A REAL OPTIONS PERSPECTIVE ON SUPPLY CHAIN MANAGEMENT IN HIGH TECHNOLOGY[1]

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Over three decades ago, Gordon Moore, one of the founders of Intel, observed that computer processing power doubles approximately every 18 months. "Moore's Law" has proved highly accurate to date—and thanks to ongoing advances in semiconductor design and manufacturing techniques, the pace of change shows no sign of slowing over at least the next decade. This exponential pace, coupled with intense competition, presents risks and challenges to technology companies, particularly in the design and delivery of successful products in highly volatile and rapidly changing markets.

Among the greatest risks confronting today's high-tech manufacturers is the unprecedented degree of uncertainty about both demand for the product and supply of the key inputs. Product demand is extremely difficult to predict, even in the short-term, because of uncertainty about the market acceptance of new products, changes in technology and technological standards, changes in competitors' offerings, and fluctuations in discretionary spending on high-tech products. If demand is higher than expected, the company may forgo profit on unmet demand, including the cost of damaged relationships and future market opportunities. But if demand is lower than expected, inventory will accumulate, which is especially costly given the short life cycle of products in this industry.

There is both price and volume uncertainty on the supply side as well. In-house manufacturing capacity may be insufficient to meet demand, and it can take up to two years to bring additional capacity online for products such as semiconductors. In the case of manufacturing capacity and components that are outsourced, there is uncertainty about the assurance of supply and level of pricing. And a shortfall in the supply of critical components can be very costly. For example, in July 1999, Agilent's stock price dropped by about 25% when the company's inability to obtain key components resulted in a sharp drop in revenue. Price risk can also have a huge impact on firm value. In October 1999, Dell Computer suffered a $470 million earnings shortfall from the effect of DRAM prices on gross margins, which triggered a 13% drop in its stock price.

Of course, the high-tech industry is not alone in being forced to cope with uncertainty about inputs and outputs. Indeed, for most industries undergoing major change in technology or market structure, the ability to manage—and even profit from—such uncertainty is increasingly recognized as a key source of comparative advantage and shareholder value. Moreover, the growing importance of coordinating supply and demand in high tech bears a striking resemblance to a challenge that financial services companies have been addressing for years—namely, managing the risk from potential mismatches between their assets and liabilities.

1. Some content from this article also appears in a forthcoming book chapter entitled "Creating and Leveraging Options in the High Technology Supply Chain" (by B. Johnson and C. Billington), to appear in *The Practice of Supply Chain Management* (publisher?).

Many of the first, and most successful, adopters of sophisticated models and methods for managing uncertainty have been commercial and investment banks with large portfolios of assets and liabilities whose values are tied to financial variables such as interest rates, foreign exchange rates, and stock prices. These banks design specially tailored option-based products and strategies to retail and institutional clients that exploit the presence of uncertainty in financial markets, and use quantitative models for measuring and hedging their residual risk exposures.

In high technology and most other industries, the development of sophisticated quantitative processes for managing and exploiting uncertainty is in a relatively early stage. This is perhaps due to the lack of well-developed markets to trade relevant commodities for immediate (spot) or future delivery, or the relative absence of expertise in designing and trading contracts or in implementing other business processes to support risk management. Nonetheless, there are many companies now actively adopting innovative approaches to creating value by managing uncertainty. Some of these new management approaches have been developed to deal with one-time major decisions such as the launch of a new product, the adoption of a new business model, or collaboration with a new corporate partner. Others focus on managing day-to-day uncertainty in the supply chain related to procurement, manufacturing, and sales.

In this article, we focus on creative approaches to managing uncertainty and creating value that are being adopted in the high-tech manufacturing industry, particularly with regard to the management of supply chains. There are several characteristics of the high-tech industry that make it interesting to explore.

- First, short product life cycles, rapid technological change, and increasingly slim profit margins that result from heated competition within the industry all work together to create significant risk exposures.
- Second, the key uncertainties in this industry, as in many other industries, are the supply of inputs and the demand for products—as opposed to financial risks, which are easier to measure and more straightforward to hedge.
- Third, the high-tech industry has undergone a transformation in which the large expenditures on R&D and manufacturing capacity—and the risks associated with them—are now distributed across companies at different stages of the value chain. By outsourcing the assembly of products to Electronic Manufacturing Services companies (EMSs) and the capital-intensive manufacturing of semiconductors to semiconductor manufacturing foundries, high-tech companies have sharpened their focus on activities like new product design, marketing, and distribution. Outsourcing has also led to increased flexibility to to exploit uncertainty on both the supply and demand ends of the supply chain.
- Fourth, the move away from vertical integration has introduced the need for procurement and sales contracts, and it is increasingly common to find options embedded into these contracts, as companies shift particular risks to other companies in the supply chain that are better able to bear them. Finally, as in other industries that have become vertically "de-integrated," spot and derivatives markets for inputs and outputs have emerged, often on Internet platforms.

But if the high-tech industry provides a good backdrop for exploring the integration of risk management and real options into corporate strategy, the ideas presented here apply to many other industries. Some of these ideas have already been implemented in commodity-based industries such as mining and agriculture. Other developments that parallel those in high-tech manufacturing can be found in heavy manufacturing industries, such as aircraft or automobiles, and in industries where vertical integration is giving way to specialization across the various segments of the value chain, such as electric power and, more recently, pharmaceuticals. For all these industries, capabilities and business processes must be developed to support risk management and the exploitation of uncertainty in much the same way that these capabilities and processes have evolved in the financial services industry.

We begin by discussing how a company's strategic positioning within its industry, its business model, and the design of its supply chain will all define the portfolio of subsequent operating options available to the company. We show that the value of these options will be driven not only by the timing of various decisions within the supply chain, but also by the scope, or diversity, of alternatives in procurement, manufacturing, and sales, and the flexibility to manage them at low cost. We also stress that, in addition to creating valuable operating options through innovative supply chain design, contractual options can be embedded into procurement and sales agreements to further manage risk. We argue that quantitative techniques should be used to value contracts with embedded options as well as to optimize the portfolio of operating and contractual options. The optimization typically involves assessing tradeoffs across several metrics over time, including metrics that focus explicitly on risk. In addition to the development of quantitative processes and skills, the abilities to negotiate contracts, monitor performance, and create smooth cross-functional integration of processes have all become critical competencies for managing risk in the supply chain.

CREATING VALUE BY EXPLOITING UNCERTAINTY

Uncertainty can be exploited to create value if a company can find ways to mitigate "downside" risk while preserving the "upside" effects of uncertainty. If such real options can be created at costs below their value, not only is a company's risk exposure decreased, but shareholder value is directly enhanced through a lower cost structure or higher revenue stream.

Real options can be created, and the value of existing options enhanced, by redesigning investment and operating strategies along two key dimensions: timing and scope. On the temporal dimension, options are created by postponing investment or operating decisions in order to make them in as "informed" a way as possible. In options parlance, the longer the maturity of the option, the more valuable it is. Since the activities that precede product introduction or determine subsequent product availability cannot be delayed indefinitely, the postponement strategy often involves breaking up a decision into a sequence of stages, so that more information can be brought to bear on later-stage decisions.

The scope dimension involves introducing an array of choices, such as different product configurations or suppliers, which creates an option to choose what turns out to be the value-maximizing alternative in the future. The more alternatives there are, the more valuable the option will be at its exercise date—though the incremental benefit of introducing more alternatives declines as the set of alternatives increases. Since it is costly for a company to provide and manage many alternatives—and for customers to process information about all the alternatives—a company will continue to increase the number of future alternatives until the derived expected value from an additional alternative no longer exceeds the associated cost.

There are many examples where high-tech companies have redesigned both the timing and scope of their supply chain decisions to create valuable real options in response to demand and supply uncertainty. We categorize these real options as being primarily linked to, or driven by, either sales, manufacturing, or procurement, though the design and exercise of many of these options typically require coordination across these three stages of the supply chain.

Sales Options

Starting upstream with sales, a diverse set of product choices can be offered to consumers. For instance, Hewlett Packard offers "branded announced" (standard products available under the HP brand name), "branded specials" (HP brand products that are discounted, for instance, to take pressure off demand for branded announced products that are facing shortages), and "second brand" (product configurations that HP doesn't wish to offer under its primary brand). This selection creates consumer value by providing choice, but it also gives HP a valuable option in that the company can respond with flexible pricing and availability once it observes demand for these products and, in so doing, maximize revenue across products.

One way in which product offerings can be greatly broadened is through the build-to-order model, in which a company informs customers what products and features are available, and at what cost, and then asks customers to specify the configuration of the particular products they wish to purchase. This model, which was pioneered by Gateway and Dell, may again appear to be placing options entirely in the hands of customers in that they choose how to configure the products they purchase. But, as we will explain shortly, most of the option value accrues to the company in that it can postpone procurement of its components until a sale is made, at which point all uncertainty is resolved. Furthermore, the company can dynamically price individual components based on current inventories or availability from the supplier, and thereby implicitly manage demand to match supply and maximize profit. This option thus derives its value by managing across the entire supply chain, from procurement to sale.

From a real options perspective, one can view the management of the end-to-end supply chain as maximizing the value of a series of "spread options" across time that span suppliers, manufacturing and distribution capacity, sales channels, and customers. The spread is the difference between the price at which the company is able to sell a product with a particular configuration and the cost of delivering the product.[2] The option involves a choice between one of several possible alternatives. While the customers ultimately exercise the options in the sense that they choose a specific product configuration, the customers' choices take place only after the company has exercised its own discretion in making particular components available at prices that reflect real-time procurement information as well as customers' needs and tastes.[3] Furthermore, since pricing is set dynamically based on procurement cost and availability schedules, and the quantity of demand is known precisely before supply is ordered, the company is able not only to optimize its profit, but to eliminate virtually all risk stemming from uncertainty about demand and supply.

For HP, the build-to-order direct-to-customer model involves HP (or a reseller like Staples) communicating information about the required components to its suppliers as soon as a sale is completed. HP requires its suppliers to keep inventory at or near HP's factories at their own risk (since uncertainty about demand is not completely resolved) and expense (the supplier bears the carrying costs). HP avoids the risks associated with purchasing the wrong components, purchasing components in the wrong amounts, building the wrong products, or building products in the wrong amounts.

While HP preserves its flexibility in this manner, the efficiency of this model hinges on the ability of HP's suppliers, such as component suppliers and EMS firms, to manage inventory, production, and capacity at a lower cost than HP can manage inventory and product demand. This efficiency comes from the pooling of demand across customers, and is enhanced by improvements in the quality and timeliness of information about the number and types of products that require the relevant component of manufacturing capability.

The shifting of the burden of inventory from companies such as HP to component suppliers and EMS firms is somewhat analogous to the relationship between insurance and reinsurance companies in the financial services industry. Inventory is in fact a form of insurance, a costly real option that pays off in periods of high demand, but expires worthless in periods of low demand. As an option, the expected cost of inventory increases with the degree of volatility (of demand), and can be a significant drain on profitability in periods of high economic uncertainty. However, the component suppliers and EMS firms, by being able to diversify some of the demand fluctuations across customers of their different supply chain partners, can effectively reduce volatility and thus the cost of insurance, much the way reinsurance companies increase efficiency in the insurance industry.

Manufacturing Options

Turning to manufacturing and assembly, the keys to creating real option value are again postponement or staging (timing), as well as the introduction of new alternatives (scope). Postponement allows products to be tailored to current customer requirements while maintaining relatively small finished goods inventories. For instance, a partly complete PC system (processor, hard drive, and chip set) can be produced in high volumes at a central location and then shipped to distribution centers closer to the customer demand points. Based on more accurate real-time regional demand forecasts, or actual realized demand, the distribution centers can then add the appropriate additional hardware (such as a graphics chip or type of power supply) and software options (e.g., in a foreign language). The accompanying exhibit "Creating Valuable Real Options at HP" describes how HP successfully redesigned their DeskJetPlus printer assembly operations so that final customization occurred as late as possible, and in a foreign location close to customers.

2. Spread options are commonly discussed in industries such as electric power ("spark spread") and refining ("crack spread"). While the concept is essentially the same as what we discuss above, power and refining companies take as exogenous a particular menu of input and output prices (which reflect current demand and supply conditions), and optimize their profit by buying and selling specific mixes of inputs and outputs at these market prices. In our high-tech example, demand enters the picture somewhat more explicitly in that consumers select particular configurations based on a price and availability schedule set by the company.

3. There are various advantages to modularity in product design and assembly. Customers benefit from choosing their own configuration of various components, and firms can create value through designing flexibility into their systems. For an in-depth discussion of the advantages of modularity, see Carliss Baldwin and Kim Clark, *Design Rules: The Power of Modularity* (Cambridge, Mass.: The MIT Press, 2000).

Creating Valuable Real Options at HP

In the mid 1990s, the worldwide supply of HP's DeskJetPlus printers was produced in Vancouver, Washington, and distributed through four regional distribution centers located in North America, Europe, Latin America, and Asia. Because the product was sold in virtually every country on every continent, substantial customization was required, including configuration to local voltage and plug conventions and manuals printed in the appropriate language. Initially, all of this "localization" activity was done at the printer factory in Vancouver.

In order to meet customer demand with a high level of availability, HP considered a range of regional inventory and logistics options, including air vs. ocean shipping. In comparison, a postponement strategy that transferred the "localization" step in the product assembly process from the factory to the distribution centers proved to be substantially more efficient.

To implement the new strategy, HP determined the optimal inventory levels at each distribution center as a function of the length and variability of the lead time to replenish the center from the factory, and the level and variability of demand at the center. Implementation of this postponement strategy reduced total inventory investment in the supply chain by 18%. Postponement reduced shipping costs as well, since printers were shipped in bulk from the factory to the distribution centers, where they were placed in individual packages after being localized. Finally, the strategy substantially increased the "local content" of the product, creating a collaborative presence for HP and reducing taxes and tariffs. All told, the real option created by HP's restructuring of its assembly process has produced in excess of 100 $million of savings, and has led to a greater awareness of the ability to create valuable options within the company wherever uncertainty is significant and can be exploited.

While reconfiguring a manufacturing process can be quite costly, this cost is frequently more than offset by the option value it creates, particularly if there is a large set of different end products that customers can choose from. In effect, an even more costly real option—inventory—is largely replaced by careful staging of the manufacturing process. Broadening the customers' choice set becomes a viable and profitable endeavor. Of course, the more uncertain the demand, the more the real option will create value, particularly in comparison with the high inventory levels that would be required to prevent product shortfalls.

A real option that focuses more clearly on the breadth or diversity dimension is "dual-response" manufacturing. As in many other industries, flexibility in high-tech manufacturing can be obtained by creating a set of alternative types of capacity or processes. These processes may differ in terms of fixed cost, variable cost, throughput, or lead time. For instance, a high-volume process with high fixed costs but low variable costs can be used as base capacity to satisfy a large component of expected demand. If demand exceeds this base level, additional capacity with lower fixed but higher variable costs can then be brought on to manage such short-term fluctuations.

A low-volume, higher cost (more manual) process can also be employed to produce the initial product volumes required to support the launch of a product a company wishes to speed to market. It can also be initially used for a product with uncertain prospects for success, without committing the substantial capital needed to build or otherwise secure high-volume capacity. If the product's likely success is established, the company can then invest in the lower-cost process.

Another way to balance capacities is to use similar processes located in regions with different economic characteristics. For instance, HP for several years combined a high-volume, low-cost production facility in Singapore with a higher-cost, shorter-lead-time facility in Vancouver, Washington in order to supply inkjet printers to the North American market.[4] Locating some of the production close to end markets

4. HP has recently moved substantial production to Guadalajara, Mexico to take advantage of both new manufacturing resources and proximity to the primary demand points in North America.

cuts down on lead time, and thus the company can delay manufacturing to more closely match demand. In option terms, the maturity date of the company's options to produce can be extended to make it closer to the sales date. While the exercise price (cost of production) may be higher, this may be more than offset by the option's longer maturity date, particularly when uncertainty is great. An optimal portfolio of capacity choices can be designed to include optionality to the extent that it adds value to the total portfolio, which will depend on factors such as variability of demand, production costs, reliability, and lead times.

Procurement Options

Companies can also create value through flexibility by designing a procurement strategy that allows for a spectrum of alternatives, both in terms of supply chain partners and types of contracts. For instance, a long-term contract that meets a defined fraction of expected demand could be coupled with short-term flexible contracts that have higher unit prices but guaranteed availability to cover short-term demand fluctuations. These structured contracts, which may be either long-term or short-term in nature and provide defined levels of commitment and risk sharing between two parties, contrast with more conventional, less structured, relationship-based procurement contracts in which commitment and risk sharing are dealt with more informally.

When structured contracts allow for flexibility in the choice of quantity purchased at each date, the purchaser has effectively bought an option from its supply chain partner. Depending on the bargaining power of the two parties, this embedded option in the contract is "purchased" for a price somewhere between the supplier's effective cost of providing flexibility and the value that the purchaser places on this flexibility.[5] Since EMSs are able to diversify across their customers' demand risk, they are able to provide flexible sourcing arrangements at attractive prices to their customers. Even if the supplier has strong bargaining power, and the effective price of the option equals its value to the purchaser (so that there may not appear to be direct NPV gains from entering into such a contract), the purchaser still benefits from a reduction in its risk exposure.

Efficient spot markets offer flexibility in the sense of providing the ability to immediately purchase or sell a commodity. But, of course, there is no preset price and, in the case of high-tech components, no assurance of availability. While at present there are few active spot markets in technology components and most procurement is still done under relationship-based contracts, this is beginning to change with the emergence of electronic marketplaces and sales channels. For example, in May 1999, HP launched an electronic marketplace focusing on component parts and finished goods, which has since developed into a multi-company electronic exchange called the "high-tech marketplace," or converge.com.[6] Spot markets have also now evolved for trading memory chips, other hardware components, and even manufacturing capacity.

Companies can thus now efficiently use spot markets when managing their procurement portfolios. While most transactions by companies such as HP involve purchases, these companies may also choose to (re)sell the components typically offered by their supply chain partners. This is most likely motivated by the need to reduce excess inventories created by weaker than expected demand for one or more of its products. On occasion, however, companies may choose to "overbuy" components to benefit from volume discounts, or may find that in certain environments the components they hold may be more valuable than the products they are able to build with them. These transactions can be thought of as the exercise of abandonment options, where the market values components for their alternative uses more highly than the company does for the specific products it is able to build with them.

FORMALIZING RISK MANAGEMENT

The various supply chain options introduced above focus primarily on creating value by managing temporary imbalances in demand and supply. The greater this uncertainty, the greater the value that can typically be created by restructuring procurement, manufacturing, and sales in ways designed to create new revenue opportunities, avoid lost sales, and pare down excess inventories. These restructuring decisions, which often involve significant up-front

5. For a discussion of natural versus contractual real options, see John Stonier and Alexander J. Triantis, "Natural and Contractual Real Options: The Case of Aircraft Delivery Options," in *Real Options Applications*, ed. A. Micalizzi and L. Trigeorgis, (Milan: Bocconi University Press), 1999, 159-195.

6. Real-time pricing for over 100 hardware components can be found at "Pricing Trends" on converge.com.

investment or establishment of new relationships, are key strategic decisions that are made relatively infrequently. In many cases, such decisions are difficult to make since it is not clear that the value of the options they create exceeds the cost required to reconfigure the firm's processes.

Managing the resulting portfolio of options is also by no means straightforward, for at least the following four reasons. First, unlike one-time strategic real options, there is a large number of operating options that mature daily (if not more frequently). Second, the exercise decisions can be quite complex since there are often many possible alternatives to choose from at the exercise date (e.g., types and volumes of configurations). Third, a company's operating options often interact with each other in complex ways. For instance, the option to sell off excess supply in spot markets affects the procurement decision by providing reversibility at potentially favorable terms. Fourth, even if all real option opportunities are seized to manage demand and supply uncertainty, the company may still face significant risk exposure, not only from residual fluctuations in demand and supply imbalances but also from price uncertainty. It may be possible to manage these residual risks by designing a portfolio of procurement contracts.

Given the large number of real options associated with the supply chain, and their complex interactions, quantitative techniques need to be used to arrive at optimal exercise (operating) decisions, as well as to assess the overall impact of the option portfolio on the value and risk exposure of the company. These techniques, and the information required as inputs, have much in common with quantitative processes that have been implemented at financial corporations (and many commodity-based companies) that hold and trade large portfolios of financial derivatives. We describe such a process below, focusing on the procurement end of the supply chain.

First, an objective must be clearly established. Each company must develop a policy that makes explicit tradeoffs between increases in value (or, equivalently, reductions in cost) and decreases in the level of risk exposure. This is somewhat analogous to a desired risk-return profile for a portfolio of financial investments. This would allow comparison of, for example, a sourcing portfolio with a low average per unit component cost but large exposure to demand fluctuations and a portfolio involving structured contracts that can assure supply to match most demand scenarios but leads to a higher average cost per unit. Unlike financial or commodity markets, where the cost and risk associated with trade-offs of this kind can be readily calculated using market pricing benchmarks, the analyis of such costs and risks in the supply chain requires estimates of the lost sales revenue and potential damage to customer relationships likely to result from shortages of varying magnitudes, and of the costs and risks of varying levels of inventories of specialized products and materials.

Once there is a clear objective for the supply chain management program, the company should try to determine what forms of procurement are most likely to help it satisfy this objective, and what terms and pricing potential suppliers are likely to provide. As discussed earlier, procurement choices include long-term relationships, structured contracts, and spot markets.

Contracts can be structured with regards to price, volume, and service. On the price dimension, there could be payment provisions such as flexible prices with floors and ceilings, payments linked to market prices (such as discounted market-price agreements), fixed payments for specified time periods or throughout the duration of the contract, and even payments linked to other indices such as foreign exchange rates. Volume provisions typically involve minimum and maximum quantities that can be purchased each period, either determined at the time of contracting or reset during the life of the contract (e.g., a buyer may be given the right to adjust the quantity purchased by 10% either up or down relative to last month's purchases, 25% relative to the prior period, etc.). Terms regarding service typically involve commitments to specified lead times and other delivery terms, liabilities, and payments, including prepayments, investments, or non-recurring engineering costs.

Once suppliers have been contacted for indications on pricing and terms, the different procurement portfolios can be formally evaluated. Simulation, optimization, and methods of determining optimal option exercise can be used to analyze the performance of the various portfolios under a wide range of scenarios. This requires specifying the distribution of key variables such as the demand for different product configurations, the supply of key materials, and the availability of necessary manufacturing resources over time. Outputs of the analysis include optimal operating policies and associated key performance metrics, such as the distribution of total sourcing cost, which reflects inventory-related costs, per-unit component costs, and costs associated with shortages (lost revenues). Each procurement portfolio produces a different trade-off between the costs and risks of material purchases, inventory, and shortages; and different supply agreements and portfolios of supply agreements can be compared based on the company's trade-off between risk exposure and value creation across these performance dimensions.

Once an evaluation of alternatives is complete, the most attractive agreements or contracts are executed. Over time, the supplier's performance in satisfying the terms of the contract must be monitored. In addition, the performance of the procurement strategy should be evaluated in terms of its ability to meet the company's objective. The process of managing the procurement strategy is a dynamic one, involving new contracts as well as potential renegotiation of existing contracts. This is particularly true because of rapidly changing conditions in product and component markets as well as the frequency of new product introductions, both of which are likely to continue. Where available, spot markets, which are used to smooth out short-term excess supply or demand, can be scanned using automated tools for current pricing to ensure that the portfolio reflects current market conditions. This applies not only to procurement of technology components, but also to other inputs such as electricity and labor.

While we have used procurement to illustrate the portfolio management process, this type of process can also be used on the sales end of the supply chain. Just as the company may be trying to optimize a procurement portfolio combining long-term "forward" contracts, shorter-term contracts with embedded options, and spot market transactions, a portfolio mix also needs to be selected in offering products and services targeted to different customer profiles. For instance, there may be corporate clients that are looking for the lowest price and are willing to wait or to buy substitute products, and others who prefer to lock in a fixed quantity at a preset price, even if they end up paying more than the prevailing future market price. Similarly, some retail customers wish to pick from a small set of standard products and will not tolerate long lead times to delivery, while others are more patient, but insist on customization.

NEW CAPABILITIES IN EMERGING BUSINESS MODELS

The combination of the rapidly increasing breadth and depth of markets for technology components, manufacturing services, and products, and the associated rapidly decreasing cost of acquiring, altering, and replacing operating options in the technology industry is generating dramatic changes in the characteristics of the real options portfolios available to technology firms. These changes are making it possible for technology firms to be both more efficient and more responsive to market opportunities, allowing them to deliver products with shorter life cycles and rapidly changing configurations in flexible volumes at competitive prices.

What trends are we likely to continue seeing in the high-tech industry and in other industries undergoing similar transformations? What organizational challenges will companies in these industries face as they adapt their business processes to these new trends in order to fully benefit from them? And how can the companies undergoing these transformations learn from experiences in the financial services and commodities industries?

New Business Models

First, the trend towards outsourcing appears to be continuing, which is creating innovative and specialized business models. EMSs and semiconductor manufacturing foundries (such as Taiwan Semicondutor Manufacturing Company and United Microelectronics Company) have introduced efficiency into the system by diversifying demand (pooling risks), thus reducing the amount of inventory and capacity buffer stock required, and by capturing economies of scale in process technology and capacity investments. Other companies have instead invested in developing specialized processes or technical expertise, including IP/design companies such as ARM, MIPS, and Rambus, as well as fab-less semiconductor companies such as Xylinx, Altera, and Nvidia.

All of these new business models involve significant risk at the outset, as companies seek to exploit narrow areas of opportunity by identifying and leveraging particular operating options for competitive advantage. Over time, they are being proven and their scope of application has widened considerably, much as HP's early movement to the contract manufacturing model and Dell's development of the build-to-order model have met with success.

The scale achieved by focused outsourcing service providers allows them to justify the cost of developing the high levels of process, technical, and other expertise required to optimize production efficiency and quality, and to specialize in other areas such as product development, supply chain design, and risk management. Thus, significant investments in staffing, professional development, processes, and infrastructure to execute these activities not only can be justified, but may prove necessary to compete. Making these investments early and consistently over time can in fact create a sustainable competitive advantage, since the resulting capabilities take time to develop, requiring refinement and organizational acceptance.

New Performance Metrics

In order to facilitate the transformation to new business models, new metrics for measuring individual and system performance and for providing controls are required. For example, while a senior manager responsible for manufacturing in an established technology firm today may have 20 years of experience in managing manufacturing operations, he or she may no longer actually manage any manufacturing operations at all. Instead, the day may be spent negotiating, contracting, and trading with external manufacturing partners and suppliers. It is clearly inappropriate for this manager's performance to be based on metrics such as return on assets or per-unit cost that have been designed to measure the efficiency of internal manufacturing processes and that ignore the importance of risk and flexibility.

To reflect the firm's current dynamic contracting and trading-based methods of doing business, performance metrics that address risk and flexibility—or, in supply chain terms, the costs and risks of not having the right products in the right places at the right times—must be used to complement existing measures of expected performance. A clear specification of performance objectives and constraints is generally more complex when risk and flexibility measures are included. For instance, under metrics frameworks driven by ROA or per-unit cost, the appropriate objective is clearly to increase ROA or reduce per unit cost. In contrast, when metrics that capture risk and flexibility are introduced, appropriate compensation for accepting risk and acceptable cost levels for increasing flexibility must be specified.

An example of a simple measure in the procurement context that incorporates both risk and flexibility is a metric called "total sourcing cost." This metric is defined as the cost of material plus the cost of inventory (the cost of having too much) and the cost of shortages (the cost of having too little). If structured contracts are used to reduce inventory and shortage costs by securing additional flexibility at a somewhat higher per-unit cost, the resulting change in total sourcing cost can be used to evaluate the net economic impact of this decision on the company. Similarly, if material cost and availability risk can be reduced by making a material purchase commitment, the change in the expected value and the distribution of total sourcing cost at various points in the future can be used to evaluate the desirability and appropriate size of such a commitment. Similar measures can be constructed for other dimensions of supply chain performance.

Given that the distribution of supply and demand imbalances depends on the distribution of each of these variables as well as their correlation, uncertainty about these variables directly affects the expected total cost measure. It is also important to track the standard deviation of total cost separately and to evaluate trade-offs between the mean and volatility of this measure based on the company's objectives. (Alternatively, specific percentile values of the probability distribution of the chosen performance metric can be used, much in the way that value-at-risk (VaR) measures are presently used in the financial industry.)

While including risk measures in performance measurement and control systems is clearly crucial if risk is to be quantified and managed, doing so presents a substantial challenge in an environment where risk, while always present, has not been explicitly addressed. This transition can be facilitated with a combination of risk management training for current staff and the gradual introduction of risk management techniques for key business risks. Both steps may initially be led by external experts in risk, working either as consultants or as new staff members recruited from industries where such practices are well established. Such a migration of people and ideas has recently taken place in the electric power industry, for example, where risk management techniques and experts have been used to set up trading operations and help manage portfolios of physical assets.

Procurement Risk Management at HP

For HP, as for many other high-tech companies, there are three key uncertainties that need to be measured and managed on the procurement end of the supply chain: the demand, availability, and prices of various inputs, which for HP include memory chips, LCD displays, and scanner assemblies. In order to cut procurement costs and decrease the variability of those costs, HP has aggressively developed and implemented a risk management program that involves new structured derivative-type contracts for these inputs, and in turn has required several fundamental changes in HP's business processes.

To begin with, a systematic analytic process was developed to optimize HP's value-risk objectives for the procurement portfolio. Proprietary software (HPRisk) is now used to examine the impact of different mixes of fixed and flexible quantity contracts (each of which may have caps, floors, or other structured price features) on expected cost and percentile cost levels. A scenario forecasting module feeds into the optimization program to provide distributions of demand, availability, and price, and these are updated through time based on newly collected data. HP's web-enabled software also supports the valuation, monitoring, and management of its contracts.

While the new software supports the sourcing function, HP recognized the need to change the metrics it uses to evaluate a buyer's performance in order to properly align incentives with value creation. In the past, performance measures would compare purchase prices to prices in previous periods instead of benchmarking to market prices. Also, buyers who paid a premium to purchase components in short supply were penalized rather than rewarded for the value created by filling an order that would otherwise have been lost. By developing measures of total cost that combine material cost together with expected storage and shortage costs, uncertainty is properly accounted for, and incentives can lead to value-enhancing performance.

These and other changes to the procurement management process have required significant development efforts, not to mention considerable resources allocated to subsequent training and implementation. However, the benefits of a formalized procurement risk management program at HP have been very tangible—anywhere from 2% to 25% in cost savings, depending on the commodity being sourced, which have translated into savings well in excess of $15 million to date. The volatility of the resulting margins on sales has also dropped significantly. Moreover, the demonstrated success to date on a handful of components is now starting to affect many other components (or inputs such as energy) as the new risk-based procurement systems spread throughout the organization.

New Information Infrastructure Needs

On the infrastructure side, new IT and software systems are required to enable the quantification and management of risk, to manage the execution of operational options, to facilitate internal coordination, and to exchange information with supply chain partners. Since uncertainty related to demand and supply forecasts is at the very core of new operational designs, incorporating uncertainty into operational processes and the supporting software infrastructure is imperative. It also requires a paradigm shift of sorts in the sense that, to properly model and manage a company's "spread options," managers must move away from the mentality of trying to match *expected* demand and supply, and become comfortable thinking about ranges of scenarios.

While this information and software infrastructure allows for increased operational efficiency–better execution of operating options and better management of the company's operational risk exposure–it also allows for better internal coordination with other functional areas such as finance and accounting. As with banks, the finance, control, audit, and reporting functions must be well integrated with the underlying operational structures. Information from various units should be easily transferred upwards in the organization, and rolled up in an enterprise-wise fashion. Similarly, information about business objectives and risk exposures and other metrics needs to be seamlessly fed back down the organization to impact execution and performance.

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The shift from vertical integration to outsourcing creates a loss of direct access to information and integrated control throughout the entire supply chain. As a result, in the past at least, some of the expected gains from outsourcing have failed to materialize due to the lack of accurate and shared information. A flexible supply chain can respond efficiently to real-time changes in the cost, quantity, or mix of products that the market demands only if there is accurate real-time information about supply and demand conditions. Drawing on the analogy of flexibility as an option, an option's value reflects the quality of the available information about the underlying asset insofar as this determines the ability to exercise the option effectively.

Similarly, in the past, the problem of limited or unreliable information has also been compounded by the strategic behavior of supply chain participants in their use of proprietary information. This behavior has led to the magnification of boom and bust cycles in product manufacturing and availability as firms over-order when concerned about potentially short supply and cancel orders when they expect a product may experience excess supply and therefore become available at a lower price. This "bullwhip" effect on production plans, inventories, and profitability can be quite significant.[7] For example, despite real-time order visibility, Cisco wrote down $2.5 billion in inventory in April 2001 as a result of over-orders by customers who canceled once product availability constraints subsided.

The emerging methods for managing risk in the supply chain—which includes allocating risk to the supply chain partner best able to manage that risk—should substantially reduce the costs of limited or unreliable information exchange across the supply chain. Specifically, the same structure in supply chain relationships that allows the effective management of risks associated with prices, quantities, or lead times should also ensure that the information about these key dimensions of supply-chain partner performance that is communicated across the supply chain is clearly specified and made credible by well-defined supporting business commitments. As a result, the customers of outsourced service providers will have access to better information about the performance expectations of their own customers and the allocation of risk between parties. And suppliers will receive well-defined guidance as to both the willingness of their customers to commit to specific purchases and the nature and extent of their requirements for procurement flexibility.

THE DAWN OF FINANCIAL ENGINEERING IN SUPPLY CHAIN MANAGEMENT

Companies and entire industries have transformed as information technology has improved the quality of and access to information. Efficiency has been gained through outsourcing specific functions, and through structuring flexible contracts with suppliers and customers. Supply chain management is increasingly viewed not as a set of tactical decisions, but rather as a key element of corporate strategy. The financial implications of improving the efficiency of the supply chain are significant for many companies, particularly those that are increasingly becoming virtual organizations by eschewing large investments in physical capital. The resulting set of real options related to sourcing, manufacturing, and sales must be carefully managed to extract maximum value out of future uncertainties.

While the examples in this article are drawn from the technology industry, there are clear parallels in other industries. The role of improved information flows and supply chain management, the application of real options techniques, and the integration of a firm's business processes with emerging business-to-business marketplaces all offer opportunities for substantial improvements in performance, both within firms and among the networks of firms that enable products to be delivered to market. The performance of companies in all these industries will increasingly depend on their ability to quantify risk and value flexibility, as well as to manage risk and flexibility effectively through innovative relationships with their supply chain partners. The tools and lessons of financial engineering need to be adapted to these new environments, and embodied in new products and services that enable these emerging capabilities.

Similar transformations have already occurred in more traditional commodity-based industries, such as energy, metals, chemicals, or agriculture,

7. See H. Lee, V. Padmanabhan and S. Whang, 1997, "The Bullwhip Effect in Supply Chains," *Sloan Management Review.*

where companies purchase primary inputs or sell primary outputs in active markets. As the technology industry, along with other industries, moves towards being more commodity-based, expertise in manufacturing facilities investment and processes—critical competencies of technology firms in the past—will become more peripheral, while expertise in market analysis, contracting, trading, and risk management will become increasingly central to the success of these firms. Companies that develop those competencies will be well positioned to create significant value for their shareholders over the long run.

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