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Innovation Measurement Framework to Determine Innovativeness of a Company: Case of Semiconductor Industry

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Abstract--**Innovation is one of the most important sources of competitive advantage. It helps a company to fuel the growth of new products and services, sustain incumbents, create new markets, transform industries, and promote the global competitiveness of nations. Because of its importance, companies need to manage innovation. It is very important for a company to be able to measure its innovativeness because one cannot effectively manage without measurement. A good measurement model will help a company to understand its current capability and identify areas that need improvement.**

This paper develops a framework to determine the innovativeness of a company in semiconductor industry by using output indicators. Output indicators are used because they cannot be manipulated. A hierarchical decision model (HDM) was constructed for the framework. Expert judgments were quantified and incorporated into the model. The hierarchy consisted of three levels: innovativeness index, output indicators and sub-factors.

According to the experts, the top three sub-factors to measure the innovativeness of a company are revenue from new products, market share of new products, and products that are new to the world.

I. INTRODUCTION

The past 30 years have shown that innovation is crucial to the sustainability of a business, and —is critical for competitive advantage. Sustainable and profitable growth comes from new products, new services, new processes, new business models or new organizational models [12]. Because of the importance of innovation, companies are expected to be able to manage their innovation optimally. However, being innovative is not easy. A company needs to assess and measure its innovativeness in order to manage it. Measuring innovativeness gives a company the ability to understand how to increase it.

Companies need a reliable framework for measuring and managing their innovation. With such a framework, they can track their innovation activities and review whether a learning loop is required to improve their innovativeness [1]. The measurement framework can provide information about the areas that need improvement, and help the company make strategic decisions, such as where investments should be made, how resources should be allocated, and how risks should be minimized.

A framework, measurement processes, and metrics to measure the innovativeness of a company are presented in this paper.. The framework shows how innovative a company is in comparison to its peers and helps the companies to improve the management of their innovation inputs in order to improve innovation outcomes.

II. LITERATURE REVIEW

The expression "innovate or die" has been an accepted phrase in the popular business environment [2]. Innovation is considered one of the most important business drivers for companies' growth and is also one of the important sources and enabler of competitive advantage [3][4][5][6]. Before a product or service reaches the maturity level or technological obsolescence (flat level on the top of the S curve), companies have to re-new business opportunities, and improved product lines or service, to maintain growth and to stay ahead of competitors. Innovation helps to fuel the growth of new products or services, sustain incumbents, create new markets , transform industry, and promote the global competitiveness of nations [7] [8] [9] [10][11]. History has proven that only those companies that innovate survive. The companies that do not innovate are not likely not survive let alone compete in the rapidly changing market [1].

Measuring innovation has attracted many researchers, using different methodologies and indicators. Some measure innovation based on a single indicator, some consider several indicators. In addition to indicators, innovation indexes also have been proposed to measure innovation, but the innovation indexes in the literature are typically used at the national level, including environmental, social, and political variables in the measurement.

This research is focused on output indicators in companies because outputs are uncontrollable and unpredictable [12], while inputs and processes can be managed and controlled by the company. Measuring something that can be controlled and managed within the firm biases the results. For example, a company can increase the R&D expenditures as high as it wants; however, that increase does not necessarily assure that the company is highly innovative. Simply having high inputs may or may not produce high outputs. The innovativeness of a company is based on outputs of the innovation activities. Inputs define the scope, context and structure of innovation. Inputs do not show the economic significance of the innovation output [13]. Outputs transform innovation activities into economic value for the company [1].

Several scholars agree with the use of output indicators to measure innovation. Kleinknecht and Bain [14] support the idea by using a literature-based methodology. They point out that counting output indicators will facilitate international comparisons. Output indicators are more viable because the data for outputs (number of new products, patents, publications, etc.) are available and thus verifiable. They can be objectively measured without creating unnecessary bias. Steward [13] agrees with Kleinknecht and Bain. Steward points out that the majority of innovation outputs are available to the public in some form. Because of their visibility, innovation outputs can be used for the development of useful indicators. Input indicators such as R&D expenditures will not be effective because obtaining such data from companies is not straightforward. Usually, input indicators are covered by accounting procedures [13]. Steward adds that measuring outputs uncovers the contributions of small firms. Output indicators show great potential for establishing innovation indicators that are internationally comparable and can be implemented and revisited on an annual basis.

Link [15] lists the advantages of measuring output, as:

- Appropriate: Output indicators are countable and can be evaluated at any given time.
- Complete: Output indicators perform as a market test for the success of the innovation process.
- Replicable: Output indicators are replicable and are from verifiable sources.

This paper identifies a number of output indicators through literature review, such as: number of new products, awards and honors, number of publication, number of patents, etc. There are also several sub-factors identified through literature review. The output indicators and sub factors are combined in a framework to help a company determine its innovativeness.

III. RESEARCH METHODOLOGY

The innovation measurement research methodology is composed of three stages: hierarchical decision model development, indicators evaluation, and innovativeness evaluation.

Stage 1 – Hierarchical Decision Model Development: Develop a hierarchical model to determine the innovativeness of a company.

Stage 2 – Indicator Evaluation: Develop a measurement for a specific industry using the Delphi method.

Stage 3 – Innovativeness Evaluation: Incorporate the values of the indicators obtained in a company into the model

A. Hierarchical Decision Model (HDM)

The hierarchical decision model (HDM) is one of the most recognizable methods for subjective approaches [16][17][18]. It is a tool that helps decision makers quantify and incorporate quantitative and qualitative judgments into a complex problem. It was developed from the analytic hierarchical process (AHP) by Saaty as a method for multi-criteria decision-making [19] [91]. HDM has been applied in a wide range of applications in different fields for the last 25 years [21][22][23].

The underlying principle of HDM is decomposing problems into hierarchies. It is a comprehensive, logical and structured framework that requires the subjective judgments of the experts to obtain weights for the criteria. Pairwise comparisons among criteria are the key step in the HDM to acquire the priority weights or relative importance of values for each criterion in the hierarchy [24]. The pairwise comparison method compares two criteria at a time and their relationship to each other. The process makes the experts more comfortable because their decisions are based on the relative preference of one criterion over another rather than an absolute preference [25]. The results of the pairwise comparisons from the experts can be verified by checking the consistency of the evaluations [26][18].

Literature research reveals that innovation is complex and cannot be measured by a single attribute. We have identified multiple attributes associated with innovation outputs. In this regard, the problem of innovation measurement is a particularly suitable application for the HDM approach.

The output indicators and sub-factors can be evaluated by a series of calculation procedures. The results of judgment quantifications from the experts are used as the input in the calculations. The mathematical expression for calculating the contribution of output indicators and sub-factors to the innovativeness is expressed below:

$$S_{n,jn}^{IX} = \sum_{n=1}^{N} \sum_{jn=1}^{Jn} (O_n^{IX})(S_{n,jn}^{O})$$

Equation 1

where

$S_{n,jn}^{IX}$ Relative value of the jnth sub-factor under the nth output indicator with respect to the Innovation Index (IX)

O_n^{IX} Relative priority of the nth output indicator with respect to the Innovation Index (IX), n = 1, 2, 3, .., N

$S_{n,jn}^{O}$ Relative contribution of the jnth sub-factor under the nth output indicator, jn = 1, 2, 3, ..., Jn, and n = 1, 2, 3, ..., N

B. Desirability Curve

The concept of the desirability curve is implemented in this paper. It represents how desirable a metric is for the decision maker. In strategic decision making, decisions are often based not on numerical values of the variables but on the 'goodness' or usefulness of those values. They are referred to as desirability values of the variables. The shape of the desirability curve could vary. The typical desirability curves are convex, concave, parabolic, or linear (straight line). Figure 1 depicts shapes of several typical desirability curves.

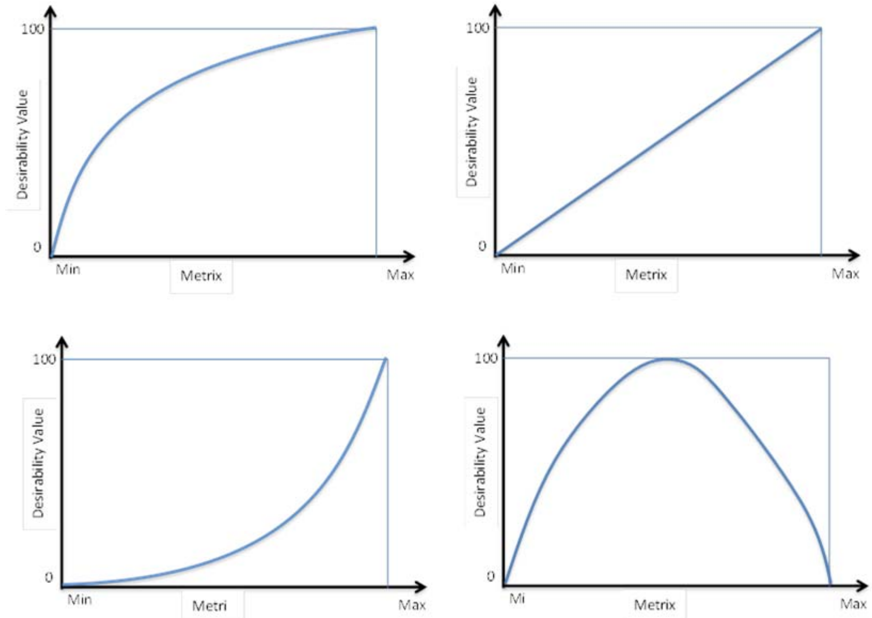

Figure 1. Various Shapes of Desirability Curves

The experts express the desirability values of the various levels of the performance measures associated with the sub-factors under the output indicators. When the desirability values are obtained, the innovativeness index of a company can be calculated. The mathematical expression for calculating the innovativeness index is expressed below:

$$IX = \sum_{n=1}^{N} \sum_{jn=1}^{Jn} (S_{n,jn}^{IX})(D_{n,jn})$$

Equation 2

where

IX Innovation Index

$S_{n,jn}^{IX}$ Relative value of the jnth sub-factor under the nth output indicator with respect to the Innovation Index (IX), jn = 1, 2, 3, ..., Jn, and n = 1, 2, 3, ..., N

$D_{n,jn}$ Desirability value of the performance measure corresponding to the jnth sub-factor under the nth output indicator

C. Delphi Method

The Delphi method is used when the availability of historical, economic and technical information is inadequate. Delphi is a technique for structuring systematic communications among a panel of experts [27]. It is used as an opinion-taking procedure in many different areas of study such as sociology and economics. The Delphi method attempts to minimize an individual's knowledge limitations and possible individual biases.

The Delphi method is different from conventional face-to-face group integration. Three distinct characteristics of the Delphi method are [28][29]:

- Anonymity: Group members do not know each other, preventing any one member from influencing the others. Also, the results are not revealed to any of the members to avoid biases.
- Iteration with controlled feedback: It is done in several iterations. Experts on the panel have the opportunity to reconsider and change their opinions and judgments between several successive iterations.
- Statistical group response: Statistical analysis for each round is performed by Delphi method moderators. Statistical information such as mean, median, and variations of the research are presented.

D. Expert Panel

This research has three expert panels to help construct a hierarchical model and to determine the value of each indicator. There are overlaps in the expert panels. The experts represent various sectors (education, government and industry) and different areas of specialization (marketing, sales, legal, new product development, etc.) in the semiconductor industry. Each expert panel has a different role in this research.

Expert Panel 1 (EP1):

This expert panel is comprised of people from various sectors and different areas of specialization in a specific industry. The different areas of specialization (cross functional) provide different points of view on the output indicators. Examples of different areas of specialization include new product development, marketing, sales, etc. Members of EP1 are leaders in industry and government, and researchers whose work is focused on innovation strategies and measurements. The experts on this panel help to identify output indicators that are recognized as signs of innovativeness in a company.

Expert Panel 2 (EP2):

This expert panel is also comprised of people from various sectors and different areas of specialization in a specific industry. The experts in this panel provide quantified judgments on the relative importance of each indicator and sub-factor with respect to the innovativeness.

Expert Panel 3 (EP3):

This expert panel is comprised of people from various sectors and different areas of specialization in a specific industry. Expert panel 3 (EP3) develops desirability functions for the metrics used for the performance measures corresponding to each sub-factors. Therefore, it captures different points of view on what is perceived as innovativeness.

The summary of the expert panels formed in this study is shown in Table 1.

E. Data Collection

Four research instruments were developed in this research. They are shown in the Appendix.. Research Instrument 1 was sent to Expert Panel 1 for model development. Research instrument 2 was used by EP2 to evaluate the relative importance of the output indicators with respect to the innovativeness. Research instrument 3 was used by EP2 to evaluate the relative importance of sub-factors with respect to the output indicators. Research instrument 4 was used by EP3 to express their desirability toward the metrics that contribute to the innovativeness of a company. The research instruments were tested and validated before being sent to the Expert Panels.

IV. RESULTS AND ANALYSIS

A. Model Development

Figure 2 shows the Hierarchical Decision Model finalized by Expert Panel 1 after Research Instrument 1 was sent to them for model development

TABLE 1. DISTRIBUTION AND BACKGROUND OF EXPERT PANEL

	Industry	Government	Academia	Affiliation	Country
EXP1			×	Delft University of Technology	Netherlands
EXP2			×	INRS	Canada
EXP3			×	German Graduate School of Management & Law	Germany
EXP4			×	German Graduate School of Management & Law	Germany
EXP5			×	University of Bamberg	Germany
EXP6			×	University of Bamberg	Germany
EXP7			×	Korea University	South Korea
EXP8			×	University of Bologna	Italy
EXP9			×	Fuzhou University	China
EXP10			×	Erasmus University	Netherlands
EXP11			×	Indian Institute Technology	India
EXP12			×	University of Exeter	UK
EXP13			×	University of Manchester	UK
EXP14			×	Innovation IMS Instruction	USA
EXP15	×			Samsung Electronic Research Institute	South Korea
EXP16	×			Lattice Semiconductor	USA
EXP17	×			FEI Company	USA
EXP18	×			TOK America	USA
EXP19	×			Tektronix, Inc.	USA
EXP20	×			Tektronix, Inc.	USA
EXP21	×			Tektronix, Inc.	USA
EXP22	×			Tektronix, Inc.	USA
EXP23	×			Intel Corporation	USA
EXP24	×			Intel Corporation	USA
EXP25	×			Intel Corporation	USA
EXP26	×			Intel Corporation	USA
EXP27	×			TriQuint Semiconductor	USA
EXP28	×			TriQuint Semiconductor	USA
EXP29	×			TriQuint Semiconductor	USA
EXP30	×			PwC	USA
EXP31	×			Cascade Mictotech	USA
EXP32	×			Novellus System	USA
EXP33	×			IPR & Innovation at Crompton Greaves Ltd	India
EXP34	×			Texas Instruments	USA
EXP35		×		Italian National Research Council	Italy
EXP36		×		Oregon Business Innovation Council	USA

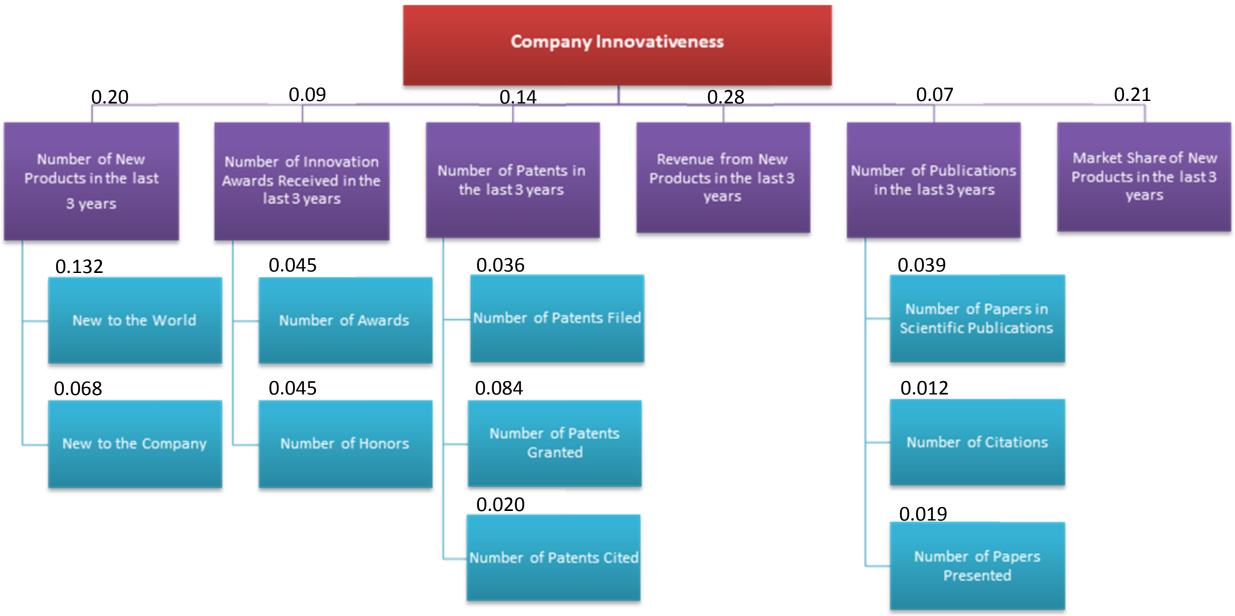

Figure 2. Innovativeness Index Framework

After the data collection and calculation, the relative contribution of each element of the decision model to innovativeness was calculated. The contribution values obtained from the quantified judgments of the experts are shown above each indicator and sub-factor in Figure 2. Based on the experts, revenue from new products, market share of new products, and number of new products new to the world are in the top 3 with relative contributions of 0.280, 0.210 and 0.132 respectively. They are followed by the number of patents granted (0.084), number of new products that are new to the company (0.068), number of awards (0.045), number of honors (0.045), number of paper published in scientific publications (0.039), number of patents filed (0.036), number of patents cited (0.020), number of papers presented (0.019), and number of papers cited (0.012).

C. Maximum Innovativeness Value

The highest possible innovativeness index is not 100. The most desirable values for many of the sub factors are not at the maximum score of 100. Thus, by taking the highest desirability value from each sub factors and multiplying it with the relative weight of each sub factors will bring the maximum innovativeness index to 76.5.

D. Simulated Application of the Framework to Intel and AMD

The model was implemented in a case study to demonstrate it in the real situation. Intel and AMD were used for this purpose. Both companies are in semiconductor industry. The data used for Intel and AMD included not all the product lines, but only notebook processors, desktop processors and server processors to make a consistent comparison between the two companies. The characteristics of Intel and AMD are normalized. Without normalization, large companies lead in all aspects since they always have higher numbers compared to medium and small companies. The purpose of the normalization is to eliminate biases and ambiguity.

Table 3 shows the profiles of Intel and AMD. Some of the values are left empty because the data are unavailable.

TABLE 2. PROFILES OF INTEL AND AMD

COMPANY	Intel	AMD
Total Products in the last 3 years [30]	530	275
Total Researchers [31][32]	1000	177
Total Revenue (in thousands US$)	103.1 Billion	11.08 Billion
New Products New to the World [30]	53	36
New Products New to the Company [30]	422	160
Number of Awards [33][34]	37	25
Number of Honors [33][34]	Data not available	Data not available
Number of Patents Granted [35]	550	100
Number of Patents Filed [35]	773	368
Number of Patents Cited [35]	Data not available	Data not available
Revenue from New Products [36]	91.759 Billion	7.867 Billions
Number of Papers Published [37]	3192	313
Number of Papers Presented [37]	Data not available	Data not available
Number of Papers Cited [37]	Data not available	Data not available
Market Share of New Products [38]	62.3%	21.3%

TABLE 3. THE PERFORMANCES METRICS OF INTEL AND AMD

Sub-Factors	Intel	AMD
New Products New to the World as the Percentage of Total Products	10%	13%
New Products New to the Company as the Percentage of Total Products	79%	58%
The ratio of Number of Awards to Total Researchers	1 per 27	1 per 7
The ratio of Number of Honors to Total Researchers	Data not available	Data not available
The ratio of Number of Patents Granted to Total Researchers	1 per 2	1 per 2
The ratio of Number of Patents Filed to Total Researchers	1 per 2	>1
The ratio of Number of Patents Cited to Total Researchers	Data not available	Data not available
Revenue from New Products as Percentage of Total Revenue	64%	42%
The ratio of Number of Papers Published to Total Researchers	>1	>1
The ratio of Number of Papers Presented to Total Researchers	Data not available	Data not available
The ratio of Number of Papers Cited to Total Researchers	Data not available	Data not available
Market Share of New Products	62.3%	21.3%

The values of characteristics for both companies were normalized to eliminate biases. Table 4 shows the performance metrics of Intel and AMD after the normalization

Intel shows strength in the revenue from new products and market share of new products. Those indicators are the top indicators according to the experts. AMD shows a slightly better performance in number of new products new to the world and number of innovation awards. The performance metrics were multiplied by the relative weights of the corresponding sub-factors to obtain the innovativeness index. Table 4 shows the innovativeness index of each company.

TABLE 4. THE INNOVATIVENESS INDEX OF INTEL AND AMD

Base-Line	Company	
	Intel	AMD
Innovativeness Index	56.7	42.11

Although the maximum possible score for innovativeness index in this research is 76.5, because some of the data are not available evaluating the innovativeness of Intel and AMD, the highest possible value for this illustration is 70.9. In this case Intel's innovativeness index is at 80% of the highest possible level, AMD's is at 60% of the highest possible level.

V. CONCLUSION

Innovation is crucial to sustain competitive advantage of a company. Because of its importance, a company needs to manage its innovation activities. A decision framework is needed to help company to measure its innovativeness. This development of such a framework with a decision model and metrics for measuring the innovativeness of a company in the semiconductor industry has been demonstrated in this paper. . Revenue of new products (0.28), market share of new products (0.21), and number of new products new to the world by a company (0.20) are perceived as the top 3 indicators to assess the innovativeness of a company in the semiconductor industry. Number of papers cited (0.01), number of papers presented (0.02), and number of patents cited (0.02) are the lowest 3 of all the indicators according to the experts.

The simulated application of the model shows that focusing on the right indicators will help a company improve its innovativeness. Regardless of the size, companies that focus on the sub-factors with highest relative importance obtain a better innovativeness index. However, even though a company performs extremely well in some sub-factors, if those sub-factors do not have high importance values, the innovativeness index will not be affected significantly.

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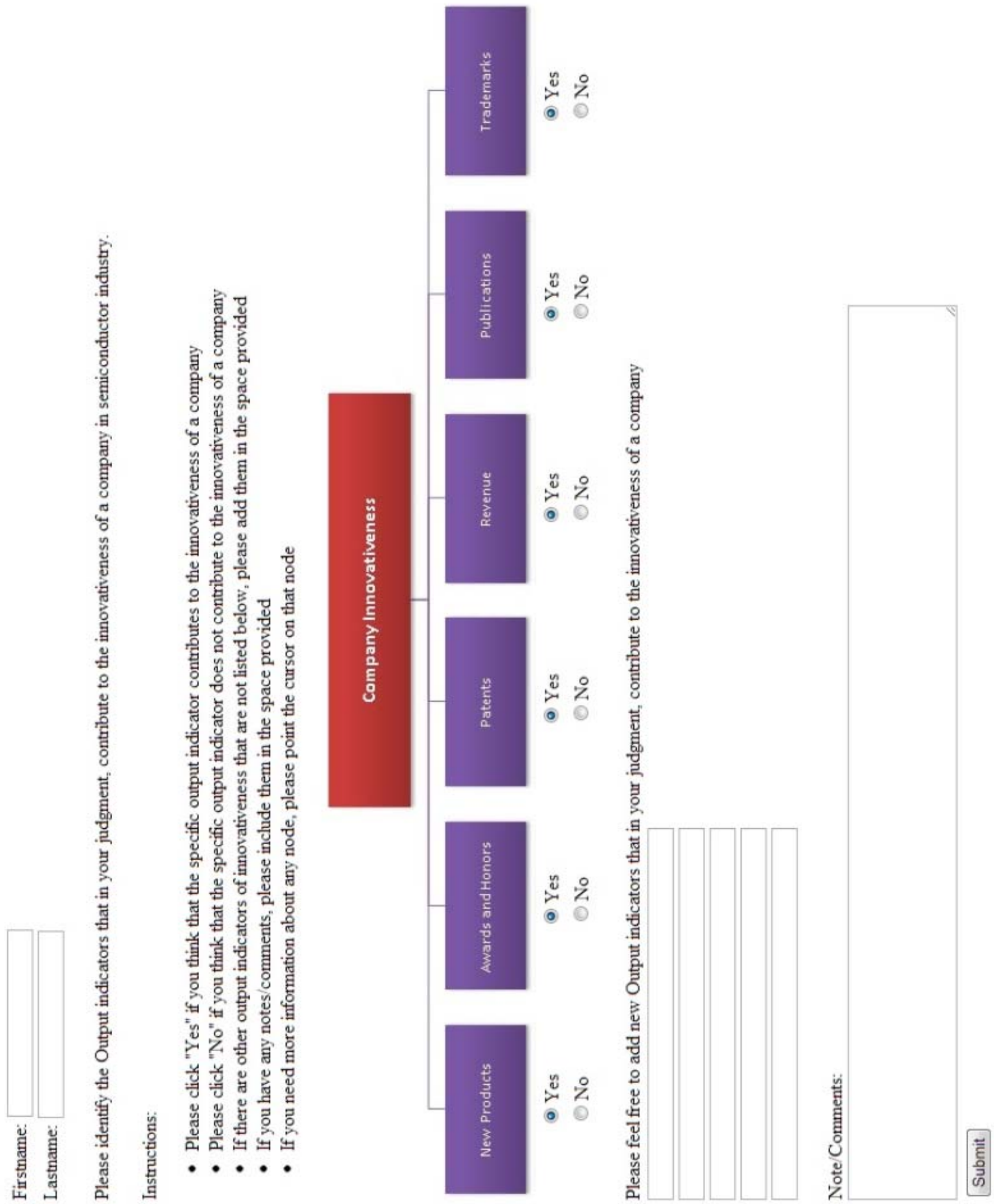
APPENDIX

Research Instrument 1 (Example)


Firstname:
Lastname:

Please identify the Output indicators that in your judgment, contribute to the innovativeness of a company in semiconductor industry.

Instructions:

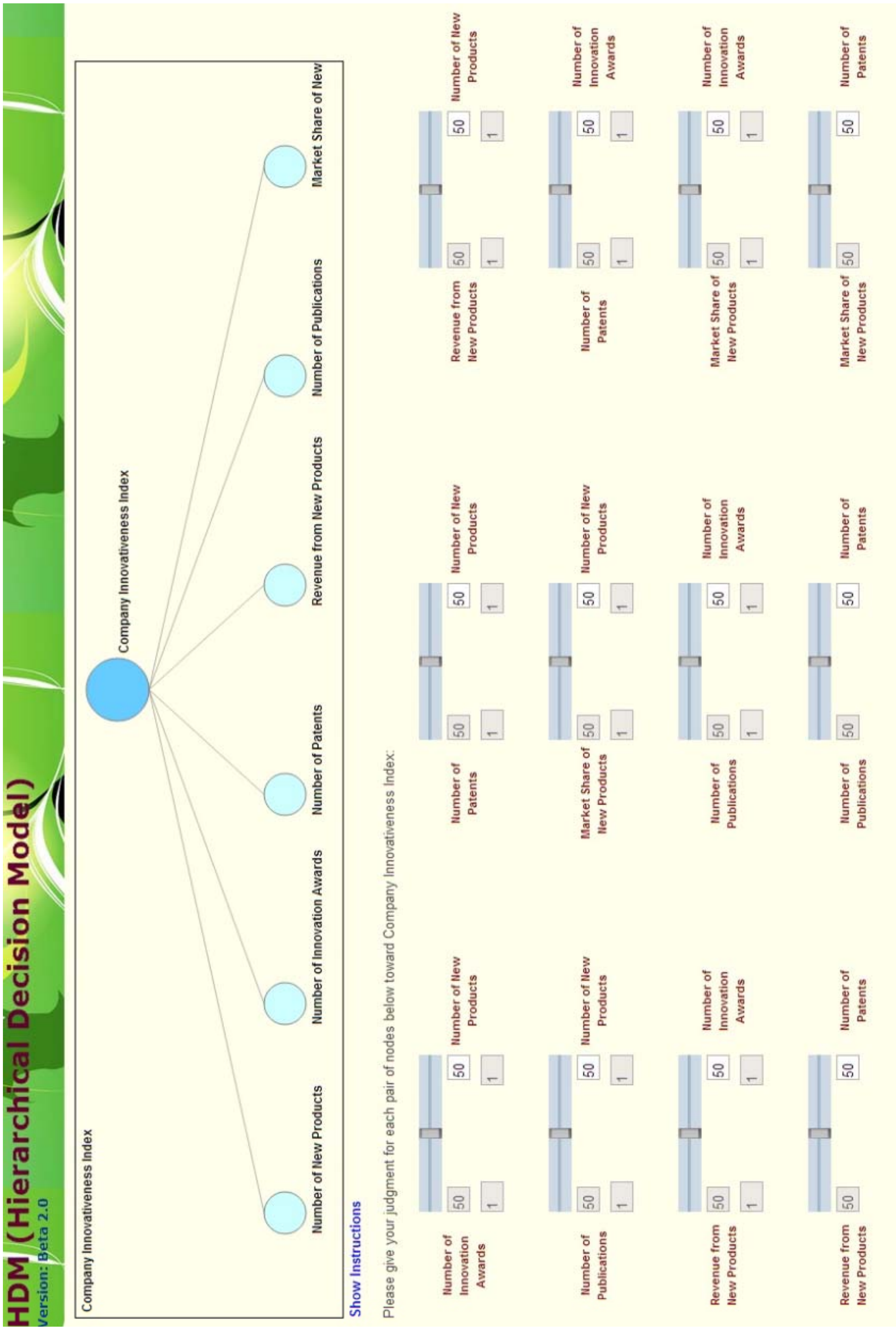
- Please click "Yes" if you think that the specific output indicator contributes to the innovativeness of a company
- Please click "No" if you think that the specific output indicator does not contribute to the innovativeness of a company
- If there are other output indicators of innovativeness that are not listed below, please add them in the space provided
- If you have any notes/comments, please include them in the space provided
- If you need more information about any node, please point the cursor on that node

Please feel free to add new Output indicators that in your judgment, contribute to the innovativeness of a company

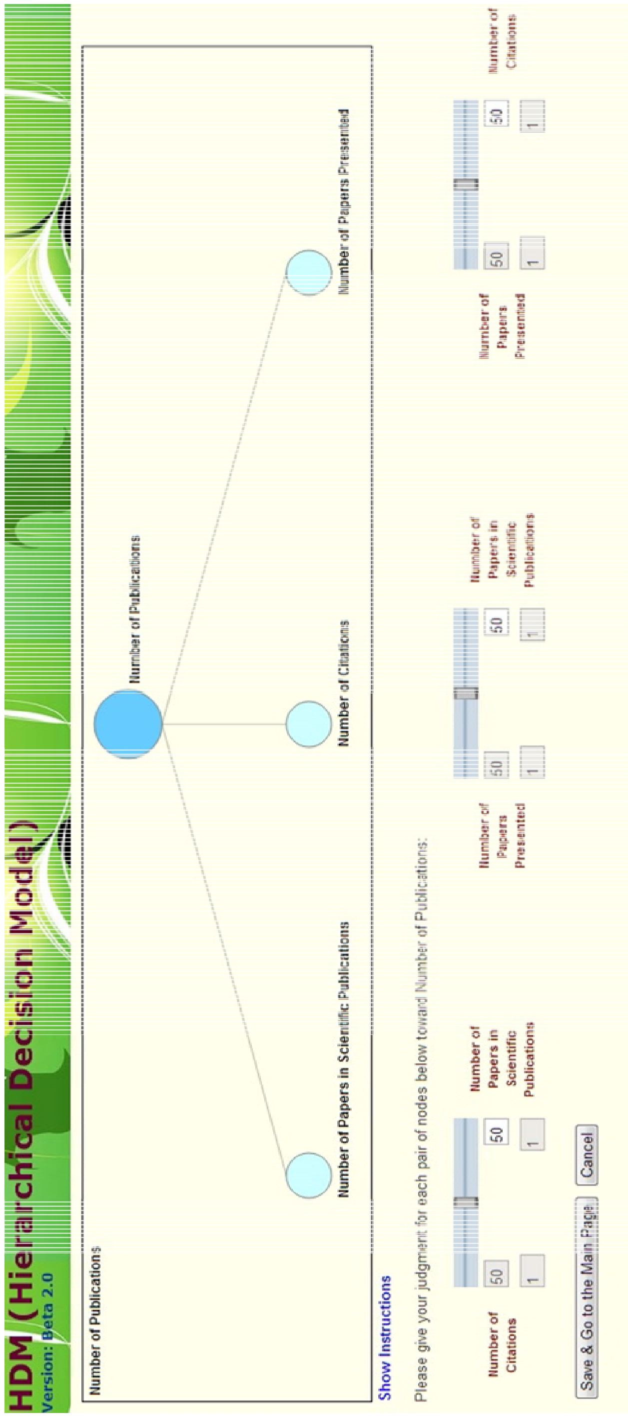
Note/Comments:

Submit

Research Instrument 2 (Example)



Research Instrument 3 (Example)

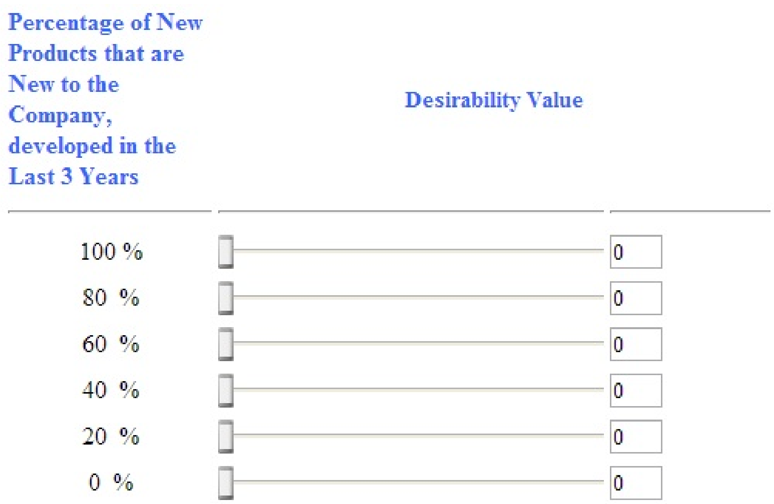


Research Instrument 4 (Example)

<u>Please develop desirability curves for new products, below</u>

Number of New Products that are new to the world in the last 3 years

The metric for this variable is the number of new products that are new to the world developed by the company, as a percentage of the total number of products of the company in the last three years.



Percentage of New Products that are New to the Company, developed in the Last 3 Years	Desirability Value	
100 %		0
80 %		0
60 %		0
40 %		0
20 %		0
0 %		0