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The Key to Competing in Capital-Intensive Industries

by Nelson Ferreira, Jayanti Kar, and
Lenos Trigeorgis

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Between 1995 and 2001, annual revenues for the U.S. commodity chemicals industry fell from $20 billion to $12 billion, while companies' operating profits fell on average by 26% a year. The collapse was in large measure caused by a tight economic environment and a rising dollar. But outside forces were 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 online, 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 hand, it must make timely, strategic investments to prevent rivals from gaining ground. On the other, it must avoid tying up too much cash in risky projects, especially during times of market uncertainty. The traditional valuation methods—namely, discounted cash flow and real options—fall short in resolving this dilemma. Neither of them, on its own, properly incorporates the impact of demand and price volatility on an industry while also taking into account additional investments that the firm and its competitors may make. We present here a valuation tool recently developed by Han Smit and Lenos Trigeorgis that overcomes the shortcomings of those analytic approaches. The tool, called "option games," combines real options (which relies on the evolution of prices and demand) and game theory (which captures competitors' moves) to quantify the value of flexibility and commitment, allowing managers to make rational choices between alternative investment strategies. Option games will be of particular value to companies facing high-stakes decisions, involving millions of dollars in capital investment, in a volatile environment in which their moves and those of their competitors clearly affect each other.

An Incomplete Tool Kit

Of the two methods managers rely on to

value corporate projects—discounted cash flow analysis and real options analysis—DCF is by far the most common. It starts with an estimate of the expected changes in the company's cash flows occasioned by the investment in question. The present value of the forecast changes (determined by using a risk-adjusted discount rate) is then compared with the investment costs to compute a net present value (NPV). If this is greater than zero under most plausible scenarios, the investment gets the nod.

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 catch is, cheap structures are usually inflexible, and if you're in a highly volatile and capital-intensive industry, the ability to adapt, reposition yourself, or withdraw from an investment has value that is not made apparent through DCF.

To put a value on flexibility, you have to use real options analysis. This methodology allows managers to create a decision tree that charts possible decision points, ascribes a value and a (risk-adjusted) probability to each of those points, and then sums up the values of the various contingent outcomes. By taking into account likely changes in price and demand, the real options approach yields a valuation that fully incorporates the value of the flexibility to adjust operations or withdraw from an investment.

Although an improvement, standard real options analysis still won't get you where you need to be. Mature, capital-intensive industries tend to be dominated by large companies with deep pockets, terrified of losing market share, as was the case in our commodity chemicals example. The investment decisions of these companies have an impact on the market beyond the external uncertain variables. So the value of a company's investment is contingent not only on the evolution of demand and prices in its industry but also on what additional investments it and its competitors make. Standard real options analysis does not take these factors into account.

The traditional framework that attempts to 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 (prices at which the quantity demanded equals the quantity supplied) of other companies that are expanding their capacity at the same time. Typically, the way to do this is to create what is called a payoff matrix, which compares your payoffs with those of a competitor under different scenarios. Unfortunately, the standard calculation of payoffs does not allow managers to factor in uncertainty for key market variables such as prices and demand, nor does it assign any value to a flexible investment strategy.

To get around this problem, we use a hybrid model that overlays real options binomial trees onto game theory payoff matrices. First, we model the potential evolution of demand for our product or service. We draw on those data as inputs to calculate the payoffs for each of four scenarios—everyone invests, no one invests, you invest but your competitor doesn't, and your competitor invests but you don't. Finally, we input the payoff values for each of the four strategic scenarios into a time-zero payoff matrix to determine the optimal decision.

To get a sense of what the payoff calculations involve, let's look at a disguised and simplified but real example of a mining company considering whether or not to add new capacity in the face of demand and competitive uncertainties.

To Mine or Not to Mine?

MineCo is planning to open a new mine to expand its capacity to produce minerals for its regional market. In this market, if demand 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 shifts in the country's political economy, and the risk that CompCo, its largest competitor, will invest in a similar project first. The current demand is 2,200,000 tons and the current price (set by imports) is $1,000 per ton.

The MineCo project involves adding 250,000 tons of capacity at a cash operating cost of $687 per ton (incurred each year the project is up and running) and a capital expenditure of

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$250 per ton, spread over three years. The CompCo project faces cash operating costs of $740 per ton annually, projected capacity of 320,000 tons, and a capex of $150 per ton, also spread over three years. The investments take three years to complete, and both new mines have a lifespan of 17 years. For the purposes of simplicity, we assume that each firm can decide to invest in Y0 (with capex in Y0, Y1, and Y2 and production starting in Y3) or in Y3 (with capex to be invested in Y3, Y4, and Y5 and production starting in Y6).

We begin by calculating the inputs that will serve as the basis for determining payoff values for each of the scenarios: 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 a year). Using historical data and surveys of the company's managers, we predict demand will move up or down by about 5% in each period. We estimate the risk-adjusted probability of an upward shift in each period at 30% (therefore, a 70% probability of a downward shift in each period). Next, we input these data into a binomial tree that tracks the evolution of demand over the next six years and overlay it with a tree that tracks the cumulative probabilities at each node in the demand tree (see the exhibit "Demand Evolution and Probability Tree"). We will refer to this tree throughout the analysis.

Now let's calculate the payoffs for MineCo and CompCo for each of the four scenarios arising from their decisions to invest now or wait until year three to decide.

Scenario 1: Both Companies Invest Now

If both firms decide to invest now, they will incur capital expenditures in Y0, Y1, and Y2, and both projects will start producing in Y3. Given this, we can model how evolution in demand and capacity will affect prices and thereby revenues and profits for each of the two companies.

First, we create a binomial tree showing how market prices might evolve (see the exhibit "Scenario 1: Both Companies Invest Now"). The price at each node is determined by demand and supply, driven by the cash operating cost of the marginal producer (the producer just barely able to remain profitable at current levels of price and demand). If demand rises and MineCo or its competitor adds capacity at a higher marginal operating cost, local prices will rise.

To calculate the annual operating profits at each node for each firm, we subtract that firm's estimated annual cash operating costs per ton from the prices at each node for each operating year and multiply that number by the demand filled by the added capacity, estimated over the remaining life of the project. To illustrate, at the upper demand node in Y5, MineCo gets a margin of $313 (the $1,000 price less its cost of $687) per ton, which for 250,000 tons of added capacity represents $78,250,000. In Y6 nodes, we have to add in the terminal value, which is an estimated present value of cash flows for the remaining 14 years of the mine's useful life. To calculate this, we assume that price and demand remain constant subsequently and apply the standard discounting formula, which gives us a terminal value of $774,569,000. We add that to the Y6 annual operating profit (again, $78,250,000), and get a total value for the upper node in Y6 of $852,819,000. The resulting tree for MineCo (with the added capacity of 250,000 tons) is shown in the second column of the exhibit. The tree for CompCo is similar (but not shown here)—the numbers are a little higher on the upside and more negative on the downside.

Our final step is to weight the numbers at each node by the corresponding risk-adjusted probability (from the demand tree) and discount those expected payoff values by 5% per year (the risk-free interest rate) back from the position of the node to the present.

We then sum up these numbers—the weighted, discounted annual operating profits at each node plus the terminal value—and subtract from that sum the present value of the annual capex investments made by each company. This gives us the net current payoff value, or final payoff value, for each company under scenario 1: For MineCo the expected payoff in Y0 is –$36 million; for CompCo, –$195 million. If both firms invest now, both lose money.

Scenario 2: MineCo Invests Now, While CompCo Waits

In this scenario, MineCo invests first, giving it the advantage of being the sole producer from Y3 to Y6, while CompCo waits until Y3 to

Idea in Brief

- Any company making big-budget investment decisions must balance competitive pressures to commit to investments against the flexibility of keeping investment options open.
- Traditional investment valuation methods do not provide a complete tool kit for resolving this dilemma.
- Option games is a new valuation tool that combines real options and game theory to quantify the values of commitment and flexibility, allowing managers to make rational investment decisions.

decide whether to invest. If demand evolves favorably, CompCo enters in Y3; if not, it abandons the project.

We begin the valuation by calculating the market-clearing prices from Y0 through Y3, using the demand tree and given the fact that MineCo has invested in extra capacity and CompCo so far has not. Next, we calculate how prices will evolve from Y3 through Y6. As we see in the exhibit, there are four possible Y3 scenarios, each with an associated probability of occurrence (see demand tree). At each of the nodes, we determine the market-clearing prices, operating profits, and terminal value for each firm assuming that CompCo does invest in Y3. In other words, for each of the four scenarios, we create a three-year binomial tree (Y4, Y5, and Y6) showing what the annual operating profits plus terminal value would look like at each node if CompCo were to invest then.

Next, for each Y3 scenario, we weight the node values by the demand probabilities for Y4, Y5, and Y6 and discount the values back to Y0, taking into account the NPV of CompCo's investment costs (Y3 through Y5) and MineCo's (Y0 through Y3). The result is four pairs of expected Y0 net payoff values: $71 million for the upper demand node in Y3, and –$114 million, –$169 million, and –$185 million for the other three nodes.

As a rational investor, CompCo will not invest in Y3 unless its payoff value is positive, which is only the case in the top node where demand evolution from Y3 is high enough to accommodate a second entrant. At all the other demand nodes, CompCo will abandon the project, preferring a payoff of zero to losing money.

We thus recalculate the operating profits plus terminal value for both companies, based on the assumption that CompCo will not invest in any but the top demand node. These expected net Y0 payoffs for MineCo and Comp-Co (taking into account the investment costs incurred in Y0 through Y2 for MineCo in each subscenario and in Y3 through Y5 for CompCo in the uppermost subscenario) are shown in the last column in the exhibit.

We finally weight these four pairs of Y0 payoff values according to the probabilities associated with the Y3 demand nodes. We arrive at the final payoff for each company by summing up the four weighted, discounted payoff numbers. For MineCo, the expected final payoff at Y0 is ($328 million × 3%) + ($263 million × 19%) + (–$6 million × 44%) + (–$64 million × 34%), which yields $35 million. For CompCo,

Demand Evolution and Probability Tree

We begin our analysis of MineCo's investment options by creating a binomial tree that shows the evolution of annual demand over the next six years and the associated cumulative probabilities of reaching each demand level in the tree. Demand is assumed to go up or down by a fixed multiple (about 5%). The probability of an upward shift is estimated to be 30% in each period, whereas the probability of a downward shift is estimated to be 70%. As shown here, the probability that annual demand will reach the highest Year 6 node, 2,970,000 tons, is 0.1%.

Demand Evolution and Probabilities

(in thousands of tons)

Y0	Y1	Y2	Y3	Y4	Y5	Y6
						2,970 **0.1%**
					2,825 **0.2%**	
				2,687 **1%**		2,687 **1%**
			2,556 **3%**		2,556 **2.8%**	
		2,431 **9%**		2,431 **8%**		2,431 **6%**
	2,313 **30%**		2,313 **19%**		2,313 **13.2%**	
2,200 **100%**		2,200 **42%**		2,200 **26%**		2,200 **18.5%**
	2,093 **70%**		2,093 **44%**		2,093 **30.9%**	
		1,991 **49%**		1,991 **41%**		1,991 **32.4%**
			1,894 **34%**		1,894 **36%**	
				1,801 **24%**		1,801 **30.3%**
					1,713 **16.8%**	
						1,630 **11.8%**

Scenario 1: Both Companies Invest Now

The first tree below shows how market-clearing prices might evolve (given the evolution of demand and capacity) if MineCo and its rival CompCo decide to invest in more capacity now. The price at each node is determined by the intersection of demand and supply, driven by the operating cost of the marginal producer. At the top nodes, prices are capped at $1,000, which is the price to customers of imports once demand exceeds local supply. The second tree shows the evolution of resulting annual profits for MineCo, given the added capacity of 250,000 tons. The values at the end nodes incorporate the terminal value from operating the mine beyond year six.

Market-clearing prices
(US$/ton)

Y 0	Y 1	Y 2	Y 3	Y 4	Y 5	Y 6
						1,000
					1,000	
				1,000		1,000
			1,000		1,000	
		1,000		740		740
	1,000		700		700	
1,000		1,000		700		700
	1,000		700		700	
		1,000		687		687
			685		685	
				685		685
					685	
						680

Annual operating profits for MineCo
(US$ thousands)

Y 0	Y 1	Y 2	Y 3	Y 4	Y 5	Y 6 *
						852,819
					78,250	
				78,250		852,819
			78,250		78,250	
		–20,833		13,250		144,407
	–20,833		3,250		3,250	
–20,833		–20,833		3,250		35,421
	–20,833		3,250		3,250	
		–20,833		0		0
			–500		–500	
				–500		–5,449
					–500	
						–19,073

* includes terminal value

To arrive at the final payoff value for each firm, we weight the annual operating profits at each node (28 nodes in total) by the corresponding risk-adjusted probability and discount those values by 5% per year (the risk-free interest rate) back from the position of each node to the present. We then add up all these numbers and subtract from that sum the present value of the annual capex investments made by the company.

Final expected payoff in Y0: MineCo, –$36 million; CompCo, –$195 million.

the expected final payoff at Y0 is ($71 million × 3%) + ($0 × 19%) + ($0 × 44%) + ($0 × 34%), which yields about $2 million.

Scenario 3: CompCo Invests Now, While MineCo Waits

This is estimated in the same way as scenario 2, but with MineCo as the follower. The final payoffs are $4 million for MineCo and –$83 million for CompCo.

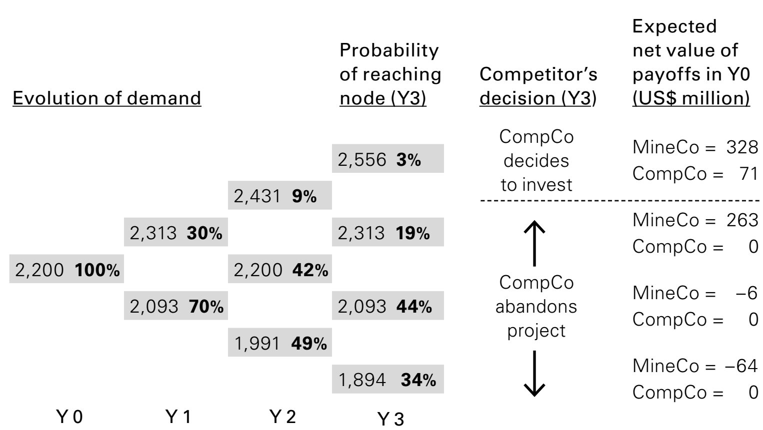
Scenario 4: Both Companies Wait

In the last scenario, where both firms wait until Y3 to decide whether to invest, we start by looking at the four possible demand nodes in Y3 (see the exhibit "Scenario 4: Both Companies Wait to Decide"). For each, we need to consider four subscenarios: both firms investing in Y3, only MineCo investing in Y3, only CompCo investing in Y3, and both abandoning. We thus have 16 subscenarios, each with its own three-year market-clearing price evolution tree. The 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 the Y3 investment decisions of MineCo and CompCo.

Let's take the upper demand node in Y3 as an example. In the first sub-scenario, both firms invest from Y3 to Y5 and enter in Y6. We calculate the expected net Y0 payoffs in the same way we did in scenario 1 but with a three-year tree, weighting annual operating profit plus terminal value, discounting back to Y0, and subtracting net present capex costs. For the upper demand node, this results in Y0 net expected payoffs of $143 million for MineCo and $71 million for CompCo. We perform similar exercises to calculate the expected net Y0 payoffs in the remaining three subscenarios, with the firm not investing

Scenarios 2 and 3: One Company Invests, the Other Waits

If MineCo invests in extra capacity now while CompCo waits until Y3 to decide and demand has evolved favorably (rising every year) by Y3, CompCo will decide to also invest. If demand does not look that favorable, CompCo will abandon the project (receiving a payoff of zero). Four possible Y3 scenarios result, each with an associated probability. At every node we determine the payoffs to both players from Y4 to Y6, weight them by the associated probabilities, and discount back to Y0. This results in four pairs of expected payoff values for each node, shown in the last column. The final step for each firm is to weight the four Y0 payoff values according to the probabilities associated with the Y3 demand nodes. We then sum up the four weighted, discounted payoff numbers to arrive at the final payoffs.



Scenario 2 final expected payoff in Y0: MineCo, $35 million; CompCo, $2 million.

The final payoff for scenario 3 is estimated in the same way as in scenario 2, but with MineCo as the follower.

Scenario 3 final expected payoff in Y0: MineCo, $4 million; CompCo, –$83 million.

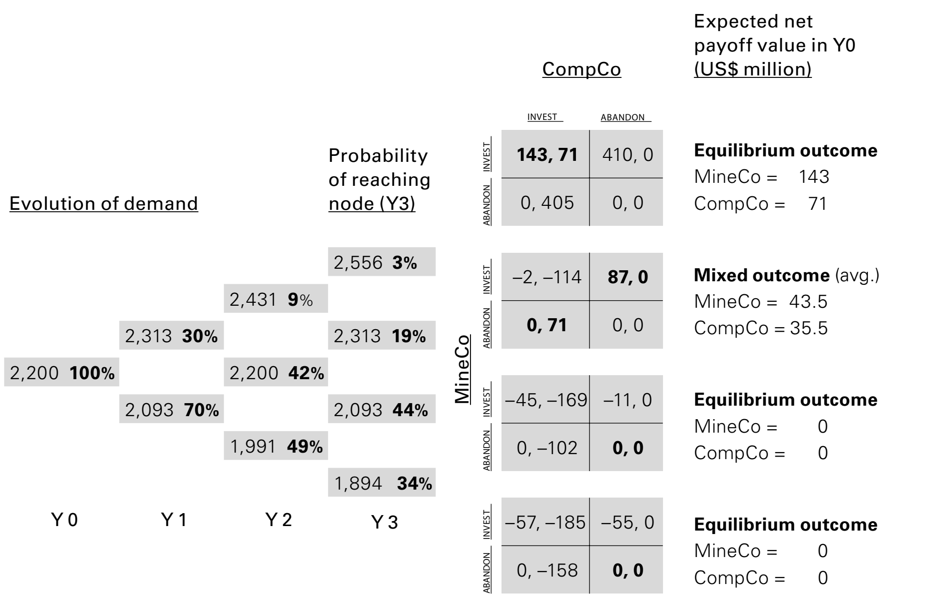
receiving a zero payoff and the firm investing receiving payoffs determined by demand evolution and industry capacity. This exercise is then repeated for the remaining three sets of subscenarios.

We present all expected net Y0 payoffs in a series of two-by-two game matrices, one for each demand node in Y3, which is when decisions are made. 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 MineCo and CompCo will find it optimal to invest in that year (receiving $143 million and $71 million, 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 two-by-two matrices are similarly analyzed to find Nash equilibria.

At three nodes (the top and the lower two) there is a single (pure) equilibrium. In one (the second), we have two. There are theories about how to determine which of two equilibria one should favor, but for the purposes of simplicity we suppose here that the companies are roughly symmetrical such that there is an equal chance that either equilibrium will prevail; in other words, each player will choose one strategy 50% of the time and the other the remaining 50%. The resulting expected payoffs from the two mixed equilibria, therefore, are simply the average of the payoffs associated with each equilibrium for each player. For MineCo, the expected net Y0

Scenario 4: Both Companies Wait to Decide

In this scenario, there are four subscenarios for each of the four Y3 demand nodes: Both firms invest in Y3, only MineCo invests, only CompCo invests, and both abandon. This results in 16 subscenarios, each with its own three-year market-clearing price evolution tree. For each subscenario we determine the Y0 payoff value for each firm. We present all payoffs in two-by-two game matrices, one for each demand node in Y3. We then identify equilibrium outcomes—those from which neither player has an incentive to deviate. (Where there are two equilibrium outcomes, we take the average.) These values are the Y0 payoffs to be used in the final payoff calculation.



The final step here is to weight the four pairs of Y0 payoff values from the last column according to the probabilities associated with the Y3 demand nodes. We subtract the net present capex costs from these numbers and then sum up the four weighted, discounted payoff numbers.

Final expected payoff in Y0: MineCo, $12 million; CompCo, $8 million.

payoff for the node is (0.5 × $87 million) + (0.5 × $0), which yields $43.5 million.

Finally, we weight these four pairs of net Y0 payoff values according to the probabilities associated with the Y3 demand nodes. We arrive at the final payoff for each company by summing up the four weighted, discounted payoff numbers. This yields an expected net Y0 payoff value for MineCo of $12 million [($143 million × 3%) + ($43.5 million × 19%) + ($0 × 44%) + ($0 × 34%)]. For CompCo the payoff is $8 million.

How Do the Results Stack Up?

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 the exhibit "Comparing the Payoffs." We see that scenario 2 (MineCo invests now and CompCo waits) is a Nash equilibrium scenario, 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, it will get $12 million instead of $35 million). CompCo cannot do better either (if it decides to invest now as well, moving to scenario 1, it will lose $195 million). The optimal decision for MineCo, therefore, is to invest at once.

Comparing the Payoffs

Having analyzed the four strategic scenarios one at a time, we now put them together into a time-zero payoff matrix for a final decision. Scenario 2 (MineCo invests now, receiving $35 million, and CompCo waits, obtaining an option value of $2 million) is the dominant scenario, as neither player has an incentive to deviate from the associated strategy choices. The optimal decision for MineCo is to invest at once.

		CompCo	
		INVEST	WAIT
MineCo	INVEST	SCENARIO 1 –36, –195	SCENARIO 2 **35, 2**
	WAIT	SCENARIO 3 4, –83	SCENARIO 4 12, 8

US$ millions

How does this recommendation compare with the traditional valuation methods? Given the data, a standard NPV analysis (assuming MineCo invests now and the competition never enters) would have indicated values for the project of $41 million for MineCo and $13 million for CompCo. This would suggest that both companies should invest immediately, with disastrous results. A conventional real options calculation using the same data would have indicated that delaying the project would add $8.5 million in flexibility value to the NPV number for MineCo and $5 million for CompCo. This would suggest that both should delay, which, although not disastrous, would still misrepresent value for both players. With the benefit of an option games analysis, each player can see how the flexibility and commitment trade-off works out for it. In MineCo's case, the flexibility value from delaying is more than outweighed by the commitment value created by investing now, whereas CompCo is better off waiting.

A Sensitive Strategic Tool

As with any valuation exercise, it pays to run a sensitivity, or "what if," analysis, and it is when we do this that the power of the tool and the strategic insights come out. For example, since a key assumption underlying demand evolution is demand volatility, we ran the option games analysis again under a set of different volatility assumptions (which essentially involves creating different demand evolution trees).

The exercise revealed that for demand volatility below 15% MineCo is better off investing now, as there is little flexibility value in waiting in a market with a relatively low level of uncertainty. From 15% to 35%, however, MineCo is better off waiting, as volatility becomes high enough to make low demand scenarios in the future likely, increasing the value of flexibility.

From 35% to 55% volatility, even though the value of flexibility increases, investment commitment once again becomes predominant. That's because beginning with 35% volatility, CompCo will find it optimal to invest if MineCo delays. The additional capacity will change industry structure and decrease market-clearing prices, eroding MineCo's flexibility value. Even though there is still option value in waiting, there is a higher value in MineCo's preempting the entry of CompCo above the 35% volatility level.

Finally, at volatility levels of 55% and above, both firms are better off waiting (as the value of flexibility for MineCo rises again). Market uncertainty in this range is so high that the risk of falling prey to very unfavorable future demand scenarios is substantial. Therefore, both players would benefit from a wait-and-see strategy.

• • •

Option gaming is clearly suited to companies in capital-intensive, oligopolistic markets facing considerable demand volatility. But it can provide valuable insight in almost any setting. It can help a divisional manager think through capacity investments or new product development projects. It can also guide corporate leaders as they seek to allocate investments across divisions, make strategic acquisitions, or enter volatile growth markets. In each case, it will help you think a little harder about the trade-off between flexibility and strategic commitment and force you to ask the right questions about investment choices, contingent scenarios, and competitive dynamics.

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