Investors in high-tech industries face a common issue: how to put a valuation on a technology based venture or project? Although classic investment valuation methods, such as discounted cash flow, are well understood, they tend to fail in this environment. Technology investments not only look into an uncertain future, they also have a business plan that is still flexible and subject to change. Both issues often make an investment decision a matter of a mere “judgment call.” In this article, we provide a compelling solution to assist investors in high-tech investment decisions: the Real Options Toolkit. This model allows one to capture and evaluate the flexibility of managers to adjust their strategy to alterations in the uncertain high-tech environment. This type of managerial flexibility is modeled as a “real option.” Based on the actual investment case of SemCo., a technology carve-out venture, we give clear guidelines on when and how to use real options analysis to evaluate technology-driven investment decisions. Beyond its appeal for pure investment valuation, the real options framework also provides another insight: the hidden “option value” in a technology investment does not just unfold by itself. Managers need to understand its logic in order to actively leverage and capture the value of their flexibility.

REAL OPTIONS CAN MAKE A STRIKING DIFFERENCE IN TECHNOLOGY VALUATION

The carve-out venture SemCo. has done extremely well over the last two years. Established by a large U.S.-based player of the semiconductor industry, it has made a huge step to take a proprietary technology out of its prototype state and closer to market success. But management is puzzled: the decision to launch the venture was very controversial just two years prior. The discounted cash flow (DCF) valuation model provided by a renowned investment advisor had clearly shown a negative present value. SemCo. looked like a clear no-go. What happened?

Our analysis showed that neither the forecast estimates nor the valuation results were wrong as such. The clear misjudgment was a matter of mistaken valuation methodology (see Exhibit 1).

Applying Real Option Valuation to the example of SemCo. reveals the actual value of a technology-based venture: $7.5 million. Using a standard DCF valuation technique suggested a negative value—prohibiting the very existence of SemCo. The striking difference lies in a substantial “value of flexibility” that is not captured by a DCF model. We call this flexibility a set of “Real Options.”

**E X H I B I T 1**
Valuation Result and Investment Decision

<table>
<thead>
<tr>
<th>Valuation Result:</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCF Value</td>
</tr>
<tr>
<td>$(5.3)$ M</td>
</tr>
<tr>
<td>Value of Flexibility</td>
</tr>
<tr>
<td>Real Option Value</td>
</tr>
</tbody>
</table>

**Why does Flexibility in Technology Investments Matter?**

How can these real options create value beyond the value of expected cash flow presented by a DCF analysis? The answer consists in the founding principles of real option value:

- Any future cash flow from a high-tech investment is uncertain. It can be described as a probability distribution showing a typical bell curvature. In case of the symmetric distribution, the peak represents its expected value. The width represents the degree of uncertainty.

- Managerial flexibility, i.e., the flexibility to adjust managerial decisions over time subject to additional information, allows one to shift this probability distribution in a powerful way. Defensive flexibility can provide downside protection, while offensive flexibility offers upside extension. This flexibility is described and evaluated as a set of Real Options. See Exhibit 2 (compare to Trigeorgis [1996, p. 123]).

The higher the level of uncertainty, the more value is tied to the ability of managerial flexibility. This makes the Real Option Valuation Toolkit an important complement to classic present value-based valuation methods. It uses the same rationale as the Nobel Prize winning techniques to value financial options commonly traded on stock markets. However, instead of valuing the option to purchase or sell a stock with an uncertain future prize, it applies a similar framework to real assets with an uncertain future value, as suggested by Trigeorgis [1996, p. 125]. By starting and running a technology venture like SemCo., the proprietor invests in a set of valuable real options tied to its capital and operations. Such options include the option to liquidate SemCo. in case the environment shows an unfavorable development, or the option to expand its operations earlier than anticipated in case of a positive development. Since the DCF analysis relies upon a single expected value (or scenarios of distinct expected values), it remains unable to capture the additional flexibility value represented by real options (Luehrmann [1997]). Revisiting SemCo., we find an early stage technology venture that operates in the highly volatile semiconductor industry. Given those prerequisites, the real option value is very likely to be of substantial size. Neglecting it, as DCF valuation does, leads to a systematic misvaluation. And often—as in SemCo.'s case—this might be the key trigger of an investment decision.

**How does Real Option Valuation Relate to Other Techniques?**

Most valuation approaches prevalent in literature and practice fall into one of the five categories introduced in Exhibit 3. While the leftmost approaches (i.e., relative valuation, asset valuation and DCF) comprise the classic techniques for valuation, the hybrid models contain more promising blended techniques, tailored to the purpose of...
technology venture valuation. The rightmost approach—Real Options—will clearly be the focus of our further discussion. In the specific context of SemCo., the manifold approaches are to be evaluated in three categories:

- The classic techniques, while easy to apply, have major shortcomings in representing the true value of a unique technology venture. While asset valuation is not applicable, relative and DCF-based valuation can merely provide rough estimates in this kind of a context. Both techniques fail in one key aspect: the value of managerial flexibility is neglected.
- Hybrid valuation models are clearly more promising, however, they are difficult to apply correctly. The simulation-based approach suggested by Schwartz and Moon [2002] pulls from continuous time finance and requires advanced numerical computation techniques to implement. The ancient decision trees (Magee [1964]) are just as complicated to handle as Real Options, yet lack a market consistent approach for discounting and volatility estimation. The venture capital method, for example in Gompers [2002], is widespread and easy to apply, however, it also fails to quantify the notion of managerial flexibility in an explicit and traceable way. While being a reasonable choice, getting it right surely takes a large amount of “gut feel” by an experienced venturing expert.
- Thus, a Real Option based valuation approach remains as the rationally correct tool to apply. However, some claim it is complex—the main reason for practitioners to hesitate applying it to their investment decisions.

Fortunately, our analysis suggests that Real Option Valuation does not have to be that complex to apply, once the right toolkit is used.

THE REAL OPTION VALUATION TOOLKIT

When it comes down to valuing real options, theorists and practitioners both agree—this part is somewhat tricky. While theorists often get lost in hyper-complex valuation models, processor bursting computer simulations, and the wide variety of possible real options to be looked at, practitioners tend to lament about two key issues: the lack of capital market relation of a real option valuation and the absence of a clear-cut valuation method that can be applied without breaking the scope of managerial finance. The Valuation Toolkit combines the best
of both worlds as the SemCo. case study shows. Building on a sound theoretical basis, the approach follows a straightforward six-step approach. Extending the process suggested by Copeland and Antikarov [2001], it can be tied into a standard DCF valuation model, and deploys capital market data to arrive at a realistic market-driven valuation result. See Exhibit 4.

In principle, it takes the following steps to put a value on real options:

1. Determine the key options for valuation
2. Calculate a discounted cash flow model
3. Map uncertainty with an event tree
4. Model managerial flexibility by adding decision nodes
5. Calculate real option value based on the Binomial Model
6. Review and test results validity and stability

As the final step shows, in the case of SemCo., the result remains fairly stable once the input parameters are deflected. See Exhibit 5.

In order to make up for their relatively strong sensitivities, the assumptions behind the three most critical parameters have been chosen with the highest level of care.

**How can Capital Market Consistency be Achieved with a Simple Valuation Model?**

Once confronted with real options, practitioners tend to see two remaining issues: their seeming lack of capital market relation and the absence of a clear cut and simple, yet accurate, valuation model. Those should be touched upon briefly.

The modeling of uncertainty is often claimed to be the critical input to a real options valuation. Within the valuation model, the measure of uncertainty is represented by the volatility parameter of a real option. Of all critical parameters found in the sensitivity analysis, this the one that clearly goes beyond the analysis needed for a DCF valuation. Other than in the case of traded securities, volatility of real options, in most instances, cannot be obtained from historic data, since the underlying often refers to a non-traded asset, as the carve out venture SemCo. does in our case. However, other established valuation techniques, see as DCF or multiples have already shown us the way to value non-traded assets effectively: a set of traded market comparables is used to derive the value of the non-traded asset. Using this as a premise for real option valuation, it is straightforward to identify the most favorable approach to estimate volatility in a capital market consistent way. As Exhibit 6 shows (represented by

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**EXHIBIT 3**

Overview of Valuation Techniques

<table>
<thead>
<tr>
<th>Principle</th>
<th>Examples</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Value based on capital market transaction data of comparable companies</strong></td>
<td><strong>Trading Multiples</strong></td>
<td><strong>Applicability in SemCo. case</strong></td>
</tr>
<tr>
<td><strong>Valuation of assets and liabilities based on book values</strong></td>
<td><strong>Transaction Multiples</strong></td>
<td><strong>Highest</strong></td>
</tr>
<tr>
<td><strong>Valuation of future cash flows generated by the firm’s assets</strong></td>
<td><strong>Liquidation Value Replacement Cost</strong></td>
<td><strong>Lowest</strong></td>
</tr>
<tr>
<td><strong>Blending of previous approaches for purpose of technology venture valuation</strong></td>
<td><strong>DCF (Entity/Equity Approach)</strong></td>
<td><strong>Medium</strong></td>
</tr>
<tr>
<td><strong>DCF model + Real Options, e.g., growth options</strong></td>
<td><strong>Decision Tree Analysis (DTA)</strong></td>
<td><strong>Highest</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Valuation of static present value plus premium for managerial flexibility</strong></td>
<td><strong>Lowest</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Venture Capital Method</strong></td>
<td><strong>Medium</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Equity Value Added (EVA)</strong></td>
<td><strong>Lowest</strong></td>
</tr>
</tbody>
</table>

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2. Map uncertainty with an event tree
3. Model managerial flexibility by adding decision nodes

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2. Map uncertainty with an event tree
3. Model managerial flexibility by adding decision nodes
**EXHIBIT 4**
The Real Option Valuation Process

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Divide venture in projects and identify key options</strong></td>
</tr>
<tr>
<td>- Split venture in mutually exclusive projects</td>
</tr>
<tr>
<td>- Analyze projects to identify option characteristics and value (size, driver estimate)</td>
</tr>
<tr>
<td>- Determine key options involved and document interdependencies if needed</td>
</tr>
<tr>
<td><strong>2. Compute static value using DCF model</strong></td>
</tr>
<tr>
<td>- Calculate base case present value ignoring any managerial flexibility if needed</td>
</tr>
<tr>
<td>- Identify major uncertainty sources and their correlation</td>
</tr>
<tr>
<td>- Understand impact of each uncertainty source</td>
</tr>
<tr>
<td><strong>3. Model uncertainty for each project using event trees</strong></td>
</tr>
<tr>
<td>- Evaluate volatility of each uncertainty source</td>
</tr>
<tr>
<td><strong>4. Model flexibility creating a decision tree</strong></td>
</tr>
<tr>
<td>- Implement lattices for underlying and option value (binomial tree) in spreadsheet model</td>
</tr>
<tr>
<td>- Synthesize value of flexibility and static NPV to obtain extended present value</td>
</tr>
<tr>
<td><strong>5. Calculate real option value</strong></td>
</tr>
<tr>
<td>- Understand sensitivities of the ROV versus estimated input parameters</td>
</tr>
<tr>
<td>- Adjust for project and option interdependency, if needed</td>
</tr>
<tr>
<td>- Review model for transparency and simplicity</td>
</tr>
<tr>
<td><strong>6. Review results</strong></td>
</tr>
</tbody>
</table>

**EXHIBIT 5**
Sensitivity Analysis Shows Stability of Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Valuation assumptions</th>
<th>Change in ROV for ±10% change in driver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present value of underlying</td>
<td>Result of DCF analysis (Business plan &amp; comparables based)</td>
<td>-17.2% 24.8%</td>
</tr>
<tr>
<td>Volatility</td>
<td>Derived from return volatility of comparables sample</td>
<td>-14.5% 19.3%</td>
</tr>
<tr>
<td>Investment expenditure</td>
<td>Reliable business plan figures</td>
<td>-7.0% 18.5%</td>
</tr>
<tr>
<td>Total expiration time</td>
<td>Business plan assumption</td>
<td>-2.5% 2.5%</td>
</tr>
<tr>
<td>Risk free rate</td>
<td>Macroeconomic market data</td>
<td>-0.5% 0.5%</td>
</tr>
<tr>
<td>Convenience yield</td>
<td>Conservative assumption</td>
<td>-0.3% 0.3%</td>
</tr>
</tbody>
</table>

**SENSITIVITY ANALYSIS**

- Critical Parameters
- Sensitivity analysis shows results stability
- Critical parameters of valuation identified

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the shaded area), we apply a direct approach employing historic capital market data to infer the volatility parameter.

In the case of SemCo., the volatility was mapped by the historic volatility in equity returns of six listed peer companies.5

Since the underlying DCF model has been set up using the analogous peer group, the valuation result provides a comfortable proximity to capital markets.

The Real Option Toolkit builds upon the well-established Binomial Model of option valuation.6

This model maps the uncertainty of future cash flows using a discrete tree of event notes. At each point in time, the asset value is assumed to either make an upward or downward movement. The size of these moves represents the degree of uncertainty the asset is exposed to. Once all future states are mapped as branches of the “binomial tree,” the option value is determined as a reverse path of optimal decisions. Compared to other option valuation techniques, which include numerical simulation techniques or stochastic calculus, the model remains appealingly simple. However, choosing a real world case as SemCo. for valuation, several options referring to the same underlying are involved at one time. Moreover, those options interfere significantly with each other, which prohibits the ability to neglect their mutual interaction effects. Using extensions to the Binomial Model as, for example, suggested by Rubinstein [1992], we spiced up the standard Binomial Model with simple, yet powerful, adaptations to arrive at an accurate result for the real option value. Exhibit 7 provides the four sub-steps needed for this

---

**E X H I B I T 6**

Uncertainty Estimate: Market Consistent Determination of the Volatility Parameter

<table>
<thead>
<tr>
<th>Estimation Approach</th>
<th>Usage of Capital Market Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect (Estimation of related volatility sources)</td>
<td>With</td>
</tr>
<tr>
<td>Direct (Estimation of volatility of underlying)</td>
<td>Without</td>
</tr>
</tbody>
</table>

- Volatility of traded uncertainty source and Monte Carlo simulation
- Estimation of individual uncertainty sources and Monte Carlo simulation
- Volatility of traded underlying or traded comparables
- Management estimates
- Time series analysis
- Implicit volatilities

Note: A similar representation was suggested by Pritsch [2000, p. 264].

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**E X H I B I T 7**

Calculation of the Real Option Value according to Real Option Toolkit

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**CALCULATION RATIONALE FOR REAL OPTION VALUE OF SemCo.**

1. Compute values of both underlying options independently
2. Dissolve interaction by taking max \([a,b]\) for each end node
3. Compute derivative option value of compound staging option
4. Subtract option acquisition costs of $1 million

---

Staging Option

\[ \begin{array}{c}
\text{\$8 million} \\
\text{[a,b]} \\
\text{[b,a]} \\
\text{[a,b]} \\
\text{[b,a]} \\
\text{[a,b]} \\
\text{[b,a]} \\
\end{array} \]

Liquidation Option

\[ \begin{array}{c}
\text{\$6.5 million} \\
\text{[a,b]} \\
\text{[b,a]} \\
\text{[a,b]} \\
\text{[b,a]} \\
\text{[a,b]} \\
\text{[b,a]} \\
\end{array} \]

\[ \text{max [a,b]} \]

Compound Option

\[ \text{\$6.5 million} \]

\[ \text{Real Option Value} \]

\[ \text{\$7.5 million} \]
WHAT ARE THE IMPLICATIONS?

As the example of SemCo showed, real option analysis offers a significant contribution to decision making in technology driven circumstances. Neglecting it can lead to a striking undervaluation and, thus, a mistaken investment decision. Therefore, the value of real options needs to be included, once two conditions are fulfilled: first, that there is a highly uncertain future, which is a given in most technology related circumstances; and second, that there is a high degree of flexibility for management to adjust the strategy to external changes over time. Those are the key drivers of option value. Nevertheless, the Real Option Toolkit needs to be understood as a complement to, but not a replacement of, the DCF method. If conditions differ, for example if a traditional large corporation is valued, the decision making power added by a real option valuation is not sufficient to justify the effort involved in conducting a quantitative real option analysis.

The Real Option Toolkit is a powerful solution to overcome the pitfalls of technology valuation. While built on a sound theoretical foundation, it uses a clear and simple approach, as demonstrated by its application to the real world investment SemCo.

Looking beyond pure monetary terms, there are substantial managerial implications: real options are not just an advanced valuation model. They provide a well-structured guideline to managers. While any valuation result might be arbitrary to some extent, one thing holds undoubtedly true. Management needs to understand and follow the optimal exercise strategy of the inherent real options in a technology investment to extract their value. Then, and only then, its “option value” can be actively unfolded.

ENDNOTES

Description of SemCo: The valuation case study deals with SemCo. (name changed), which was established as a carve-out venture by a large U.S. based player of the semiconductor industry. SemCo. was meant to extract value of a proprietary technology that had been developed to a first prototype state by its parent company. Since the R&D project behind this technology had been loss bearing, the alternatives were either a complete closure of the unit, or, more favorably, a carve-out to generate cash. The parent company intended to extract additional value with an innovative business design that was rewarded with higher market valuation. Based on preliminary research, the venture’s goal was to develop a proprietary semiconductor packaging technology that provided high performance packaging solutions for next generation integrated circuits. Once developed, this technology (or respectively its intellectual property) could then either be licensed out, or utilized in house by a packaging facility that provided special miniature series IC assembly services to large semiconductor manufacturers. Oliver Wyman’s Private Equity Group was engaged to create the business design and to prepare the vending process of SemCo.

1 Compare to Damodaran [2002, chapter 2] for a good overview of the four basic categories of investment valuation. We introduce a fifth category, “Hybrid Models,” to summarize special blend approaches for the purpose of technology valuation.

2 Event trees and decisions trees follow the idea of binomial trees (see “Binomial Model”), which map the uncertain future value of an asset by allowing for a distinct upward or downward move within a set time period.

3 The Binomial Model presented by Cox, Ross, and Rubinstein [1979] is one of the fundamental pricing techniques for options. Especially in the area of real options, it is clearly advantageous compared to the Nobel Prize winning model developed by Black and Scholes [1973].

4 In case of a DCF valuation, beta-values are commonly inferred from market comparables to determine a market consistent cost of capital. In case of multiples valuation, the known relation of various P&L items (Revenue, EBITIDA etc.) to market value is used to value non-traded assets.

5 Once daily equity return data is obtained for the peer group companies, a simple transformation is needed to obtain an annualized volatility figure to be used as an input parameter for the option valuation model. Since the value of the underlying is supposed to follow a specific stochastic process (i.e., a geometric Brownian Motion), the volatility parameter is obtained as the standard deviation of logarithmic returns. The formula shows how the stochastic movement of the underlying asset is solved for volatility:

\[
V_{n+1} = V_n e^{\mu \sigma\epsilon} \Rightarrow \ln \left( \frac{V_{n+1}}{V_n} \right) = \mu + \sigma\epsilon
\]
Finally, the time-series standard deviation has to be annualized by multiplying it with the square root of the number of data points (observations) per year.

$$\sigma_{\text{annualized}} = \sigma_{\text{periodic}} \sqrt{n}$$

Parameter nomenclature: $V =$ Value of the underlying, $t \to t + 1 =$ Infinitesimal time interval, $\mu =$ Expected return, $\sigma =$ Standard deviation of returns, $\epsilon =$ Error term with $E(\epsilon) = 0$.

The general $n$-step Binomial Model for the value of a call option $C$ is represented by the following formula:

$$C = \sum_{i=0}^{n} \frac{u^i (1-p)^{n-i} \max[0, u^i d^{n-i} - K]}{(1+r)^n}$$

The first part of the numerator of the quotient in this formula represents the binomial distribution formula. It yields the probability for the underlying asset to take $i$ upward jumps over $n$ steps, each with the risk neutral probability $p$. The second part of the numerator represents the value of the call option at maturity contingent upon the underlying following $i$ upward movements (and $n-i$ downward moves) over $n$ steps. Finally, the probability-weighted sum of all terminal option values discounted at the risk free rate over $n$ periods equates to the call option value $C$.

In order to apply the model, the return volatility of the underlying has to be included appropriately. This can be done by determining the parameters $u$ and $d$ by the following approximation:

$$u = e^{\sigma \sqrt{t}}, \quad d = e^{-\sigma \sqrt{t}} = u^{-1}$$

It can be generally stated that the more steps are added assuming a constant time $T$ until the option matures, the more accurate becomes the valuation result. For $n$ approaching infinity (with the incremental time steps $t$ approaching zero) the binomial tree of asset values converges to a geometric Brownian motion. This implies that in the limit, the Binomial Model converges to the analytic model of Black and Scholes [1973].

REFERENCES


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