage.
Decision variables	NPV (Global 100 Index is reflected in cash flows).	The optimal value of the Global 100 Index Conversion and the expected conversion time points for each stage.
The project value function, income function, cost function and initial capital input function at each stage	According to model, there is a function type relationship between the main income, cost of cash flows. The Global 100 Index is the average index.	<ol style="list-style-type: none"> <li>1. It is the presentation of cash flows and potential strategic values at each stage.</li> <li>2. The Global 100 Index is the change index of a stochastic process obeying geometric Brownian motion.</li> </ol>
Comparison of cash flows	Evaluation of the NPV at the starting point of each stage.	Estimation of the overall value of cash flows at the decision-making conversion points of each stage.
Comparison of capital gains (potential strategic values)	N/A	Impute the Global 100 Index under geometric Brownian motion change based on the theory of ROA.
Comparison of mathematical and physical research methods	Static decision-making evaluation criteria.	Dynamic random evaluation criteria.
Comparison of decision-making threshold values	Judgment of immediate execution and/or abandonment based on NPV value.	Look for the most suitable and feasible implementation strategy conversion threshold values and evaluate the best timing for conversion.
Risk aversion comparison	Single discount rate (risk premium) is more likely to incur difference in long-term strategic risk valuation.	ROA has the characteristics that the theory itself is a kind of options evaluation method with risk aversion features.
Comparison of the characteristics and applicability of sustainable operation	Immediate judgment at the starting point of each stage of the long-term sustainable operation decision-making that introduces environmental cost or social cost is relatively weak in flexibility in response to external environmental changes.	Regardless of the environmental and strategic changes in each stage, the evaluation of introducing the potential strategic values and the judgment of the time point for introducing the environmental cost and social cost are more flexible.
The project value of Stage 0	The project value is equal to the expected net cash flows at the beginning of Stage 0 during the period from the fixed Stage 0 to the fixed Stage 1.	The project value is equal to the expected total cash flows at the time point when Stage 0 is converted to Stage 1, plus the potential strategic value of the expected capital gains at that point.
The project value of Stage 1	The expected net cash flows (NPV of financial and economic returns minus environmental costs) at Stage 1 is estimated from fixed Stage 1 to fixed Stage 2.	<ol style="list-style-type: none"> <li>1. When the Global 100 Index reaches the optimum value of the decision variables from Stage 0, i.e., <math>E[I_{t_1}]</math> the environmental costs are invested and converted to Stage 1 (i.e., Stage 1 is not a fixed time point).</li> <li>2. Environmental costs increase with the increase of the Global 100 Index and the financial benefit value of the economics facet of enterprises increase with the increase of the Global 100 Index.</li> <li>3. The project value is estimated to be the expected overall cash flows from Stage 1 to Stage 2 (also a non-fixed time point), plus the expected potential strategic value (financial benefit value of the economics minus environmental costs plus potential strategic value).</li> </ol>

Table 1. Cont.

NPV		ROA
The project value of Stage 2	Net cash flows at fixed Stage 2 (financial and economic benefits minus environmental and social costs).	<ol style="list-style-type: none"> <li>1. When the Global 100 Index reaches the optimum value of the decision variables, i.e., <math>E[I_{t_2}^*]</math>, social costs are invested.</li> <li>2. Social costs increase with the increase of the Global 100 Index, while enterprises continue to invest in environmental costs.</li> <li>3. The financial benefit value of the economics facet of enterprises increase with the increase of the Global 100 Index; the project value is equal to the expected cash flows during the whole period of Stage 2 (expected financial benefit value of the economics minus the input environmental and social costs).</li> </ol>
Value matching condition	N/A	<ol style="list-style-type: none"> <li>1. The expected project value at Stage 0 and that at Stage 1 are the same at the conversion point of Stage 1.</li> <li>2. The expected project value at Stage 1 and that at Stage 2 are the same at the conversion point of Stage 2.</li> </ol>
Smooth pasting condition	N/A	<ol style="list-style-type: none"> <li>1. The expected marginal revenue of the project at Stage 0 and that at Stage 1 are the same at the conversion point of Stage 1.</li> <li>2. The expected marginal revenue of the project at Stage 1 and that at Stage 2 are the same at the conversion point of Stage 2.</li> </ol>
Decision-making criteria	Whether the NPV at fixed Stage 0/1/2 is positive or not.	Look for the conversion time points of Stage 1 and Stage 2 and the expected decision-making threshold values of the Global 100 Index and estimate the expected project value of each stage.

## 2. Method and Model Construction

### 2.1. The TBL (Triple Bottom Line) Model

Reference [16] introduced the TBL model, noting that corporations' sustainability development must consider environmental, social, and economic dimensions. The supply of raw materials for food has become unstable due to global warming, climate change, and water shortages, which have caused the cost of raw materials to continuously increase. Additionally, the frequent food safety issues that have occurred in recent years have added potential risks to business operations.

The food industry's economic benefits in the sustainable business process will gradually decrease as the Global 100 Index becomes more popular. Corporations should bear the social responsibilities of maintaining food safety by reducing their carbon emissions and waste of water resources, improving environmental effectiveness, reducing packaging waste, and using a green supply chain. Corporations should gradually add environmental and social responsibility costs with an increasing Global 100 Index. While their financial performance in the economic dimension might decrease in the short-term due to increasing costs, their economic benefits will increase in the long-term, eventually causing an increase in financial performance. The later a firm adds environmental and social costs, the lower the effectiveness those economic benefits will have. Therefore, it is necessary to determine the most optimal time to enter the process.

This study considers the close relationship between frequent food safety problems and environmental issues. The value of sustainable business includes tangible, intangible, and potential value, as environmental and social costs will reduce the financial value but increase the value of its sustainable business. When the food industry seeks value in business sustainability, after first considering the economic dimension, they often consider the environmental dimension, followed by the impact of the social dimension. The theoretical framework of social, environmental, and financial performance in the past mostly referred to the relationship between social and financial performances and was mainly based on the concept of social corporate responsibility and corporate social

performance [29,30]. Although environmental issues and social issues are different, the development of the theoretical framework is valid for these two factors of corporate performance [31]. Reference [32] stated that a company has to organize its culture, thus further meeting the challenges of society and the environment. The key idea is that, as a company moves towards sustainable development, it must develop an organizational culture for sustainable development [33]. This study assumes that, when a company sequentially invests in environmental and social costs, the company's sustainable development culture will be formed and its investments in environmental and social costs will not be reduced or stopped; therefore, a potential exit item value will not occur. The TBL model of this study determines how to properly add environmental and social costs into the decision-making process, identifies the threshold values that match the corresponding Global 100 Index, and uses them as a basis to develop the overall model. This paper also refers to the focus of Economical Writing [34], which clearly expresses the assumptions and development of this research model in a systematic manner in the subsequent paragraphs, and carries out numerical simulation and sensitivity analysis.

## 2.2. Model Assumptions

According to Reference [35], theoretically, if the normal state has a skew of 0 and a kurtosis of 3, then it is a normal distribution. In large samples (more than 30 samples), it may have statistical significance even if it slightly deviates from normal. In other words, the Global 100 changes under large samples and may follow a normal distribution. The Standard Wiener Process [36] is the change in the process under the assumption of a normal distribution, while the geometric Brownian motion (GBM) changes follow a lognormal distribution.

Assume  $V_i(I_t)$  is the TBL project value at  $I_t$  in each stage, where  $i = 0, 1, 2$ ,  $t_1^*$ ,  $t_2^*$  are the optimal timing to enter environment costs in Stage 1 or to enter environment cost/social costs in Stage 2. This study assumes that Stage 0 is the initial stage, meaning the enterprise has not introduced environmental costs or social costs. The TBL project value generated through the financial value is  $V_0(I_t)$ ; as the time continues to advance, the threshold values of enterprise  $t_1^*$  is reached and the corresponding expected Global 100 Index is the threshold values of  $E[I_{t_1^*}]$ . The enterprise will invest in environmental cost  $B_i(I_t)$ , which is the environmental cost at  $I_t$  in Stage  $i$ ,  $i = 1, 2$ , and then enter Stage 1. The TBL project value of this stage is  $V_1(I_t)$ . When the time reaches the enterprise decision threshold  $t_2^*$ , the corresponding expected Global 100 Index is the threshold values of  $E[I_{t_2^*}]$  and the enterprise will invest in social cost  $S_2(I_t)$ , which is the social cost at  $I_t$  in Stage 2. At the same time, based on the consideration of the sustainable operations of the enterprise, it will continue to invest in environmental cost  $B_i(I_t)$ . At this time, it will enter Stage 2, and the TBL project value at this stage will be  $V_2(I_t)$ . The changes in the status of various stages are shown in Figure 1, while the list of variables and their descriptions are shown in Appendix A.

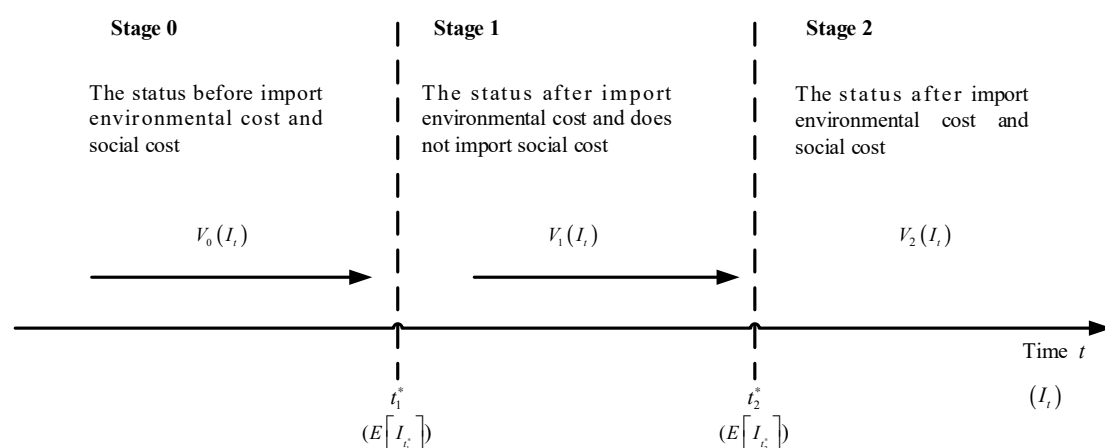


Figure 1. Framework of the Promoted Model.



This manuscript describes the change of the Global Index in the GBM type with the model assumption as follows.

(1) Assume that at time  $t$ , the Global 100 Index  $I_t$  of a decision variable follows a GBM with drift  $\alpha$  and volatility  $\sigma$ . The GBM process is appropriate for economic variables that grow exponentially at an average rate (mean) of  $\alpha$  and have volatility of geometric Brownian motion with  $\sigma$  proportional to the level of the variable.  $dt$  is the smallest positive real number and  $dW_t$  is the volatility quantity per unit time, which follows an identical independent distributed (*iid*) Standard Wiener Process (normally distributed random variable with zero mean and  $dt$  variance) [36], and the expected Global 100 Index  $E[I_{t_1}^*]$  is obtained via geometric Brownian motion expectation characteristics  $E[I_{t_1}^*] = I \times e^{\alpha t_1^*}$ ,  $E[I_{t_2}^*] = I \times e^{\alpha t_1^*} e^{\alpha(t_2^* - t_1^*)}$ , where  $I$  is the Global Index of the initial value, as seen in the following equation:

$$\frac{dI_t}{I_t} = \alpha dt + \sigma dW_t, dW_t \sim iid N(0, dt), I_0 = I(\text{initial value at time 0 and given}) \quad (1)$$

According to the derivation steps of [36], the TBL project value at various stages equals the cash flows value plus the capital gains value.

In this paper,  $F_i(I_t)$ ,  $i = 0, 1, 2$  represents the cash flows of project value at  $I_t$  in each stage, and  $P_i(I_t)$ ,  $i = 0, 1, 2$  represents the capital gains of project value at  $I_t$  in each stage. Figure 2 shows the time points for the sustainable operation, optimal environmental cost, and social cost in each stage:

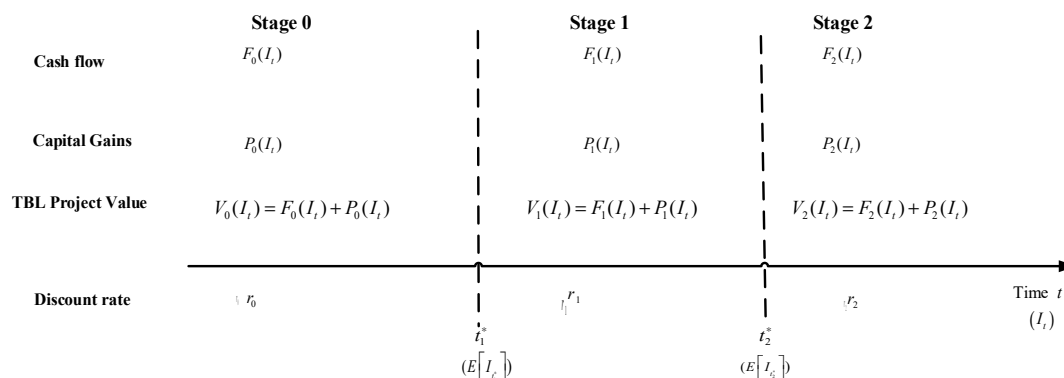


Figure 2. TBL Project Value and Optimal Investment Time.

(2) According to practice, the enterprise's payments of environment and social costs will be introduced in different stages in order to avoid having too many expenditures at one time, which may produce unbearable pressure. When the financial benefit value of the economic facet does not import the environmental cost  $B_i(I_t)$  of the environmental aspect and the social cost  $S_2(I_t)$  of the social aspect, the financial value of the economic facet  $\pi_0(I_t)$  will be a value function that assumes a decreasing function with an increase in the Global 100 Index; this represents a more stringent requirement for sustainable operations, which will result in a decline of financial value, and this decrease is an increasing function (the second-order derivative function is positive):  $\frac{d\pi_0(I_t)}{dI_t} < 0$ ,  $\frac{d^2\pi_0(I_t)}{dI_t^2} > 0$ .

(3) When time  $t$  reaches threshold point  $t_1^*$ , the input environmental cost  $B_1(I_t)$  must be considered, and this environmental cost will increase with a rise in the Global 100 Index. The rate of increase is a decreasing function (the second-order derivative function is negative):  $\frac{dB_1(I_t)}{dI_t} > 0$ ,  $\frac{d^2B_1(I_t)}{dI_t^2} < 0$ . If environmental cost  $B_1(I_t)$  is considered but social cost  $S_2(I_t)$  is not, then the financial value of the economic facet will be  $\pi_1(I_t)$ . When the financial benefit value of the economic facet introduces the environmental cost of the environmental facet but not the social cost of the social facet, then the financial benefit value of the economic facet  $\pi_1(I_t)$  will rise with an increase in the Global 100 Index, and this increase will be a decreasing function (the second-order derivative function is negative):  $\frac{d\pi_1(I_t)}{dI_t} > 0$ ,  $\frac{d^2\pi_1(I_t)}{dI_t^2} < 0$ .

(4) When  $t$  reaches threshold time  $t_2^*$ , input social cost  $S_2(I_t)$  must be considered, and this social cost will increase with the increase of the Global 100 Index. The rate of increase is a decreasing function (the second-order derivative function is negative):  $\frac{dS_2(I_t)}{dI_t} > 0$ ,  $\frac{d^2S_2(I_t)}{dI_t^2} < 0$ . At this stage, environmental cost  $B_2(I_t)$  will continue to accrue and will increase as the Global 100 Index increases. The rate of increase is a decreasing function (the second-order derivative function is negative):  $\frac{dB_2(I_t)}{dI_t} > 0$ ,  $\frac{d^2B_2(I_t)}{dI_t^2} < 0$ . The financial value of the economic facet after considering environmental cost  $B_2(I_t)$  and social cost  $S_2(I_t)$  will be  $\pi_2(I_t)$ . In addition, the social cost affected by the Global 100 Index will be less than the environmental cost affected by the Global 100 Index. When the financial benefit value of the economic aspect introduces the environmental cost of the environmental aspect and the social cost of the social aspect, the financial benefit value of the economic facet  $\pi_2(I_t)$  will increase with a rise in the Global 100 Index and the rate of increase rate will be a decreasing function (the second-order derivative function is negative):  $\frac{d\pi_2(I_t)}{dI_t} > 0$ ,  $\frac{d^2\pi_2(I_t)}{dI_t^2} < 0$ .

(5) The assumptions of financial value  $\pi_i(I_t)$ , environmental cost  $B_i(I_t)$ , and social cost  $S_2(I_t)$  of this study are as follows:

1 Assume the financial value is:

$$\pi_i(I_t) = a_i I_t^{p_i} + b_i I_t^{p_i-1} + c_i \quad (2)$$

where,  $p_i \geq 2$ ,  $i = 0, 1, 2$ , and  $a_i, b_i$  are the different impacted scale parameters of the Global 100 Index in Stage  $i$ ,  $i = 0, 1, 2$ ,  $p_i$  is the power parameters of the financial value of the Global 100 Index in Stage  $i$ ,  $i = 0, 1, 2$ , and  $c_i$  is the fixed parameter of the financial value in Stage  $i$ ,  $i = 0, 1, 2$ . In addition, assume that:  $\pi_2(I_t) > \pi_1(I_t) > \pi_0(I_t)$ . Assume that  $\frac{d\pi_0(I_t)}{dI_t} < 0$ ,  $\frac{d^2\pi_0(I_t)}{dI_t^2} > 0$ , which satisfies the condition  $a_0 > 0, b_0 < 0, p_0 \geq 2$ , then:

$$\frac{d\pi_0(I_t)}{dI_t} = a_0 p_0 I_t^{p_0-1} + b_0 (p_0 - 1) I_t^{p_0-2} < 0 \quad (3)$$

Here,  $b_0 < -(I_t \times a_0 \times \frac{p_0}{p_0-1})$  can be calculated, and at the same time:

$$\frac{d^2\pi_0(I_t)}{dI_t^2} = a_0 p_0 (p_0 - 1) I_t^{p_0-2} + b_0 (p_0 - 1) (p_0 - 2) I_t^{p_0-3} > 0 \quad (4)$$

thus, it obtains  $(a_0 p_0 I_t + b_0 (p_0 - 2)) I_t^{p_0-3} > 0$ , where  $a_0 > -\frac{p_0-2}{p_0} \times \frac{b_0}{I_t}$  has the limitation of  $a_0 > 0$ . It then finds  $a_0 > \max\left\{0, -\frac{p_0-2}{p_0} \times \frac{b_0}{I_t}\right\}$ , so  $a_0 > -\frac{p_0-2}{p_0} \times \frac{b_0}{I_t} > 0$ . Assume that  $\frac{d\pi_i(I_t)}{dI_t} > 0$ ,  $\frac{d^2\pi_i(I_t)}{dI_t^2} < 0$ ; if  $i = 1, 2$ , and it satisfies the conditions  $a_i < 0$ ,  $b_i > 0$ ,  $p_i \geq 2$ , then:

$$\frac{d\pi_i(I_t)}{dI_t} = a_i p_i I_t^{p_i-1} + b_i (p_i - 1) I_t^{p_i-2} > 0 \quad (5)$$

where  $b_i > -(I_t \times a_i \times \frac{p_i}{p_i-1})$  can be calculated. When

$$\frac{d^2\pi_i(I_t)}{dI_t^2} = a_i p_i (p_i - 1) I_t^{p_i-2} + b_i (p_i - 1) (p_i - 2) I_t^{p_i-3} < 0 \quad (6)$$

$a_i < -\frac{p_i-2}{p_i} \times \frac{b_i}{I_t}$  can be calculated, with the limitation of  $a_i < 0$ .

2 Assume that the environmental cost is  $B_i(I_t) = j_1(\log I_t) + k_i$ ,  $i = 1, 2$ , where  $\log I_t$  is the function representing the lessening degree of impact from  $I$ ,  $j_i$  is the scale factor of the environmental



cost in Stage  $i$ ,  $i = 1, 2$ , and  $k_i$  is the fixed parameter of environmental cost in Stage  $i$ ,  $i = 1, 2$ . If  $k_i > 0$ ,  $j_i > 0$ , then

$$B_i(I_t) = j_i(\log I_t) + k_i, \quad i = 1, 2 \quad (7)$$

and it is easy to find  $\frac{dB_i(I_t)}{dI_t} > 0$ ,  $\frac{d^2B_i(I_t)}{dI_t^2} < 0$ ,  $i = 1, 2$ .

- 3 Assume that the social cost is  $S_2(I_t) = f_2(\log I_t) + g_2$ , where  $\log I_t$  is the function representing the lessening degree of impact of  $I$ ,  $f_2$  is the scale parameter impacted to the Global 100 Index of the social cost in Stage 2,  $g_2$  is the fixed parameter of the social cost in Stage 2, and  $\frac{dS_2(I_t)}{dI_t} > 0$ ,  $\frac{d^2S_2(I_t)}{dI_t^2} < 0$ . If  $g_2 > 0$ , then:

$$S_2(I_t) = f_2(\log I_t) + g_2, \quad (8)$$

and it is then easy to obtain  $\frac{dS_2(I_t)}{dI_t} = \frac{f_2}{I_t} > 0$ , where  $f_2 > 0$ .

### 2.2.1. TBL Project Value

The real options is mostly used for investment planning decisions, as in Reference [37], to review the delay or start-up of an investment, as in Reference [38], to consider the impact of interest rate changes on the value of a project as well as the investment waiting strategy, as in Reference [26], to explore the real options during a project evaluation, or resource allocation under uncertainty. This study adopts the evaluation mode of the real options in previous literature, such as References [23,36,39], and modifies the decision-making variables and function correspondences according to the model assumptions to evaluate the project value. In addition to estimating the net cash flows, the assessment of the project value includes the potential value of the policymaker's strategy, including the potential value of entering the market and the potential value of exiting the market [40].  $g_2 > 0$ ,

The cash flows of the project values at each stage of the study are as follows.

1. TBL's cash flows of the project value before environmental and social costs are invested:

$$F_0(I_t) = \pi_0(I_t) \quad (9)$$

2. TBL's cash flows of the project value with the input of environmental costs and without the input of social costs:

$$F_1(I_t) = \pi_1(I_t) - B_1(I_t) \quad (10)$$

3. TBL's cash flows of the project value after environmental and social costs are invested:

$$F_2(I_t) = \pi_2(I_t) - B_2(I_t) - S_2(I_t) \quad (11)$$

Ito's Lemma is used to derive the value of this research project, and the detailed process is in reference to Reference [36]. The project value of  $V_i(I_t)$ ,  $i = 0, 1, 2$  in this study is:

$$V_i(I_t) = A_i I_t^{\beta_i} + \gamma_i F_i(I_t), \quad i = 0, 1, 2 \quad (12)$$

According to the geometrical Brownian motion's second-order differential equations, which are composed of general solutions and particular solutions, the general solution form is  $V_i(I_t) = A_i I_t^{\beta_i}$  and the particular solution form is  $V_i(I_t) = \gamma_i F_i(I_t)$ . The particular solution (expected cash flows) is shown in Equation (13). The derivation is as follows [23,36].

Because the cash flows are  $\gamma_i F_i(I_t)$ , we can easily obtain  $\gamma_i = \frac{F_i(I_t)}{r_i F_i(I_t) - \alpha_i F_i(I_t)} = \frac{1}{r_i - \alpha_i}$ ; therefore, cash flows are shown as follows:

$$\gamma_i F_i(I_t) = \left(\frac{1}{r_i - \alpha_i}\right) F_i(I_t); i = 0, 1, 2 \quad (13)$$

Here,  $\alpha_i I \frac{dV_i(I_t)}{dI_t} + \frac{1}{2} \sigma_i^2 I^2 \frac{d^2 V_i(I_t)}{dI_t^2} - r_i V_i(I_t) = 0$  is the Ordinary Differential Equation (ODE) of the general solution, where  $r_i$  is the risk-free rate at Stage  $i$ . This study brings the particular solution to each ODE [23,36,40] for the total solution form. The general solution is substituted into each ODE as  $r_i A_i I_t^{\beta_i} = \alpha_i I_t \times \beta_i A_i I_t^{\beta_i-1} + \frac{1}{2} \beta_i (\beta_i - 1) A_i I_t^{\beta_i-2} \sigma_i^2 I_t^2$  (cash flows is removed for general solution calculations) and the general solution is obtained, as shown in Equation (14). This study refers to [23,36] for related derivations:

$$\frac{1}{2} \sigma_i^2 \beta_i^2 + \left(\alpha_i - \frac{1}{2} \sigma_i^2\right) \beta_i - r_i = 0; i = 0, 1, 2 \quad (14)$$

The assumptions of the project values at each stage of this study are explained as follows, and Equations (15)–(17) refer to [23,36,39]. At the same time, it is modified according to the parameters and variables assumed in this research model.

**Stage 0:** The project value of sustainable operations without the introduction of environmental and social costs includes the TBL project value before environmental and social costs are invested  $V_0(I_t) = F_0(I_t) + A_0 E[I_t^{\beta_0}] = \pi_0(I_t) + A_0 E[I_t^{\beta_0}]$ , where  $A_0$  is the scale coefficient of the expected potential strategic value in Stage 0 and  $\beta_0 = \left[\left(\frac{1}{2} \sigma_0^2 - \alpha_0\right) + \left[\left(\alpha_0 - \frac{1}{2} \sigma_0^2\right)^2 + 2r_0 \sigma_0^2\right]^{\frac{1}{2}}\right] / \sigma_0^2 > 0$  (note: as this project has no potential exit value, there is no negative root).

Since the TBL project value before environmental and social costs are invested is affected by the rise of the Global 100 Index and the project value is declining, it inevitably affects the chances for the sustainable development of the company. Therefore, the company must consider how to import environmental costs to reduce the negative impact on the company's economic aspect by increasing its awareness of environmental protection.

**Stage 1:** With the input of environmental costs but without the input of social costs, the project value of sustainable operations includes TBL project value  $V_1(I_t) = F_1(I_t) + A_1 E[I_t^{\beta_1}] = \pi_1(I_t) - B_1(I_t) + A_1 E[I_t^{\beta_1}]$ , where  $A_1$  is the scale coefficient of the expected potential strategic value in Stage 1 (refer to [23,36] for related derivations), and  $\beta_1 = \left[\left(\frac{1}{2} \sigma_1^2 - \alpha_1\right) + \left[\left(\alpha_1 - \frac{1}{2} \sigma_1^2\right)^2 + 2r_1 \sigma_1^2\right]^{\frac{1}{2}}\right] / \sigma_1^2 > 0$ . (note: as this project has no potential exit value, there is no negative root).

Although the TBL project value with the input of environmental costs and without the input of social costs increases with the rise of the Global 100 Index, the failure of investing in the social facet will impact the company's future opportunities for sustainable development. Therefore, the company must consider how to introduce the social facet to reduce the negative impact on the company's economic aspect from the increasing pressure of social responsibility.

**Stage 2:** The project value of sustainable operations with the input of environmental and social costs includes the investment of both social and environmental facets. The TBL project value is  $V_2(I_t) = F_2(I_t) = \pi_2(I_t) - B_2(I_t) - S_2(I_t)$ . Based on the enterprise's sustainable management considerations, it will continue to invest in environmental costs and social costs; thus, there is no potential strategic value at this stage.

The project values at each stage of this study are as follows.

In Stage 0, the TBL project value  $V_0(I_t)$  is:

$$V_0(I_t) = \int_0^{t_1^*} e^{-r_0(t_1^* - t)} \pi_0(I_t) dt + A_0 E[I_{t_1^*}^{\beta_0}] \quad (15)$$

In Stage 1, the TBL project value (project value)  $V_1(I_t)$  is:

$$V_1(I_t) = \int_{t_1^*}^{t_2^*} e^{r_1(t-t_1^*)} (\pi_1(I_t) - B_1(I_t)) dt + A_1 E[I_{t_2^*}^{\beta_1}] \quad (16)$$

In Stage 2, the TBL project value  $V_2(I_t)$  is:

$$V_2(I_t) = \int_{t_2^*}^{\infty} e^{r_1(t-t_1^*)} (\pi_2(I_t) - B_2(I_t) - S_2(I_t)) dt \quad (17)$$

According to the Law of One Price, the Value Matching Condition, and the Smooth Pasting Condition proposed by Reference [23], as well as the derivation steps of Reference [36], the project value at various stages = cash flows value + capital gains value. Figure 3 shows the time points for sustainable operation, optimal environmental cost, and social cost in each stage:

(1) Value Matching Condition, such as Equations (18) and (19) [23]:

$$E \left[ \int_0^{t_1^*} e^{r_0(t_1^*-t)} \pi_0(I_t) dt \right] + A_0 E[I_{t_1^*}^{\beta_0}] = E \left[ \int_{t_1^*}^{t_2^*} e^{-r_1(t-t_1^*)} (\pi_1(I_t) - B_1(I_t)) dt \right] + e^{-r_1(t_2^*-t_1^*)} \times A_1 E[I_{t_2^*}^{\beta_1}] \quad (18)$$

$$E \left[ \int_{t_1^*}^{t_2^*} e^{r_1(t_2^*-t)} (\pi_1(I_t) - B_1(I_t)) dt \right] + A_1 E[I_{t_2^*}^{\beta_1}] = E \left[ \int_{t_2^*}^{\infty} e^{-r_2(t-t_2^*)} (\pi_2(I_t) - B_2(I_t) - S_2(I_t)) dt \right] \quad (19)$$

This study utilizes the formula of high-order expectation and the moment generating function (MGF)  $E[e^{NdY}] = e^{N(\alpha - \frac{1}{2}\sigma^2)dt + N^2 \frac{1}{2}\sigma^2 dt}$  [41] into the potential expected value of the first phase, in which  $t = t_1^*$  is obtained, as follows:

$$A_0 E[I_{t_1^*}^{\beta_0}] = A_0 I^{\beta_0} \times e^{(\beta_0(\alpha - \frac{1}{2}\sigma^2) + \frac{\beta_0^2}{2}\sigma^2)t_1^*} \quad (20)$$

With the same rule, the potential expected value of the second phase  $t = t_2^*$  is obtained, as follows:

$$A_1 E[I_{t_2^*}^{\beta_1}] = A_1 I_{t_1^*}^{\beta_1} \times e^{(\beta_1(\alpha - \frac{1}{2}\sigma^2) + \frac{\beta_1^2}{2}\sigma^2)(t_2^* - t_1^*)} \quad (21)$$

Assuming  $I_{t_1^*}^{\beta_0}$  is known, the parameters are defined to simplify the formula, as follows:

$$\begin{aligned} \sum(\beta_i) &\equiv \beta_i(\alpha - \frac{1}{2}\sigma^2) + \frac{1}{2}\beta_i^2\sigma^2, i = 0, 1, 2 \\ \sum(p_i) &\equiv p_i(\alpha - \frac{1}{2}\sigma^2) + \frac{1}{2}p_i^2\sigma^2, p_i \geq 2 \\ \sum(p_i - 1) &\equiv (p_i - 1)(\alpha - \frac{1}{2}\sigma^2) + \frac{1}{2}(p_i - 1)^2\sigma^2, p_i \geq 2 \end{aligned}$$

The value matching conditions in Equation (18) are put into the potential expected values (Equations (20) and (21)), and the value matching conditions of Equation (22) is obtained, as follows:

$$\begin{aligned} &\frac{a_0}{\sum(p_0) - r_0} \times I^{p_0} \times e^{\sum(p_0)t_1^*} + \frac{b_0}{\sum(p_0-1) - r_0} \times I^{p_0-1} \times e^{\sum(p_0-1)t_1^*} + A_0 I^{\beta_0} e^{\sum(\beta_0)t_1^*} \\ &- \left( \frac{a_0}{\sum(p_0) - r_0} I^{p_0} + \frac{b_0}{\sum(p_0-1) - r_0} I^{p_0-1} + \frac{c_0}{r_0} \right) \times e^{r_0 t_1^*} - \frac{c_0}{r_0} \end{aligned}$$

$$= \frac{j_1}{\Sigma(p_1)-r_1} I^{p_1} (e^{(\Sigma(p_1)-r_1)t_2^*} \times e^{r_1 t_1^*}) + \frac{b_1}{\Sigma(p_1-1)-r_1} I^{p_1-1} \times (e^{\Sigma(p_1-1)t_2^*} \times e^{r_1 t_1^*}) - \frac{j_1}{\Sigma(p_1)-r_1} I^{p_1} e^{\Sigma(p_1)t_1^*} - \frac{b_1}{\Sigma(p_1-1)-r_1} I^{p_1-1} \times e^{\Sigma(p_1-1)t_1^*} + \frac{j_1(\alpha - \frac{1}{2}\sigma^2) + k_1 - c_1}{r_1} \times (e^{-r_1 t_2^*} e^{r_1 t_1^*}) - \frac{j_1(\alpha - \frac{1}{2}\sigma^2) + k_1 - c_1}{r_1} \quad (22)$$

Assume that  $\Sigma(p_2) - r_2 < 0$ ,  $\Sigma(p_2 - 1) - r_2 < 0$  and  $\delta \equiv c_2 - (j_2 + f_2)(\alpha - \frac{1}{2}\sigma^2) - (k_2 + g_2)$ , The value matching conditions in Equation (19) are put in the potential expected value (Equation (21)) and the value matching conditions of Equation (23) is obtained, as follows:

$$\begin{aligned} & \frac{a_1 I^{p_1}}{\Sigma(p_1)-r_1} (e^{\Sigma(p_1)t_2^*} - e^{(\Sigma(p_1)-r_1)t_1^*} \times e^{r_1 t_2^*}) + \frac{b_1 I^{p_1-1}}{\Sigma(p_1-1)-r_1} \times (e^{\Sigma(p_1-1)t_2^*} - e^{(\Sigma(p_1-1)-r_1)t_1^*} e^{r_1 t_2^*}) \\ & - \frac{c_1}{r_1} (1 - e^{-r_1 t_1^*} e^{r_1 t_2^*}) + A_1 I^{\beta_1} e^{\Sigma(\beta_1)t_2^*} \\ & = \frac{a_2 I^{p_2}}{r_2 - \Sigma(p_2)} \times e^{\Sigma(p_2)t_2^*} + \frac{b_2 I^{p_2-1}}{r_2 - \Sigma(p_2-1)} e^{\Sigma(p_2-1)t_2^*} + \frac{\delta}{r_2} \end{aligned} \quad (23)$$

## (2) Smooth Pasting Condition [23]:

1. The smooth pasting condition (Equation (24)) is obtained by differentiating the value matching conditions of Equation (22), as follows:

$$\begin{aligned} & \frac{\Sigma(p_0)}{\Sigma(p_0)-r_0} a_0 I^{p_0} e^{\Sigma(p_0)t_1^*} + \frac{\Sigma(p_0-1)}{\Sigma(p_0-1)-r_0} b_0 I^{p_0-1} e^{\Sigma(p_0-1)t_1^*} + A_0 \Sigma(\beta_0) I^{\beta_0} e^{\Sigma(\beta_0)t_1^*} \\ & = \left( \frac{r_0}{\Sigma(p_0)-r_0} a_0 I^{p_0} + \frac{r_0}{\Sigma(p_0-1)-r_0} b_0 I^{p_0-1} + c_0 \right) \times e^{r_0 t_1^*} \end{aligned} \quad (24)$$

2. The smooth pasting condition (Equation (25)) is obtained by differentiating the value matching conditions of Equation (23), as follows:

$$\begin{aligned} & \frac{\Sigma(p_1)a_1 I^{p_1}}{(\Sigma(p_1)-r_1)} e^{\Sigma(p_1)t_2^*} - \frac{r_1 a_1 I^{p_1}}{(\Sigma(p_1)-r_1)} (e^{(\Sigma(p_1)-r_1)t_1^*} \times e^{r_1 t_2^*}) + \frac{\Sigma(p_1-1)b_1 I^{p_1-1}}{(\Sigma(p_1-1)-r_1)} \times e^{\Sigma(p_1-1)t_2^*} \\ & - \frac{r_1 b_1 I^{p_1-1}}{(\Sigma(p_1-1)-r_1)} (e^{(\Sigma(p_1-1)-r_1)t_1^*} \times e^{r_1 t_2^*}) - c_1 (e^{-r_1 t_1^*} \times e^{r_1 t_2^*}) + A_1 \Sigma(\beta_1) I^{\beta_1} e^{\Sigma(\beta_1)t_2^*} \\ & = \frac{\Sigma(p_2)a_2 I^{p_2}}{r_2 - \Sigma(p_2)} \times e^{\Sigma(p_2)t_2^*} + \frac{\Sigma(p_2-1)b_2 I^{p_2-1}}{r_2 - \Sigma(p_2-1)} \times e^{\Sigma(p_2-1)t_2^*} \end{aligned} \quad (25)$$

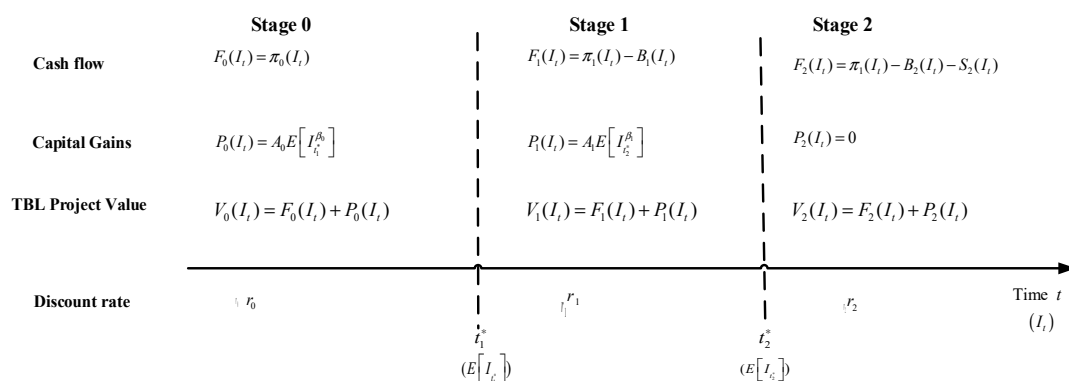


Figure 3. TBL Project Values at Each Stage.

## 3. Numerical Example Analysis

Based on the above model assumptions and by referring to the 2010-2018 Global 100 Index, this paper constructs the assumptions for each parameter. Assume that the average growth rate of the Global 100 Index  $\alpha$  is 0.0125, and the rate of change  $\sigma$  is 0.06. Assuming that the Global 100 Index starting value is  $I_0 = I = 75$  at the same time, the profit rate of the company at each stage will then be  $r_0 = 0.09$ ,  $r_1 = 0.10$ , and  $r_2 = 0.11$ ; the fixed income at each stage  $c_0$ ,  $c_1$ ,  $c_2$  is 1000 (unit: NT\$1 million);

the fixed environmental cost  $k_1$  and  $k_2$  at each stage are assumed to be 90 and 50 (unit: NT\$1 million), respectively; and the fixed social cost of Stage 2,  $g_2$ , is assumed to be 20 (unit: NT\$1 million). Based on the above assumptions, numerical examples are analyzed to determine the optimal time points for the input of environmental costs and social costs by food industry vendors after they have satisfied the financial benefits of the economic aspect. The various parameters and values are shown in Table 2.

**Table 2.** Parameter Assumptions and Numerical Examples.

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
$a_0$	0.3	$c_0$	1000	$r_0$	0.09	$k_2$	50
$a_1$	−0.1	$c_1$	1000	$r_1$	0.10	$f_2$	1
$a_2$	−0.2	$c_2$	1000	$r_2$	0.11	$g_2$	20
$b_0$	−46	$p_0$	2	$j_1$	2	$\alpha$	0.0125
$b_1$	16	$p_1$	2	$j_2$	2	$\sigma$	0.06
$b_2$	31	$p_2$	2	$k_1$	90	$I_0$	75

According to the above numerical examples, the analysis results of using POLYMATH software show that the potential value of the first-stage entry parameter is  $A_0 = -2.1 \times 10^{-4}$  and  $t_1^* = 9.86$  years, and when the expected Global 100 Index corresponding to  $t_1^*$  reaches 84.84, environmental costs should be applied to reduce the environmental damage caused by the food production process. At the same time, the company can increase the financial value of the long-term economic facet with the input of environmental costs, which is a result of their spending on environmental costs. According to the latest Global 100 indicator, as released in 2018, the average index of the top five companies in the Global 100 in 2018 was 82.54. Since environmental costs have high monetary and time consumption, the food industry's considerations regarding the input of environmental costs have become a major issue for operations.

According to the results of the above numerical examples and the social cost input of Stage 2, the potential values of the entry parameters are  $A_1 = 1.1 \times 10^{-5}$  and  $t_2^* = 19.01$  years. According to the results of the numerical examples, the potential entry value of Stage 2 is very low; at the same time,  $I_2 = 95.12$  corresponds to  $t_2^*$ ; thus, the financial value of the economic facet of the company shows that the company should invest in social costs when the Global 100 Index grows to about 95.12.

Global warming and climate change have caused environmental issues to receive a great deal of attention in recent years. Industrial development has caused an increase in carbon emissions, while the scarcity of water resources and high business waste have caused serious damage to the environment. Hence, companies should immediately invest in the environmental facet, thereby reducing environmental damage. As the raw materials for the food industry are derived from agricultural and livestock products, animal husbandry is considered to be the chief culprit for the large increases in carbon emissions. According to the Food and Agriculture Organization of the United Nations (FAO), livestock farming accounts for nearly two-thirds of agricultural greenhouse gas and 78% of methane emissions; thus, greenhouse gas emissions contribute to global climate change. The risk of food-borne diseases also shifts from one region to another, thereby threatening public health in new ways [42]. According to Reference [43], agricultural drainage and agricultural wastewater account for 32% of the total water consumption (1,257 km<sup>3</sup> per year); thus, control of agricultural wastewater and water resources should cause more concern than the control of urban wastewater. To reduce the damage to the environment caused by the food industry and agriculture, the food industry's investment in environmental facets has become an immediate concern.

#### 4. Sensitivity Analysis Result

Based on the sensitivity analysis of the Global 100 Index average growth results shown in Table 3, this study shows that when a company's fixed income is 950 (unit: NT\$1 million) and the average growth rate of the Global 100 Index is 0.01, the company should immediately invest in the environment

facet when the Global 100 Index reaches around 82.09; when the Global 100 Index reaches around 89.60, the company should invest in the social facet; when the average growth rate of the Global 100 Index is 0.0125 and the index reaches around 84.6, the company should immediately invest in the environmental facet; when the Global 100 Index reaches 95.37 it should invest in the social facet; when the average growth rate of the Global 100 Index is 0.013 and the index reaches 85.15, the company should immediately invest in the environmental facet; when the Global 100 Index reaches 96.62 it should invest in the social facet; when the average growth rate of the Global 100 Index is 0.0147 and the index reaches 87.17, the company should immediately invest in the environmental facet, while the social facet must wait until the Global 100 Index reaches 101.17.

**Table 3.** Sensitivity Analysis of Alpha.

Fixed Income (Unit: Million NT\$)	Parameter	$\alpha$			
		0.01	0.0125	0.013	0.0147
950	$A_0$	$-3.6 \times 10^{-5}$	$-2.1 \times 10^{-4}$	$-3.0 \times 10^{-4}$	$-8.7 \times 10^{-4}$
	$A_1$	$2.0 \times 10^{-6}$	$1.2 \times 10^{-5}$	$1.6 \times 10^{-5}$	$4.6 \times 10^{-5}$
	$t_1^*$	9.03	9.64	9.76	10.23
	$t_2^*$	17.78	19.22	19.49	20.36
	$E[I_1]$	82.09	84.60	85.15	87.17
	$E[I_2]$	89.60	95.37	96.62	101.17
1000	$A_0$	$-3.4 \times 10^{-5}$	$-2.1 \times 10^{-4}$	$-2.9 \times 10^{-4}$	$-8.5 \times 10^{-4}$
	$A_1$	$2.0 \times 10^{-6}$	$1.1 \times 10^{-5}$	$1.6 \times 10^{-5}$	$4.5 \times 10^{-5}$
	$t_1^*$	9.37	9.86	9.99	10.46
	$t_2^*$	17.49	19.01	19.28	20.17
	$E[I_1]$	82.37	84.84	85.40	87.47
	$E[I_2]$	89.34	95.12	96.36	100.88
1100	$A_0$	$-3.3 \times 10^{-5}$	$-2.0 \times 10^{-4}$	$-2.8 \times 10^{-4}$	$-8.1 \times 10^{-4}$
	$A_1$	$1.9 \times 10^{-6}$	$1.1 \times 10^{-5}$	$1.5 \times 10^{-5}$	$4.4 \times 10^{-5}$
	$t_1^*$	9.79	10.27	10.40	10.88
	$t_2^*$	17.09	18.65	18.92	19.84
	$E[I_1]$	82.72	85.27	85.85	88.01
	$E[I_2]$	88.98	94.69	95.92	100.39
1200	$A_0$	$-3.1 \times 10^{-5}$	$-1.9 \times 10^{-4}$	$-2.6 \times 10^{-4}$	$-7.7 \times 10^{-4}$
	$A_1$	$1.8 \times 10^{-6}$	$1.1 \times 10^{-5}$	$1.5 \times 10^{-5}$	$4.3 \times 10^{-5}$
	$t_1^*$	10.16	10.63	10.75	11.25
	$t_2^*$	16.77	18.34	18.62	19.55
	$E[I_1]$	83.02	85.65	86.25	88.48
	$E[I_2]$	88.69	94.33	95.54	99.97

When the company's fixed income is 1100 (unit: NT\$1 million) and the average growth rate of the Global 100 Index is 0.01, when the index reaches 82.72 the company should immediately invest in the environmental facet; when the Global 100 Index reaches 88.98, it should invest in the social facet; when the average growth rate of the Global 100 Index is 0.0125 and the index reaches 85.27, the company should immediately invest in the environmental facet, and when it reaches 94.69 it should invest in the social facet should be invested; when the average growth rate of the Global 100 Index is 0.013 and the index reaches 85.85, the company should immediately invest in the environmental facet; at the same time, when the Global 100 Index reaches 95.92, the company should invest in the social facet; when the average growth rate of the Global 100 Index is 0.0147 and the index reaches 88.01, the company should immediately invest in the environmental facet, while the social facet must wait until it reaches 100.39.

When the company's fixed income is 1200 (unit: NT\$1 million) and the average growth rate of the Global 100 Index is 0.01, when the index reaches 83.02, the company should immediately invest in the environment facet, and when the Global 100 Index reaches 88.69 it should invest in the social facet; when the average growth rate of the Global 100 Index is 0.0125 and the index reaches 85.65, the company should immediately invest in the environmental facet, and when the Global 100 Index reaches 94.33 it should invest in social costs; when the average growth rate of the Global 100 Index is 0.013 and the index reaches 86.25, the company should immediately invest in the environmental



facet, and when the Global 100 Index reaches 95.54 it should invest in the social facet; when the average growth rate of the Global 100 Index is 0.0147 and the index reaches 88.48, the company should immediately invest in the environmental facet, while the social facet must wait until the Global 100 Index reaches 99.97.

According to the results of the sensitivity analysis, when the company's fixed income is declining, the optimal timing for the company to invest in the environmental facet will be advanced, while the timing for investment in the social facet will be delayed. When the company's fixed income rises, the optimal timing for the company to invest in the environmental facet will be delayed, while the timing for investment in the social facet will be advanced.

When the average growth rate of the Global 100 Index declines, the optimal timing for the company to invest in both the environmental and social facets will be advanced. When the average growth rate of the Global 100 Index rises, the optimal time point for companies to invest in both the environmental and social facets will be delayed. As the average growth rate of the Global 100 Index is low, the company's investment in both the environmental and social facets will have greater benefits for increasing the business value of the company. Because investment in the former is often regulated by laws and regulations, when a firm's fixed income declines, the company should choose to prioritize its investment in this facet, hence complying with statutory requirements. The investment in the latter is mostly due to the autonomous behavior of the company to give back to society; thus, the company will be more willing to invest in it when the company's fixed income increases.

The sensitivity analysis of the Global 100 Index change rate in Table 4 shows that, when  $\alpha = 0.0125$ , the fixed income of the enterprise is NT\$1 million. When the rate of change  $\sigma$  of the Global 100 Index increases, the time for the company to invest in environmental costs and social costs will be advanced. When the rate of change  $\sigma$  of the Global 100 Index decreases, the time for the company to invest in the environmental and social facets will be postponed. According to the results of the sensitivity analysis shown in Table 4, when increasing  $\sigma$  from 0.06 to 0.08, the time for enterprises to invest in the environmental facet will be advanced from 9.77 years to 9.63 years, and the corresponding Global 100 Index will be reduced from 84.74 to 84.59; the time to invest in the social facet will be advanced from 19.04 years to 17.44 years, and the corresponding Global 100 Index will be reduced from 95.16 to 93.26. On the contrary, when  $\sigma$  is reduced from 0.06 to 0.03, the time for enterprises to invest in the environmental facet will be extended from 9.77 years to 10.24 years, and the corresponding Global 100 Index will increase from 84.63 to 85.25; the time for investing in the social facet will rise from 19.04 years to 21.02 years, and the corresponding Global 100 Index will increase from 95.16 to 97.54.

Table 4. Sensitivity Analysis of Sigma.

Parameter	$\sigma$						
	0.03	0.04	0.05	0.06	0.07	0.08	0.09
A0	$-5.17 \times 10^{-7}$	$-4.81 \times 10^{-6}$	$-3.61 \times 10^{-5}$	$-2.10 \times 10^{-4}$	$-9.56 \times 10^{-4}$	$-3.53 \times 10^{-3}$	$-1.10 \times 10^{-2}$
t1	10.24	10.08	9.92	9.77	9.66	9.63	9.68
A1	$1.09 \times 10^{-8}$	$1.49 \times 10^{-7}$	$1.53 \times 10^{-6}$	$1.15 \times 10^{-5}$	$6.37 \times 10^{-5}$	$2.75 \times 10^{-4}$	$9.58 \times 10^{-4}$
t2	21.02	20.47	19.80	19.04	18.24	17.44	16.66
$E[I_1]$	85.25	85.08	84.90	84.74	84.63	84.59	84.65
$E[I_2]$	97.54	96.87	96.06	95.16	94.21	93.26	92.36

$\alpha = 0.0125$ , Fixed income = 1000 (Unit: million NT\$)

Based on the concept of options hedging, an increased risk will increase the value of the options [18]. The greater the change in  $\sigma$ , the greater the risk and uncertainty for the enterprise. Therefore, the enterprise will tend to invest in the environmental and social facets earlier to improve the value of sustainable operations. When the change in  $\sigma$  is small, the global concept of sustainability tends to be more stable and the environmental and social facets of the enterprise will be less effective on the value of its sustainable operations; thus, the enterprise will consider the impact of investment costs on income and will tend to delay investment in environmental and social facets.

## 5. Discussion and Conclusions

The main purpose of this study is to determine the optimal investment timing for a company's input in environmental and social facets under the background of global sustainable development issues by considering the financial income of the company's economic aspect and taking the Global 100 Index as the threshold. The results can provide a reference for sustainable business operations. The five main environmental assumptions are as follows. First, the Global 100 Index is used as a decision variable and its changes follow GBM, where the average growth rate is  $\alpha$ , the rate of change is  $\sigma$ , and the change in unit time is subject to the Standard Wiener Process. Second, considering the economic aspect, the company first invests in the environmental facet during the stage 1 ( $t_1^*$ ) and invests in the social facet during the stage 2 ( $t_2^*$ ). Third, before investment in these two facets, the financial return value  $\pi_0(I_t)$  of the economic aspect will decrease with an increase of the Global 100 Index (the first-order derived function is negative), and the decreasing amplitude will be an increasing function (the second-order derived function is positive). Fourth, during the stage 1, investment in the environmental facet  $B_1(I_t)$  is considered, and the environmental cost will increase as the Global 100 Index increases (the first-order derived function is positive). Its rising amplitude is a decreasing function (the second-order derived function is negative), the financial return value  $\pi_1(I_t)$  of the economic aspect will increase as the Global 100 Index increases (the first-order derived function is positive), and the increasing amplitude will be a decreasing function (the second-order derived function is negative). Fifth, during the stage 2, investment in the social facet  $S_2(I_t)$  is considered, and the social cost will increase as the Global 100 Index increases (the first-order derived function is positive). The increasing amplitude will be a decreasing function (the second-order derived function is negative), the financial return value  $\pi_2(I_t)$  of the economic aspect will increase with an increase of the Global 100 Index, and the increasing amplitude will be a decreasing function (the second-order derived function is negative). Based on the numerical examples and sensitivity analysis results, the theoretical and practical implications of this study are as follows.

### 5.1. Implications for Theory

By referring to the 2010–2018 Global 100 Index, this paper constructs the assumptions for each parameter. Based on the results of the sensitivity analysis, this study finds that when the average growth rate of the Global 100 Index is low, the optimal time for the company to invest in environmental and social facets will be advanced; when the average growth rate of the Global Index is high, the time for the enterprise to invest in the two facets will be delayed. When the rate of change  $\sigma$  of the Global 100 Index increases, the time for the company to invest in the two facets will be advanced. When the rate of change  $\sigma$  of the Global 100 Index decreases, the time for the company to invest in the two will be postponed. When the fixed income of the enterprise declines, the optimal time for the enterprise to invest in the environmental facet will be advanced, and the time for investment in the social facet will be delayed. When the fixed income of the enterprise rises, the optimal time for the enterprise to invest in the environmental facet will be postponed, and the time for investing in the social facet will be advanced. Numerical examples show that, based on the value of the economic facet, enterprises should invest in environmental costs as early as possible, while it is recommended that they delay the timing of social costs investment.

Even as the food industry undergoes globalization and global technological trends, food safety incidents continue to occur, and such incidents seriously undermine consumer health and confidence in the food industry. Therefore, companies should pursue sustainable development and be in compliance with government regulations, energy conservation, and carbon reduction. Social responsibility is more than a mere slogan. Enterprises are under tremendous pressure to measure and report their social, environmental, and economic performance, as well as their sustainability performance, thus enabling companies to adopt stakeholder values and develop strategies that consider more than shareholder performance [44]. Using the TBL model with the Global 100 Index as a function of the economic efficiency of a company, and based on value matching and smooth pasting conditions, this study

identifies the expected value of the Global 100 Index as the threshold values, thus providing enterprises with the optimal time points for spending on environmental and social facets. Identifying the optimal time points, as based on expected values, can also provide policy makers with more objective and flexible decision-making considerations, which will then enable companies to carefully consider the timing of investments in terms of the environmental cost and social cost, while at the same time expanding their financial value. The concept of this study is consistent with Reference [45], meaning the triple bottom line concept, which suggests that enterprises must engage in socially and environmentally responsible behaviors, while achieving positive financial benefits in the implementation process. The findings herein can be used as a reference for building a viable strategy for sustainable business operations.

## 5.2. Implications for Practice

As Reference [46] pointed out, for the essence of sustainable development, meaning the establishment of strategies and values that cannot be analyzed under pure financial conditions, companies must commit themselves to being exposed to the principles of balanced development among the economy, environment, and society. Over the past decade, due to continuous scandals involving agro-food products, consumer confidence in the food industry has declined, and to rebuild consumer confidence, more and more agro-food processing companies have implemented CSR in their production processes [47]. At the same time, consumers' emphasis on health and the increased demand for CSR have led the food industry to implement more measures under the framework of CSR [48]. Consumers are increasingly concerned about the quality, completeness, safety, diversity, and sustainability of food. To meet consumer expectations, many companies have begun to incorporate sustainability into the management of their businesses, thus fulfilling their CSR requirement [49].

This study considers the timing of social facet input from the financial aspect. As investment costs cause a decrease in the short-term financial return of a company, it is recommended to postpone investing in the social facet. However, from the perspective of sustainable business management, manufacturers cannot consider CSR, protect the interests of stakeholders, or take care of disadvantaged people from just a single financial value. Therefore, this study suggests that food industry manufacturers should invest in the social facet as soon as possible, thus establishing non-financial value for the company. Although this method sacrifices the company's short-term financial performance, it will enhance the overall business value of the company in the long-term and create opportunities for the company's sustainable development.

Based on the model design and settings of various hypotheses, this study identifies the best time points for a company to invest in environmental and social costs through numerical analysis and sensitivity analysis and provides a reference for corporate sustainable operation. The contributions of this study are as follows:

1. This study replaces the conventional net present value model with the options evaluation model. In addition to measuring the value of corporate cash flows, it considers the potential strategic value of inputting environmental and social costs and provides a more complete reference for enterprises in decision-making evaluations.
2. The Global 100 Index is used as a threshold for decision-making. Based on changes in global sustainability indicators, global sustainable development is considered a reference for providing indicators for global operations and sustainable development.
3. This study identifies the decision points that correspond to the optimal input of the environmental and social costs of the global sustainability indicators and makes up for the gaps in recent studies, which have less discussion regarding input time and decision-making variables.

### 5.3. Research Limitations

This study is limited by only targeting the above-mentioned assumptions. We offer the following suggestions for future researchers: (1) the changes in the Global 100 Index can be described in various random processes in accordance with the actual situation, such as the Poisson process; (2) the cost-benefit correspondence can be changed or the parameters or variables can be increased in the model according to actual conditions; (3) the timing of the company's input of environmental costs and social costs can be considered from the non-financial aspect and the order of inputting environmental and social costs can be changed according to different conditions; (4) subsequent research can introduce variables other than the Global 100 Index to represent sustainable business value and consider the subsequent expansion of the model into double or multiple variables; and (5) changes to environmental or safety regulations can be reflected in the model parameters, as well as how to adjust the model when environmental and safety regulations are varied in subsequent research. Finally, while the Global 100 Index cannot fully represent the value of sustainable business, it is one of the important reference indicators; thus, subsequent research can consider the possibility of adding other indicators to the assessment.

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### Appendix A. Variable/Function Definitions

Variable/Functions	Definition
$I_t$	The Global 100 Index at time $t$
$t_1^*, t_2^*$	The optimal timing to enter environment cost in Stage 1 or to enter environment cost/social cost in Stage 2
$i$	Each stage, $i = 0, 1, 2$
$V_i(I_i)$	The TBL project value at $I_t$ in each stage, $i = 0, 1, 2$
$\alpha$	Average rate (mean) of geometric Brownian motion with $I_t$
$\sigma$	Volatility of geometric Brownian motion with $I_t$
$dt$	Unit time in continuous time
$dW_t$	The standard Wiener process, $dW_t \sim iid N(0, dt)$
$E[I_{t_1^*}], E[I_{t_2^*}]$	The expected Global 100 Index at optimal timing $t_1^*$ to switch Stage 1 or at optimal timing $t_2^*$ to switch Stage 2
$B_i(I_i)$	The environmental cost at $I_t$ in Stage $i$ , $i = 1, 2$
$S_2(I_i)$	The social cost at $I_t$ in Stage 2
$F_i(I_i)$	The cash flows of project value at $I_t$ in Stage $i$ , $i = 0, 1, 2$
$P_i(I_i)$	The capital gains of project value at $I_t$ in Stage $i$ , $i = 0, 1, 2$
$\pi_i(I_i)$	The financial value of the economic facet at $I_t$ in Stage $i$ , $i = 0, 1, 2$
$p_i$	The power parameters of the financial value of the Global 100 Index in Stage $i$ , $i = 0, 1, 2$

Variable/Functions	Definition
$c_i$	The fixed parameter of the financial value in Stage $i$ , $i = 0, 1, 2$
$a_i, b_i$	The different impacted scale parameter of the Global 100 Index in Stage $i$ , $i = 0, 1, 2$
$j_i$	The scale factor of the environmental cost in Stage $i$ , $i = 1, 2$
$k_i$	The fixed parameter of environmental cost in Stage $i$ , $i = 1, 2$
$f_2$	The scare parameter impacted to the Global 100 Index of social cost in Stage 2
$g_2$	The fixed parameter of social cost in Stage 2
$r_i$	The risk-free rate or discount rate at Stage $i$ , $i = 0, 1, 2$
$A_0, A_1$	The scale coefficient of the expected potential strategic value in Stage 0 and Stage 1

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