Risk Practice

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"Option games": filling the hole in the valuation toolkit for strategic investment

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Introduction

Between 1995 and 2001, revenues in U.S. commodity chemicals fell from U.S. $20 billion to $12 billion, while operating profits fell on average by 26 percent a year. The collapse was in large measure caused by a tight economic environment, a rising dollar, and the 2001 terrorist attacks. But that was only part of the story – industry players also made some very poor decisions. Managers were only too eager to invest excess cash in new capacity, fearing that competitors' growth would outpace their own. As the new capacity came on line, it exacerbated the pressures on prices and profitability.

It's a story that regularly plays out in many industries. Indeed, any company making big budget investment decisions faces the same basic dilemma. On the one side they must confront competitive pressures to invest in order to avoid being beaten by rivals. On the other market uncertainty favors keeping investment options open.

As we argue in the following pages, the traditional investment valuation methods do not provide a complete toolkit for resolving the investment dilemma because they do not properly incorporate the impact of competitive moves into the valuation of investment projects under market uncertainty. We present a new valuation tool, recently proposed by Han Smit and Lenos Trigeorgis, that overcomes the shortcomings of those traditional analytic approaches. This new tool, called "Option Games," combines real options and game theory to quantify the values of both commitment and flexibility, allowing managers to make rational choices between alternative investment strategies or structures.

The hole in the valuation toolkit

Discounted cashflow analysis

There are two main corporate valuation methodologies: discounted cash flow analysis (DCF) and real options analysis. DCF is used more commonly, and starts with an estimate of the expected changes in the company's cash flows occasioned by the investment in question. The present values of the forecast changes (determined by using a risk-adjusted discount rate) are then compared to the investment costs to compute the net present value (NPV). If this figure is greater than zero under most plausible scenarios, the investment is approved.

A problem with this approach is that it encourages managers to reduce the cash costs of the investment as much as possible, because the lower the investment costs the higher the NPV. The analysis thus fails to account for the fact that cheap structures are usually inflexible, and in highly volatile and capital-intensive industries, value is present in the ability to adapt, reposition oneself, or withdraw from an investment. The value in this flexibility is not made apparent through DCF, and so this tool is poor guide for managers making the expensive investment decisions these industries are known for.

Real options analysis

To put a value on flexibility, real options analysis must be used. This methodology, based on valuation models developed in the financial sector, allows managers to create a decision tree or lattice, charting the various decisions, ascribing a value and a (risk-adjusted) probability to each of those decisions, and then summing up the values of the various contingent outcomes. The result is a valuation that fully incorporates the value of the right to adjust operations or withdraw from an investment.

Real options analysis certainly improves on the value picture with respect to flexibility, but despite the improvement, standard real options analysis still leaves much of the impact of a company's investment decisions unaccounted for. Large capital-intensive industries are often dominated by large companies with deep pockets, terrified of losing market share. As with commodity chemicals, the investment decisions of these companies have an impact on the market beyond the uncertain external variables. The value of such investments is contingent not only on the evolution of demand and prices in the industry, but also on what additional investments a company and its competitors make. Standard real options analysis usually does not take these decisions into account.

A framework from game theory and a new hybrid model

A framework that could capture the impact of competitors' decisions is based on game theory, developed by John von Neumann and John Nash in the 1940s and 1950s. Using game theory models, managers can incorporate the collective effect on market-clearing prices of other companies expanding their capacity at the same time. One way to do this is to create what is called a payoff matrix that compares the payoffs to Company A and to its competitors under different scenarios – everyone invests, no one invests, Company A invests but its competitors do not, and the competition invests but Company A does not. Unfortunately, the standard calculation of payoffs does not allow managers to factor in uncertainty in key market variables such as prices and demand, nor does it assign any value to a flexible investment strategy, all of which make standard game theory models inadequate as stand-alone valuation tools.

To get around this problem, we have extended and applied a hybrid model developed by Smit and Trigeorgis that overlays the binomial trees of real options analysis, with their ability to model market uncertainty and flexibility, onto the game theory payoff matrices that capture competitive interaction. By this method, managers can model the potential evolution of demand for their product or service as a binomial tree and then draw on that model to calculate the payoffs for each of the four outcomes in the two-by-two matrix. To get a sense of what the payoff calculations involve, we shall look at a disguised and simplified but real example of a mining company considering whether or not to add new mine capacity, while facing demand and competitive uncertainties.

To mine now or wait?

MineCo is planning to open a new mine to expand its capacity to produce fertilizer minerals serving its regional market. If demand in this market exceeds local supply, customers will import from foreign sources, which effectively sets a cap on prices. From MineCo's perspective, there are two key sources of uncertainty: the growth rate of local demand, which has varied in recent years with the country's political economy; and the risk that CompCo, its largest competitor, will invest in a similar project first. Current demand is 2,200 kilotons and the current price (set by imports) is $1,000/ton. The MineCo project involves adding a capacity of 250,000 tons with a cash operating cost of $687/ton (incurred each year the project is up and running) and a capital investment cost of $250/ton (spread over 3 years). The CompCo project faces a cash operating cost of $740/ton annually and a capex of $160/ton. The investments take 3 years to complete. Each firm can decide to invest in Year 0 (with capex in years 0, 1, and 2, and production starting in Year 3), or in Year 3 (with capex to be invested in years 3 to 5 and production in Year 6).

We begin by calculating the stochastic inputs common to all the scenarios in the pay-off matrix: demand evolution and the probabilities of upward and downward shifts in demand. We assume that demand will go up or down by a fixed multiple in each period; in this case, the period is 1 year. We further estimate the size of the up and down moves from historical volatility (5 percent), and also estimate the probabilities of up or down moves. We start with historical data, which we supplement by surveying the company's managers, and adjust for risk. Based on this information, MineCo predicted demand to move up or down by about 5 percent in each period. We estimated the risk-adjusted probability of an upward shift at 30 percent and, therefore, a 70 percent probability of a downward shift. Using this data, we drew a binomial tree that tracks the evolution of demand over the next 6 years and assessed the cumulative probabilities for reaching each node in the tree. The result is shown in Exhibit 1.

Exhibit 1

Demand evolution and probabilities

Demand evolution

Per year in thousands of tons

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
						2970
					2825	
				2687		2687
			2556		2556	
		2431		2431		2431
	2313		2313		2313	
2200		2200		2200		2200
	2093		2093		2093	
		1991		1991		1991
			1894		1894	
				1801		1801
					1713	
						1630

Probabilities of reaching node

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
						0.1%
					0.2%	
				1%		1%
			3%		3%	
		9%		8%		6%
	30%		19%		13%	
100%		42%		26%		19%
	70%		44%		31%	
		49%		41%		32%
			34%		36%	
				24%		30%
					17%	
						12%

Given the estimated demand evolution tree and the probabilities of up and down moves, we now calculate the payoffs for MineCo and CompCo for each of the four scenarios arising from their decision to invest now or wait to decide until Year 3.

Scenario 1: Both companies invest now

If both firms decide to invest now, they will incur capital expenditures in years 0 to 2 and both projects will start producing in Year 3. Given these parameters, we can model how evolution in demand and capacity will affect prices and thereby revenues and profits for each of the two companies.

The first tree in Exhibit 2 (see below) shows how market prices might evolve as a binomial tree. The price at each node is determined by the intersection of demand and supply, and is driven by the cash operating cost of the marginal producer. If demand rises and MineCo or a rival adds capacity at a higher marginal operating cost, local prices will rise. MineCo has a small operating cost advantage (at \$687 vs. \$740/ton) and can enter at a lower level of demand than CompCo. Prices are capped at \$1,000, the cost of imports, once demand exceeds local supply. The cap applies to prices in the upper two nodes in years three and four, and the upper three nodes in years 5 and 6. The total probability of arriving at one of the upper three nodes in Year 6 is around 7 percent (the sum of the cumulative probabilities of reaching each of the nodes as shown in exhibit 1). Given that import parity (at \$1,000) is the only price level at which the two projects recover their full operating and capital costs (of \$937 and \$900/ton, respectively), the firms will likely lose money if they operate at lower prices.

Exhibit 2

Scenario 1: Both firms invest now

Market-clearing prices
(US\$/ton)

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
						1000
					1000	
				1000		1000
			1000		1000	
		1000		740		740
	1000		700		700	
1000		1000		700		700
	1000		700		700	
		1000		687		687
			685		685	
				685		685
					685	
						680

Payoffs for MineCo
(US\$ million)

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
						852819
					78250	
				78250		852819
			78250		78250	
		(20833)		13250		144407
	(20833)		3250		3250	
(20833)		(20833)		3250		35421
	(20833)		3250		3250	
		(20833)		0		0
			(500)		(500)	
				(500)		(5449)
					(500)	
						(19073)

To calculate the payoffs to each firm, we subtract that firm's estimated cash operating costs per ton from the prices at each node for each operating year (if positive), times the demand filled by the added capacity. The resulting payoff tree for MineCo (with added capacity of 250,000 tons) is shown at the lower part in the exhibit. The tree for CompCo is similar (the numbers are little higher on the upside and more negative on the downside). We next weight these numbers by the corresponding node risk-adjusted probabilities and discount those expected payoff values by 5 percent per year (the risk-free interest rate) from the position of the node to the present, which produces a present value at year zero. The estimated project payoff for each firm at year zero is the sum of all the discounted node payoffs for that firm. We finally subtract from those numbers the present value of the capex costs made by each company over the first three years of the project to determine the project's net current payoff value. This exercise gives Scenario 1 an expected current payoff value for MineCo of – $36 million and for CompCo of – $195 million.

Scenario 2: MineCo invests now while CompCo waits

In this scenario, MineCo invests first, giving it the advantage of being the sole producer from years 3 to 6, while CompCo decides to wait until Year 3. If demand evolves favorably by Year 3 the competitor enters; if not, it abandons the project.

We start by looking at the demand and price scenarios in year three, given that MineCo has invested and CompCo so far has not. This exercise reveals four possible Year 3 nodes scenarios. At each of these four nodes we determine the market-clearing prices and payoffs to each player that would ensue from Year 4 to Year 6 if CompCo invests in Year 3, in essentially the same way as we did in Scenario 1. We then weight the various payoffs by the associated probabilities (cumulated forward starting from each demand scenario from year three) and discount them back to Year 3. The results of these calculations provide four pairs of pay-off values corresponding to each of the four nodes in Year 3 as shown in Exhibit 3.

Assuming that CompCo is a rational investor, it becomes clear that CompCo will not invest in Year 3 unless its payoff value is positive. This would only be true in the top node, where demand evolution from Year 3 is high enough to accommodate a second entrant, giving CompCo a positive payoff of $71 million upon entry in Year 3. At all the other demand nodes CompCo will have a negative payoff, which means that it will not invest, preferring a zero payoff to a negative one. Knowing this will obviously change the payoffs to MineCo, which we now recalculate on the assumption that CompCo will not invest in all but the top demand nodes. These payoffs are shown in the next-to-last column in Exhibit 3 (see following page).

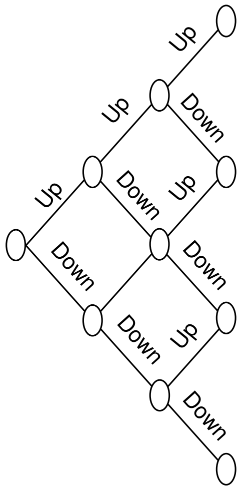
We finally weight these four demand-contingent payoff values according to the probabilities associated with the Year-3 demand nodes (as determined earlier) and discount them back to Year 0. For MineCo, the expected payoff value at Year 0 is ($328 MM x 3% + $263 MM x 19% – $6 MM x 44% – $64 MM x 34%) / (1 + 0.05)3, which yields $34 million. For CompCo we have ($71 MM x 3% +$0 x 19% + $0 x 44% + $0 x 34%)/(1.05)3 which gives about $2 million.

Exhibit 3

Scenario 2: MineCo invests now and CompCo waits until Year 3

Evolution of demand to Year 3

Y0 Y1 Y2 Y3



Probability of reaching node (Y3)	Competitor's decision (Y3)	Expected value of payoffs in Y3 U.S. $ millions	Payoffs if both invest now (Y0) U.S. $ millions
3%	CompCo decides to invest	• **MineCo = 328** • CompCo = 71	• **MineCo = 262** • CompCo = 185
19%	**CompCo abandons project**	• **MineCo = 263** • CompCo = ∅	• **MineCo = 5** • CompCo = -142
44%	**CompCo abandons project**	• **MineCo = -6** • CompCo = ∅	• **MineCo = -48** • CompCo = -211
34%	**CompCo abandons project**	• **MineCo = -64** • CompCo = ∅	• **MineCo = -66** • CompCo = -234

Scenario 3: CompCo invests now while MineCo waits

Scenario 3 is estimated in the same way as Scenario 2, only with MineCo as the follower. The expected Year 0 payoffs are U.S. $ 4 million for MineCo and –$83 million for CompCo.

Scenario 4: Both companies wait

For each of the four possible demand nodes in Year 3, we need to consider four competitive decision sub-scenarios: both firms investing in Year 3, MineCo only investing in Year 3, CompCo only investing in Year 3, and both abandoning. We thus have 16 sub-scenarios, each with its own 3-year market-clearing price tree. The market price at each node, as ever, is based on the demand evolution (captured by the demand tree) and on total industry capacity, which varies depending on how many players add capacity (e.g., the Year 3 investment decisions of MineCo and CompCo).

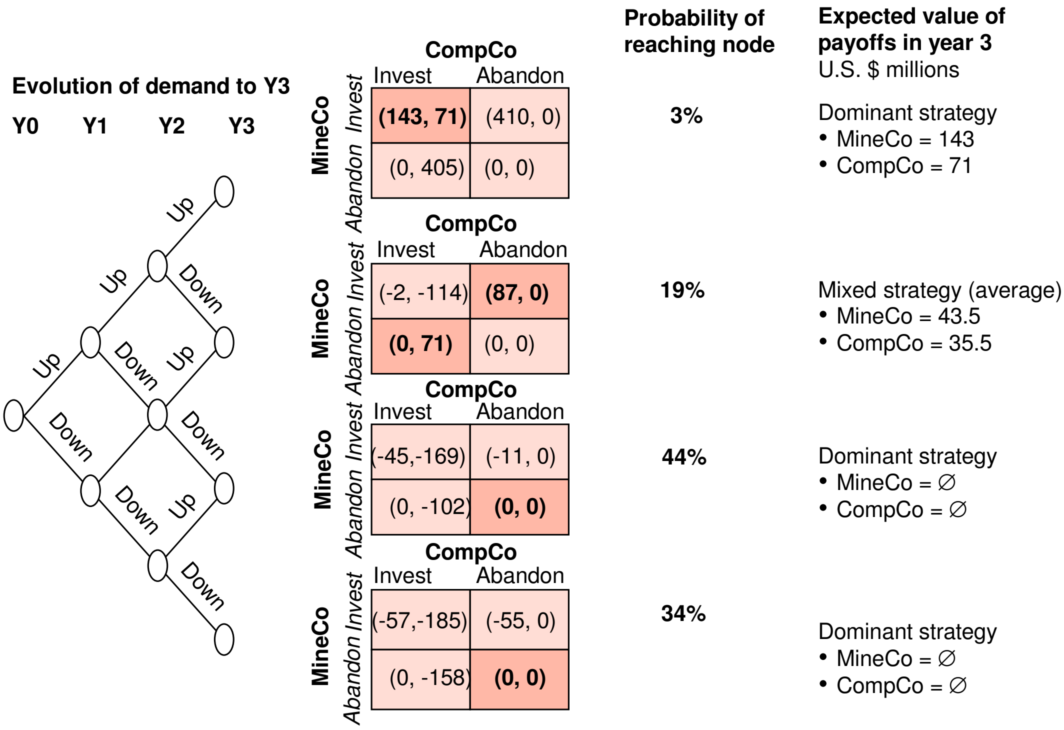
Consider the upper demand node in Year 3 as an example. In the first sub-scenario both firms invest from Year 3 to Year 5 and both enter in Year 6. We already know the potential demand nodes from Year 3 to 6, so we can calculate prevailing prices and payoffs in Year 3 in the same way that we did in Scenario 1, only with a 3-year forward tree rather than a 6-year tree. This exercise results in payoffs of U.S. $143 million for MineCo and $71 million for CompCo.

We perform similar exercises to calculate the payoffs in the remaining three sub-scenarios, with a firm not investing receiving a zero payoff and the firm investing receiving payoffs determined by demand evolution and industry capacity.

We present all payoffs in a series of two-by-two game matrices, one for each demand node in Year 3, as shown in the Exhibit 4. We then identify what in game theory parlance are called "Nash Equilibria" – outcomes from which neither player has an incentive to deviate. In the top demand node, for example, we see that both players will find it optimal to invest in that year (receiving 143 and 71, respectively). MineCo cannot do better since the alternative (abandoning) would entail a lower (zero) payoff whatever CompCo does; CompCo reaches the same conclusion. The remaining three 2 x 2 matrices are similarly analyzed to find Nash Equilibria for each of the three other demand nodes in Year 3.

Exhibit 4

Scenario 4: Both firms wait until Year 3 to make decision



At three nodes (the top and the two lower ones), there is a clear single (pure) equilibrium. In one node (the second), we have two points of equilibrium. There are theories about how to determine which of the two equilibria should be favored, but for the purposes of simplicity we here suppose that the players are roughly symmetric, and that each equilibrium has a 50 percent chance of prevailing. Thus each player will choose one strategy 50 percent of the time and the other the remaining 50 percent. The resulting expected payoffs from the two mixed equilibria, therefore, are simply the average of the payoffs associated with each equilibrium for each player (e.g., 0.5 x $87 million + 0.5 x $0 = 43.5 for MineCo).

We now bring the equilibrium payoffs for each demand node back to Year 0 weighting with the corresponding probabilities for each Year-3 demand node and discounting back for 3 years at the risk-free rate. This result yields an expected current payoff value for MineCo of U.S. $12 million (($143 MM x 3% + $43.5 MM x 19% + $0 x 44% + $0 x 34%) / $(1.05)^3$). For CompCo the payoff is $8 million.

Having analyzed the four different strategic scenarios one at a time, we now put them together into a time-zero payoff matrix for a final decision, as shown in Exhibit 5. We see that Scenario 2, in which MineCo invests now and CompCo waits, is a Nash Equilibrium scenario (34, 2), as no player has an incentive to deviate from the associated strategy choices. MineCo cannot do better: if it decides to wait as well, moving to Scenario 4, MineCo would get U.S. $12 million instead of $34 million. CompCo can do no better either: if it decides to invest now as well, moving to Scenario 1, it will receive a negative payoff of –$195 million. The optimal decision for MineCo, therefore, is to invest at once.

Exhibit 5

Integrating all 4 strategic scenarios in a game matrix for final decision

Expected net present value of payoffs in each strategic scenario
U.S. $ Millions

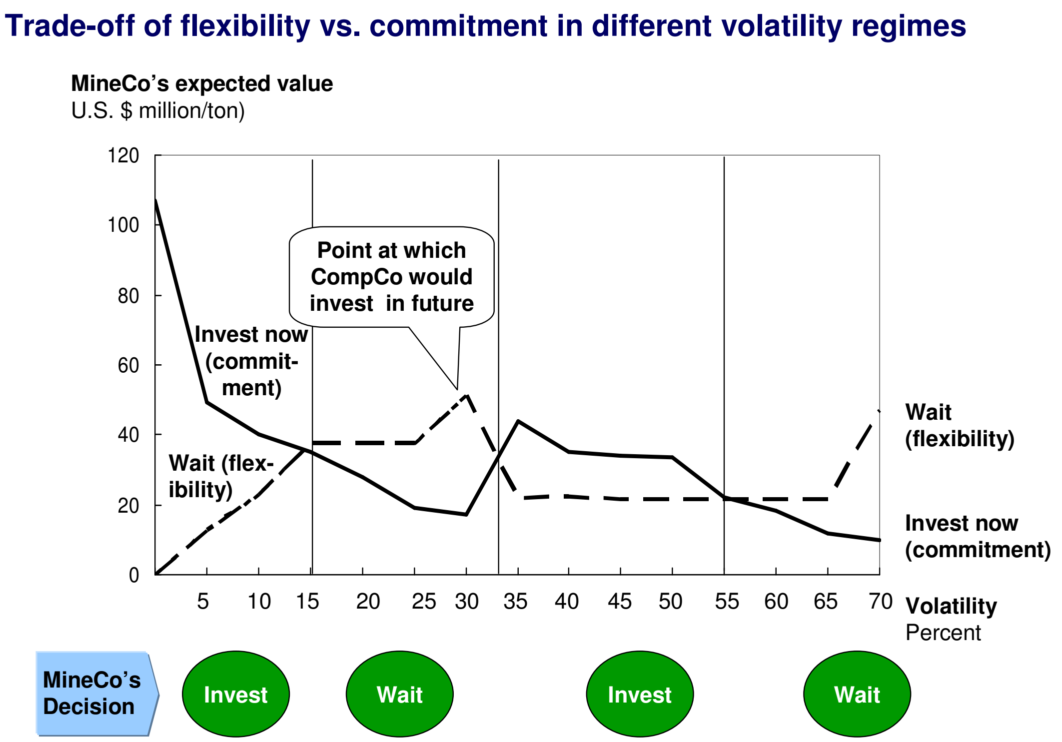
		CompCo	
		Invest	***Wait***
MineCo	***Invest***	1 (–36, –195)	2 **(34, 2)**
	Wait	3 (4, –83)	4 (12, 8)

Based on a standard real options analysis, MineCo might have delayed its investment for the wait-and-see value. Given the data, a standard NPV analysis based on the assumption that MineCo invested now and the competition never enters would have indicated a stand-alone value for the project of $41 million. A conventional real option calculation using the same data would have indicated that delaying the project would add $8.5 million in flexibility value to that number. With the benefit of the foregoing analysis we can see that the flexibility effect was more than outweighed by the strategic commitment effect – the differential or savings from avoiding competitive value erosion – which represented some $30 million in value.

A sensitive strategic tool

As with any valuation exercise, it pays to run a sensitivity or "what if" analysis. Here the power of the analysis and the strategic insights really become apparent. For example, since a key assumption underlying demand evolution is demand volatility, we ran the option games analysis under a set of different volatility assumptions which essentially involved creating different demand evolution trees. Exhibit 6 summarizes the impact of the different volatility assumptions on the value of flexibility and the strategic commitment value of investing at once – and therefore on what investment decision MineCo should make.

Exhibit 6



For demand volatility below 15 percent MineCo is better off investing now as there is little flexibility value in waiting in a market with relatively low uncertainty levels. With volatility of between 15 and 35 percent, however, MineCo is better off waiting for volatility to become high enough to make low demand scenarios in the future likely, increasing the value of flexibility.

Investment commitment once again becomes predominant as volatility rises to 35 to 55 percent, even though there is increasing positive value in flexibility. This is so because at 35 percent volatility and above, CompCo will find it optimal to invest if MineCo delays. That additional capacity investment will change industry structure and decrease market-clearing prices, eroding MineCo's flexibility value (hence the sudden drop in the dotted line representing MinCo's flexibility value). This is the volatility range on which our case was focused. Though there is still option value in waiting, there is a higher value for MineCo to preempt the entry of CompCo above the 35 percent volatility level (shown in the rising solid line).

Finally, from 55 percent volatility upwards, both firms are better off waiting (the dotted line for MineCo rises again). Market uncertainty in this range is so high that the risk of falling to very unfavorable future demand scenarios is substantial. Therefore, both players would benefit from a "wait and see" strategy.

* * *

As a strategic tool, "option games" is clearly suited to companies operating in capital-intensive, oligopolistic markets with a history of demand volatility. But it can provide valuable insight in almost any investment decision-making setting. It could help a divisional manager think through major capacity additions or new product development projects. It can also guide corporate leaders as they address investment allocation decisions across divisions, make strategic acquisitions, or enter new volatile growth markets, such as China. In each setting, option games can help top managers think a little harder and more deeply about the trade-off between flexibility and strategic commitment, and allow the right questions on investment choices, contingent scenarios and competitive dynamics to emerge.

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