Art and Science: Valuating Early Stage Technologies

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Early technology valuation has been a critical element in the process of technology commercialization. Current methods have been overly theoretical in methodology and an aggregated view is yet to be witnessed. In this research, a series of field interviews and existing literature guided us to develop a new procedure that comprehensively integrated quantitative and qualitative techniques in early technology valuation. Two heuristic methods were also developed to implement necessary computational methods.

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I. INTRODUCTION

The past decade has witnessed the ups and downs of technology innovation and the tech-centric economy. Now, we are only fortunate to observe another abruption of new technologies and quite possibly another revolutionary change to our economy, led by the unprecedented deployment of online infrastructure and portable devices in every aspect of our society. The recent round of prosperity greatly benefited from the latest developments of commercializing invented technology, such as well-established technology licensing procedures, abundant supply of funding channels, and better commercialization infrastructures and resources etc. However, technology commercialization is still a process that is full of uncertainties and difficulties. A general commercialization process involves the following steps: disclosing the discoveries and innovations (i.e., intellectual property (IP)), evaluating the IP's economic prospects, securing a patent, copyright or trademark for the IP, commercializing the technology through licensing, forming a joint venture, or selling. Figure 1 presents a typical view of technology commercialization.

Later stage investment decisions hinge on the soundness of early stage assessment in order to keep the investment stream continuous and sustainable. A common question that keeps coming back and frustrates technology management professionals is on the value of a technology at a certain stage. The financial value stays vague at the early stages due to data availability issues and the higher level of foreseeable/unforeseeable risks. Chiesa et al. (2007) presented factors that could influence the value of technology asset and classified them into asset related factors, firm related factors, context related factors, risk related factors, and transaction related factors.

Most current technology valuation methods disproportionally concentrated on assessing technology value at Stage D and E indicated in Figure 1. Early stages of technology valuation have been often overlooked or under-represented. The early stage technologies are even riskier due to their inadequacy of commercial development and market applicability. Amram (2005) claimed that more than 95% of patents fail to earn any revenues so that the majority of patents were valueless. Dissel et al. (2005) found that pure quantitative technology valuation methods derived from financial valuation techniques and decision theory (e.g., the use of discounted cash-flows, and decision trees and real options) could be mathematically challenging but contextually naïve for early stage technologies. On the other hand, pure qualitative technology valuation techniques (e.g., the use of score cards, and roadmaps) merely attempted to structure reasoning and served as trivial aids to decision makers. Hence, it is highly desirable to come up with a prompt, reliable and meaningful valuation process for technologies at their early stages. In this study, we attempted to achieve two goals. First, identify the current valuation practices for early stage technologies in the Silicon Valley area; Second, propose a conceptual model/process, in combination of quantitative and qualitative methods, to value early stage technology. To the best of our knowledge, a comprehensive model of early stage technology valuation is yet to be witnessed in extant literature.

The next session briefly reviewed existing literature on technology valuation. In Section three, we described the research procedure and our interview results. Section four presented our conceptual framework of early stage technology valuation. Section five concluded this paper with general discussions and future research.

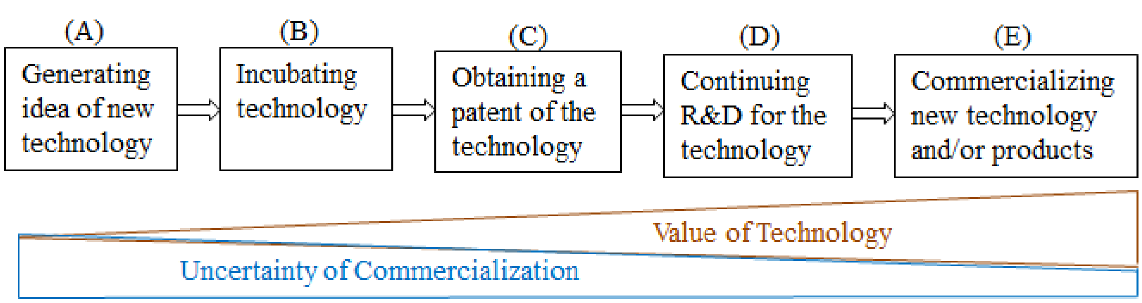

FIGURE 1. THE SPECTRUM OF TECHNOLOGY VALUE AND ITS UNCERTAINTY OVER THE COURSE OF TECHNOLOGY COMMERCIALIZATION

II. LITERATURE REVIEW

Pricing innovations, new product ideas, and technologies always gets a great attention and interest from researchers and industry practitioners. To this end, there has been a longstanding research literature available on technology valuation. Sampath Kumar, et al. (2004) listed some reasons for technology valuation as follows: ranking of projects for the allocation of resources between them; determining whether to proceed to the next stage of development; for disposal or sale; for raising capital, lenders are increasingly accepting intellectual property as collateral to secured financing; evaluating potential merger or acquisition; evaluating the commercial prospects for early stage research & development; evaluating technology licensing. Park and Shin (2010) investigated the reasons for technology valuation and the stages of commercialization at the time of technology valuation based on the data collected from 956 cases which were the technology valuation reports conducted during the latter half of 2000s. The value of technology was assessed mostly for technology transfer, technology investment, and loan on security. Most of those technology valuations were conducted after R&D, which indicates that once the technologies were relatively fully researched and developed, rather than at the early stage of technology invention, the inventors and/or other parties of interest in the technologies would like to investigate the potential value of technologies. Raymond (2010) presented in the generic technology vector, technology's value and niche market are increasing as the innovation of a technology is getting intensified. Thus, assessing the value of technology at the early stage is most likely a science and an art.

There are various valuation methods in the technology and innovation fields, ranging from intuitive judgment to complex options model available in the literature (Chiesa et al., 2005; Dissel et al., 2005; Park and Park, 2004; Hunt et al., 2003). The techniques can be classified into quantitative techniques (e.g., discounted cash-flows, decision trees, and real options) and qualitative techniques (e.g., score cards and roadmaps). Current literature (Dissel et al., 2005, Park and Park, 2004, and Hunt et al., 2003) briefly explained the methods:

(1) Discounted Cash Flow

The Discounted cash flow (DCF) analysis is a valuation method used to estimate the attractiveness of an investment opportunity. It uses future free cash flow projections and discounts them (most often using the weighted average cost of capital) to arrive at a present value. The use of discounted cash flow (DCF) for early stage technologies is difficult due to high uncertainty levels, which results in poor accuracy. Decision making during these stages requires flexibility. The DCF, however, does not allow for this flexibility.

(2) Real Options and Decision Trees

The technology valuations using the cost, market and income methods all have limitations in that those methods consider given technological assets without reflecting the opportunity and risk in the course of commercializing the technology. The option to invest if appropriate is not something that is given a value by DCF. DCF methods tend to penalize uncertainty by using higher discount rates, even when there is flexibility in a project to profit from this uncertainty. There is sometimes value to be obtained through waiting for more complete information, and this value is also not incorporated in the DCF. This issue of flexibility has been addressed by Real Option (RO) theory.

(3) R&D Portfolio Methods

Portfolio management is a decision process where a business's list of active new products and R&D projects is constantly updated, reviewed and revised. In this process, new products are evaluated, selected and prioritized; existing products may be accelerated, killed or de-prioritized. R&D portfolio management methods aim to provide a balanced approach to risk and reward. The visual representation of the existing portfolio gives a starting point for the consideration of the impact and potential value of early stage technologies.

(4) Roadmapping
Roadmapping is a technique to structure and support brainstorming based on the future potential of technologies. It is being used in industry, both at the company and sector levels, to support a variety of strategic goals. Roadmapping supports the valuation of early stage technologies as it plots the potential future of the technology against a timeline and clarifies the enablers and barriers to value creation. Thus a better judgment on the future value of the technology can be extracted from the roadmap.

(5) Expert Judgment and "Gut Feel"
Decision makers may rely on expert judgment and gut feel in a range of technology valuation situations.

(6) Cost-based approaches.
This equates the cost of replacing the technology with identical or equivalent technology to its value. One common approach is to add up all the expenses associated with developing the technology and convert that to the current value. Another approach is to estimate the cost of recreating the technology.

(7) Scoring and ranking methods.
Attributes of a technology such as market size or market environment are used. These are weighted and scored, resulting in a combined score. With a comparable reference of value to a standard weighted score, the relative value of the technology can be determined.

III. RESEARCH APPROACH AND INTERVIEW FINDINGS

The previous sections documented a set of procedures and methodologies that industrial practitioners and academic researchers have employed to come to a close range of the true value of a technology. One comment from existing studies truly inspired us in developing and pursuing a creative approach. A group from the University of Cambridge (Dissel et al., 2005) discussed the pros and cons of all major evaluation methods. Through case studies, their very first finding was "A major issue is that the method being used should be understood not only by the user, but also by the receiver. In the majority of our cases we found that the person responsible for the valuation was not responsible for the decision. The input requirements of the decision maker can be different to the outputs obtained from the method selected by the evaluator." A true user perspective, which included both the evaluator and decision makers, was still lacking. Identification of such discrepancies has been enlightening and directed us to pay more attention to consolidate theoretical methodological developments and actual needs by decision makers. Hence, a research approach that could connect the academic world with practical concerns has been the most paramount criteria in evaluating how we would go about and achieve our research goal. This triggered our simultaneous cross-validation approach in this project.

The simultaneous cross-validation approach consisted of two parts. Part one, a historical perspective that thrived to aggregate and synchronize all existing studies, theories, and methodologies by documenting and reviewing major extant studies. Part two, a realistic and contemporary perspective that thrived to communicate, conceptualize, and define the actual practices by industrial professionals from various industries. A strategic plan was developed to reach out to all critical members of the technology valuation industry. For instance, Cromley (2004) briefly listed twenty steps in evaluation an intellectual property, which included patent valuation and research, market research and determine the point of profit maximization etc. The twenty-step procedure involved professionals from quite a diverse set of industries, which guided us in our research target selection. First, patent professionals and licensing offices should be necessary as patentability has been mentioned by numerous literature and professionals as a key factor for technology valuation. Second, experience and intuition could very often supplement the decision of technology valuation, especially in the case of qualitative inputs. To obtain the expert perspective, we contacted and successfully secured interview opportunities with executives of technology companies. Third, investors should be the most relevant receivers of technology valuation information. It is their investment return at stake on any commercialization decision. Investors had to have a procedure, optimized or not, to evaluate investment opportunities and reach decisions accordingly. We contacted professional investors to gather information on their perspectives. We randomly selected professionals in each group of research targets in order to avoid sample selection bias to the best we could. This generated a series of in-depth interviews and valuable insights.

Our interviewees varied from directors of university licensing officers to professional venture capitalists. There seems to be a convergence in terms of factors that influence the valuation decision across all the interviews. The following factors have very often been mentioned by professional practitioners through the whole chain of technology valuation:

- Patent/intellectual property: The number of filed or pending patents as well as the likelihood of protecting a technology played a critical role in determining the value. The stream of income accompanying patents, on top of incomes from exclusive rights, could also be expected from royalty payments, buyouts, litigation payments etc in the form of cash payment or equity shares.
- Market potential: This could come from a set of sources after the application of a variety of valuation apparatuses. Boer (2005) had an eloquent argument of market potential. He named the projected yet foggy future of a technology as the strategic value. As several of our interviewees mentioned, such potential could be estimated using methods varying from simple confirmation from users, expert opinions, and existing products to comparable business entities or business models. Judgment calls have been inevitable when it comes to parameterization of opinions or approximations. The process is no short of subjectivity. Discounted cash flow, cost evaluation, and real option theory in combination with qualitative information are common devices in the toolbox of technology valuation professionals.
- The milestones: The earliness of a technology could be marked by several milestones. Early ideas, patent approval, demo/operation, or paying customers could be perceived along a monotonically increasing curve, where each step triggers a positive marginal change.

- Investment and funding end: Investors or buyers could choose from cash up-front payment, royalty payments, licensing, and buyout etc. The means of funding certainly makes difference on the timing and amount of returns, which in turn should gauge valuation. One of the interviewees also brought up the concerns of future dilution of equity rights, which would not be a major concern for the purpose of this project.
- Desirability of a scientific model or technology: A unanimous agreement has been reached on the desirability of a scientific model for the industry to valuate new technologies. Industrial practitioners have not been fully confident on the feasibility of implementing a quantitative method in complete replacement of existing practices.

IV. CONCEPTUAL MODEL OF TECHNOLOGY VALUATION

In this section, we presented a conceptual model that aimed to establish a preliminary framework for early stage technology valuation. The conceptual model basically followed a structure of stage, action elements, and methods in a matrix form. For each of the stages, we identified stage specific action elements and achieving methods for each of the elements. There were three major stages in our conceptual model, namely, initial description, information collection & processing, and definitive results. The three stages followed a chronological order where the descriptive beginning served as the start and the final delivery came out of definitive result stage. Figure 2 showed the basic flow of our conceptual model.

The three stages are strategically designed to reserve the comprehensiveness of information for the scale of technology valuation and promote a lean and simple structure for the efficiency of actual implementation. At the end of each stage, there would be a decision of moving forward or not until the very last stage where technology valuation would be the ultimate output. The decision node was represented by the green stars. The little scroll symbolized the final valuation. The initial descriptive stage served as the beginning communication and preliminary information collection step. We prescribed two steps for both the vendors and the receivers to successfully accomplish the stage.

In the first stage, a vendor of new technologies would be bonded to clearly present its technology in comprehensible terms to the receiving end, buyers or investors. Carefully prepared information on two basic aspects would be communicated: the technical newness and market newness. Under the technical newness, a vendor would need to convincingly present the pure technical improvements the proposed technology could offer. Thorough understanding of the current state of technical developments would be a must. More challengingly, the vendor would also need to articulate on developmental feasibility and hurdles for the technology. The vendor would also need to prepare at least a fundamental understanding of the technology's market potential to supplement its technical feasibility arguments. These defined the vendor side stage specific elements. On the buyer or investor side, the stage specific elements included verifying vendor provided information, backend basic market research and segmentation, and research on patents and patentability etc. The final decision of moving forward or not lent itself to the application of the classic analytical hierarchy process (AHP). Figure 3 summarized the above discussion. Notice that Figure 3 exactly followed our basic structure as discussed above.

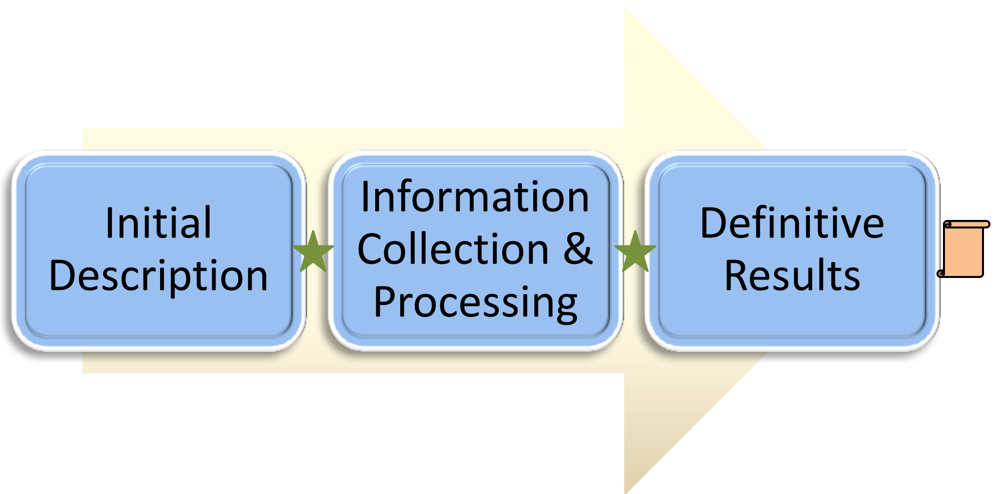

FIGURE 2. CONCEPTUAL MODEL

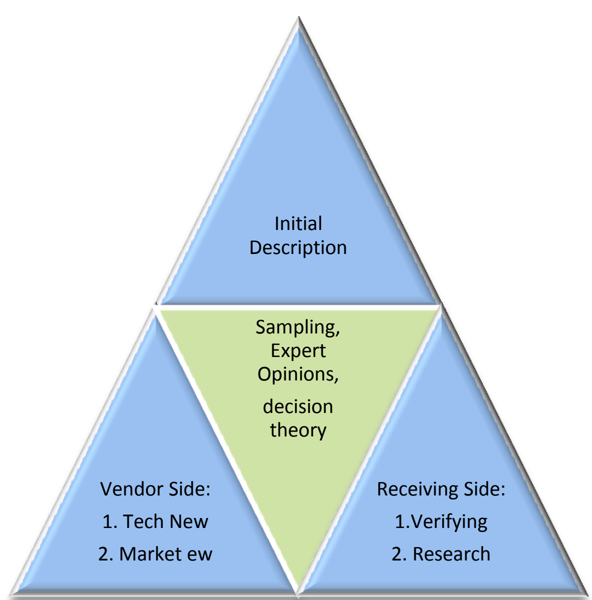

FIGURE 3. STAGE ONE

Stage two has been the most information intensive stage in our model. It not only included collecting more detailed information, but also entailed a reliable and efficient processing that directly offered guidance to stage three. The vendor side would simply feed information by request at this stage as we assumed most of the information should be already provided at stage one. Most of the activities would burden the receiving end for time and efforts. A preliminary verification in stage one would not be adequate, where a more in-depth research should be conducted in this stage. This entailed a larger scale user sampling and scientific/professional expert opinions. The extensive verification would generate more precise qualitative and/or quantitative data. A method that could provide great effectiveness for organizing and analyzing qualitative information would be the technology road mapping (Garcia and Bray, 1997) or value roadmap method (Dissel et al., 2005). We abbreviated them as TRM and VRM. Simultaneously or sequentially, more quantitative data and processing would come to the focal point along with above verification research. Many of our interviewees mentioned cost data, capital requirement data, revenue projection, market potential estimation, break even analysis and timing etc. The data could be processed by the discounted cash flow (DCF) method and/or real option theory (ROT) method. At the end of this stage, the higher quality data and basic analysis results should guide the decision of if the technology would still worth further efforts. If the answer would be a yes, then the last stage of valuation would be needed. Figure 10 described this stage.

If a technology would be valuable enough to move to stage three, a valuation result should be identified for the technology. An intriguing method mentioned by our interview with a venture capital firm inspired us to use comparable sample, in combination of the quantitative data and analysis results, to reach an estimated value of the technology. This stage should be the most computational intensive stage to our definition. We creatively came up with two heuristic methods for estimating the technology value. The heuristic methods are described as below.

A. Heuristic Method 1

1. Given a technology, an expert panel or previous database would guide the research team to identify a set of criteria for the evaluation of comparable technologies. Existing theories and methods on identifying customer needs could easily provide guidance on selecting a set of comparable technologies. The result of the first step is a set of criteria, where $x_i \in X$ represents the set.
2. Once $x_i \in X$ and a set of candidate comparable technologies have been identified, the closeness should be calculated. We propose two methods to calculate the closeness. In either case, a panel of experts or rich historical data would offer values for the set of criteria in step 1 for each comparable technology. The final results would be a closeness result, $d_j \in D$.
    a. An expert opinion panel with AHP, which produces closeness scores for each option.
    b. The classic data similarity measurements, such as the Jaccard coefficient, the cosine similarity, or the extended Jaccard coefficient etc. (Tan et al., 2006).
3. The closeness results could be then used as weights or convex combination parameters to aggregate quantitative data or analysis results. For instance, the revenue data from all comparable technologies could be aggregated by a weighted average with the closeness results as the weights. In this case, we would have:

$$\sum_{j=1}^{J} R_j W_j,\ W_j = \frac{d_j}{\sum d_j}$$

where J stands for the number of comparable technologies.

4. More interestingly, we can also allow for stochastic variations of the value estimation. In this case, the expert panel or historical data would feed our heuristics a range of values, instead of a value point. This approach allows for a much higher level of flexibility and could also take into consideration of risk and uncertainty. Step three would produce a range of weighted average results, which could serve as the feed for a statistical simulation to generate an estimation of statistical distributions for a technology. The result can allow us to present the likelihood for a certain valuation to come to reality.

Milestone information and funding options could also be factored into the heuristic method or discussed after the heuristic calculation. Our heuristics method seamlessly aggregated qualitative information with quantitative analysis to produce the estimation of a value or a range of values. Figure 5 described the last stage.

We included a numerical example here to better guide our readers in understanding the specks of our proposed process. Above interviews offered convenient valuation factors for the implementation of the AHP process. We used four criteria common to most technology valuation process to demonstrate the weight development procedure. A hypothetical expert was asked to evaluate the relative importance of the four criteria. The result was shown in Table 1, where a 9 represented a situation where a criterion was extremely more important than the other one.

Following an AHP process, we calculated the AHP weights that reflected the relative importance of each criterion, as shown in Table 2.

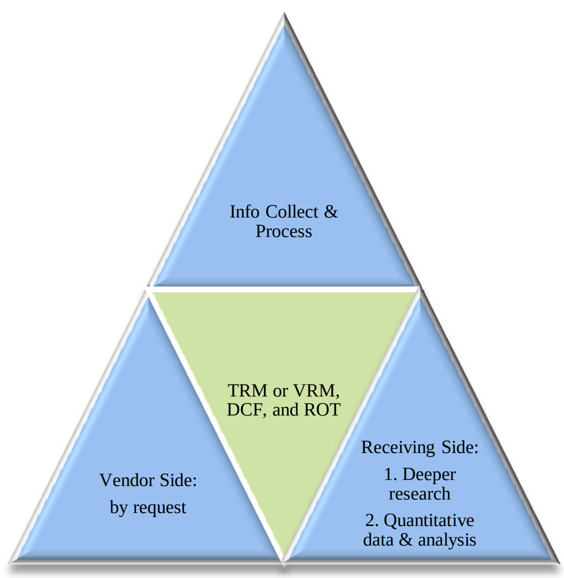

FIGURE 4. STAGE TWO

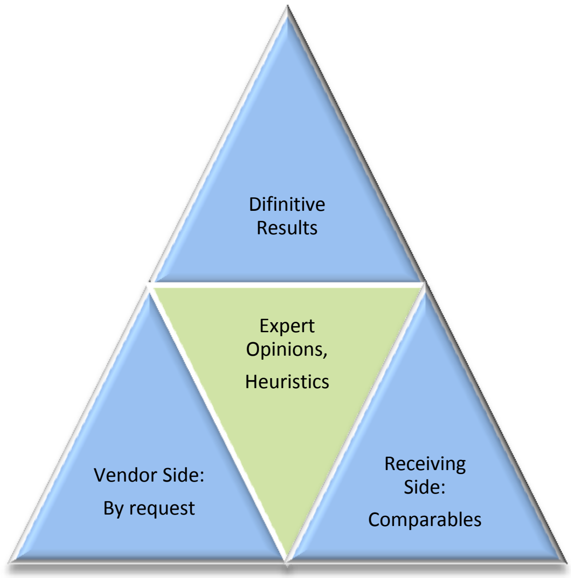

FIGURE 5. STAGE THREE

TABLE 1. RELATIVE IMPORTANCE

	Technology Risk	Market need	Capital need	Management/Technology Team experience
Technology Risk	1.00	0.25	3.00	0.37
Market need	4.00	1.00	9.00	4.00
Capital need	0.33	0.17	1.00	0.26
Management/Technology Team experience	2.70	0.25	3.90	1.00

TABLE 2. AHP WEIGHTS

	Weights
Technology Risk	0.13
Market need	0.59
Capital need	0.06
Management/Technology Team experience	0.22
Consistency Ratio	0.10

The weights developed could certainly be used to evaluate a technology given the set of weights. In order to score the technology in relativity to other existing technologies, one could easily compare the technology at focus with other technologies following similar AHP process or to use the Jaccard coefficient, which requires a whole set of scaled values for each of the dimensions. When the valuation came short of a single value, due to a variety of reasons, our method could allow for a range of evaluation. For instance, a relative importance would be within the range of 2 and 3. Any value in the range of [2, 3] would be feasible. The following example showcased the range flexibility. We drew a random sample of six weights to calculate the mean and standard deviation of the weights. Similar calculations could be easily applied to other parts of the valuation process. Please see Table 3 for details. A normal distribution was assumed.

Ideally, with the supply of larger samples or better historical records of new technologies, we could even go further to better train the data in order to obtain the best weights and other parameters for estimation with better strength and accuracy. When the data sample is small, one can easily apply boot-strap methods to better estimate the key properties of weight distribution.

B. Heuristic 2

The Heuristic 2 uses a comparable approach with relative potential success scores of factors which are considered in the technology valuation, compared with those of comparable technologies. Hastbacka (2004) presented a ValuGrid Modified Market Comparables Approach which was developed and used successfully for years by TIAX LLC. He stated that the market comparables approach is based on the premise that, within a given industry, the complementary tangible and monetary assets required to realize value from technology-based intangible (intellectual) assets are reasonably comparable among that industry's participants. Consequently, the key determinants of the value of the technology-based intangible assets are the technology itself and the economic return the technology creates. Sampath Kumar, et al. (2004) expressed that the price of the technology largely depends on the incremental utility provided by the unique aspects of the new technology, over any comparable old technologies, and then formalized it as $T_{new} = T_{comp} + X_{new}$, where T_{new} is the potential price of the technology of interest, T_{comp} is the comparable price of the related old technology, and X_{new} represents the incremental value offered by the new technology. While T_{comp} can be obtained through surveying the comparable old technology prices, the more challenging task has been in quantifying the incremental value of the technology (Bergstien and Estelami, 2002).

From the view of the comparables approach described above, Heuristic 2 aims to determine a potential success possibility of a new technology, compared with its comparables in the facet of selected comparison factors. For example, set the functionality of a comparison factor for a comparable as 1. Suppose that an expert assess the functionality and marketability of a comparison factor for the new technology as superior to the comparable by 20%. Then, the potential success possibility of a new technology for the comparison factor is 120% over that of the comparable technology. Continuing the evaluation of the new technology in comparison with the comparable for all comparison factors, we can get the results shown in Table 4.

By multiplying an importance weight by a superiority score to the comparable technology for all factors and then summing them up, a weighted total potential success score for the new technology over its comparable would be 1.125; in other words, the new technology has 12.5% more potential success possibility than its comparable. If financial data for the comparables are available, the value of comparable technologies can be calculated using technology valuation methods described in Section IV: Types of Technology Valuation Models, such as discounted cash flow, real options, cost method, income method, etc. Once the value of comparable technologies is calculated, the value of a new technology can be estimated by multiplying it by 1.125. If the financial data for the comparable technologies are not available, the weighted total potential success score can be used as a commercialization success index.

The procedure of Heuristic 2 is illustrated in Figure 6.

TABLE 3. WEIGHT RANGES AND DISTRIBUTIONS

1.00	2.00	3.00	4.00	5.00	6.00	MEAN	STDEV
0.15	0.15	0.15	0.14	0.12	0.13	0.14	0.01
0.56	0.55	0.56	0.58	0.59	0.59	0.57	0.02
0.09	0.08	0.08	0.07	0.08	0.06	0.08	0.01
0.20	0.21	0.21	0.22	0.21	0.22	0.21	0.01

TABLE 4. AN EXAMPLE OF COMPARING A NEW TECHNOLOGY WITH ITS COMPARABLE

Factors	Importance weight	Superiority score to the comparable technology
F1	0.35	1.2
F2	0.15	0.7
F3	0.25	1.1
F4	0.25	1.3

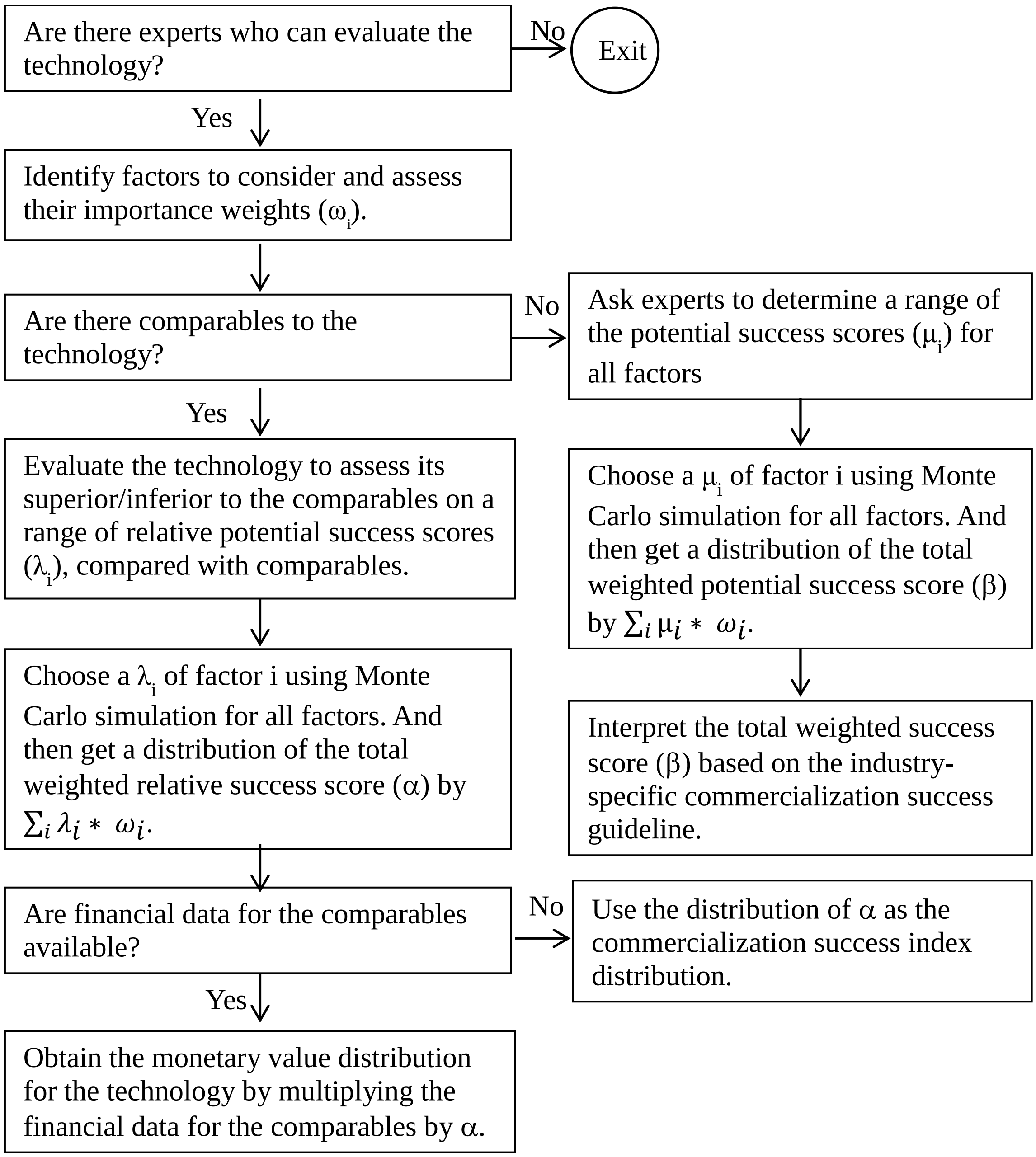

FIGURE 6. A PROCEDURE FOR TECHNOLOGY VALUATION.

V. CONCLUSIONS AND FUTURE RESEARCH

A conceptual model of early technology valuation and two heuristic methods were presented in this study. Different from previous literature, our model specifically dealt with the issue of early stage technology valuation. The model is neither purely quantitative nor purely qualitative. The model presented served as an action plan that was easily executable. The model and its heuristic concepts have been field tested by interviews and communications with technology management professionals in the Silicon Valley area. Our interviews also revealed other critical elements of technology valuation and current practices of early technology valuation in the high-tech industries. Future research may want to better validate the process with empirical studies if data availability becomes more manageable.

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