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McKinsey on Semiconductors

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Highlights

McKinsey on Semiconductors is written by experts and practitioners in McKinsey & Company's Semiconductors Practice along with other McKinsey colleagues.

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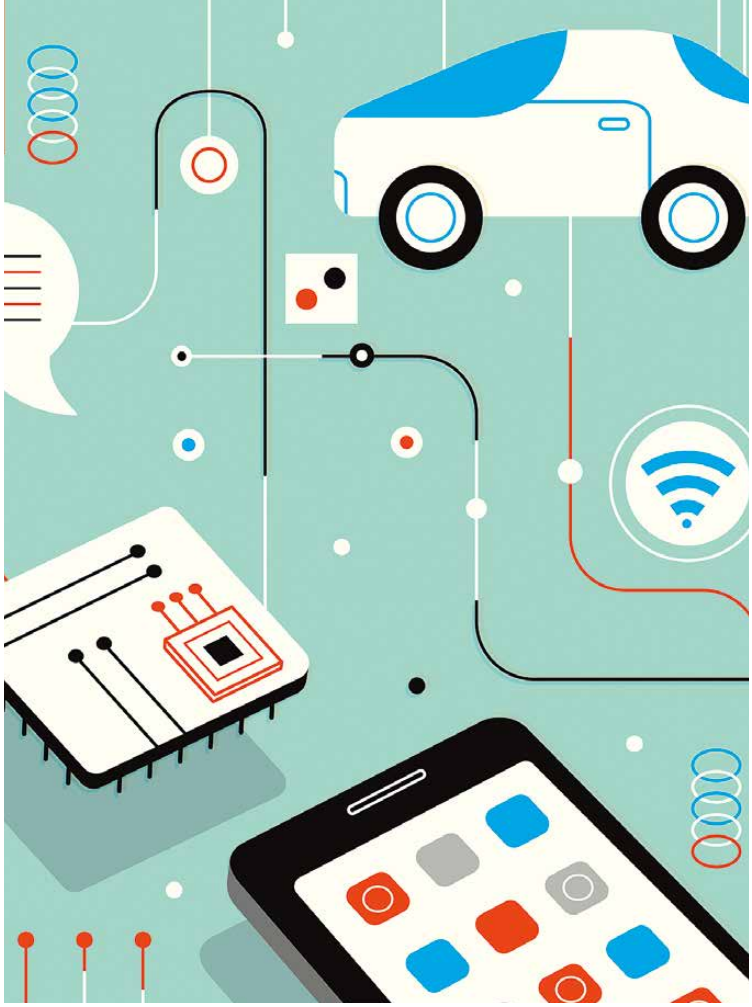
Table of contents



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Introduction

Welcome to the fifth edition of *McKinsey on Semiconductors*. The big question facing the sector is what it will take to move beyond the current period of sluggish returns. Will the next year herald the start of the Semi 2.0 era—a new period of improved performance and value creation? Or will revenues and growth remain relatively flat? The articles in this issue directly address these questions.

Some insights garnered from the past 20 years of semiconductor growth will help in our assessment of future trends. Let's consider this period as two distinct eras. During the Semi 1.0 era, from 1995 to 2008, the sector was Wall Street's darling, delivering a 7 percent compound annual growth rate (CAGR) and a total return to shareholders (TRS) nearly three times that of the broader market (Exhibit 1). For the Semi 1.5 era, which extends from 2008 until today, the story is much different. Although some semiconductor players continue to thrive, both growth and revenue have declined. So, what market and technology forces made these eras so different? And how did semiconductor companies adapt to the changing environment?

Semi 1.0: Full speed ahead

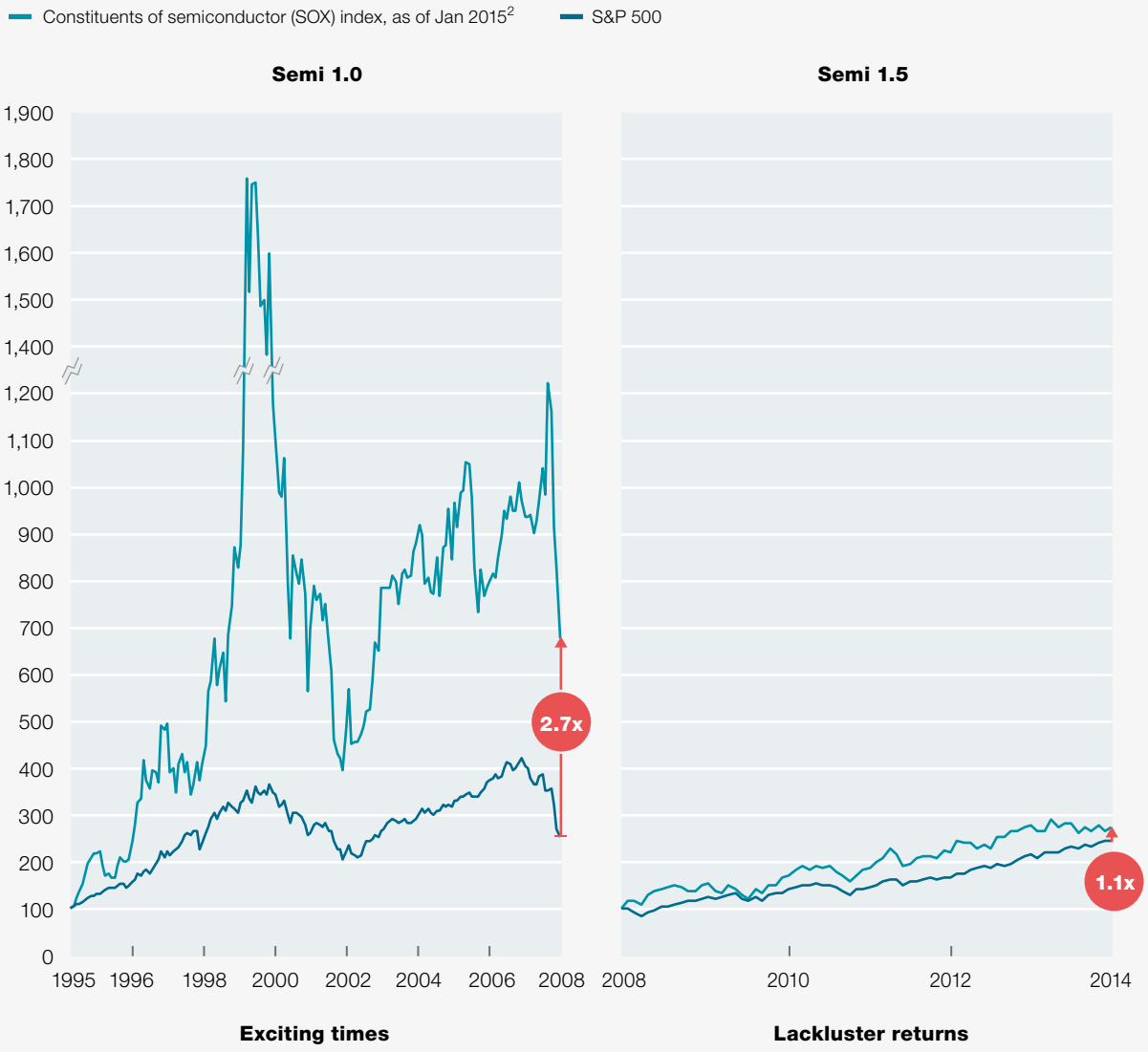
Many of the strong returns in the Semi 1.0 era can be traced to shifts in the mobile segment, where unit sales rose 29 percent annually from 1995 through 2008. Simultaneously, mobile phones became more complex, offering Internet access, texting capabilities, and new frequency bands such as code-division multiple access (CDMA). Semiconductor companies benefited from the increased sales volume in mobile, as well as the need for better performance in processor speed and radio technologies.

Exhibit 1

Growth in the semiconductor industry has been lagging in recent years.

Performance of semiconductor companies vs broader market, total return to shareholders[1]

Value at end of 1994 and 2008 set as 100



[1]For the Semi 1.0 period, 1995 data are as of Jan 1, 1995, and data recorded for other years represent results on Dec 1. For the Semi 1.5 period, data recorded for each year represent results on Jan 31.
[2]Basket of constituents in the Philadelphia SOX Index as of Jan 2015 (n = 30); weighted average based on market capitalization.

Source: Capital IQ; McKinsey analysis

A strong computer marketplace was the second major force promoting growth during Semi 1.0. First, there was a trend away from a single PC for the household to two or more, which caused unit sales to increase by an average of 13 percent annually. Then, in the mid-2000s, the transition from desktop computers to laptops provided further growth opportunities.

Semiconductor companies capitalized on the strong growth in the mobile and PC segments and were soon obtaining more than half of their revenue from them. Their 15 percent increase in total return to shareholders was higher than their 11 percent revenue growth, partly propelled by investor expectations (Exhibit 2).

In the Semi 1.0 era, the most successful players reinvested in R&D—increasing spending from 8 to 17 percent annually during this period—and this investment was directly correlated with growth. The industry was highly specialized, with 68 percent of companies deriving most of their revenue from a single component category. For instance, some memory players made memory cards for phones but did not explore other opportunities in mobile. The specialized nature of the industry meant that the leading competitors for each component category were different, with only a few companies holding a top position in more than one category. With profits rising and strong growth continuing, CEO turnover was low (less than 7 percent annually in a 2013 multi-industry survey of 2,500 companies, compared with about 11 percent for all industries).

Semi 1.5: Regression to the mean

The strong growth seen in Semi 1.0 could not last forever. From 2008 to 2014, CAGR for the semiconductor industry fell from 7 percent to 3 percent. What explains this shift? First, demand dropped in the two categories that drove growth in the Semi 1.0 era. For instance, unit sales for mobile rose only about 8 percent annually from 2010 to 2014, while PC sales decreased by 4 percent over this period. No major growth driver emerged to compensate for the slowdown in these segments. Given these trends, the few companies that did show strong returns during Semi 1.5 were closely tied to the mobile sector.

While demand slowed, semiconductor companies were also grappling with increased competition as system-level players reached down the stack, taking on a greater role in chip design. These include Apple and Samsung in the mobile space and hyperscale players in the data-center segment.

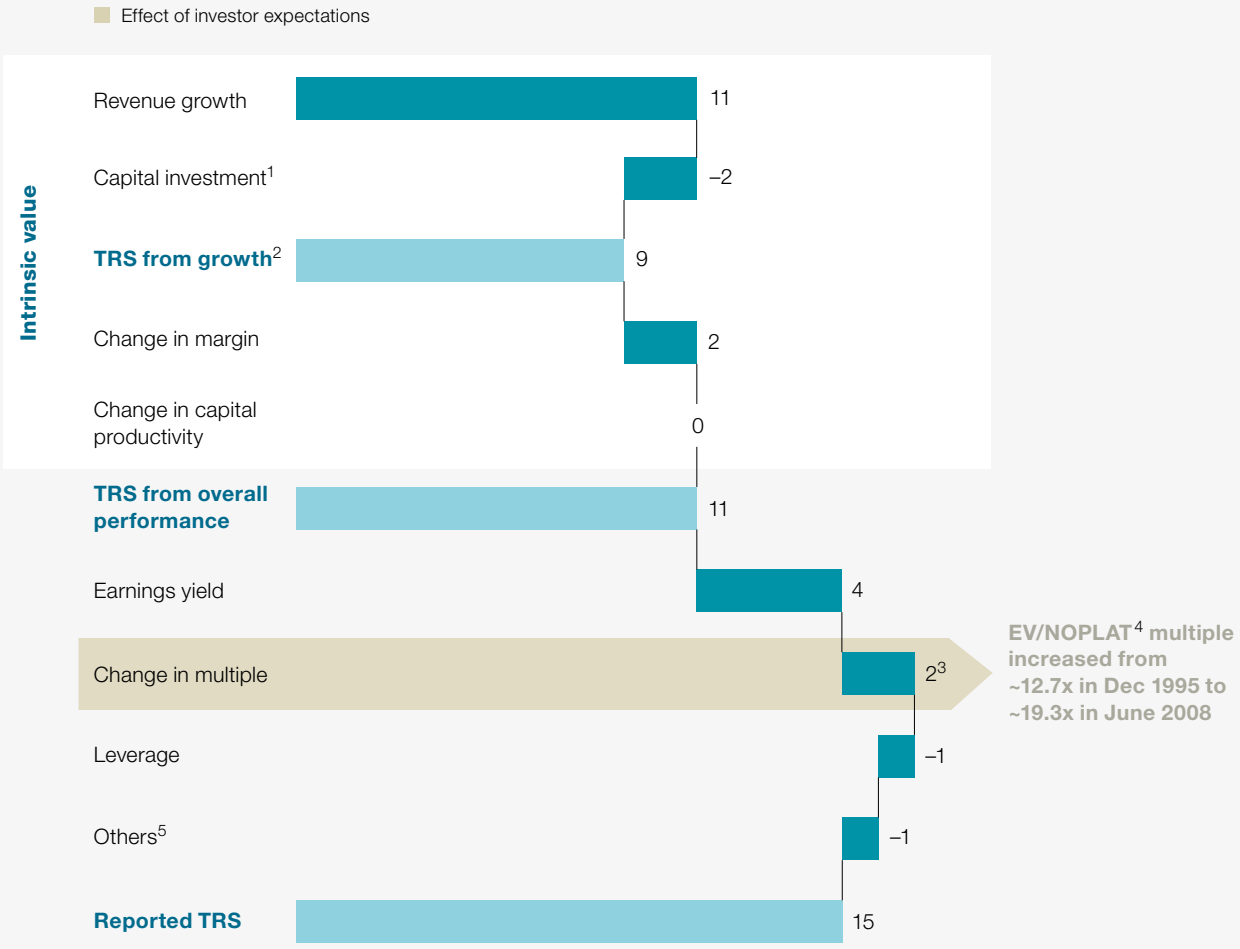
Faced with a tough market, semiconductor companies became more specialized, with 82 percent receiving most of their revenues from one component category. The diversified integrated device manufacturer started to become the exception rather than the rule. Average annual R&D spending decreased slightly, to about 15 percent of revenue, and was no longer correlated with near-term growth. Meanwhile, the number of mergers and acquisitions also rose because many companies saw inorganic growth as their only option for capturing additional growth.

As companies struggled, CEO turnover at semiconductor companies accelerated to 19 percent annually, compared with an average of 13 percent in the multi-industry survey. The number of founder CEOs among the top 100 semiconductor companies worldwide also declined 55 percent. Investors voiced their disappointment in the performance of semiconductor companies by becoming more vocal about their concern, with activist actions such as

Exhibit 2

In the Semi 1.0 era, share performance outpaced revenue growth, partly driven by investor expectations.

Decomposition of Semi 1.0 total return to shareholders (TRS), compound annual growth rate 1995–2008, %



[1]Includes goodwill.
[2]TRS from growth, net of investment.
[3]Includes change in TRS from Dec 2007 to June 2008.
[4]Enterprise value/net operating profit less adjusted taxes.
[5]Captures effects of noncash changes in equity, pension liabilities, and so on, on TRS.

Source: Capital IQ; Datastream; McKinsey analysis

proxy fights increasing by 300 percent. In response, many semiconductor companies increased their dividends or reduced R&D spending.

Semi 2.0: What comes next?

Will the lackluster returns of the Semi 1.5 era persist, or is the semiconductor sector poised for change? On the positive side, a number of segments could promote growth, including cloud infrastructure, security, mobile, next-generation memory, connected cars, and the Internet of Things. Furthermore, China's economic rise has become an engine for semiconductor growth, fueled by product demand from a middle class that is now larger in size than that of the United States. We cover most of these topics in this issue.

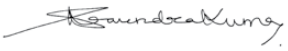
Other articles examine a number of operational and strategic questions relevant to the Semi 2.0 era. How will innovative technologies and shifting demand patterns affect the capital-equipment segment? Can semiconductor companies improve their margins through new approaches to fab ramp-ups and distribution? Are mergers and acquisitions a good option for semiconductor players? How can advanced analytics help companies gain a competitive edge in manufacturing, sales, and R&D?

We are also pleased to include an interview with Ray Stata, cofounder and chairman of the board of Analog Devices. Stata provides perspective on the semiconductor industry's evolution, discusses current trends, and offers strategic advice for CEOs.

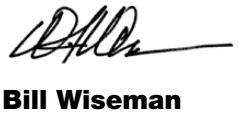
McKinsey on Semiconductors is written, first and foremost, for industry executives who are passionate about their organizations' development and success. We hope that you find these perspectives helpful and a source for discussion and debate about the industry's future. ■

Harald Bauer
Director

Mark Patel
Principal



Nick Santhanam
Director



Bill Wiseman
Director

A new world under construction: China and semiconductors

The ongoing transformation of the Chinese semiconductor sector requires all parties to raise their game.

Christopher Thomas

Business in China has become a top-of-mind issue for semiconductor executives and investors over the past year. While traditionally an important consumption market for chips, three related factors have now made it more important for companies to understand the opportunity and proactively refresh their China strategies. First, the government is actively attempting to reshape the domestic semiconductor market and assist local companies in becoming national champions. Second, Chinese consumers and companies are becoming increasingly important to the growth of the global semiconductor market. Third, Chinese capital—from both government and private sources—is actively pursuing merger, acquisition, investment, and partnership opportunities worldwide.

These changes raise important questions for Chinese and multinational companies. How can they continue to capture growth in China? Do market and policy changes require new capabilities or approaches? And how can local and international players form mutually beneficial partnerships?

The factors behind China's increasing prominence

It's worth examining in detail the political, economic, and financial-market factors behind China's growing role in the global semiconductor industry, as they may shape the market for years to come.

A supportive government

In June 2014, the State Council of China released the National Guidelines for Development and Promotion of the Integrated Circuit (IC) Industry, its long-awaited policy for improving the country's semiconductor sector (see sidebar, "China's national guidelines for the development and promotion of the IC industry").

The new guidelines lay out ambitious targets for industry revenues, production volume, and technological advances. While they do not represent the Chinese government's first attempt to support the indigenous semiconductor industry, they differ from previous policies in three important ways:

- The government's investment is 40 times higher than previous targets, with a five-year investment target of about $19 billion. Overall, the government hopes that the industry will receive about $100 billion to $150 billion from all sources, including state-owned enterprises and other investors.
- There is a greater focus on creating segment winners, or national champions, through M&A and other consolidating moves.
- The government is adopting a more market-based investment approach by giving local private-equity firms responsibility for allocating public funds—a bold experiment designed to improve the likelihood of success.

China's national guidelines for the development and promotion of the IC industry

China's 2014 policy for expanding the local semiconductor industry sets ambitious targets through 2030, with specific goals for various horizons, as shown in the exhibit below.

Exhibit **China has set ambitious targets for the local semiconductor industry.**

By 2015	By 2020	By 2030
Integrated-circuit (IC) industry overall revenue (design, manufacturing, packaging, and testing) exceeds 350 billion yuan (about $55 billion)	Compound annual growth rate of revenues ≥20%	World-class IC industry value chain
Volume production of 32- and 28-nm[1] chips	Volume production of 16/14-nm chips	Set of leading companies considered tier 1 players in global semiconductor market
Wireless and telecom IC design capabilities approach world-class level	World-class IC design in applications such as wireless, telecommunications, cloud computing, Internet of Things, and big data	
>30% of total packaging and testing revenues come from middle- to high-end products	World-class packaging and testing technology	
45- to 65-nm semiconductor equipment in production; 12-inch silicon wafers and other key materials in production	Integration of key equipment and consumables from China into global supply chain	
	Development of advanced, safe, and secure IC industry value chain	

[1] Nanometer.

Source: McKinsey analysis

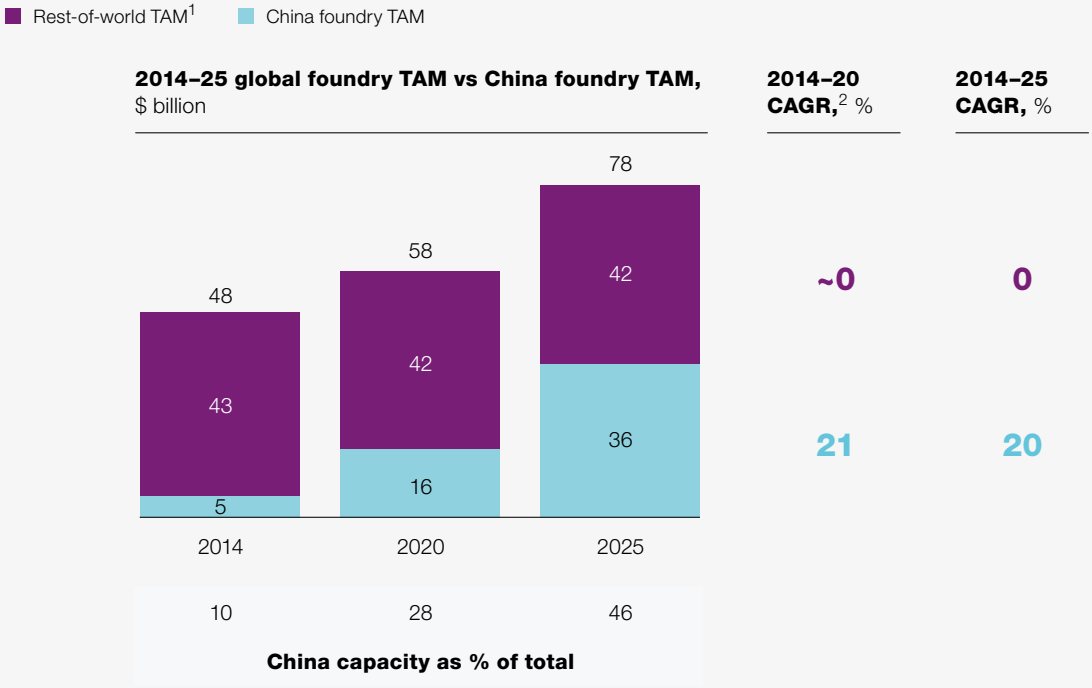
Since the release of the guidelines, the government has become even more ambitious about semiconductors. In May 2015, for instance, the State Council announced the "Made in China 2025" policy, which focuses on building indigenous capabilities in high-end precision manufacturing, with semiconductors as the first priority segment. The goal of this policy is to have China increase its self-sufficiency rate for integrated circuits to 40 percent by 2020 and to 70 percent by 2025. While the definition of self-sufficiency is unclear and there are no guarantees of hitting policy objectives, these targets clearly indicate that the government has ambitious aspirations. Consider the digital-foundry segment. If Chinese manufacturers were to hit the 2025 self-sufficiency goals the government has laid out for this segment, roughly all incremental foundry capacity installed globally over the next ten years would have to be in China (Exhibit 1).

Surging demand

Semiconductor consumption in China continues to outpace the overall market; it rose by 9 percent in 2014 to reach about $160 billion, or 50 percent of the global total. Chinese fabless companies and Chinese branches of fabless multinationals saw even greater growth in 2014, with sales rising by 20 percent. The fast growth of China-based customers, especially in the mobile space, helped fuel this rise. For instance, leading Chinese smartphone brands (such as Huawei, Lenovo, Meizu, and Xiaomi) increased their global market share from 15 percent in the fourth quarter of

Exhibit 1

To meet the 'Made in China 2025' targets, all incremental foundry capacity globally would have to be in China over the next ten years.



[1]Total available market.
[2]Compound annual growth rate.

Source: IHS Application Market Forecast Tool 2015; McKinsey analysis

2013 to 27 percent in the second quarter of 2015. Like China's overall economy, its mobile market has cooled considerably, however, with 2015 smartphone consumption flat year on year, after rising fivefold since 2010.

This slowdown, which is mirroring a global cooling of the smartphone market, is winnowing out weaker original-equipment manufacturers (OEMs), increasing price-based competition, and creating uncertainty about long-term growth prospects for mobile devices and the semiconductors they contain.

Increased capital activity

In the 18 months from the launch of the 2014 policy to the writing of this article, six Chinese government investment vehicles, with approximately $32 billion under management, had been announced—the Sino IC National Fund, as well as city investment vehicles for Beijing, Hefei, Shanghai, Wuhan, and Xiamen. These funds may receive additional capital: for instance, the Xiamen investment vehicle received $47 million during the first phase of funding and has a target size of about $157 million. The six funds have already invested in various Chinese players, including AMEC, JCET, Sanan, SMIC, and Spreadtrum.

China-based corporate and financial investors are looking outward and have recently announced roughly $15 billion in controlling or minority investments in ten global semiconductor companies across the value chain. Although this was a dramatic increase over the previous year's activity, it still represents only about 15 percent of the $100 billion in semiconductor M&A deals announced globally since the government's 2014 policy was made public. In the same time frame, the global industry invested nearly $80 billion in capital spending and R&D—about 20 times what local Chinese semiconductor companies did.

Global players have also made increasing commitments to the China market over the past year, including greater efforts to collaborate with local players. Consider just a few recent moves:

- Qualcomm announced that it will partner with SMIC on 28-nanometer products and 14-nanometer process-technology development.
- UMC is collaborating with the Xiamen government and FuJian Electronics and Information Group on a $6.2 billion investment in a foundry.
- Intel invested $1.5 billion in a subsidiary of Tsinghua Unigroup, which owns RDA and Spreadtrum, two of the largest fabless-design companies.

Building Chinese champions

The semiconductor industry is global, with products rarely customized for specific regions. There are no Taiwanese packages, South Korean memory chips, or Japanese industrial semiconductors—these products all serve a global clientele. The search for Chinese champions is thus something of a misnomer; it would be more appropriate to say that domestic companies should aim to become global champions with roots in China.

Global leadership matters to Chinese players because of the efficiencies derived from scale and experience. In fact, McKinsey research shows that the top one or two semiconductor players, by industry segment, earn 100 percent of total economic profit, while their competitors lose money. Furthermore, no profitable leader confines its market to a single geography—they are global players. Given these patterns, it is important for companies to strive for one of the top two global positions over time.

For Chinese companies, achieving this status requires three fundamental shifts. The first is a significant increase in technical skills and global management capabilities. The second involves adopting a technology-leader mind-set.

The third required shift is encouraging the development of patient capital willing to invest over long horizons and through business cycles.

Enhancing capabilities

To become international champions, Chinese companies must build the capabilities needed to run far more complex businesses. Following the example of leading semiconductor multinationals, they must also invest years in developing relationships and extending competencies beyond their home borders. Although many emerging Chinese semiconductor leaders have made strides in this direction, there is much room for improvement. For instance, domestic companies need to create global sales and customer-service teams to win business abroad. They will also likely need to manage multiple R&D facilities, with centers of competence spread around the world.

Companies involved in deal making must master the art of M&A. Rather than just buying companies, they must drive synergies and improvements from acquired targets. And as Chinese players search for growth in new areas, such as the Internet of Things, they will need to enhance their capabilities beyond silicon, investing in areas such as software development, ecosystem management, solutions selling, and reference designs.

Several areas of capability building require special attention, with talent management topping the list. Recruiting, training, and retaining the best (and often scarce) global talent is difficult, especially in hardware architectures, firmware, and applications. The situation may be even more challenging in China, since the most experienced semiconductor talent is typically based in other regions. In cases where talent is brought into a company through acquisition, effective postmerger management is essential—for instance, the systematic integration of new teams with existing Chinese teams or of new engineering tools and flows with existing ones.

Chinese players also need to strengthen their development, management, and protection of intellectual property (IP). First, they should develop a systematic approach to identifying, choosing, and executing an IP strategy. This will require each company to have a well-thought-out IP road map separate from its product offerings. The road map should clarify which intellectual property needs to be proprietary and developed in-house and which can be sourced from partners or IP suppliers. Second, Chinese semiconductor companies should encourage the continued strengthening of their country's IP regime, both to protect their own innovations and to develop an environment in which multinationals are willing to undertake IP and R&D partnerships with Chinese players.

Finally, Chinese companies will need to master all aspects of postmerger integration (not just the talent-related ones mentioned above) in both a domestic and a global context. Historically, outcomes of M&A in the high-tech sector have been quite variable. Well-managed mergers that leverage the strengths of both parties have created substantial value, while poorly integrated acquisitions tend to have disastrous results. Since employee retention is critical to success, Chinese leaders must strive to develop an esprit de corps and a spirit of collaboration. Controlling product and project fragmentation is also essential, as McKinsey research suggests that spreading semiconductor R&D efforts across multiple sites leads to an average efficiency loss of more than 10 percent.

Companies that can build strong, unified teams from multiple cultures and geographic locations—and effectively focus those teams on the right programs—will emerge as winners. The bar is higher than normal for Chinese-driven deals in the semiconductor space, since most of these efforts aspire to transfer technology from global clusters to China. Synergies have typically been more difficult to realize from R&D and IP transfers than from go-to-market or manufacturing operations.

Adopting a technology leader's mind-set

Technology innovation and leadership matter in semiconductors, to companies competing on both the lagging and leading edge of process technology. By choice and necessity, Chinese companies now generally focus their efforts on mature technologies, modifying and removing cost from innovations developed by others. (There are, of course, exceptions, such as HiSilicon, which is making baseband chips at roughly the same technology cadence as market-share leaders.) While mature products can generate profits because of their lower risk and investment requirements, they alone are not sufficient to transform a company into one of the top two in its segment.

McKinsey has surveyed Chinese companies that purchase semiconductors about their key buying factors. Similar to their global counterparts, they consistently cite product performance and leading technologies as their primary consideration when purchasing. As a result, the leading suppliers to these companies continue to be vendors that define and deliver leading technologies across multiple areas, including circuit design, product integration, and production processes, as well as "above chip" features such as firmware, reference designs, and software.

Chinese players cannot rely solely on technology transfers and acquisitions as a means to promote indigenous technology leadership. Export controls and other limits on purchasing "crown jewel" technology make many desired team, IP, or company acquisitions impossible. Furthermore, much cutting-edge knowledge is tacit and impossible to transfer through contracts or other means. And perhaps most critically, technology development never stops. Even after technology is purchased by or transferred into a Chinese company, competitors in other countries will be improving and pushing innovations forward, requiring the Chinese company to do the same. For all these reasons, Chinese companies will need to become leaders at internally developing, commercializing, and scaling the science and engineering breakthroughs required to become suppliers that take a sustainable leading share in a market segment.

Running a company that leads in technology is different from running a follower. The shift will likely require Chinese companies to change their business and investment models and their engineering mind-set. The shift should occur in a deliberate, measured fashion, allowing the country's players to keep a strong foundation in their existing businesses even as they strive for technological leadership and invest in innovation.

With so much at stake, Chinese companies cannot take an ad hoc approach to building the required new capabilities, key performance indicators, and processes. They must develop a systematic road map of improvements, tying together business opportunities, technology trends, capability requirements, and skill-building initiatives into one cohesive plan. It will be paramount to align diverse stakeholders, including the government, investors, and potential global partners, to support this plan. Goals should be set by global benchmarking to reflect where competition is today and where it will be in the future.

Chinese companies have a large task ahead, given their talent and capability gaps, the high bar for global leadership, and the need for the country's global champions to be the top one or two players in their segments. The more segments and technologies in which China attempts to be number one, the more diffuse industry and government efforts will be. The more companies that attempt to become the Chinese champion for a certain segment, the more the best talent will be spread across too many teams. And the more investment vehicles that chase after the best global and local acquisition targets, the higher the prices that will be paid. However, a top-down approach that limits competition may stifle innovation and trap talent in the wrong roles. Therefore, the government, investors, and business leaders should seek the right balance.

Ensuring investors are willing to provide patient capital

Although enhanced capabilities are the most important factor separating winners from losers, patient capital is also essential. Under its new policy, the Chinese government is having local private-equity firms manage its investments in the semiconductor industry, since earlier bureaucrat-led efforts did not produce the desired results. As these firms make decisions about funding, they will adhere to the government's goals and objectives—but also strive to meet market rates of investment return.

The ability of these investors to continue funding during economic or industry downturns is important. The semiconductor sector's unique capital requirements may complicate these efforts, however. First, the industry has long development cycles and high business cyclicality. Second, its returns are lower than average. Most private-equity players have a hurdle rate—or minimum expected return on investment—of 8 percent. Semiconductor companies, in aggregate, have earned lower returns on equity than that over the past 40 years. In fact, many segments have experienced down cycles when returns were negative for several years straight. Finally, the semiconductor sector's horizon for generating profits is typically longer than average, especially in the process and manufacturing segments. Payback times of 5, 10, or 15 years are typical. Investing steadily and intelligently through the entire cycle and the long term will be a challenge for financial investors with multiple options for their capital.

Investor challenges will be particularly acute for acquisitions. There is a healthy market for well-performing semiconductor companies and assets, so private-equity funds will be competing with corporate investors with lower cost of capital and the ability to generate synergies from acquisitions. As a result, corporate investors could pay higher prices for the same assets.

Multinationals in China: Moving ahead thoughtfully

Non-Chinese multinationals have a different set of objectives and constraints when doing business in China. Since most already have global capabilities, they are likely to focus on maximizing their Chinese market share and developing strategies to compete with emerging Chinese players.

Many multinationals—even those with long experience in China—have a fragmented view of the situation on the ground. Local country leadership, the CEO, and the heads of business units and global functions may all hold different perspectives based on their own experiences, priorities, and the business or functional lens through which they observe China. These different perspectives emerge during the development of detailed strategies for China and often stall progress. To rectify this issue, multinationals should invest in building a common and aligned fact base to accelerate decision making. As part of this process, corporate leaders should try to reach agreement on the answers to various questions, including those in Exhibit 2.

Indeed, companies have debunked internal myths about winning in China by answering these questions. For instance, one multinational believed that Chinese customers want to buy from local companies and therefore thought it needed to develop a large joint-venture R&D center in the country. However, structured interviews with customers showed that their preferences varied by tier. Smaller ones with simpler technical needs desired local suppliers, while larger customers aspiring to an international presence wanted global, non-Chinese suppliers with local customer-service teams. Another company was certain that a Chinese competitor offered much less expensive products because it was comfortable with lower margins. But a product-teardown analysis proved that the competitor likely had higher gross margins than the multinational because it

Exhibit 2 **Multinational companies must ask strategic questions when determining their China strategy.**

How important is it to win in China?	Are we winning today in China?	How local do we need to be to win in China?	How does our "localness" stack up against the competition, and will it meet the government's expectations?
Where does China rank among revenue and profit priorities? Is it a must win, an important battleground, or a nice to have? Is it worth addressing difficult trade-offs between engaging in China and pursuing other opportunities? How does the global economy affect the specific segments where multinational companies compete?	How does performance in China stack up against performance globally? Is the company growing as fast as the competition, Chinese customers, or Chinese end markets? How do customers grade the company against the competition on global factors such as product performance and local factors such as technical support?	What are the key buying factors for customers, and which of these require a strong local presence? What does a local presence entail (eg, technical support, product road map, equity participation by Chinese players)? How do these buying factors vary by segment or by customer type (eg, are there relevant differences between state-owned enterprises and private companies)?	What is the balance between what a multinational company receives from China, such as revenues and subsidies, and what the company contributes to China, in the form of taxes, local employment, intellectual property, and other benefits? How do government stakeholders view a multinational company's contribution to the Chinese industry and to China overall?

Source: McKinsey analysis

had a simpler, de-featured product design for the lower-priced segments where Chinese OEMs competed.

An aligned fact base also simplifies the debate about alternative approaches to improving performance in China, since it helps leaders propose solutions that truly resolve problems. For instance, companies may be looking for tactical improvement in China, such as faster technical support or localized reference designs. In such cases, the solutions may be a simple matter of greater investment and improved on-the-ground execution. In more complicated situations, such as when the government requires local ownership to obtain important R&D subsidies or certain tenders, multinationals may need more comprehensive solutions that involve forming partnerships with Chinese companies. If partnerships are required, multinationals and domestic companies must develop the elusive but desirable "win-win" partnership structure.

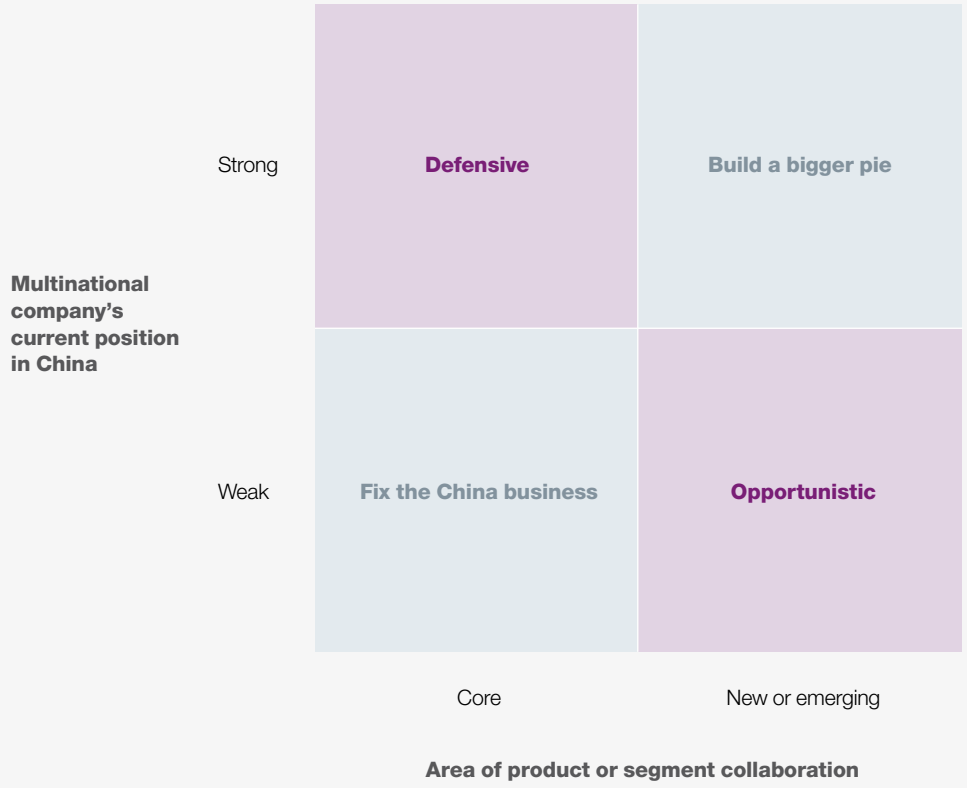
Forming partnerships that work

Outside the semiconductor sector, multinationals have long made deals in China, essentially by trading technology for market access and capital. This approach is now front and center for global semiconductor companies.

Multinationals may encounter many challenges forming partnerships. For instance, they need to find sustainable, lasting business value for both themselves and their partners when defining the terms of a deal. Complications may also arise when integrating Chinese and non-Chinese teams and operations. But multinational companies can mitigate many potential issues by pursuing part-

Exhibit 3

Multinational companies should base partnership objectives both on their current position in China and their product-line goals.



Source: McKinsey analysis

nerships systematically rather than making ad hoc decisions. This may be difficult under the circumstances, since many multinationals are approached by multiple Chinese investors, government entities, or corporations with ideas. In such situations, multinationals should actively pursue a comprehensive partnership strategy, rather than simply responding to entreaties. A few best practices have emerged.

Define explicit objectives

Multinationals can pursue many different types of partnerships. If they have a strong position in China, their efforts represent a defensive stance; if their China position trails their global status, a partnership is an opportunity to capture additional value. Similarly, some multinationals may want partnerships that support all business operations, while others may want assistance only with a single business unit or product. Multinationals should take a broader approach, evaluating the ways Chinese capital and support can further their objectives outside China. The simplified framework in Exhibit 3 suggests possible types of partnerships based on a company's current market position and its product areas of focus.

Assess Chinese partners based on specific objectives

China's business landscape is diverse, and the universe of potential partners is broad, from pure-play private IC companies to state-owned industrial conglomerates. In addition, deals will likely involve interaction with multiple government agencies. Each of these entities brings different capabilities, relationships, and objectives to the table. The fit between partners will vary based on deal objectives. For instance, a go-to-market partnership designed to increase local market share may prioritize engaging distributors, while a manufacturing effort would prioritize partners with extensive on-the-ground production experience. Multinationals should develop goal-specific, objective criteria to evaluate and prioritize potential partners.

Rank the benefits of different engagement archetypes for each potential partner

Partnerships can differ in multiple ways—business scope, geographic reach, IP and R&D collaboration, or the split of roles, responsibilities, and ownership. They can generally be classified into one of several archetypes, such as contractual relationships between distributors and suppliers or full R&D and manufacturing joint ventures with dual control. For each archetype, a multinational should objectively identify the benefits for itself and the partner, noting zones of mutual advantage worth pursuing.

As one example, a multinational may want a partnership that only involves sales in China because its primary goal is to build up a market presence there. The multinational's counterparts in China, on the other hand, may want to build a global business. Assessing the value of the short- and long-term benefits and the cost of these geographical sales limits for the parties will enable the multinational to see if the deal can be configured to confer equitable benefits.

Stress-test preferred options with a war-gaming approach

Multinationals cannot assume a static environment as they survey their path forward, since all industry players—competitors, customers, other Chinese companies—will make their own moves, both proactively and in response to those of the multinationals. Partnerships cannot be unwound easily and have to be robust under a variety of competitive responses. Multinationals should thus rethink pursuing engagements whose benefits can be negated by strategic reactions of competitors. They should also avoid situations in which a partner or a competitor would obtain significantly more benefits. War-gaming the competitive response helps to clarify the desired partnership and the series of moves needed to engage and negotiate with partners.

Follow best practices in China partnership development

Regardless of segment or product line, multinationals should observe some general rules of engagement in China:

- Be cognizant that China is not monolithic; no single partner, company, or investor owns or drives the China strategy. No company or investor can commit for China—only for its own sphere of influence.

- Acknowledge that no single expert has a clear picture of everything going on in China. Multinationals should thus leverage multiple information sources when developing their perspective.

- Be clear up front and throughout the process about the deal constraints, whether in product strategy, the scope of operations, ownership, or IP transfers. These areas are most likely to be

contentious, leading to difficult conversations and negotiations. Being honest will build trust.

- Plan partnerships with the exit in mind. At some point, a multinational's objectives will diverge from those of its partner so substantially that the deal no longer makes sense. Multinationals should therefore define contractual mechanisms for ending partnerships peacefully and fairly.

The attempted transformation of the Chinese semiconductor sector, which requires all industry players to raise their game, will have repercussions for both multinational and Chinese semiconductor companies. The greatest change may be in how the parties interact with one another. In a winner-takes-all industry with stringent government regulations, heavy capital requirements, and dynamic technology road maps, deep and lasting partnerships will be difficult to construct and execute. Add cultural differences and the mixed history of deals between Chinese companies and multinationals in other industries, and the need for all players to be thoughtful and deliberate is clear. ■

The author wishes to thank Gaurav Batra, Mark Patel, and Tiankai Zhu for their contributions to this article.

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The Internet of Things: Opportunities and challenges for semiconductor companies

The nascent Internet of Things could open vast opportunities to semiconductor companies—provided that they prepare now.

Harald Bauer, Mark Patel, and Jan Veira

The Internet of Things (IoT) has generated excitement for a few years now, with start-ups and established businesses placing bets on the industry's growth.[1] Some of the earliest investments have begun to pay off, with smart thermostats, wearable fitness devices, and other innovations becoming mainstream. With new IoT products under development or recently launched—ranging from medical-monitoring systems to sensors for cars—some analysts believe that the Internet of Things is poised for even greater gains.

Semiconductor companies, perhaps even more than other industry players, might benefit from the IoT's expansion. With growth rates for the smartphone market leveling off, the Internet of Things could serve as an important new source of revenue. Given the size of the potential opportunity, McKinsey recently collaborated with the Global Semiconductor Alliance (GSA) to investigate the Internet of Things more closely, with a focus on risks that could derail progress. In addition to assembling a fact base, we surveyed and interviewed senior executives from the semiconductor sector and adjacent industries (see sidebar, "Our methodology").

Our research suggests that the Internet of Things does indeed represent a major opportunity for semiconductor companies—one that they should begin pursuing now, while the sector is still developing. We also found, however, that the timing

and magnitude of the IoT's growth may depend on how quickly industry players can address several obstacles, including inadequate security protections, limited customer demand, marketplace fragmentation, a lack of standards, and technology barriers. Semiconductor companies, which have encountered similar problems in other nascent technology sectors, are well positioned to serve as leaders in resolving these issues.

Another important insight relates to the nature of semiconductor companies themselves. Their traditional focus on silicon, which allowed them to profit in many industries, may not be optimal for the Internet of Things because chips represent only a small portion of the value chain. Instead, semiconductor companies will be required to provide comprehensive solutions—for instance, those that involve security, software, or system-integration services in addition to hardware. As with any major change, this move entails some risk. But it could help semiconductor companies transform from component suppliers to solution providers, allowing them to capture maximum benefits from the Internet of Things.

A new source of growth

The McKinsey Global Institute recently estimated that the Internet of Things could generate $4 trillion to $11 trillion in value globally in 2025. These large numbers reflect the IoT's transformational potential in both consumer and business-to-business applications. Value creation will stem from the hardware, software, services, and integration activities provided by the technology companies that enable the Internet of Things.

Analysts also estimate that the current IoT installed base—the number of connected devices—is in the range of 7 billion to 10 billion. This is expected to increase by about 15 to 20 percent annually over the next few years, reaching 26 billion to 30 billion by 2020.

In keeping with these projections, many executives we interviewed stated that the Internet of Things would significantly boost semiconductor revenues by stimulating demand for microcontrollers, sensors, connectivity, and memory. They also noted that the Internet of Things represented a growth opportunity for networks and servers, since all the new devices and services will require additional cloud infrastructure. Overall, the Internet of Things could help the semiconductor industry maintain or surpass the average annual revenue increase of 3 to 4 percent reported over the past decade. These results are particularly significant in light of slower growth in the smartphone market, which has served as the major driver for the past few years.

Our interviews did reveal some ambiguity about whether the Internet of Things would be the semiconductor industry's top growth driver or just one of several important forces. In particular, interviewees questioned whether the Internet of Things will trigger demand for new products and services or if there will just be an increased need for existing integrated circuits. Similarly, our survey showed that executives from GSA member companies had mixed feelings about the IoT's potential, with 48 percent stating that it would be one of the top three growth drivers for the semiconductor industry and only 17 percent ranking it first.

Despite the size of the IoT opportunity, some semiconductor companies have hesitated to make significant investments in this sector. The greatest issue is that products within the Internet of Things tend to appeal to a niche market and generate relatively low sales volumes. With individual products delivering a relatively low return on investment, some semiconductor companies have limited their R&D expenditures for IoT-specific chips, preferring instead to adapt existing products. For instance, wireless system-on-a-chip players may offer repurposed wireless processors and chip sets for the Internet

of Things, while microcontroller players often bundle lower-end processors and connectivity chip sets to compete for the same opportunity.

As the IoT market matures and increases in scale, semiconductor companies may decide to pursue new approaches more aggressively. Before moving ahead, however, they should first determine which verticals and applications are growing strongly and assess when their markets will be large enough to justify significant investment. While semiconductor companies could potentially capture growth in many IoT verticals, six of the most promising markets—those where we chose to focus our research—include the following:

- wearable devices such as fitness accessories
- smart-home applications like automated lighting and heating
- medical electronics
- industrial automation, including tasks like remote servicing and predictive maintenance
- connected cars
- smart cities, with applications to assist with traffic control and other tasks within the public sector

The challenge ahead

Like many other high-tech innovations, the Internet of Things is garnering intense interest in the press, with reports of connected cars and smart watches making headlines. Although we do not want to diminish the IoT's potential, our research suggests that the following six issues could derail its growth:

- inadequate security and privacy protections for user data
- difficulty building customer demand in the absence of a single "killer application"
- a lack of consistent standards
- the proliferation of niche products, resulting in a fragmented market and an unprofitable environment for creating application-specific chips
- the need to extract more value from each application by providing comprehensive solutions, rather than focusing solely on silicon
- technological limitations that affect the IoT's functionality

These problems are not insurmountable, particularly if semiconductor companies are willing to take an active role in solving them.

Security and privacy: High stakes, serious consequences

A majority of our interviewees cited security as an important requirement for growth in IoT applications. One called it the "critical enabler," claiming that many developers and companies initially underestimate its importance when creating IoT devices. He noted, "Security is not a key issue while your application or product has not reached scale, but once you are at scale and maybe have a first incident, it becomes a most important problem." Our survey results echoed the interview findings, with respondents ranking security as the top challenge to the IoT's success. Recent hacks to online car systems also highlight the importance of addressing security challenges for connected devices, vehicles, and buildings.

Ensuring security will not be easy, however, given the numerous applications and verticals within the Internet of Things, each with its own quirks and requirements. For instance, fitness wearables might only require relatively basic security measures that ensure consumer privacy, such as software-based solutions. But IoT applications that control more critical functions, including medical electronics and

Our methodology

The joint work of the Global Semiconductor Alliance (GSA) and McKinsey, which was led by a steering committee composed of McKinsey semiconductor experts and 11 senior executives from GSA member companies, had multiple components. To gain a leadership perspective on the Internet of Things (IoT), McKinsey interviewed 30 GSA members who had leadership roles at semiconductor companies or at companies in adjacent industries that are customers of semiconductor companies and part of the IoT ecosystem, such as network equipment and industrial automation. We also surveyed 229 semiconductor executives at GSA member companies in November 2014 to gain a broader industry perspective. Finally, McKinsey consultants assembled a fact base on the Internet of Things, focusing on issues relevant to semiconductor companies.

industrial automation, need much higher security, including hardware-based solutions.

Most executives we interviewed believed that the technology needed to secure the Internet of Things was already available. They were concerned, however, with the piecemeal nature of most security products and wanted to ensure that players protected the entire IoT stack—cloud, servers, and devices—rather than focus on only one of these areas. As one executive said, "Overall security is only as good as its weakest point."

Semiconductor companies can assist with end-to-end solutions by providing on-chip security, partitioning processor functions on chip, or supplying comprehensive hardware and software services, including authentication, data encryption, and access management. Those that specialize in security might be able to use their own products to provide comprehensive solutions, but others will need to undertake M&A or form partnerships with players further up in the stack to gain broader expertise in software or the cloud. For instance, semiconductor companies could lend their knowledge of hardware security to application designers or network-equipment manufacturers, since this information would assist with the design of secure software.

Customer demand: Developing the end market

Many of our interviewees envisioned a future in which IoT applications are more common than cell phones are today. Others were more cautious, however, with one noting, "No one really knows when the volume will show up; this is a clear challenge. . . . If you cannot show a $1 billion opportunity, then it's hard to get attention."

In other technology sectors, a single groundbreaking application or use case—a so-called killer app—has often spurred explosive demand. Such was the case in 2007, when the introduction of the iPhone triggered significant growth in the smartphone market. While the Internet of Things could potentially follow this path, most of our interviewees felt that growth would stem from a string of attractive but small opportunities that use a common platform, rather than from a single killer app.

Some of the most innovative IoT applications—and those most likely to stimulate customer demand—could come from start-ups. Businesses outside the technology sector, such as retailers, insurers, and oil and gas players, might also develop interesting products that appeal to a wide customer base, although some of our interviewees felt that these companies would face tough odds. Semiconductor players could help indirectly stimulate demand for IoT devices if they adopt new strategies to help these players thrive. For instance, start-ups and nontechnical businesses often have limited experience with semiconductors, so they might appreciate simple solutions and more hands-on support, including guidance from dedicated field engineers who assist with board-level design and solution integration (from silicon through applications in the cloud). IoT customers might also prefer one-stop solutions—complete platforms with all relevant elements that

an IoT device needs, including connectivity, sensors, memory, microprocessors, and software. For some small businesses with limited funds, such platforms may be the only economically feasible option.

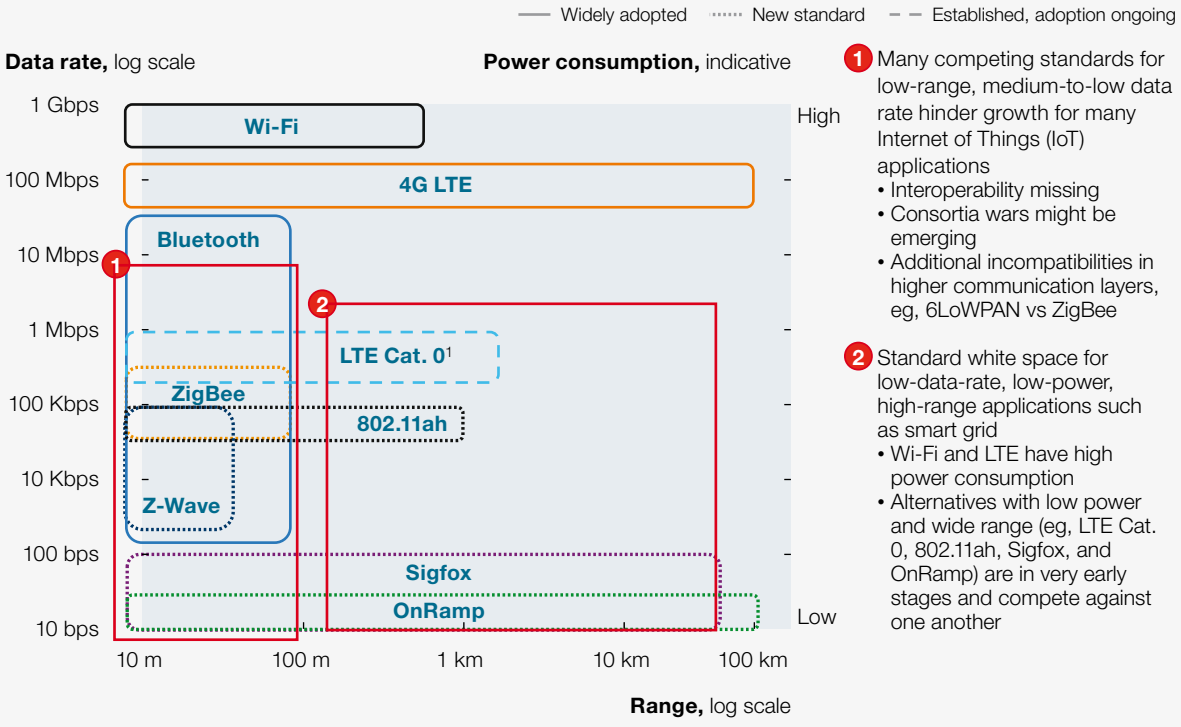
IoT standards: The need for consistency

Some layers of the IoT technology stack have no standards, and others have numerous competing standards with no obvious winner. In our survey and interviews, most respondents cited this situation as a major concern, with one executive stating, "What is critical is which standards will win and when this will happen."

To see how a lack of uniform standards can complicate product development and industry growth, consider connectivity issues. There are competing, incompatible connectivity standards for devices with a low range and medium-to-low data rate—for instance, Bluetooth, LTE Category 0, and ZigBee. With so many options, product designers may be reluctant to create new devices, since they do not know if they will comply with future standards. Similarly, end users may be reluctant to buy devices that may not be interoperable with existing or future products of the same type (Exhibit 1).

Although multiple organizations, including interest groups and industry consortia, are attempting to establish standards, it is impossible to predict which ones will prevail in each IoT vertical. Faced with this uncertainty, semiconductor players should pursue a hedging strategy, focusing on selected standards that are likely to gain widespread acceptance while simultaneously planning for alternative scenarios. In all cases, semiconductor players should actively

Exhibit 1 **Standards for the Internet of Things are not mature in many categories, including connectivity.**



[1]Preliminary specifications.

Source: Global Semiconductor Alliance and McKinsey IoT collaboration; McKinsey analysis

engage with industry associations or other groups that are trying to develop IoT standards, with the goal of supporting the best ones.

How to address a fragmented marketplace: Creating common platforms

IoT devices have widely varying requirements for power, data-processing speed, form factor, price, and other dimensions. Smart water meters, for instance, need to run for months, if not years, independent of power supply. They also require high-range connectivity, but data rates can be under one kilobit per second. By contrast, IoT devices used for industrial automation typically require a direct connection to a power supply and high data rates, but their connectivity range is lower than that for smart meters.

These variations in device specifications become significant when considering R&D costs for a single chip. Assuming typical integrated-circuit design costs and product lifetimes, semiconductor companies will need to ship 20 million to 70 million chips annually to break even.[2] Only a few segments, such as wearables, are large enough to require so many chips, making it impractical to create customized solutions for individual applications. But rather than abandon the IoT market, semiconductor companies should investigate an approach that involves classifying devices into archetypes based on their specifications and then creating a single platform to cover each one.

Products from multiple verticals can fall under one archetype as long as they have similar specifications. For instance, many low-cost applications have common requirements for short-range, medium-data-rate connectivity and limited data processing. If semiconductor companies create a common platform for applications that fit this archetype, they will simultaneously increase demand and reduce R&D spending. One downside of a platform approach is that the chips may not deliver optimal performance for every application they cover.

Extracting value beyond silicon: Opportunities in software and more

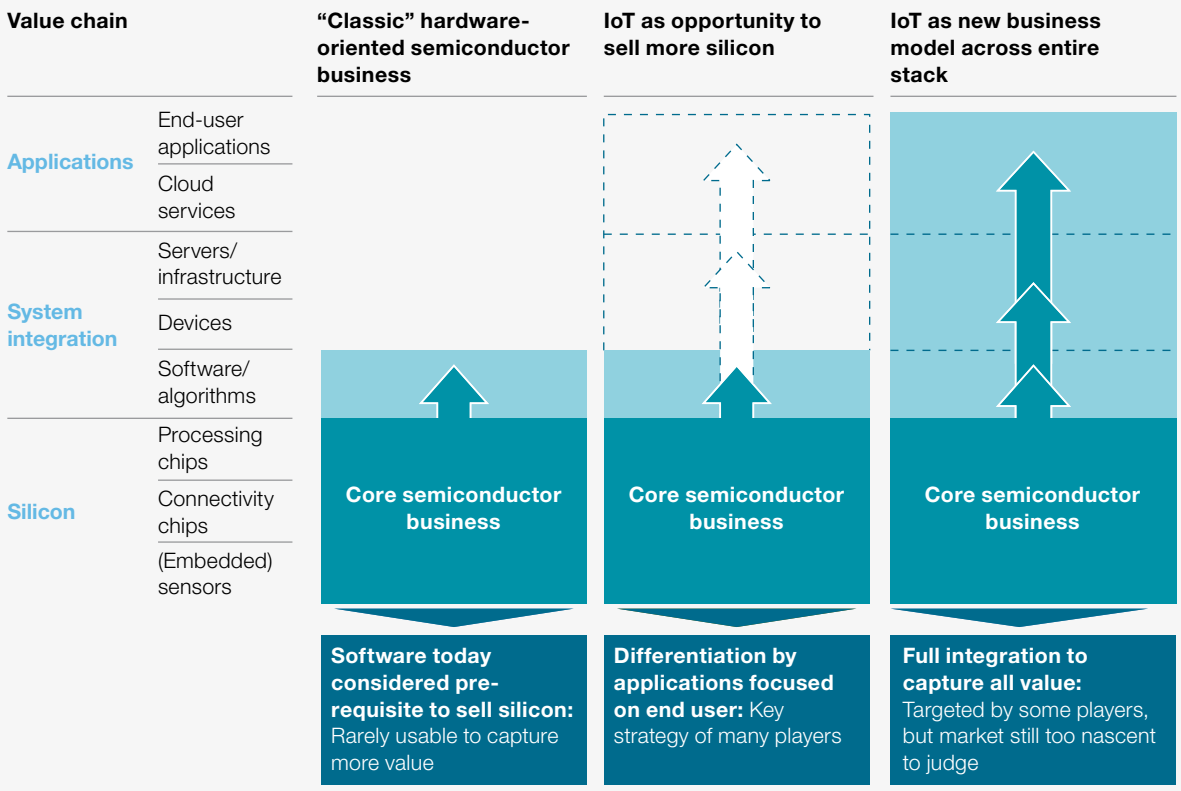
Semiconductor companies have a well-deserved reputation and track record for technological innovation, with some of their inventions spurring advances in personal computing, mobile telecommunications, and elsewhere. But they are also known—fairly or unfairly—for failing to extract full value from their innovations, with other high-tech players, such as software firms, profiting most from device enhancements. Our analysis suggests that semiconductor companies might face a similar dilemma with the Internet of Things. One executive we interviewed noted, "Value extraction has always been a particular challenge for semiconductor players, and it becomes particularly challenging in the Internet of Things, as even more players participate in the stack and business models are still immature." Other interviewees stated that big data and cloud companies were positioned to capture far more value from the Internet of Things than semiconductor businesses.

To tackle this problem, some semiconductor companies have already begun to create complete solutions that cover multiple layers of the technology stack, especially since nontraditional customers—start-ups and businesses outside the technology sphere—prefer this approach. It is still too early to identify winning strategies, but the advantage may go to companies that pursue the following three opportunities (Exhibit 2):

- *Software.* Semiconductor companies have been complementing integrated circuits with supporting software for many years, but this trend will become even more important as the Internet of Things grows. Many semiconductor companies have recently sought to build their software skills through M&A or partnerships, while others have focused on improving their in-house capabilities.

Exhibit 2 **Semiconductor companies must seek value beyond silicon and software.**

Semiconductor players' approaches to a business model for the Internet of Things (IoT)



Source: Global Semiconductor Alliance and McKinsey IoT collaboration

- *Security.* As noted earlier, the Internet of Things requires end-to-end security across the stack. Semiconductor players have traditionally provided chip-security solutions, but they may find additional opportunities in other layers, particularly if they can offer software products.

- *System integration.* One interview subject asked, "Today most players have a partial but not full solution for integrated systems, so who is the integrator?" Semiconductor companies could fill this role, especially if they provide system- or application-level software supporting integrated circuits. However, some interviewees noted that this might be too much of a departure from their core competencies.

Technological issues: Finding opportunities within the challenge

In our survey, two-thirds of respondents stated that technological issues present little to no challenge to the success of the Internet of Things.[3] The remaining respondents were split evenly between those who thought that technological issues were above average in importance and those who considered them a major challenge. Executives may hold varying opinions because technological issues differ by vertical and application. For instance, the interviewees agreed

that wearable technology needs improvement. "With wearables, there is a constant issue of charging," one executive stated. "We need to make devices last for a trip." By contrast, technology for smart-home applications is well advanced, but there are few standards governing interoperability, which has limited their adoption.

When we asked our interviewees about the most crucial technological innovations for the Internet of Things, most focused on lower power consumption and better battery life. A step change in the time between charges will increase demand for existing devices while also enabling product designers to create new applications. Wearable computers, distributed sensors for agricultural applications, and retail beacons are just a few of the applications that require improvement. Innovation in power and battery life will likely come from various sources, such as on-device power management, further advances in storage, over-the-air and wireless charging, and energy harvesting.

Although semiconductor companies that offer leading-edge technological advances will find themselves in high demand, not every player has to focus on innovation. Those companies that offer more dated solutions will still have a role in the Internet of Things, since many applications—particularly the sensors they contain—will continue to rely on existing (albeit highly specialized) technology.

Implications for semiconductor players

Semiconductor companies that want to capture the IoT's enormous growth potential might be tempted to move ahead quickly, without changing their existing operating model, but this could be a mistake. The Internet of Things is unlike any high-tech segment that they have previously served, and their traditional strategies may not succeed with the new customer base. With so much at stake, semiconductor companies need to reevaluate all aspects of their businesses and potentially make some significant changes. From a strategic perspective, three tactics will be particularly important.

Finding the right niches suited to your competencies

There are likely to be many profitable IoT niches within the fragmented market, and semiconductor companies will need to identify the most promising ones that represent a fit with their capabilities. The use of a platform approach to cover multiple niches will be important, since R&D costs may otherwise be prohibitive. When companies are selecting the right niches, one of the most important considerations is their own expertise. Semiconductor players that have strong ties to consumer-electronics companies and possess full system-integration capabilities might

Important technological innovations for the Internet of Things will involve lower power consumption and better battery life. Greater time between charges will increase demand for existing devices while also enabling new applications.

best focus on wearables and smart-home devices, developing silicon, software and algorithms, and device-level designs. They could also potentially provide server-side software, connectivity gateways, and associated infrastructure. By contrast, a company with specific expertise in high-reliability integrated circuits and security might be well suited to provide full IoT solutions for medical applications.

Developing a solid strategy to seek value beyond silicon

Semiconductor companies are mostly well aware that their chips represent only one small part of the IoT value chain, so they are exploring opportunities in software, the cloud, and other services. But they may also need to consider more radical approaches to improve the value captured, including a shift to new business models. For instance, a move to usage-based pricing would allow semiconductor players to capture revenue for the entire lifetime of a device or service, not just at the time of chip purchase. (This might only be possible if a semiconductor company is willing to provide the full system or partner with a system-level player.) To mitigate risks and avoid moving too far from their core competencies, however, semiconductor companies should carefully evaluate new solutions. The fact that the IoT has many niches will be helpful during the evaluation process, since companies can test solutions in one of them and make necessary adjustments before undertaking a broader rollout.

Revisiting (and revolutionizing) the corporate operating model

Operating models focusing on hardware and embedded software helped semiconductor companies thrive in many high-tech segments, but they may not be well suited to IoT customers. For instance, most companies now include a limited number of large business units, a focus on direct sales and field-application engineers, and an emphasis on application-specific R&D programs. A more appropriate organizational structure for the Internet of Things would emphasize a multimarket sales approach and a greater reliance on channel partners, such as distributors, as part of the go-to-market strategy. This arrangement is well suited to the IoT's fragmented market, which contains very different companies, including many small businesses, with unique needs. Other possible areas for improvement include the following:

- *R&D.* The move from customized chips to a platform approach should occur as soon as possible, but this does not always entail massive internal changes. Instead, companies may be able to license another player's intellectual property to build a platform—for instance, for image processing—thereby gaining access to new technologies without increasing development costs.

- *Investments.* Rather than making a limited number of large portfolio bets under the direction of a business-unit lead, companies should investigate numerous applications in diverse markets. This approach will help companies avoid the common mistake of allocating most funds to core products, rather than using them to develop new applications.

- *Change management.* If leaders want employees to cultivate new capabilities or develop innovative products, they may need to revise their key performance indicators. For example, companies should provide incentives that encourage R&D to develop chip platforms that are appropriate for several verticals, such as connected cars and industrial automation, rather than to optimize integrated circuits for a single vertical. Likewise, leaders that want to focus on mergers or other outside alliances must

help companies recognize their importance by encouraging such partnerships more aggressively.

Our survey, interviews, and research show that semiconductor executives are optimistic about the Internet of Things and its potential to transform the industry. More important, they recognize its ability to help society as a whole, with one executive calling it "a chance to change and enrich our lives." The exact form that this change will take is still uncertain, as is the point at which the Internet of Things will be widely adopted. It is clear, however, that the semiconductor sector will play a major role in its ascent. Those companies that take action now, while the Internet of Things is in its early stages, stand to gain the most.

[1] For the purposes of this article, we defined the Internet of Things as a network containing all smart devices with some sort of sensing mechanism that can communicate via the Internet with other smart devices or the cloud without human interaction. Most executives in our survey preferred this definition. Our findings would also be relevant to the Internet of Things if it were more broadly defined as a network consisting of any object that can be accessed through the Internet, including PCs, tablets, and smartphones.

[2] Design costs are assumed to be $12 million for low-complexity integrated circuits and $40 million for high-complexity integrated circuits, based on benchmarking data from Numetrics (a McKinsey Solution). Product lifetime is assumed to be five years in a market with ten competitors, 40 percent incremental margin, and $3 average selling price.

[3] Survey respondents were asked to distribute 100 points across seven different challenges. If a challenge received 10 or fewer points, it was classified as having little to no importance. Those that received 11 to 25 points were considered above average in importance, and those that received more than 25 points were considered key challenges.

The authors wish to thank the executives from GSA member companies and beyond who participated in the interviews and survey that helped serve as a basis for this article.

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Memory: Are challenges ahead?

The memory segment has been profitable since 2012. Can this continue as new technologies emerge and the competitive landscape evolves?

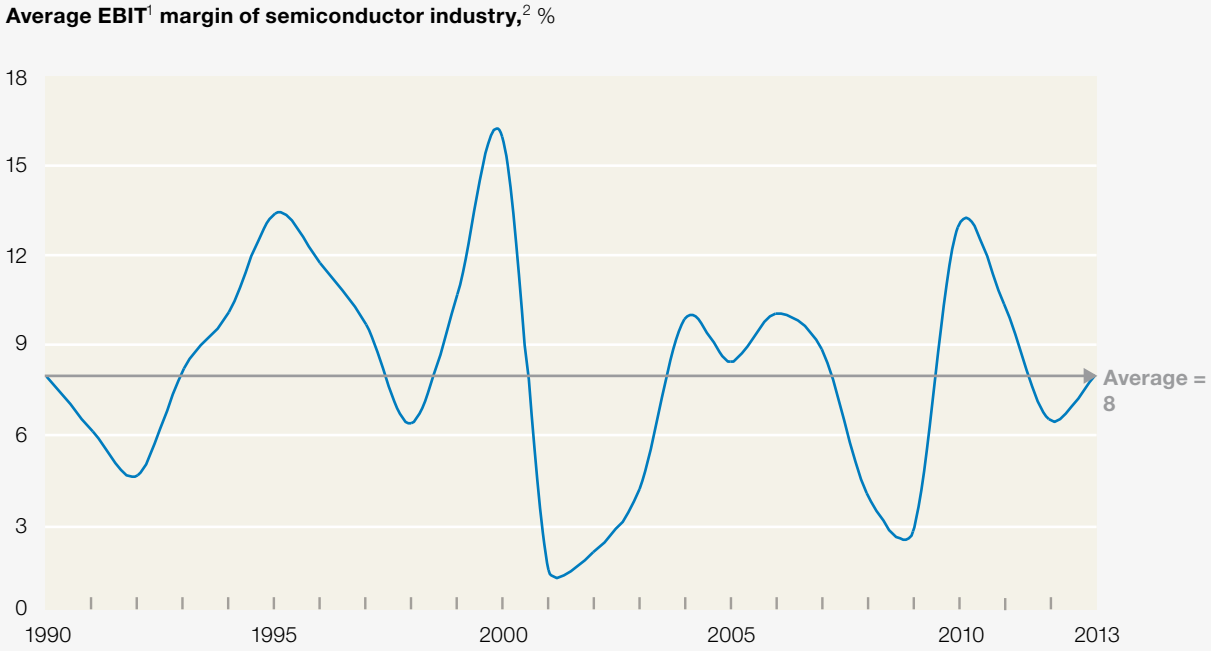
Harald Bauer, Stefan Burghardt, Sid Tandon, and Florian Thalmayr

The semiconductor sector is highly cyclical, with profitability typically rising and falling in tandem with overall economic trends. A review of the past two decades shows that earnings before interest and taxes (EBIT) for major semiconductor players were highest in 2000, at the height of the dot-com craze (Exhibit 1). Profits reached their lowest points in 2001, when the economy struggled, and during the recession from 2008 to 2009. As with the semiconductor sector as a whole, the memory segment is strongly influenced by economic trends. From 2008 through 2009, for instance, memory's EBIT plummeted as consumer demand fell for PCs, mobile phones, and other high-tech products.

Although a weak economy may contribute to poor results, fundamental structural factors have an even greater influence on the memory sector. In fact, they may largely explain why memory suffers more than other semiconductor segments during downturns and why memory players were not able to create economic value between 1996 and 2012, even though their technological innovations significantly contributed to the semiconductor industry's growth.[1] First, competition was intense. Second, both DRAM and NAND flash were commoditized and primarily differentiated based on price per gigabyte.[2]

Over the past few years, however, the memory segment has been profitable even though products—particularly DRAM—are still commoditized. The weighted average EBIT for memory players has edged upward since 2012 and has been higher than the semiconductor-industry average since that time (Exhibit 2). The past two years have shown particularly strong results, with the weighted average EBIT for the memory sector coming in above 15 percent since the second quarter of 2013 and

Exhibit 1 **The semiconductor industry's earnings before interest and taxes are highly cyclical.**



[1]Earnings before interest and taxes.
[2]Average across various value-chain steps (electronic design automation, equipment, fabless, foundry, integrated device manufacturing, intellectual property, materials, and semiconductor automation and test services). Average is not weighted by size of value chain or size of sample participants.

Source: Capital IQ; Datastream; McKinsey analysis

reaching a peak of 25 percent in 2015. Structural changes are primarily responsible for memory's recent performance: higher barriers to market entry, segment consolidation in DRAM, more diversified demand, lower-than-expected capacity expansion because of a slowdown of Moore's law, and more rational player behavior.

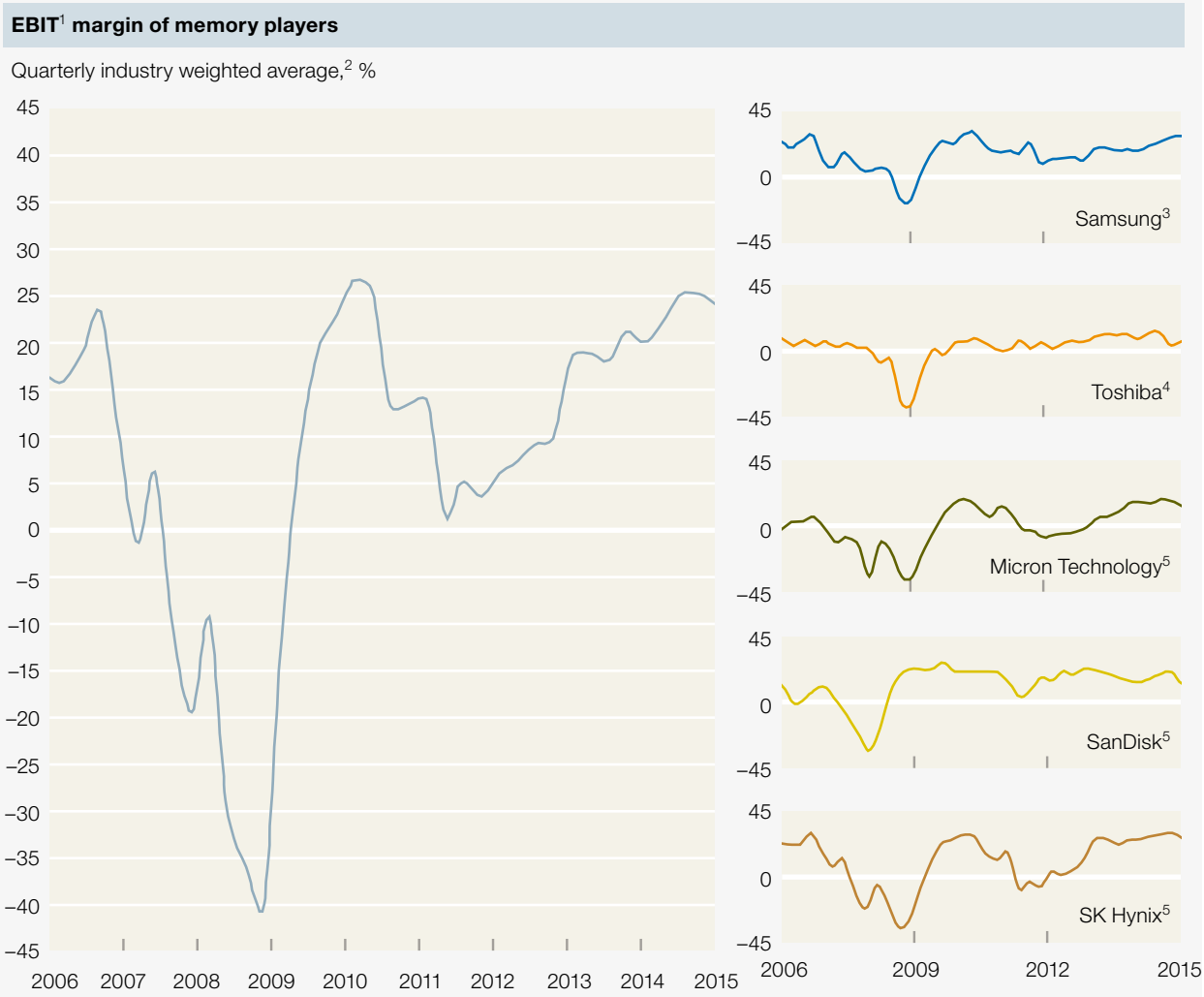
Despite these structural shifts, the memory segment's recent profitability may not continue indefinitely. While DRAM players should continue to benefit from segment consolidation, they may have to contend with an oversupply, as well as competition from next-generation memory technologies. The NAND segment is seeing some shifts, including increasing moves to vertical and horizontal integration, that potentially offer opportunities to improve overall profitability. However, NAND faces new competition from entrants at the system level. The transition to 3-D NAND and next-generation nonvolatile-memory (NVM) technologies may pose significant challenges for the NAND segment. For all memory-segment players, the emergence of China's semiconductor sector poses many questions.

This article reviews the structural changes that have led to memory's recent strong performance. We also discuss the greatest challenges that DRAM and NAND players face.

A good run: Structural factors behind memory's strong performance from 2012 to 2015

Segment consolidation, one of the trends that has helped improve memory EBIT, is specific to DRAM.

Exhibit 2 **Since 2012, earnings before interest and taxes for memory players has trended upward.**



[1]Earnings before interest and taxes.
[2]Average EBIT weighted by business-unit revenue.
[3]Samsung Electronics business-unit margin for Device Solutions.
[4]Toshiba business-unit margin for Semiconductor & Storage Products.
[5]Corporate margin.

Source: Bloomberg; Datastream; iSuppli; McKinsey analysis

All other structural changes have benefited both DRAM and NAND players.

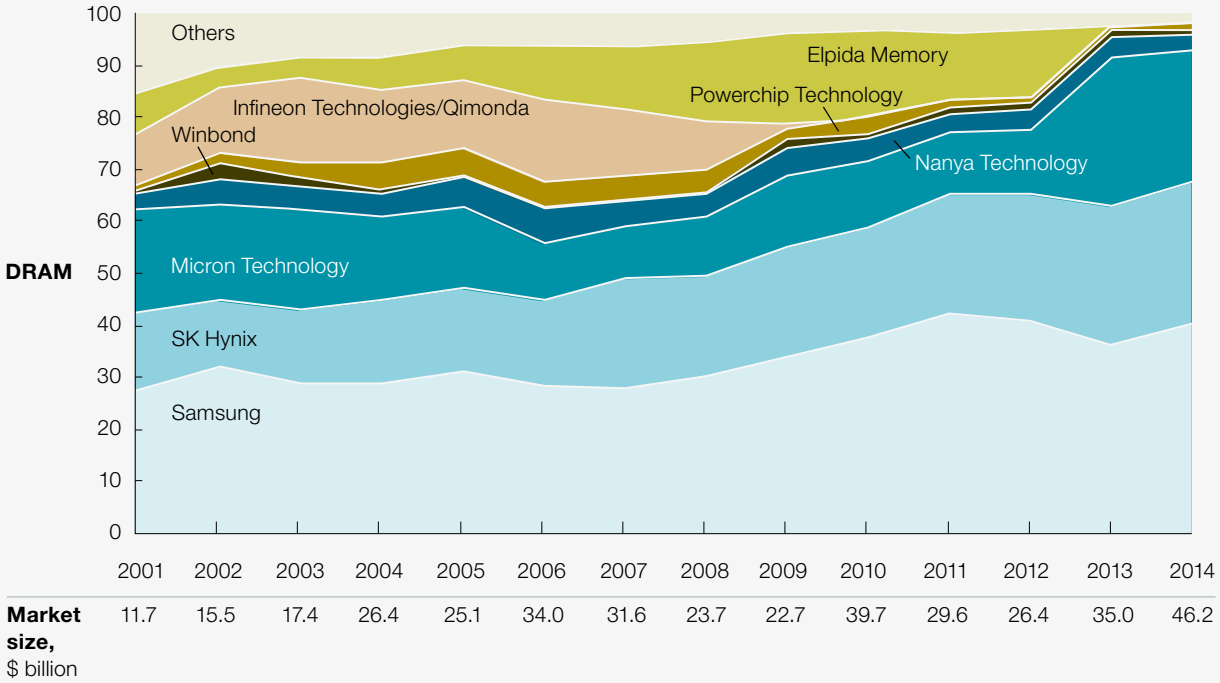
DRAM-segment consolidation

Since 2012, most of the memory sector's strength can be attributed to consolidation within the crowded DRAM segment. In 1995, the top ten DRAM players accounted for about 80 percent of market share. Since then, the market has been consolidating. By 2012, three players led the market: Micron Technology, Samsung, and SK Hynix. In 2013 and 2014, these three accounted for more than 90 percent of market share. In contrast, the number of NAND players has been relatively small since the technology was launched, so consolidation has not been a major factor in this

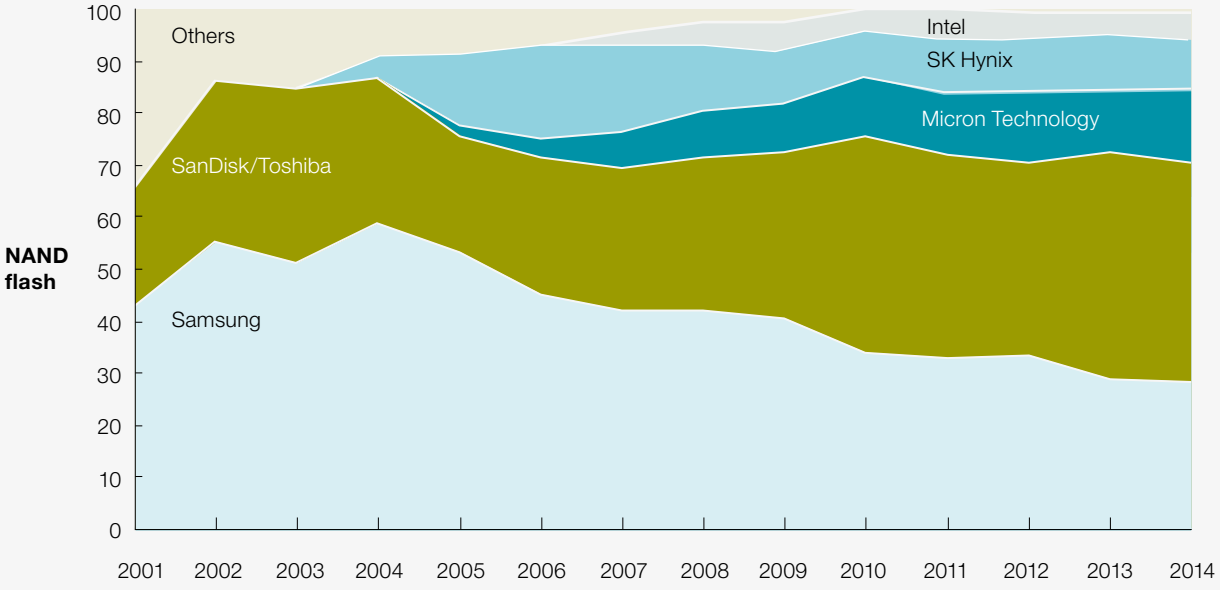
Exhibit 3

The memory segment has been consolidating, particularly within DRAM.

Market share for DRAM and NAND flash, by supplier, %



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Market size, $ billion	11.7	15.5	17.4	26.4	25.1	34.0	31.6	23.7	22.7	39.7	29.6	26.4	35.0	46.2



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Market size, $ billion	0.9	2.2	4.2	6.6	10.8	12.4	13.9	11.8	13.6	21.3	24.0	22.3	30.2	32.0

Source: iSuppli; McKinsey analysis

market. Exhibit 3 compares consolidation trends for DRAM and NAND.

The commoditized nature of DRAM products helps explain the consolidation trend. When demand fell, players tried to gain a competitive edge by decreasing prices sharply, since price per gigabyte was the primary product differentiator. In addition, memory players tended to run fabs at full capacity, even when demand dropped, because their fixed costs (including depreciation) were high. This practice resulted in severe oversupply when the market slowed, putting prices and margins under pressure. Together, the price decreases and high supply caused DRAM players to suffer more than other segments when demand declined.

DRAM consolidation accelerated between 2008 and 2012 because the economic downturn reduced demand in major end markets. In addition, the manufacture of PCs slowed after the 2011 floods in Thailand curtailed the supply of hard-disk drives. Companies that exited the market in response to these pressures include Qimonda, a pure-memory player that was a German spinoff of Infineon Technologies. Despite the company's power-saving trench technology and its leadership in the transition to 300-millimeter wafers, Infineon/Qimonda never displayed high profitability and was heavily dependent on revenues from DRAM for PCs and servers. After the 2008 economic crisis decreased DRAM prices and revenues, Qimonda filed for bankruptcy. Elpida Memory, a leading Japanese player, suffered a similar fate because the decline in DRAM prices and a strong yen made its cost structure unsustainable when demand decreased. Elpida Memory went bankrupt in 2012 and was acquired by Micron.

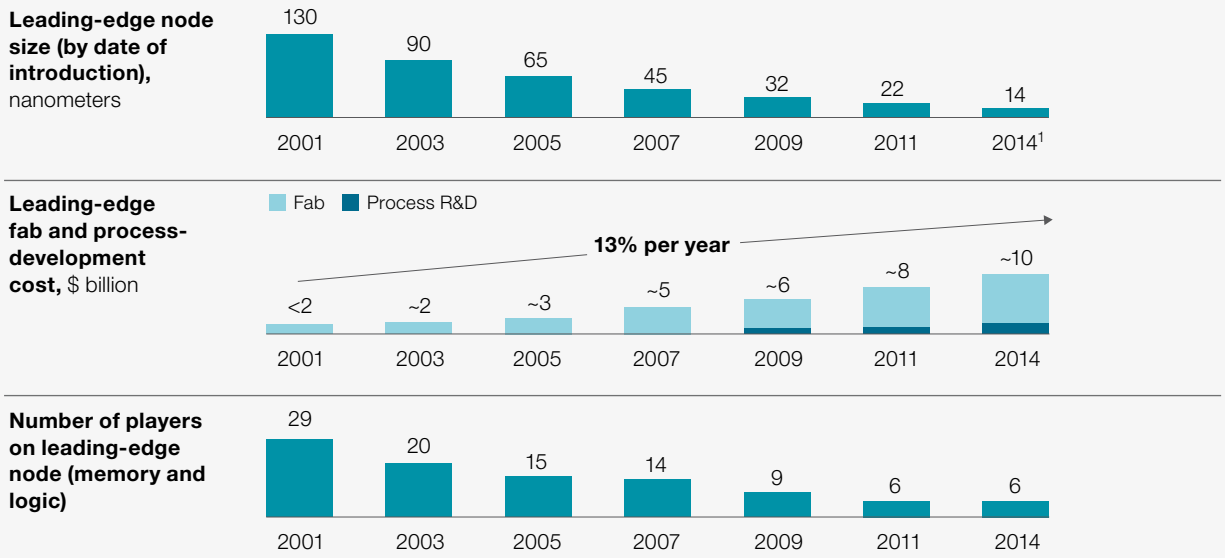
In addition to pure-memory players, diversified integrated device manufacturers also suffered from low memory-segment profitability and high segment volatility, causing Hitachi, IBM, LG Electronics, Mitsubishi Electric, NEC, and Texas Instruments to exit the sector. Today, there are only three major players in DRAM, accounting for more than 90 percent of market share: Micron, Samsung, and SK Hynix. The industry structure is similar with NAND, where Micron/Intel, Samsung, SanDisk/Toshiba, and SK Hynix dominate.

Barriers to entry: Large scale and strong technological capabilities are essential

To be competitive in the memory segment, players must have large scale and strong technological capabilities. These requirements have created high barriers to entry for the past 20 years, and no serious new competitors have emerged over the past 10. The size of leading-edge nodes decreased from 130 nanometers in 2001 to just over 20 nanometers in 2014. This "shrink" caused fab and process-development costs to soar by 13 percent annually, with the steepest increases reported over the past few years (Exhibit 4). The cost of building a new fab with the technology required for a leading-edge node can reach as much as $10 billion, up from about $1.7 billion in 2001.[3] Memory players are under pressure to migrate all capacity to a smaller node size because memory produced on them is cheaper from a dollar-per-bit perspective. (More than 90 percent of memory devices today are produced on leading-edge nodes, although the slowdown of NAND node-size shrink may reduce that number, as discussed later.)

Technology requirements also pose a challenge for entering the memory segment. Currently, only a few leading semiconductor companies have all the necessary success factors: sufficient intellectual property, strong design and process-engineering capabilities, and a track record for improving yield to sustainable levels. These scale and capability requirements help explain why the number of players with leading-edge nodes (in memory and logic) fell from 29 in 2001 to 6 today.

Exhibit 4 **Growing capital-equipment requirements are a high barrier to entry for technologies that require leading-edge nodes.**



[1]Delay of 14- and 10-nanometer nodes considered in calculations.

Source: IC Knowledge; iSuppli; SEMI World Fab Watch; McKinsey analysis

A broader demand base

Before 2008, the memory segment primarily depended on sales of PCs and, to a much lesser extent, enterprise servers. With no other sectors providing a meaningful buffering effect, demand varied greatly as PC sales surged or lagged. Between 2007 and 2009, for example, demand for desktop PCs dropped by 18 percent, resulting in an oversupply of DRAM.

Today, however, the demand base for memory products is much broader, primarily because of rising demand in the mobile sector. Current smartphones and tablets require much more memory than previous mobile devices, which has contributed to the sector's consistent double-digit growth in recent years. This increase has helped counterbalance the continued decline of PC sales, which fell 19 percent between 2011 and 2014. In fact, the mobile segment overtook PCs in demand for DRAM in 2014.

Other developments that have helped diversify the demand base include the increased need for data centers for Internet and cloud applications, as well as the emergence of applications for NAND in enterprise storage. For instance, the number of so-called hyperscale data centers and other cloud data centers is growing rapidly and may reach a market size of $17 billion in 2018, up from $9 billion in 2013, according to a Bernstein analysis.

Supply: Slowdown in bit-capacity growth

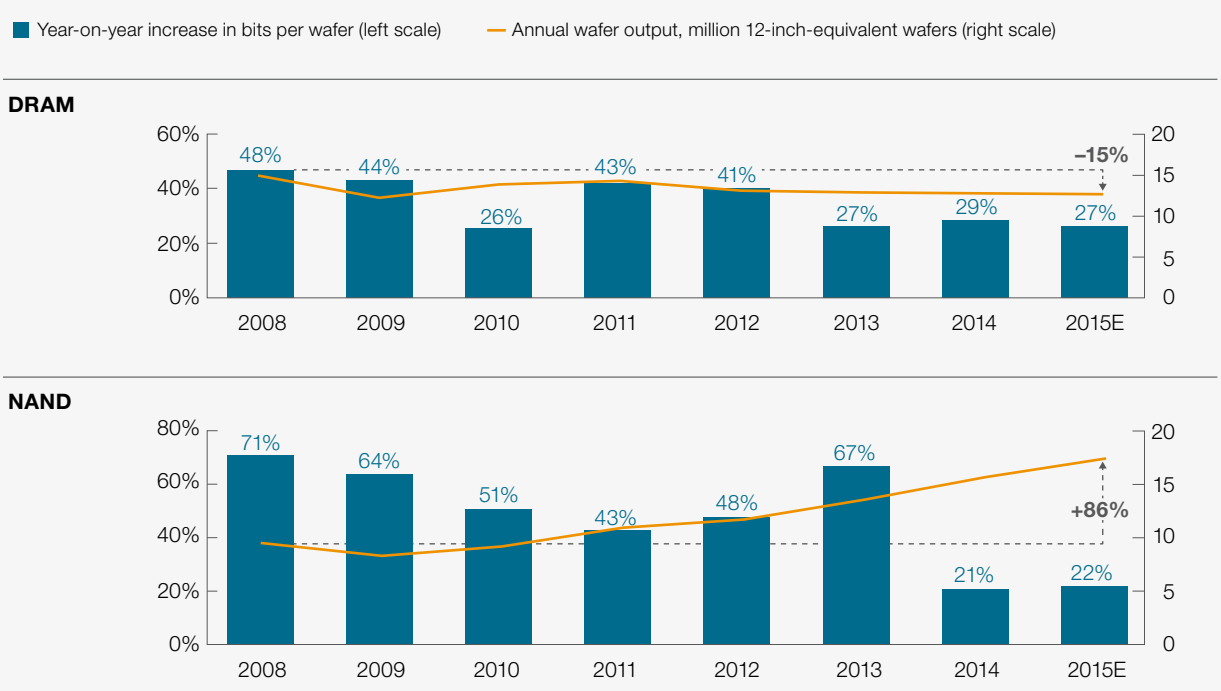
Memory bit capacity is determined by two factors: capacity for memory wafers worldwide and the number of bits per wafer. Over the past few years,

slower growth in both factors has prevented the segment from running into an oversupply situation, as was often the case before 2012.

According to iSuppli, a research house, the capacity for memory wafers for DRAM and NAND more than doubled between 2005 and 2008, going from about 850,000 wafer starts per month to about 2,100,000. This increase led to an oversupply in memory, especially DRAM. Between 2008 and 2015, however, no significant DRAM capacity was added; in fact, consolidation of the segment led to DRAM output declining by 15 percent over this period (Exhibit 5). NAND wafer-capacity output grew by 86 percent from 2008 to 2015, while revenue for this segment increased by 180 percent.

The number of bits per wafer—the second factor that influences memory bit capacity—has traditionally been driven by node-size shrink. For many years, shrink doubled roughly every two years, according to Moore's law. But semiconductor companies now have difficulties maintaining this pace because of increasing technological challenges. As a result,

Exhibit 5 **Growth in bit capacity per wafer has slowed since 2008.**



Source: iSuppli; McKinsey analysis

the year-on-year increase in bits per wafer significantly slowed in 2015 for both DRAM and NAND, as Exhibit 5 shows. Toshiba already announced that a shrink of NAND below the current leading edge of 15 nanometers does not make economic sense and stated that the further increase in bits per wafer will have to come through other approaches, such as 3-D NAND. The latest consensus forecast of the International Technology Roadmap for Semiconductors also states that NAND node shrink has slowed.

Player behavior: A new focus on profitability over market share

For many years, memory players prioritized market-share gains over profitability in this much-commoditized segment, with many expanding capacity even though greater chip supply drove prices down and had little positive impact on revenues. Samsung, for instance, aggressively invested in capacity to become the leading DRAM player. The focus on market share and capacity expansion, which players in many other semiconductor segments also displayed, has long been a factor in the industry's low profitability.

In some cases, government subsidies or credits may have skewed the market and encouraged players to expand or kept them in business. These subsidies and credits were popular because many governments considered the memory sector to be strategically important, and they wanted to help companies recover from difficult circumstances. Several countries still offer subsidies and incentives, particularly those in Asia, where most memory capacity is located. However, subsidies and incentives are now less common in other locations, so their impact is more limited.

Although the memory market is still very competitive, players have behaved more rationally since 2012, when consolidation reduced the number of major DRAM players to three. These top three players—Micron, Samsung, and SK Hynix—are now clearly focused on profitability, as transcripts of recent earnings calls demonstrate. For instance, some leaders mentioned that they wanted to focus on profit maximization; others announced that they would not add capacity to gain market share or stated that they do not expect to undertake aggressive expansion efforts. The new profit-focused outlook is also reflected in the fact that some players have started to employ experts from capital-intensive industries with commoditized products, such as oil and gas.

Questions for the memory segment

Although the memory segment appears to be on the right track, several challenges lie ahead. Some are specific to DRAM or NAND, while others will affect both segments.

A possible mismatch between supply and demand in DRAM

DRAM supply may continue to outstrip demand, creating pressure on prices, margins, and profitability. The following factors are among those contributing to this situation:

- a continuing decline in PC unit sales, which still constitute 25 percent of memory demand
- a slowdown in growth of the smartphone end market
- an increase in DRAM supply, resulting from the shift to smaller node sizes and increased investment in capacity

Consider a few recent developments. Samsung began shipping 20-nanometer nodes in March 2014, and Micron and SK Hynix followed. The transition from

25-nanometer to 20-nanometer node size (and smaller) will increase bit capacity by 30 percent at existing production facilities. There is also clear evidence that leading companies plan to increase current production capacity. For example, Samsung is building a $14 billion memory fab in South Korea, and SK Hynix recently announced that it plans to invest $26 billion in the construction of two new memory fabs over the next ten years. This may result in periods of oversupply in DRAM as new capacity comes online.

The transition to 3-D NAND

Compared with DRAM, the overall prospects for NAND may initially look robust. The overall market size and demand for NAND chip-level products is expected to grow by about 10 percent annually, reaching a market size of more than $40 billion in 2017. But the ongoing shift in the underlying architecture of NAND—the move from planar to 3-D—may create challenges.

The transition to 3-D NAND will require massive investments and may result in periods of supply-demand imbalance. The total required industry investment for building and retooling manufacturing sites is expected to be in the range of $35 billion to $45 billion over the next three to five years. Currently, all players are ramping up yields of 3-D NAND. Samsung was the first to make a concerted push into 3-D NAND technology; Intel, Micron, SanDisk/Toshiba, and SK Hynix are expected to start ramping up 3-D NAND in 2016. Companies making this move will have to deal with several issues. For instance, challenges with 3-D stacking still remain, and the opportunity in scaling (with respect to number of layers) remains to be seen. Therefore, some players are continuing to invest in 15-nanometer planar NAND to ensure they obtain continued cost improvements while 3-D is ramping up.

One challenge to the successful forward integration of NAND chip-level players comes from new entrants at the system level. NAND chip-level players Intel, Micron, Samsung, SanDisk/Toshiba, and SK Hynix have successfully increased profitability and captured additional value through forward integration to the NAND system level, with offerings such as solid-state drives for enterprise data centers and cloud computing, and embedded solutions. However, large high-tech companies, such as Apple and Google, are thought to have begun designing their own NAND chip-based systems, and other large players may follow if the early adopters are able to keep pace with rapidly evolving NAND technology. The NAND segment is also likely to see increased M&A activity as forward integration gains momentum. For instance, the recently announced $19 billion acquisition of SanDisk by Western Digital Technologies was partly driven by opportunities in forward integration.

Developments affecting DRAM and NAND

All players will need to address two issues in coming years, and there is much uncertainty in both areas. The first development involves the emergence of next-generation NVM memory. Newly emerging NVM technologies, which offer increased speed and durability compared with NAND, are expected to begin playing a significant role and encroach on the market share of both DRAM and NAND by 2019 or 2020. For instance, Intel announced that it plans to reenter memory manufacturing, which it left in 1985, specifically for 3-D XPoint, a type of NVM.[4] SanDisk has been working on new NVM technologies and recently announced a collaboration with Hewlett-Packard on its resistive-RAM technology. However, adoption of these new technologies will require significant changes in computer-system architecture, including applications and operating systems.

The second issue relates to the role of China. Given the resources at its disposal, China can significantly alter the memory segment's future structure and economics through its investments. Already, large Chinese players have been aggressively pursuing a significant role in the memory segment. For instance, Tsinghua Unigroup made a $23 billion bid for Micron and a bid for minority investment in SK Hynix, but both were unsuccessful. Tsinghua has also hired leading executives from the Taiwanese DRAM industry. In other developments, current memory-market leaders have been expanding their engagement with China. Samsung recently established its first large 3-D NAND fab in China, while Intel announced that it will invest $5.5 billion to convert its fab in Dalian, China, into a facility that can produce 3-D NAND and 3-D XPoint. On the investment side, Western Digital has announced a proposed minority investment by Unisplendour of about $3.8 billion.

Over the past three to five years, the memory segment has transformed into a more stable and profitable part of the semiconductor space. Players have the opportunity to create economic value by pursuing a diverse set of applications and moving up the stack into devices and systems. However, they will also face major challenges, including supply-demand imbalances (which may be temporary), significant technology transitions, uncertainties related to China, and the emergence of new technologies. Companies that are flexible and rapidly adjust their strategies to suit the evolving memory landscape may increase their chances of success in the exciting times ahead. ■

[1] For more information on value creation in the semiconductor industry, see Kai Steinbock, Jan Veira, and Florian Weig, "Value creation remains a challenge," *McKinsey on Semiconductors*, Autumn 2013, mckinsey.com.
[2] For simplicity, NAND flash is referred to as NAND.
[3] We consider leading-edge nodes to include the two to three smallest available.
[4] Intel has produced NAND since 2006, but in a joint venture with Micron Technology.

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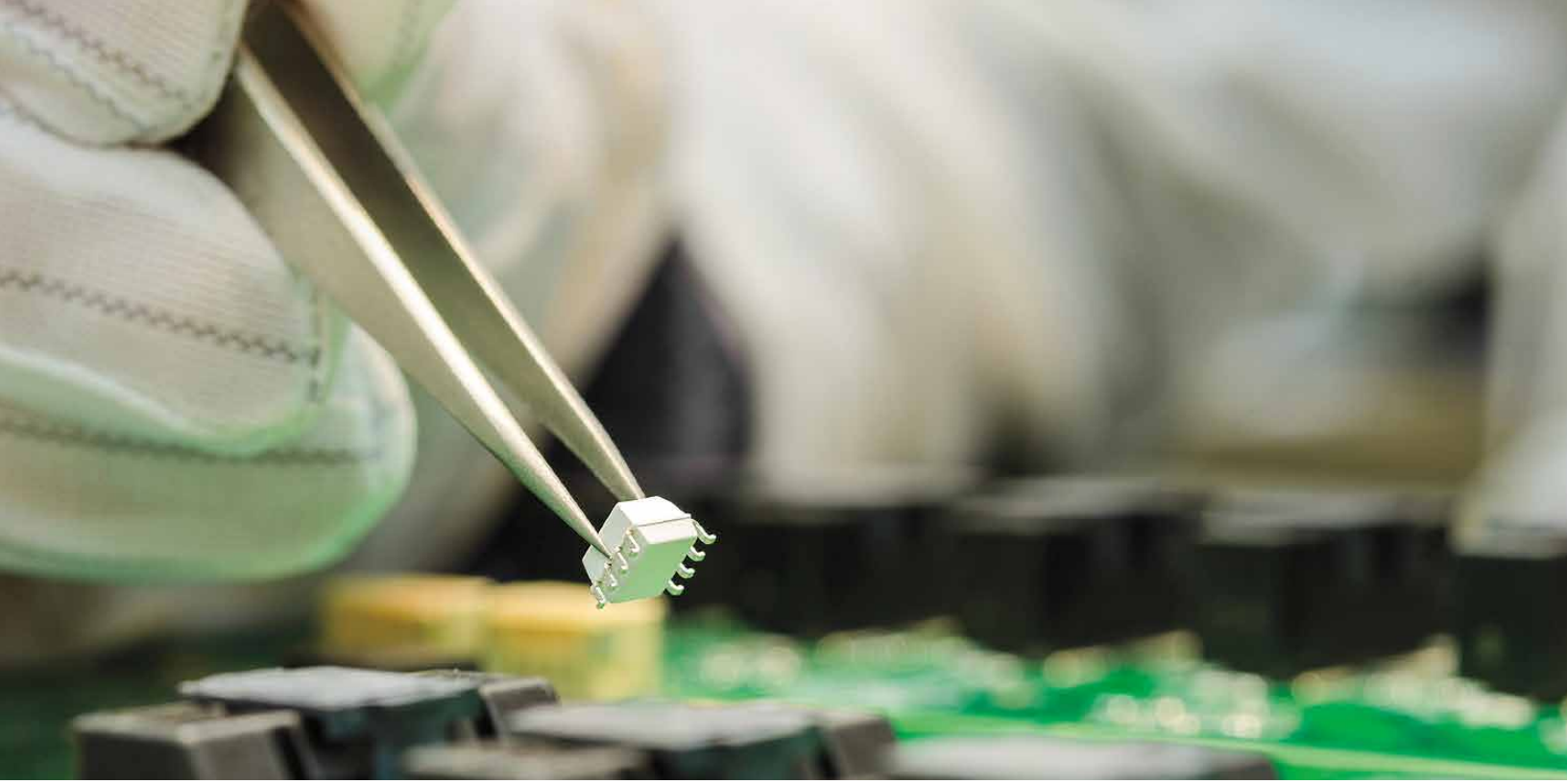


Ray Stata on the evolution of the semiconductor industry

The cofounder of Analog Devices looks back on his long career and assesses the state of semiconductors today.

Abhijit Mahindroo and Nick Santhanam

Ray Stata, cofounder of Analog Devices, has always charted his own course. "Early on, I decided I wanted to start my own company and be my own boss. I had a serious aversion to authority," he says. His independent streak and willingness to challenge conventional wisdom helped make Analog into a worldwide leader in data conversion and signal-processing technology. In this edited conversation with McKinsey's Abhijit Mahindroo and Nick Santhanam, Stata looks back on the factors that contributed to Analog's success. He also reviews the rapidly evolving semiconductor landscape, offering advice to executives who are trying to develop their own winning strategies.

McKinsey on Semiconductors: *The path to a start-up can be complicated. Can you tell us how Analog came to be?*

Ray Stata: After graduating from the Massachusetts Institute of Technology [MIT], I started working for Hewlett-Packard to learn about business, since I wanted to start my own company. Matt Lorber, a fellow student at MIT with whom I shared an apartment, also had the itch to start a business. We talked a lot about what to do and how to do it without any great ideas. So we took the plunge without a real business plan and little money and founded Solid State Instruments, based on our experience at MIT's

Instrumentation Labs. The company was a failure from most perspectives, except that it was acquired by Kollmorgen's control division within a year. The sale provided a nest egg to fund Analog Devices later. More important, through our experience building instruments and controls for Kollmorgen, we learned about the emerging market for modular operational amplifiers. At Solid State, we decided to buy the op amps used in our instruments, rather than design and manufacture them. We later started Analog Devices to compete with our suppliers.

McKinsey on Semiconductors: *New companies might benefit from hearing how Analog Devices grew from a start-up to a mature enterprise. What helped you in this journey?*

Ray Stata: First, we had a tolerance for risk and readily adapted to changes in the environment. When we founded Analog Devices in 1965, there were no linear integrated circuits [ICs]. We designed op amps using discrete transistors, resistors, and capacitors. In 1967, the first IC op amps were introduced. The performance of these devices was no match for our hand-assembled modules, but they became better each year and were an order of magnitude cheaper. So I decided in 1969 to get into the semiconductor business and to design and manufacture IC op amps, targeted at high-performance applications in the instrumentation and military markets where our modular op amps were selling well.

It was a huge risk for a small company to shift from profitable modules, where the business was growing 80 percent annually, to ICs. We had no experience in IC design and manufacture, and the large semiconductor companies had a compelling head start. We had just gone public, and the board wouldn't approve the shift, so I personally took the risk of funding a start-up and gave Analog the option of purchasing it later, if it succeeded, with no gain to myself. Well, the start-up succeeded, and Analog bought it to enter the semiconductor business.

We also had a capacity for unconventional thinking. Take our decision to set up our own international distribution system and sales organization. Most small companies used sales representatives and distributors, especially internationally. But we directly sold and delivered products to customers in the US and abroad. This allowed us to provide superior customer service and technical support compared with competitors.

McKinsey on Semiconductors: *Can you describe some of the most important elements of your strategy?*

Ray Stata: Our strategy has always been to focus on innovation as the driver of business success and to invest in market segments where we could achieve and sustain the best performance and largest market share. To differentiate our performance from the large semiconductor companies, we pioneered the development of wafer-level laser trimming of thin-film resistors, which were deposited on the surface of standard bipolar wafers.

Although we ventured into new technologies, we always remained focused on our traditional base—op-amps customers—when deciding what other linear functions to develop. This led us to converters, multipliers, radio-frequency [RF] circuits, voltage references, sensors, and a host of other products. Our focus gave us coherence and a sense of identity—and eventually brand recognition—as the market leader in what we labeled real-world signal processing. Today, we are able to integrate our broad range of signal-processing functions into more complete solutions for wireless communications, healthcare instrumentation, and automotive safety- and entertainment-system applications. But it is still about real-world signal processing.

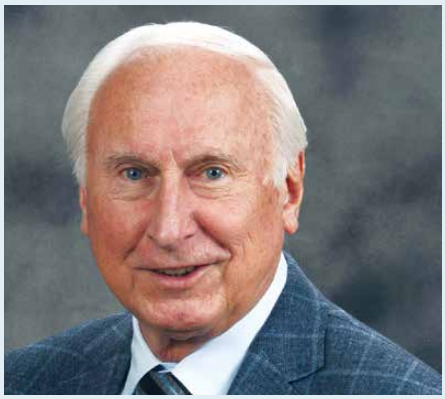
McKinsey on Semiconductors: *Do you recall any mistakes you made? What could other semiconductor leaders learn from them?*

Ray Stata: In the early days, as we were struggling to build our competence as a semiconductor company, I was worried about our long-term survival and ability to compete. As a hedge, we put together a team to integrate vertically into computerized data-acquisition systems. But when the IBM PC emerged, this idea didn't get very far. The lesson for me was to stay the course and concentrate on overcoming obstacles and risks. Hedging compromises focus and actually increases the risk. You can't do it all. You have to excel at something.

McKinsey on Semiconductors: *Let us shift focus to the semiconductor industry today. How is it different from the past?*

Ray Stata: The biggest shift is that many large customers no longer want to buy components and design their own board-level systems. They want to buy more complete solutions. Thus, semiconductor companies have to become more adept at designing silicon systems. For this, you can't just focus on the performance of the separate functions. You have to design the functions to work together to achieve the best performance at the lowest cost. Although some semiconductor companies have pursued a system strategy from the outset, most have focused

Ray Stata



Vital statistics

Born in Pennsylvania

Married, with 2 children

Education

Holds a master's and a bachelor's degree in electrical engineering from the Massachusetts Institute of Technology (MIT)

Career highlights

Stata Venture Partners
(1999–present)
Founder

Analog Devices
(1965–present)
Cofounder, with MIT classmate Matt Lorber

(1973–present)
Chairman of the board

(1971–96)
CEO, president

Solid State Instruments
(1962–63)
Cofounder; company was acquired by Kollmorgen Corporation's Inland Controls division in 1963

Fast facts

Cofounder and first president of the Massachusetts High Technology Council (1977)

Member of MIT's executive committee, the American Academy of Arts and Sciences, and the National Academy of Engineering

Life trustee, Boston Symphony Orchestra

on specific components like op-amp converters or RF circuits, all with relatively low levels of functional integration. It is challenging for these companies to make the shift to systems solutions, since you have to be competent in both components and system-level ICs, which are very different businesses. It requires new competencies that go well beyond silicon-circuit design and manufacturing, such as system design, software and algorithms, and packaging technology. Another problem is that semiconductor customers are accustomed to buying silicon by the square millimeter and have trouble seeing the value in less tangible features, like embedded software.

But there are many advantages to a systems strategy. As a component company selling into board-level designs, you have to compete for every socket on the board. In the systems business, the winner takes all. There's an opportunity to capture more of the value.

McKinsey on Semiconductors: *What role do you see China playing in the global semiconductor industry? Will the entry of Chinese players alter the current industry structure?*

Ray Stata: China is already the largest consumer of semiconductors, and its market is growing most rapidly, so the country has a positive impact on global demand. There's no doubt that China will capture a larger share of the semiconductor market over time, but the country has far to go in terms of creating innovative, state-of-the-art semiconductor products. It takes decades to develop the depth and breadth of talent in research, design, process technology, and entrepreneurship that you see in the United States and other developed countries. Even as China makes strides in the right direction, industry leaders will be developing more innovative technologies, and the leading edge will keep moving forward at a blistering pace. It is important for China to emphasize technology and innovation as the means to improve the quality of life and solve social problems, and the country is doing just that. Through acquisitions, China may be able to accelerate domestic innovation and technology capabilities, but it will take a very long time to catch up in this fast-paced industry.

McKinsey on Semiconductors: *Some people believe the semiconductor sector is not as attractive to young engineers as other disciplines, such as computer science. What is your view of the talent entering the industry today?*

Ray Stata: It is true that interest in electrical engineering, not just semiconductors, has declined relative to computer science. In the United States, however, we benefit from foreign students who come here to pursue an engineering education and then stay after graduation. It would certainly make it easier to retain foreign students after graduation if we reform immigration laws. Most US semiconductor companies also benefit by setting up design centers overseas to capture the great abundance of engineering talent in other locations.

From an academic perspective, engineering education and research are increasingly interdisciplinary. Thus, more engineering students will pursue joint degrees and new interdisciplinary degree programs like bioengineering. This will help to create interest and allow more students to see the exciting developments in electrical engineering and semiconductors.

McKinsey on Semiconductors: *How do you see the semiconductor industry evolving?*

Ray Stata: As I mentioned, the shift toward complex systems solutions is changing the profile of the semiconductor industry and what it takes to be successful. These factors will drive further consolidation because companies need a breadth of products and capabilities to provide more complete

solutions. There will be less investment in the component business.

You hear it said that the semiconductor industry is maturing. It's true that industry growth has slowed, but this has occurred because technology and innovation have decreased prices so rapidly, not because there are fewer opportunities. With lower costs, increased performance, and more capabilities, semiconductors may now, more than ever, provide the solution to society's greatest challenges in energy, healthcare, transportation, communications, automation, and defense. They may also be the greatest enabler of new opportunities and new markets. Who would have thought of drones as a multibillion-dollar market just a few years ago?

We can't imagine where the industry's new capabilities will take us. But the opportunities that are already visible are truly exciting—the potential for a thousand-fold increase in wireless-communications capacity at one-tenth the cost, the potential of the ubiquitous Internet of Things, or the mastery of speech recognition to reliably enable voice commands for smartphones and to accurately translate speech to text.

McKinsey on Semiconductors: *What advice would you give to CEOs about succeeding in the future semiconductor market?*

Ray Stata: You should rethink your views on what it takes to be successful. You'll need a deeper and more comprehensive understanding of your customer's business to excel at solutions. You'll also have to make bigger bets and assume higher risks. You can't afford many losers.

I'd also say that semiconductor companies have to become much better at forming true partnerships with customers—long-term alliances in which both parties develop the trust to share ideas and possibilities. These partnerships will help semiconductor companies reduce risks and capture more opportunities. ■

Abhijit Mahindroo (Abhijit_Mahindroo@McKinsey.com) is an associate principal in McKinsey's Southern California office, and **Nick Santhanam** (Nick_Santhanam@McKinsey.com) is a director in the Silicon Valley office.

Winning through M&A?
Deal making in the semiconductor sector

Semiconductor companies have much to gain through M&A—if they can overcome their misconceptions and upgrade their execution strategy.

Helen Chen, Vineet Gupta, Mark Patel, and Maggie Stringfellow

After a number of years of limited deal making, the semiconductor industry has been experiencing an uptick in mergers and acquisitions. The reasons behind the shift are clear: revenues are slowing, forcing players to seek other sources of growth, and customers increasingly prefer purchasing integrated solutions from one company. In response, semiconductor companies are acquiring or merging with enterprises that will take them into new areas of the value chain. Each deal prompts other companies to consider M&A to gain scale and remain competitive.

This article went to press in late 2015, before fourth-quarter results were available, but M&A activity for the year had already set records for volume and value. Even with this surge in deals, semiconductor companies are still less likely to engage in M&A than their counterparts in other high-tech sectors. What explains this pattern? Are semiconductor companies justified in their restraint, or should industry consolidation accelerate?

How semiconductor M&A is evolving

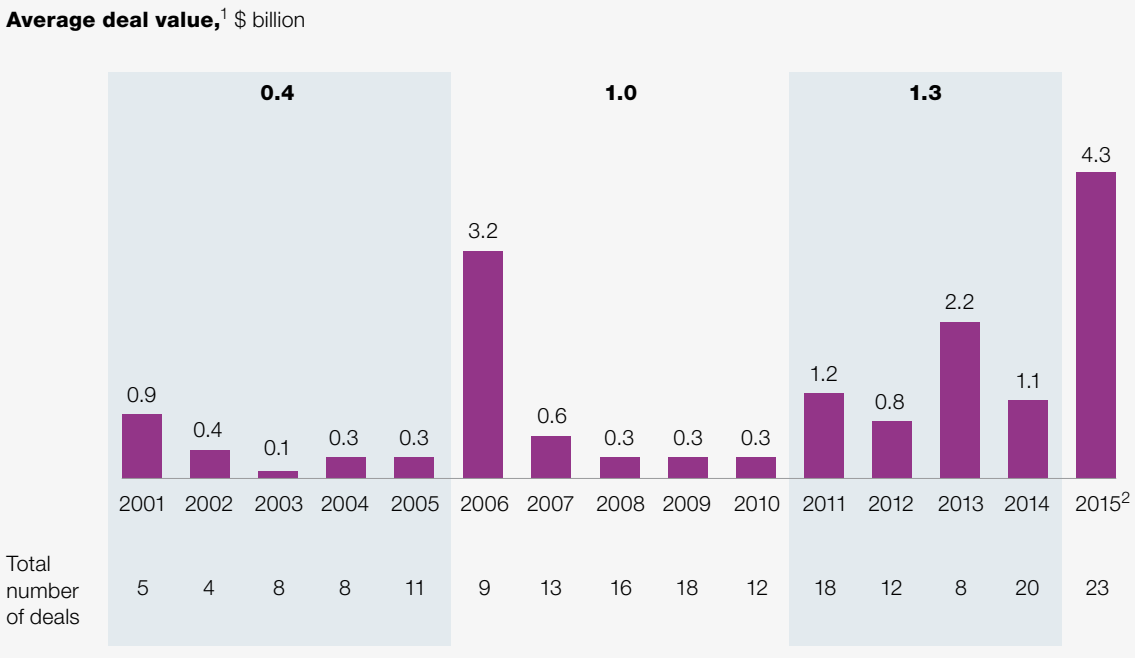
The growth in semiconductor M&A is most apparent when comparing the activity of the past few years with historical patterns. From 2001 through 2005, semiconductor companies conducted only about 7 deals per year, with an average value of $0.4 billion each. Between 2011 and 2014, by contrast, they completed about 15 deals per year, with an average

value of almost $1.3 billion each (Exhibit 1). Results for the first three quarters of 2015 suggest that M&A activity is becoming even more intense; companies closed 23 deals, with an average value of $4.3 billion.

Despite these trends, the deal-making volume for semiconductor players, on average, is lower than that of other computer and electronics manufacturers (Exhibit 2). The sector's annual activity would be even lower were it not for another statistical aberration: the average deal value for semiconductor companies is about 75 percent greater than in other high-tech industries. While high price premiums are responsible for the large valuations, the industry's low volume is driven by a less quantifiable force: the industry's belief that M&A benefits do not justify the risks entailed or the effort required.

It's easy to understand why semiconductor players have historically been reluctant to undertake M&A. With targets commanding such high price premiums, the consequences of undertaking the wrong deal are severe. But this conservatism—although admirable in theory—may have been holding the sector back, according to a recent McKinsey analysis that looked at more than 15,000 M&A deals executed by the world's top 1,000 nonbanking companies. The analysis found that the companies with the best growth rates followed a high-volume deal strategy.[1] Of those companies on the list in December 1999, only 423 were

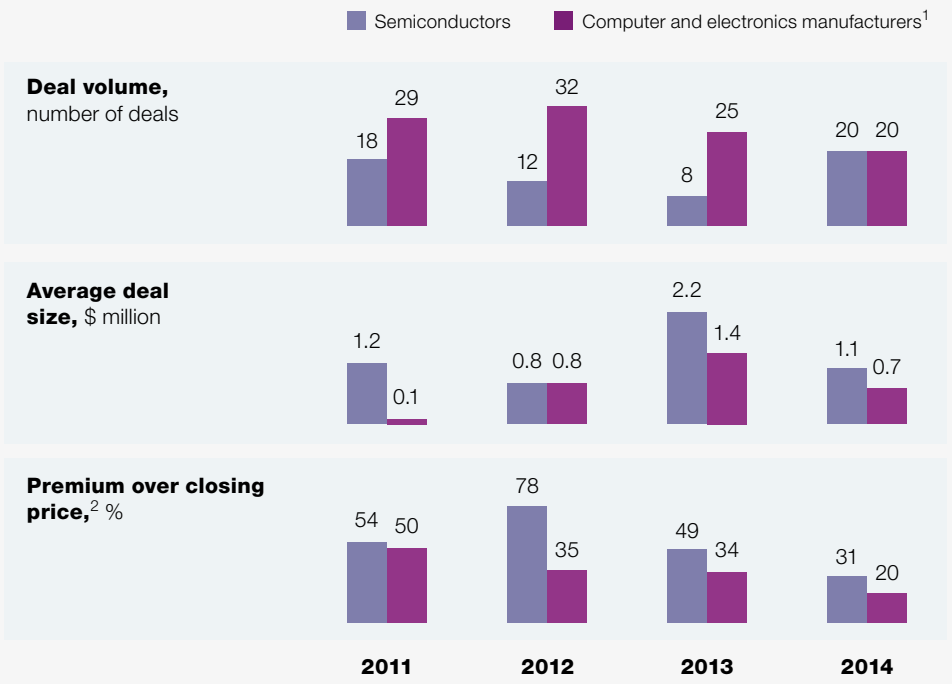
Exhibit 1 **Semiconductor M&A activity has been gaining momentum.**



[1]Private-equity transactions are included.
[2]Includes data through Dec 10, 2015.

Source: Dealogic; McKinsey analysis

Exhibit 2 **Compared with other computer and electronics manufacturers, semiconductor companies have used a low-volume, large-deal M&A strategy.**



[1]Includes manufacturers of PCs and peripherals, networks, components, memory devices, and other related electronics products.
[2]Premium ultimately paid compared with share price 1 day prior to announcement date.

Source: Dealogic; McKinsey analysis

still in the top 1,000 by December 2012. Notably, 55 percent of the survivors frequently engaged in M&A. The results are even more striking when restricted to the top 100 companies by market capitalization, showing that 78 percent of survivors followed a high-volume strategy.

The survey also revealed that the most active deal makers had the highest returns. Companies that made more than five deals per year had a median excess total return to shareholders (TRS) of 3.8 percent from December 1999 through December 2012. This was higher than that for companies with three to five deals (2.2 percent) and those with one to three deals (0.8 percent) (Exhibit 3).

A look at common misconceptions

If companies in other industries benefit from M&A, why do semiconductor players hold back? Does deal making produce less favorable results in this sector, or are other forces at play? In our research on the industry, we found that many semiconductor companies refrain from M&A because they believe that high price premiums are unjustified, that deals do not produce value, and that the market will not reward partnerships between dissimilar companies.[2] They also believe that executing a deal is difficult. When we looked at selected semiconductor deals completed between 2006 and 2013, we found a few cases where these beliefs were justified. Overall, however, the reality was quite different.

Why high price premiums may be justified

Recent semiconductor deals have had high price premiums. In fact, the average company sold for 40 percent more than its closing stock price from 2006 through the first half of 2015. But after examining 15 semiconductor deals, we found that the value created typically exceeded the price premium—often by a significant margin.[3] In 12 of the 15 deals we examined, the value captured—defined as the product of reported synergies and the enterprise multiples of the target and acquirer—was higher than the premium paid.[4] In one-third of the deals, the value captured was more than twice the premium paid.

Semiconductor companies may be underestimating potential synergies because they typically review high-level data when assessing opportunities. For example, most companies will look at the overall general and administrative costs for each partner, rather than assessing opportunities by function, such as human resources, finance, and legal.

A bottom-up analysis of the supplier and customer bases at both companies is also valuable because it might identify redundancies in sales and operations. Likewise, a detailed analysis of all engineering and R&D activities required to support the product and technology road maps can provide more insight into synergy potential than a simple comparison of overall R&D spending.

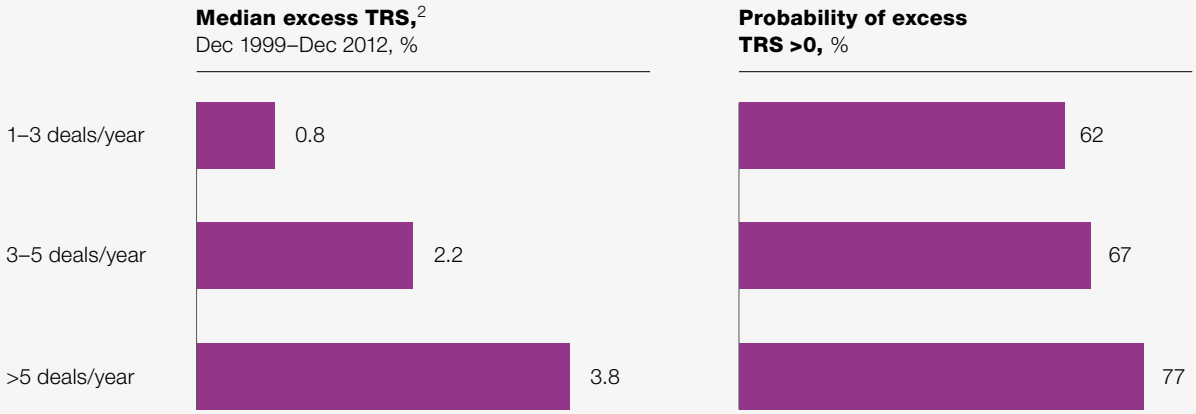
Deals can add value quickly

Many semiconductor companies doubt that they will derive value from M&A, or they expect to wait years for strong returns. But our analysis showed that 8 of 11 recent major deals—about 70 percent—were accretive within a year of closing, including

Exhibit 3

The most active deal makers earn the highest returns across industries.

Global 1,000 companies,[1] by number of deals



[1]Companies that were among the top 1,000 by market capitalization as of Dec 31, 1999 (>$4.9 billion), and were still trading as of Dec 31, 2012; excludes companies headquartered in Africa or Latin America.
[2]Total return to shareholders.

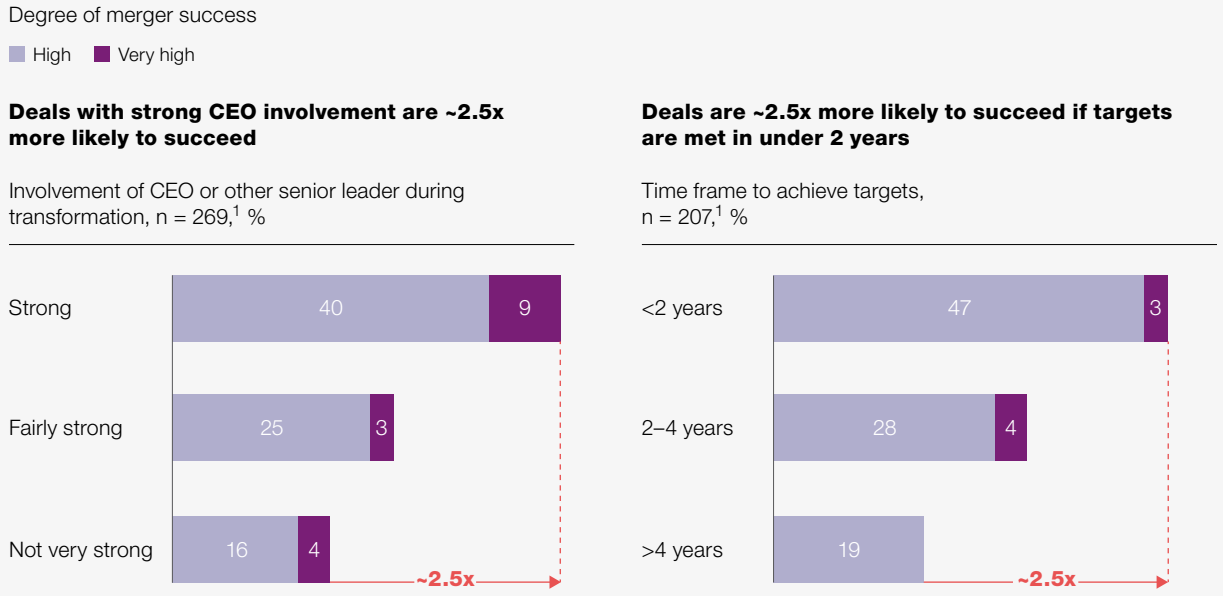
Source: Dealogic; TPSi; McKinsey analysis

acquisitions of companies with lower profitability. Furthermore, more than half the deals were accompanied by an increase in the enterprise multiple within a year of closing.

The market may reward M&A between dissimilar companies

When considering M&A, semiconductor players typically look for targets within their own segment, believing that their share price will not rise substantially if they buy a dissimilar company. But many unconventional alliances have produced substantial gains, since they allow players to offer more comprehensive products while simultaneously diversifying the customer base—changes that the market will perceive favorably. Consider one recent merger of a company that makes discrete components and another player with lower margins that makes logic circuits. Before the deal, the discrete manufacturer was highly dependent on its top three customers, which accounted for 38 percent of revenues. High customer concentration is a risk, since a drop in sales from just one company can have a significant bottom-line impact. In this case, the merger allowed the company to diversify its customer base, with revenues attributed to the top three falling to 29 percent. The annual cost synergies from the deal, estimated at $400 million,

Exhibit 4 **Value creation should occur rapidly after a deal and be driven from the top.**



[1]Unweighted data.

Source: Expert interviews; McKinsey survey on transformational change, Jan 2010

were also significant. As with many deals involving dissimilar companies, most synergies existed within back-office functions, such as human resources and procurement, rather than engineering. The market responded favorably to these developments, and the company's share price rose 25 percent postmerger.

Deals can be executed rapidly and efficiently

Most semiconductor companies are not well prepared for handling the increased work load required for successful integration. Many postdeal tasks are complex, and companies may not capture full value if they are done poorly.

While M&A does present many challenges, semiconductor companies can overcome them with a more disciplined and rigorous approach to deal execution. Two factors that can significantly increase the likelihood of success include leadership support and a commitment to rapid integration. Our research shows that companies that achieve their value-capture targets within the first two years after a deal are two and a half times more likely to report success, as are those with strong CEO involvement in post-integration activities (Exhibit 4). Appointing a dedicated leader for postmerger management also contributes to smooth execution.

By nature, M&A activity entails a degree of risk. However, conservative players that overestimate the potential dangers may overlook rewarding opportunities. To succeed in M&A, companies should consider a broad set of potential partners rather than focusing on those within their own segment. They should also seek cost savings and efficiencies through a detailed analysis of potential synergies. With a solid execution strategy that guides them from planning through postmerger management, the semiconductor industry can add value from M&A.

[1] Based on a survey conducted by McKinsey's Corporate Finance Practice. For more, see Anders Nielsen, Robert Uhlaner, and Bill Wiseman, "Creating value through M&A and divestiture," *McKinsey on Semiconductors*, Autumn 2012, mckinsey.com.

[2] Based on interviews with corporate officers at semiconductor companies in 2014.

[3] This analysis only included deals greater than $100 million in value.

[4] The enterprise multiple is used to define company value. It is calculated by looking at two metrics. The first is a company's enterprise value (EV), which is defined as its market capitalization plus debt, minority interest, and preferred shares, minus total cash and cash equivalents. The second metric is a company's earnings before interest, taxes, depreciation, and amortization (EBITDA). To compute the enterprise multiple, EV is divided by EBITDA.

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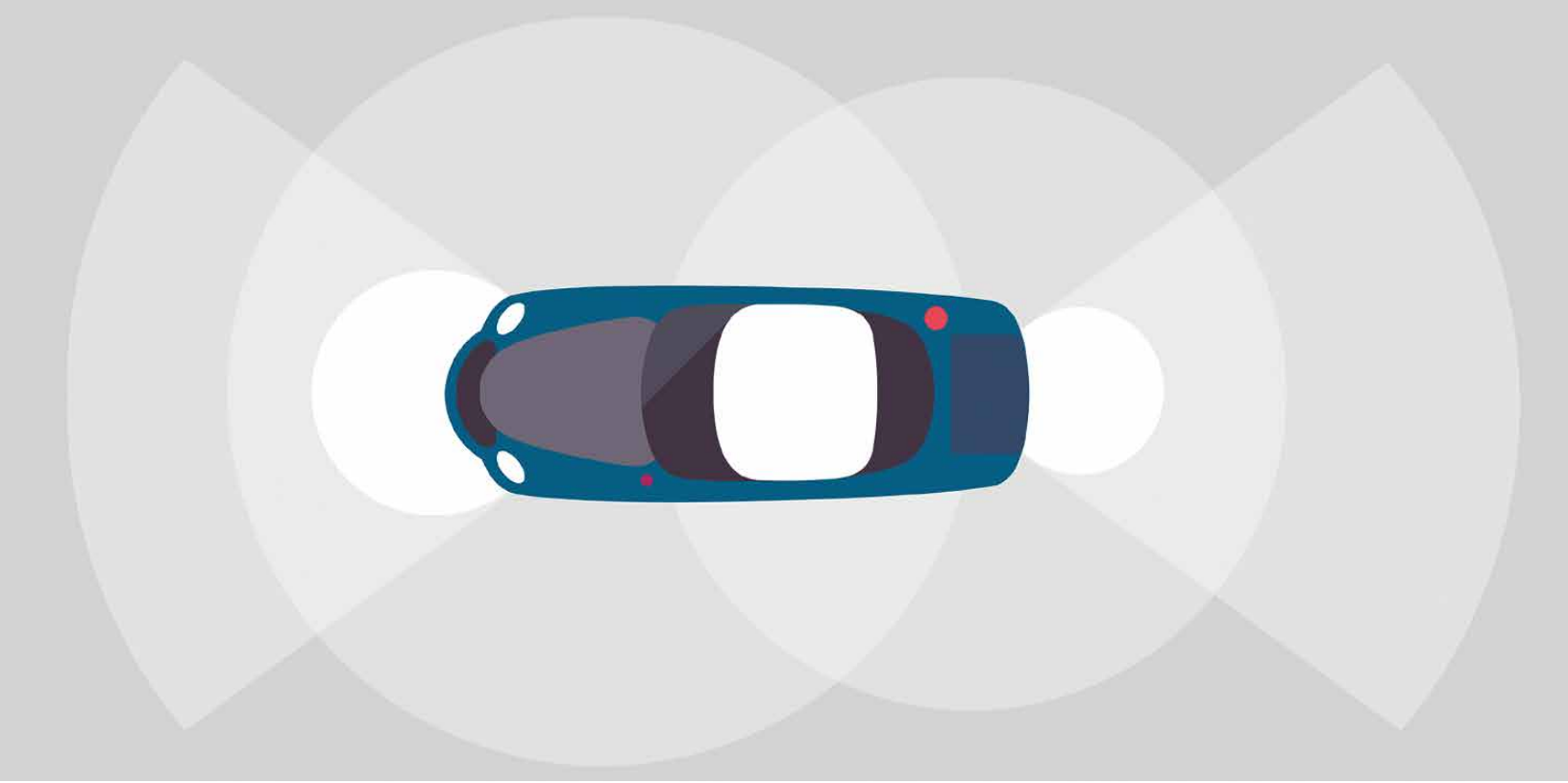


Capturing the opportunity in advanced driver-assistance systems

Semiconductor companies can help take applications for these systems to a new level—provided that they are ready to embrace change.

Seunghyuk Choi, Florian Thalmayr, Dominik Wee, and Florian Weig

Demand for advanced driver-assistance systems (ADAS)—those that help with monitoring, warning, braking, and steering tasks—is expected to increase over the next decade, fueled largely by regulatory and consumer interest in safety applications that protect drivers and reduce accidents. For instance, both the European Union and the United States are mandating that all vehicles be equipped with autonomous emergency-braking systems and forward-collision warning systems by 2020. A recent McKinsey survey also suggests that car buyers are becoming even more interested in ADAS applications that promote comfort and economy, such as those that assist with parking or monitoring blind spots.

Although ADAS applications are still in their early days, original-equipment manufacturers (OEMs) and their suppliers realize that they could eventually become the main feature differentiating automotive brands, as well as one of their most important revenue sources. And the same technologies that enable today's ADAS offerings could also be used to create fully autonomous vehicles, which are now a major focus of research and development, both at OEMs and at high-tech players that have recently entered the automotive sector, including Google. Any ADAS technology that gains early support could therefore have an advantage if self-driving cars reach the market.

Many semiconductor companies—even some that have not traditionally participated in the automotive sector—now offer ADAS products or are developing them. As with any new technology, however, much uncertainty persists about the market, including how consumers will respond to more advanced applications in which a computer controls or assists with steering and other critical driving functions. In the first part of this article, we address some of the most pressing questions about ADAS, touching on future demand, technical challenges, and the evolving competitive landscape. The second part of the article looks at ADAS from a semiconductor perspective, describing how companies can capture more value by expanding their offerings beyond hardware, collaborating directly with OEMs, and differentiating their technologies based on safety and security features.

The opportunities and challenges ahead

Although ADAS technology has the potential to transform the automotive sector, its current annual revenues—which range from about $5 billion to $8 billion, according to most sources—are modest compared with those for other automotive systems. For instance, 2015 revenues were about $30 billion for audio and telematics and about $60 billion for climate control. Part of the problem is that many of the most promising ADAS applications are still being refined or have not yet hit the market; still others are expensive and mostly available in premium cars. But one of the most important factors inhibiting demand may be a lack of consumer awareness. In a recent online survey of more than 4,500 car buyers in five countries conducted by McKinsey, many respondents were unfamiliar with ADAS applications, and few purchased cars with this technology (Exhibit 1). The survey offered reason for optimism, however, since it revealed that the repurchase rate for those who did buy a vehicle with ADAS was quite high, ranging from 87 to 89 percent. This finding suggests that once consumers become familiar with ADAS, they will prefer cars with these features.

Even though industry experts hold different opinions about 2015 revenues and growth prospects for ADAS, most expect to see an annual increase of more than 10 percent from 2015 to 2020. For instance, one leading analyst predicts 16 percent growth during this period, and a second predicts 29 percent growth (Exhibit 2). This could give the segment one of the highest growth rates in the automotive sector and related industries. However, with the base price for cars remaining relatively stable (with a compound annual growth rate of about 1 percent), semiconductor companies and other suppliers may face pressure from OEMs and customers to keep ADAS costs low, even as the technology becomes standard. In consequence, we predict that growth in ADAS value may proceed at a slower rate than growth in unit volume.

ADAS technology: Overcoming limitations to ensure active, autonomous safety

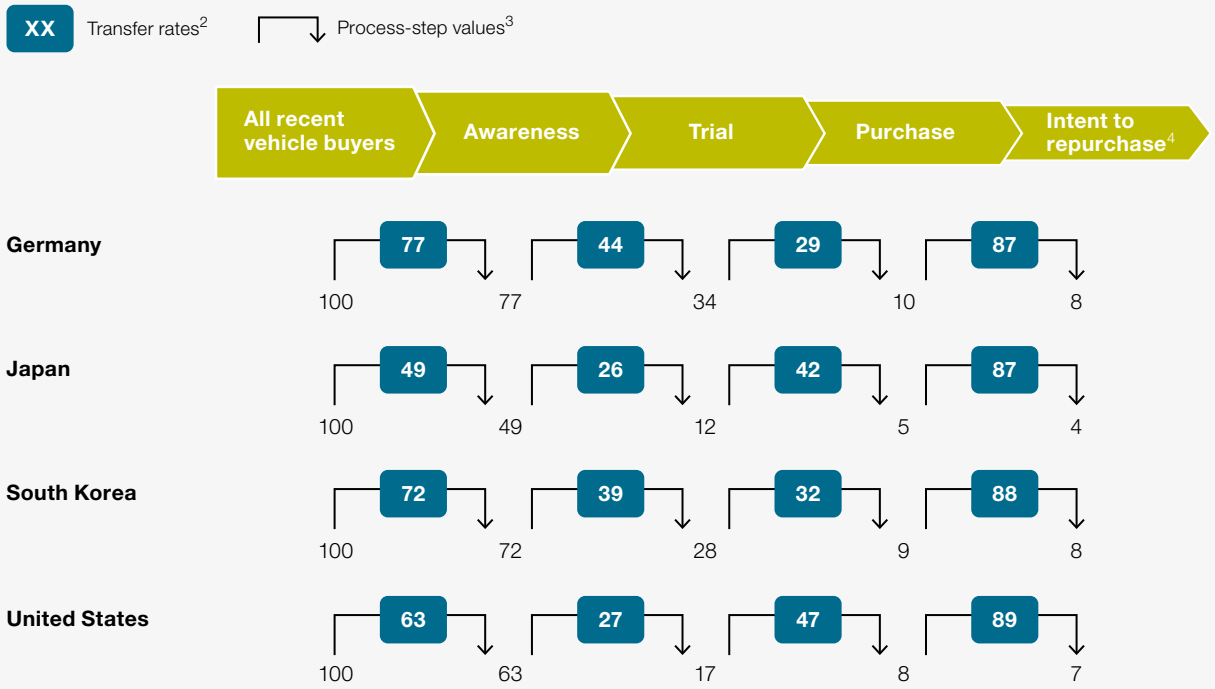
One factor that could influence ADAS uptake is the rate at which the technology advances. Although semiconductor companies and other players have made important enhancements in recent years, there is much room for improvement. For instance, forward-collision warning systems still have difficulty identifying objects when a vehicle is traveling at high speeds. A typical ADAS application incorporates many technologies, as shown in Exhibit 3, but four stand out with regard to the challenges they present: processors, sensors, software algorithms, and mapping.

Processors. Electronic control units (ECUs) and microcontroller units (MCUs) are essential for most ADAS applications, including autonomous driving. For ADAS to advance, processors need better performance, which could be enabled by multicore

Exhibit 1

Many car buyers are still unaware of the technology for advanced driver-assistance systems.

Transfer rates and process-step values in the consumer decision journey for advanced driver-assistance systems in selected countries, %[1]



[1]The online survey included 4,500 car buyers in China, Germany, Japan, South Korea, and the United States.
[2]% of buyers moving from one stage of the consumer decision journey to the next.
[3]% of all recent vehicle buyers that reach a given step of the consumer decision journey. Figures may not sum, because of rounding.
[4]Includes consumers who said they would definitely or probably purchase cars with ADAS features.

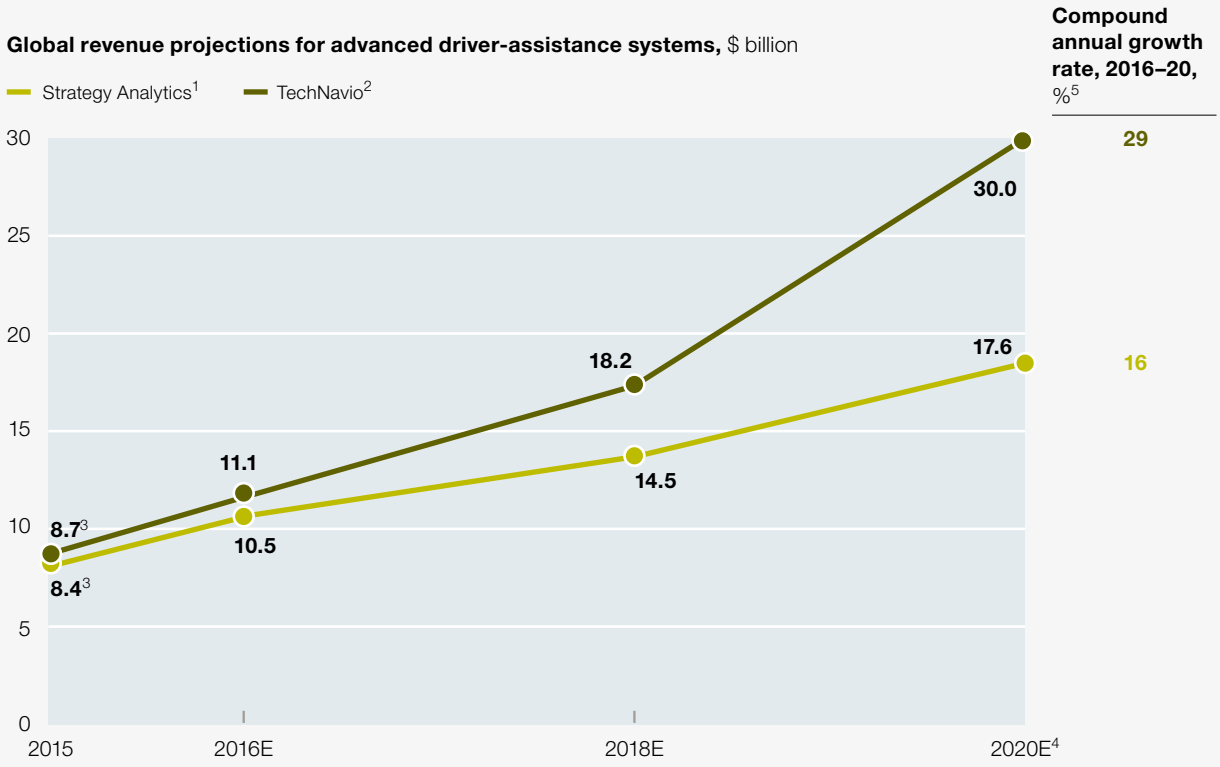
Source: McKinsey survey on connected cars, 2015

architectures and higher frequencies, as well as lower power-consumption requirements.

Sensors. These devices gather information on their immediate environment, such as pedestrians and oncoming cars. Most have a limited measurement range and signal bandwidth, which makes it difficult to distinguish between "signal" (for example, obstacles in the road) and system "noise." It is especially difficult for sensors to track moving objects during less-than-ideal environmental conditions, such as rain and fog.

Many industry players are trying to improve individual sensors. They are also attempting to optimize system performance through better sensor fusion—the coherent combination of data from multiple sensors. On the hardware side, intersensor communication is a major challenge because it requires high bandwidth and solutions for preventing network overloads.

Exhibit 2 **The market for advanced driver-assistance systems is expected to show strong momentum through 2020.**



[1]Includes autonomous emergency-braking system, adaptive cruise control, forward-collision warning, lane-departure warning, parking assistance, back-side monitoring, night vision, driver monitoring (eg, for fatigue), and traffic-signal recognition.
[2]Also includes adaptive front lighting and heads-up display.
[3]Most sources estimate 2015 revenues between $5 billion and $8 billion.
[4]2018–19 compound annual growth rate used to derive 2020 market size for Strategy Analytics and TechNavio forecast.
[5]Figures may not sum, because of rounding.

Source: IHS; SBD; Strategy Analytics; TechNavio; McKinsey analysis

Players are currently optimizing the partitioning and distribution of system architecture to address this issue. On the software side, the fusion of image and nonimage data is particularly challenging. Some OEMs and tier-one suppliers are working together with academia to address this challenge, as can be seen in Daimler's collaboration with the Karlsruhe Institute of Technology and the University of Ulm.

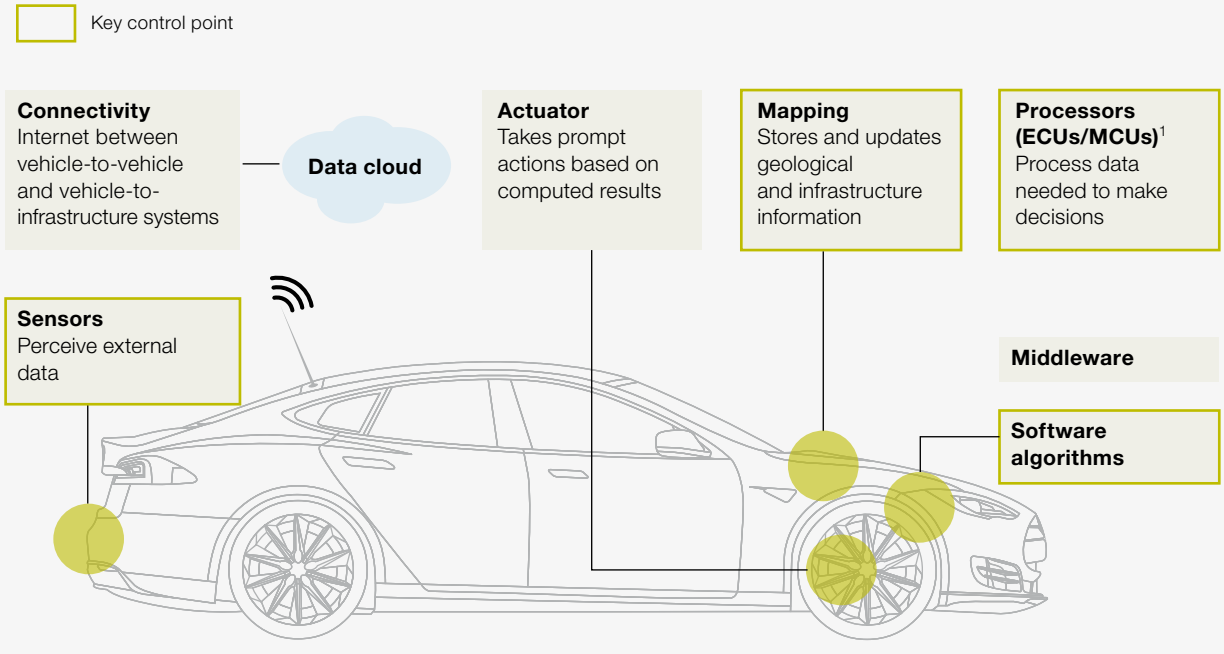
The limited functionality of today's sensors, combined with their high cost, may be the greatest constraint to ADAS uptake. Many companies are making progress on both fronts, however. As one example, Mobileye and various start-ups are trying to improve the functionality of camera-based solutions, which typically have difficulty detecting obstacles during rainstorms or in other situations when visibility is limited. If camera-based solutions catch up to radar and lidar in functionality, they could eventually dominate the ADAS market because of their lower cost. "One box" solutions that combine lasers and cameras may also become popular because they are less expensive than radar or lidar alone. This is an important development, since experts believe that

semiautonomous driving will not become a reality until the industry has a cost-effective lidar system that is fully integrated with other sensors.

Software algorithms. Running on ECUs and MCUs, algorithms use the input from sensors to synthesize the environment surrounding a vehicle in real time (going above and beyond the processing that sensors have already completed). The algorithms then provide output to the driver or specify how the system should actively intervene in vehicle control. This could require some of the most complex in-car-software integration ever created, since any decisions that the algorithms specify, such as the application of emergency brakes, are critical to ensuring safety.

In response to developments in sensor fusion, the industry is about to transition from embedded software running on a single ADAS-specific ECU to software platforms running on centralized ECUs or MCUs. These software platforms have a higher level of abstraction to allow flexible integration of sensor-fusion algorithms. Industry players are now focusing on creating such algorithms, which allow for more accurate synthesis of sensor data and more efficient processing, because they will help prevent data overload or slowdowns. Another priority is creating algorithms that allow for safer car navigation and more accurately predict all possible human behavior—including potentially irrational responses—in various situations, such as when a collision between two cars appears imminent.

Exhibit 3 **Four control points in advanced driver-assistance systems are key for autonomous driving and product differentiation.**



[1] Electronic control units/microcontroller units.

Source: McKinsey analysis

Mapping. When GPS coverage fails, such as during tunnel travel, detailed and accurate mapping systems can help prevent accidents. These systems also store geographical and infrastructure information, making updates as needed, and communicate with onboard sensors to determine a car's exact location. OEMs and other players in the automotive industry are looking for lower-cost methods to construct and maintain maps. Some of the most recent solutions include deploying "mapping cars" equipped with 3-D lasers and 360-degree high-definition cameras. Map developers are also leveraging data from sensors installed on commercial fleets, such as FedEx, as well as GPS data from drivers.

An evolving competitive environment

Many players are aware that regulators will require vehicles to be equipped with certain ADAS applications over the next five years, and they are already preparing to capture growth. This activity is triggering unprecedented changes in the automotive industry. First, more established high-tech companies, including semiconductor players, are actively pursuing ADAS opportunities, even if they did not previously have a presence in the automotive sector. For instance, Intel, NVIDIA, Panasonic, Qualcomm, Samsung, and Sony are going after such opportunities, including those related to sensors, ECUs and MCUs, systems, and systems on a chip. In addition, many start-ups and other small to mid-size companies in the high-tech and automotive sectors are now trying to capture market share. These include GestureTek, Hawk-Eye Innovations, and IntelliVision, all of which have specialized expertise in image processing and computer vision.

In another active shift, OEMs—once the primary drivers of automotive innovation—may now be more willing to collaborate with semiconductor companies and other tier-two suppliers whose technologies facilitate their development of ADAS. Similarly, both tier-one and tier-two suppliers are aggressively pursuing mergers and acquisitions to ensure they have all the capabilities needed for ADAS, including software capabilities.

How semiconductor companies should approach the ADAS opportunity

Semiconductor companies now receive moderate revenue from ADAS—less than $2 billion in 2015, compared with $29 billion for automotive electronic systems—but this is expected to grow rapidly. To ensure that they capture full value, semiconductor companies must decide where, how, and when to compete (in other words, they need to choose whether to be early entrants or fast followers). This could involve rethinking their product focus on hardware, since branching out into software will offer more opportunities, and developing new strategies for collaborating with OEMs. Companies that move quickly and establish themselves as ADAS players may gain the most when the market moves into a phase of even higher growth.

Where to play: Opportunities in hardware and beyond

We investigated ADAS hardware opportunities for semiconductor companies through 2025 using a model that considered various factors, including expected end-market adoption and price erosion for systems and components. We found that overall revenues could increase steadily, reaching about $4.6 billion to $5.3 billion in 2025. Parking-assistance systems may generate the most revenue for semiconductor players, followed by automated emergency braking, adaptive cruise control, and forward-collision warning. For system components, the best opportunities appear to be in processors (generating an anticipated 37 percent of total revenue) and optical semiconductors (28 percent), as Exhibit 4 suggests.

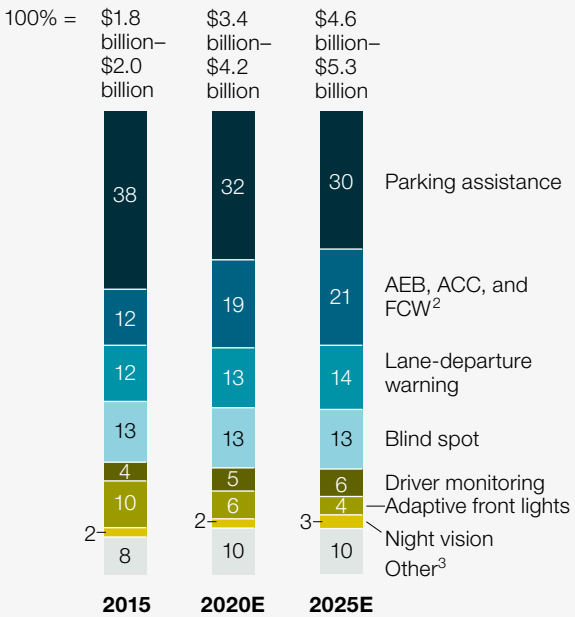
With processors and sensors expected to account for most revenues, it makes sense for semiconductor companies to consider competing in these segments by creating differentiated offerings. In addition

to hardware, which still accounts for most of their revenues, semiconductor companies could capture value by expanding their offering into software and algorithms.

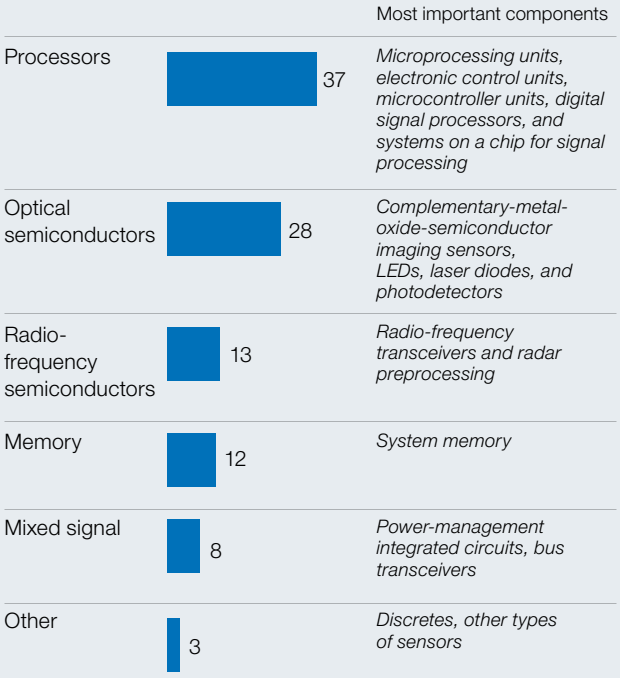
Processor enhancements. Those players with experience in adjacent industries, such as consumer, mobile, or data processing, could be best positioned to improve processor performance—the most important selling point. Since fast processors are found on the smallest nodes, they require huge investments in R&D and manufacturing. Sales in the automotive market alone will not justify these investments, so semiconductor companies may need revenue from other sectors to receive a decent return on investment. In addition, players with experience in adjacent industries may be able to adapt some of their products for ADAS applications, reducing development time. For instance, NVIDIA adapted its Tegra platform, which was originally developed for gaming devices, smartphones, and tablets, for use in automotive systems.

Exhibit 4 **For semiconductor companies, processors and optical semiconductors are expected to account for most hardware revenues for advanced driver-assistance systems in 2025.**

Semiconductor revenue in advanced driver-assistance systems per application, %[1]



Semiconductor revenue distribution on device types in 2025, %[1]



[1]Figures may not sum to 100%, because of rounding.
[2]Autonomous emergency braking, adaptive cruise control, and forward-collision warning.
[3]Includes, among other categories, back-side monitoring and traffic-signal recognition.

Source: McKinsey analysis

Sensor enhancements. Many different types of sensors exist, but three are most important for ADAS. The first and most cost-efficient option involves optical sensors and camera-based solutions. These sensors are versatile and can assist with a wide range of ADAS functions, but they are easily affected by poor weather conditions and other environmental hazards. Optical sensors and camera-based solutions also require complex software algorithms to recognize objects, such as pedestrians and other vehicles.

The second category involves lidar systems, which use a scanning laser to generate a complete 3-D image of the environment. Unlike optical sensors, lidar is less sensitive to weather conditions and directly provides the location of objects around the vehicle. But the lidar systems with the greatest range—100 meters surrounding a vehicle in all directions—are large and typically require external mounting. Although prices have fallen in the past decade, dropping from many tens of thousands of dollars to less than $10,000, they are still too expensive for deployment, and further price reductions are necessary to enable their adoption in ADAS. Lidar systems with a more limited range, such as those that can detect obstacles within ten meters in a single direction, have already been incorporated into some cars. For instance, Continental has offered short-range lidar for some time.

Finally, ADAS often incorporates short- and long-range radar using electromagnetic waves in the range of 20 to 80 gigahertz for determining the distance, speed, and direction of objects. These sensors function better than others during adverse weather conditions, but they typically involve compromises in measurement range and angle. For instance, long-range radar can detect obstacles up to 250 meters away, but the measurement angle is quite narrow. In consequence, adaptive cruise control often combines long-range radar with short-range radar, which has a wider measurement angle.

Although sensors generate less revenue than processors, semiconductor companies may prefer to work in this area because scale is of lesser importance, and it is easier to differentiate products. In fact, many sensors are required to be application specific, with different performance levels and signal-processing capabilities for their ADAS applications. As with processors, semiconductor companies may gain an advantage if they have experience in adjacent industries—for instance, creating complementary-metal-oxide-semiconductor image sensors for the consumer market—since that will facilitate product development. One challenge in adapting products may involve customizing them to meet specific automotive requirements, including those for safety.

Software. Moving into the software space may be difficult, since semiconductor companies often lack advanced software skills. To compete, they may need to build their software skills internally or undertake mergers and acquisitions with players that have the necessary capabilities.

Semiconductor companies should consider bundling hardware with nonsilicon offerings—both software (for instance, drivers, operating-system adoption, and codecs) and algorithms, including those used for real-time processing of sensor data. Bundling may generate more value than simple hardware enhancements, such as improved memory or central-processing-unit performance. In addition, semiconductor companies could attempt to provide more modules or integrated solutions, such as systems on a chip. OEMs may prefer modules and integrated solutions, including software, over single-component solutions because they provide better performance, require much less effort to implement, and make them less dependent on tier-one suppliers.

How to play: Strategies for standing out from the crowd

The changing automotive market offers new opportunities for semiconductor companies, but it

will also be intensely competitive. Three factors may be crucial to winning market share: strong working relationships with OEMs, collaborations with other players across the value chain, and product differentiation based on safety and security features.

Strong relationships with OEMs. Although OEMs have long relied on tier-one suppliers to provide innovative components, they are willing to take a much more active role in ADAS development. In fact, OEMs may eventually assume the lead because the systems found in fully autonomous vehicles must work together closely. If they drive ADAS development, OEMs will have the freedom to select the best subsystems—including sensors and general control systems—from a variety of tier-one suppliers, rather than relying on a single source. Taking charge of ADAS development would also ensure that OEMs have a better chance of differentiating themselves from competitors for both driver-support and autonomous-driving functions.

The need to develop innovative ADAS technologies is prompting OEMs to collaborate more closely with tier-two suppliers, thereby giving these suppliers a more critical role in vehicle design and manufacture. The exact assistance that an OEM requests will vary by company and application, so semiconductor companies should be prepared to provide different types of support. For instance, they might actively help OEMs with integration, assist with the development of customized integrated systems, or support the optimization of system performance.

Semiconductor players that are able to build strong relationships with OEMs may have an advantage, as will those with the ability to locate or assign field engineers near their partners. Companies can also create new relationships by demonstrating their capabilities at trade shows or by reaching out to OEMs to offer development support.

Multiple collaborations across the value chain. Numerous nontraditional automotive players and small to midsize businesses are now trying to capture value from ADAS. Semiconductor companies could pursue multiple collaborations with these players—even those that may be competitors or customers. For instance, they may seek to complement their hardware knowledge through partnerships with competent software players that have strong automotive track records. In some cases, two or more semiconductor companies may work together. For example, Renesas Electronics collaborates with more than 150 companies, including other semiconductor players, on infotainment and ADAS capabilities. By collaborating with multiple players, semiconductor companies may develop high-quality solutions that differentiate them from competitors. They may also reduce costs, optimize resource use, and decrease time to market. While many semiconductor companies may form partnerships with existing players, they could also consider collaborating with start-ups that offer strong solutions.

Differentiation through safety and security. ADAS technologies already have high safety requirements, and these will increase as applications take more active control of cars. In fact, many future ADAS technologies will be rated at Automotive Safety Integrity Level D, the classification reserved for components or systems where a malfunction poses the risk of injury or death. ADAS security requirements are also among the highest because the consequences of a hacker's interference with steering, braking, or other vehicle functions could be catastrophic. Already, there have been some well-publicized hacks on non-ADAS vehicle systems, such as those that locate, unlock, and start cars.

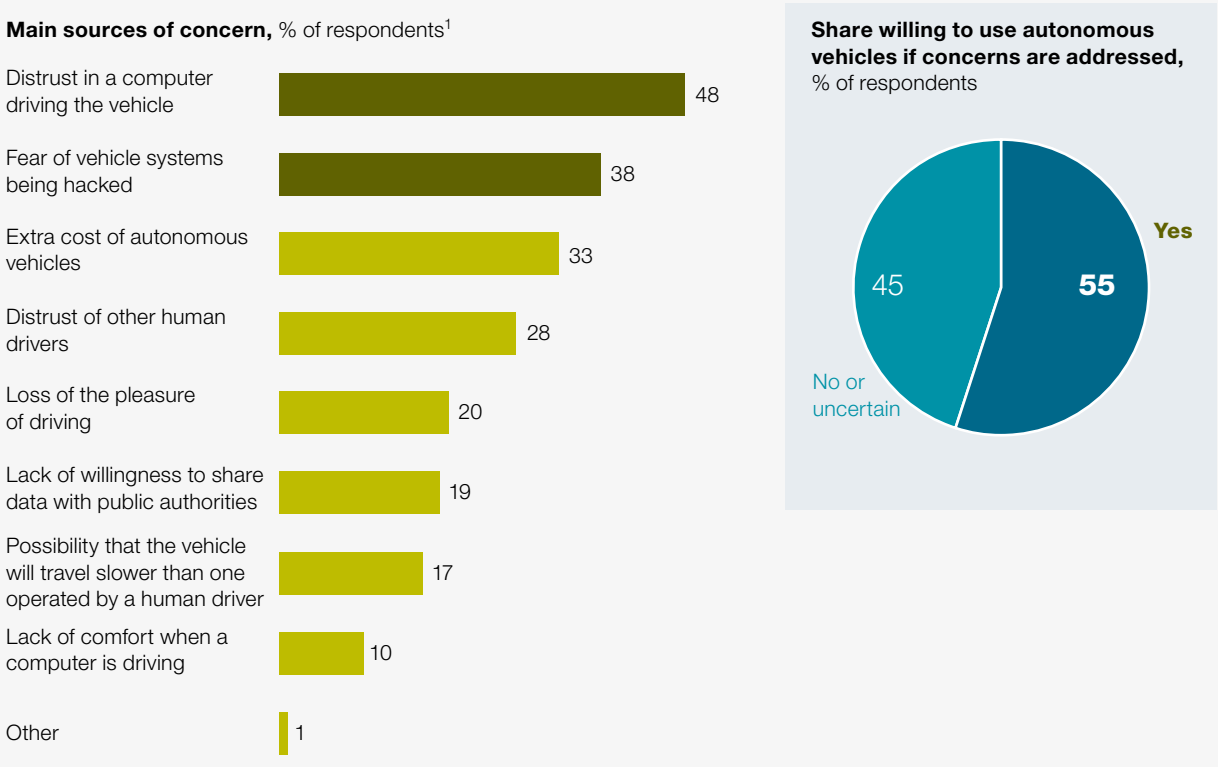
The recent McKinsey survey on connected cars confirmed that consumers are concerned about the safety of ADAS autonomous-vehicle offerings. When asked about autonomous driving, almost half of respondents expressed distrust about the computers that control the vehicle, and 38 percent stated that they feared hacking. However, more than half

of respondents said they would be willing to use an autonomous vehicle if their concerns were addressed (Exhibit 5).

Since safety and security issues could derail the ADAS market, it would be helpful for semiconductor companies to become familiar with Automotive Safety Integrity Level risk-analysis methods and perform them during the earliest stages of product development, thereby eliminating any potential for component or system-level failures. As products advance in development, semiconductor companies may need to conduct extensive testing that evaluates the safety of the ADAS component and the entire system under different environmental and operational conditions.

Autonomous driving is supported by cloud data, car-to-car communication, and car-to-infrastructure communication. In consequence, ADAS systems must link to a vehicle's communication module directly to enable fully autonomous driving. Although these modules have intrinsically secure connections, additional protections will be needed. Advanced hardware firewalls, incorporated network-level security elements (for instance, crypto chips), and

Exhibit 5 **Despite reservations about autonomous driving, more than half of surveyed drivers would use this technology if their concerns are addressed.**



[1]Based on responses from car buyers in China, Germany, Japan, and South Korea (n = 3,500); data from US respondents were not available for this question at the time of publication.

Source: McKinsey survey on connected cars, 2015

support of virtualization technologies are opportunities for semiconductor companies to differentiate their products in security.

When to play: The advantages of early entry

Some semiconductor companies are hesitant to enter the ADAS market because the technology is not yet mainstream. Although their caution is understandable, our research suggests that early entry may provide long-term benefits.

First movers may have a chance to shape the industry—for instance, by helping to establish technical standards or defining fundamental system-design architecture. And companies that secure intellectual property for their ADAS technology early could potentially collect royalties over a longer period, as Bosch did when it created the controller-area-network bus system that became an automotive standard for many years. Since there are only a limited number of technical solutions for ADAS, fast followers may also find that the best ideas have already been patented. Even those that create innovative solutions will have to abide by decisions earlier players made about technical standards and system architecture, even if they are not optimal for their own products. Consider what happened with telecommunications: Qualcomm, as a first mover, successfully pushed many of its own technologies into the LTE standard for wireless communication. Other companies must now adhere to these standards, while Qualcomm receives royalties for its technologies.

Early entry may also make sense when considering the customer base and the industry. OEMs need to screen and prioritize their ADAS suppliers now, since automotive design cycles are long, so first movers may be best positioned to capture value when sales volumes increase. They could also gain a long-term advantage because OEMs and tier-one suppliers may want to stick with trusted, well-known suppliers as they develop next-generation technologies to create fully autonomous vehicles, which are expected to reach the broad market between 2025 and 2030. This is not to say that fast followers cannot succeed, however—only that they may encounter more difficulties and capture less value than companies that aggressively pursued ADAS opportunities early on.

ADAS applications may represent the next critical business opportunity in the automotive sector, and semiconductor companies are well positioned to capture it. Their technological expertise—always valued by OEMs—is now more important than ever, especially if they can provide components and solutions that improve system-level capabilities. But it may be equally vital for semiconductor companies to adapt their traditional business model by expanding into software and integration capabilities and by developing new strategies for working with OEMs and various players throughout the value chain. Those companies that take action now, while the ADAS market is still in its early days, may emerge as the winners.

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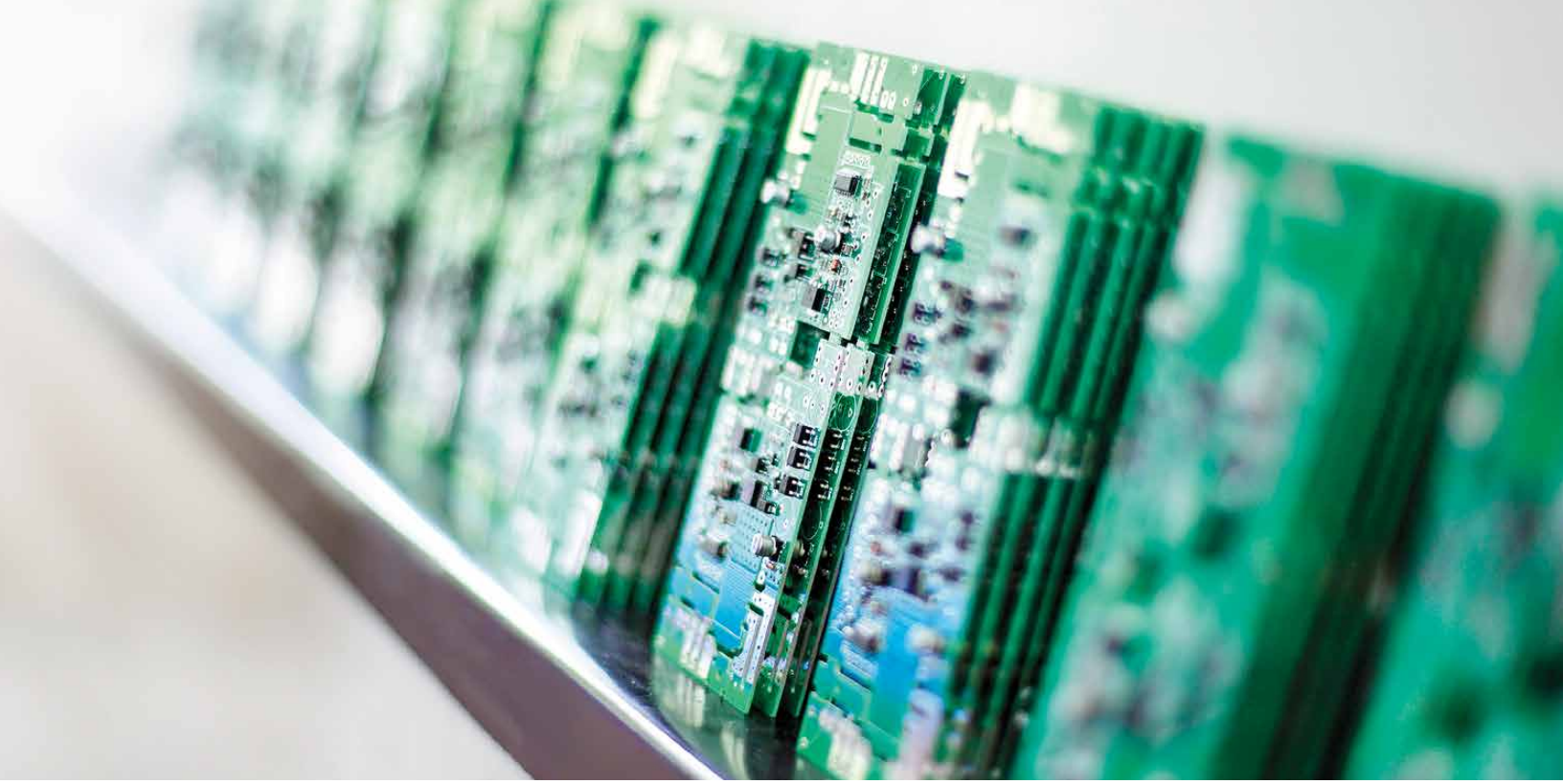

Creating mutually beneficial partnerships with distributors

By taking a new approach to sales-channel strategy and execution, semiconductor manufacturers are unlocking significant value from distribution.

Gaurav Batra, Sean Cheng, Brendan Liverman, and Nick Santhanam

Most chip manufacturers work with one or more distributors, often maintaining close, long-term relationships. It seems like a mutually beneficial situation: semiconductor companies get to reach customers around the world, including small businesses that might otherwise be overlooked, while distributors receive compensation for their expertise. So why are many chip makers now reevaluating their distribution partnerships?

The answer lies in recent semiconductor-industry trends. Over the past few years, the customer base has consolidated, costs have soared, and margins have shown limited growth. In response, manufacturers have been closely analyzing all expenses and revenue streams, and many have concluded that they are not capturing full value from distribution. Some problems arise because manufacturers do not fully understand their customers and thus do not deploy resources appropriately. Other issues occur because manufacturers fail to provide distributors with appropriate support and incentives.

To improve the situation, manufacturers need to take a more analytical, collaborative approach to distribution. They should closely examine all distribution data, including detailed sales information for individual regions, products, and customers. They must also reexamine their working relationships to determine if they are providing distributors with appropriate incentives and support. This article will help manufacturers achieve these goals by discussing strategies that can lead to more fact-based decision making and stronger working

relationships with distributors. It begins by describing the evolving distribution landscape to provide context and then discusses various improvement levers in detail.

A rapidly evolving landscape

Distributors handle 24 percent of the semiconductor industry's revenues. They often provide the most effective way for manufacturers to reach the "long tail" in many countries—the tens of thousands of small customers whose orders would be more expensive to serve with a full-time, in-house sales force. Many manufacturers also have distributors manage mature customers and product lines that do not require internal sales or technical support, since they provide a low-cost solution for maintaining the business.

Use of the distribution channel varies by company, with some obtaining more than half their revenues from it and others much less. Some manufacturers concentrate on direct sales for legitimate reasons, such as a focus on large customers who can be most efficiently served by the internal sales force. In other cases, however, companies may be overlooking important opportunities to reach more customers and provide better service through distributors.

Geographic variations in use of distributors

Several geographic patterns are obvious when looking at distribution. For instance, distributors account for more sales in China than in other countries or regions, and their influence has been growing. We expect this trend to continue, mainly because logistical challenges, language barriers, and customs requirements often make it difficult to reach Chinese customers directly (see sidebar, "The challenges of distribution in China"). By contrast, Japan has recently experienced a sharp drop in distributor revenues in response to the declining yen and high price competition. Distributor revenues have been mostly stable in other Asia–Pacific countries; Europe, the Middle East, and Africa; and the United States (Exhibit 1).

There are three major distributors globally, but their market share varies by geography. According to Gartner research, Arrow Electronics and Avnet obtain 70 percent of distributor revenues in the Americas and 63 percent in Europe, making them the top two companies in these regions. They have gained much of their strength by acquiring smaller companies, but further market consolidation is unlikely because few American and European targets remain.

Gartner research also suggests that WPG Holdings leads the market in the Asia–Pacific region (excluding Japan), accounting for 22 percent of revenues. Avnet is second at 8 percent, and Arrow comes in third with 3 percent. The distributor market is far more fragmented in the Asia–Pacific region because language and customs barriers often make it difficult for foreign companies to establish a presence, leaving small local players in a stronger position. While Asia–Pacific may see more mergers and acquisitions in the future, the trend toward consolidation has not yet taken off.

How should semiconductor companies and distributors work together in the future?

While the distribution channel is crucial to most manufacturers, serious problems often impede its use. We see these as four major areas for concern:

- *A lack of customer insights.* Manufacturers may not use distributors efficiently, because they lack a detailed understanding of their customers, including how their needs vary by project or region.

- *A myopic view of the distributor relationship.* Manufacturers may be unfamiliar with distributor operations and thus fail to provide appropriate incentives or support. All too often, they just focus on decreasing distributor margins—a strategy that could alienate loyal partners.

- *Insufficient product insights.* Many companies set their distribution policies at the portfolio level,

Exhibit 1 **Semiconductor distributors handle almost a quarter of the industry's revenues.**

[1]Distributor figures are measured as pure prime cost, which excludes distributor margin, inventory dealings, and interdistributor revenues.
[2]Compound annual growth rate; figures may not sum, because of rounding.
[3]Europe, Middle East, and Africa.

Source: Gartner; McKinsey analysis

establishing price lists or implementing design-registration changes for entire product lines. But so much heterogeneity exists within the portfolio and customer base that such blanket decisions often result in value loss.

- *Intermittent attention.* Even when distribution strategies are initially effective, problems may occur if manufacturers fail to reevaluate them periodically. For instance, a customer's need for technical support may change. Other challenges arise because distributors' capabilities are constantly evolving. They may stop investing in a particular product line or hire new field-application engineers to specialize in a particular end market.

Setting up mutually beneficial partnerships with distributors

Semiconductor companies can mitigate or eliminate many of the problems inherent in distributor relationships by developing a detailed understanding of their individual product and customer needs. But they also need to understand their distributors—the capabilities they possess, the incentives that motivate them, and the support they need to succeed.

Obtaining detailed insights about products and customers

As a first step to improving distributor relationships, manufacturers should create an extensive fact base that includes detailed information on individual products, such as data on total and served available

market. But looking at spreadsheets alone is not enough, since in-house sales and technical staff have important insights about different subregions, including the role that distributors should play in the go-to-market strategy for individual products or customers.

Manufacturers will also need to decide whether distributors should be used for fulfillment, demand creation, or both. With demand creation—which is associated with higher margins—manufacturers might benefit by developing a heat map that classifies customers based on strategic importance, sales and marketing needs, and penetration. For instance, a customer that has repeatedly purchased a product is unlikely to require additional technical-support services unless the design has materially changed. In such cases, distributors should only be asked to provide order-fulfillment services, rather than be encouraged to create demand. By contrast, manufacturers may want to encourage distributors to create demand in subregions where customers are unfamiliar with their products. To achieve the right level of detail, the map should include data for individual product lines and regions (Exhibit 2).

One integrated-circuit manufacturer that reexamined its distribution strategy discovered that it was assigning distributors to create demand at accounts where the direct sales force already had a strong presence. Meanwhile, distributors were not giving sufficient coverage to accounts where the direct sales force spent little time because the margins were too low. After concluding that the distribution support provided for 58 percent of the products in its portfolio was inappropriate, the manufacturer adjusted its strategy.

Picking the right partner and creating a more effective alliance

When selecting a partner, manufacturers should consider the results of their earlier analyses, in which they determined where distributors could add value by customer, product, and geography. They should then select a distributor who has the strengths and expertise most aligned with those needs. To ensure that they make an accurate and objective choice, manufacturers should assess potential distributors on a market-by-market basis using the following three core criteria:

- *Customer relationships.* What is the distributor's local market share relative to others? How well positioned is it to reach the long tail? What growth has it demonstrated over the past few years?

- *Product knowledge.* Is the distributor seen by local customers as a leader in the category? Can it provide expert technical support on both the current and likely future portfolio?

- *Sales capabilities.* Have the manufacturers with which the distributor works achieved strong sales in the region? Does the distributor have capacity to provide the desired levels of customer outreach and relationship management?

For all distributors, regardless of market, manufacturers should also assess operational excellence—the ability to service customers quickly and efficiently with minimal risk of supply disruption. It is also essential to identify products that distributors sell for other manufacturers, assessing whether these offerings are complementary or could pose a competitive challenge.

As with earlier analyses, manufacturers should gather insights from internal teams as well as external sources. For instance, they could ask customers if distributors are able to answer all their product questions or else consult local industry experts about demand trends in their region. An examination of the distributor's organization, such as the number of field-application engineers it has for a particular product category, can also provide insights about their capabilities.

Exhibit 2

A heat map can identify customers and products that would benefit from demand creation.

[1]Europe, Middle East, and Africa.
[2]Supplier addressable market.

Source: McKinsey analysis

One manufacturer decided to take a close look at the four distributors that handled its sales, examining the criteria described above. The analysis revealed that the distributors often lacked the capabilities or geographic reach necessary to deliver optimal service. Some, for instance, had limited expertise with particular products or lacked the engineering skills needed to assist customers with the design process. To address these gaps, the manufacturer expanded its network to include 35 distributors that together had all necessary skills. The new strategy paid off, with distribution revenues growing more than 12 percent within the first year.

Creating mutual benefits through incentives

After identifying the right partner, manufacturers must create appropriate incentives that encourage distributors to focus on target products, customers, and geographies. For instance, companies could specify that distributors will only receive compensation

for increasing sales in a particular product category where the manufacturer is struggling or where new competitors have begun to take the lead for design registrations. Incentive programs should also ensure that distributors complement in-house sales efforts, rather than replicate them or provide supplemental services that add little value. Targeting underserved geographies and customer segments is far more likely to yield significant returns than attempting to supercharge existing efforts for a blockbuster product in a major market, where the manufacturer's own sales and technical resources may already be approaching the saturation point for customer outreach.

Manufacturers should not change the incentive system in any way that would penalize distributors, such as by compressing margins to achieve short-term gains. Instead, they should focus on designing incentives that help distributors reprioritize their efforts and identify gaps in the sales landscape, such as customers who are not receiving sufficient coverage. This approach produces mutual benefits: manufacturers are more likely to achieve their specific goals across the entire product portfolio, and distributors will know exactly what they need to do to maximize their compensation.

Going beyond incentives to optimize distributor relationships

In addition to high margins, the following factors may help manufacturers improve their interactions with distributors:

- *An emphasis on capability building.* Since sales representatives deal with many different product lines, including some that may be outside their area of expertise, they appreciate manufacturers that help build their knowledge and capabilities. For instance, they may respond favorably if manufacturers provide technical and support staff to help them run programs to certify field-application engineers. Ideally, manufacturers will provide in-person training using a field-and-forum approach, in which sales representatives attend a classroom or online session and then apply their skills in the workplace before returning for more instruction. Whenever possible, manufacturers should supplement these sessions with remote training, such as online modules with tests that representatives can complete at their convenience.

The challenges of distribution in China

The distribution market in Asia, particularly China, contains myriad subdistributors and resale networks, with tier-one distributors frequently selling products to tier-two distributors or resellers, who then connect with end customers. Manufacturers thus have many options for the distribution channel. They can work with tier-one distributors who sell to customers, or to those tier-one companies that sell to tier-two distributors or resellers. Alternatively, manufacturers can work directly with tier-two distributors—either having them serve the entire customer base or restricting their efforts to established customers.

With so many potential distributors, including small players without established reputations, manufacturers must conduct a detailed analysis of all their options, considering both benefits and risks. For instance, a small distributor might sell products through channels that are legal but not part of a manufacturer's traditional strategy, making them part of the gray market. Other important considerations include margin stacking—the cost or profit margin that each distributor or other member of the supply chain contributes—and the quality of a distributor's customer service.

- *Availability of frontline coaching.* The easiest way to lose customers is by appearing slow or unresponsive to their questions, including requests for price quotes. Manufacturers can help distributors provide rapid answers by holding real-time chat sessions or by placing employees on site at the distributor to work directly with sales representatives. Some manufacturers have also created small teams to support distributors in specific regions, allowing them to respond to customer questions within 24 hours.

- *Strong supporting materials.* Manufacturers should create a variety of supporting materials, such as sheets with frequently asked questions, brochures, videos, and podcasts. Case studies and white papers that describe how distributors can provide full solutions are particularly important. All materials should be easily accessible through online portals or other means.

- *Clear expectations.* Service-level agreements should establish clear expectations, such as the number of field-application engineers that a distributor will send to a client. Manufacturers should also be straightforward about the benefits that they are willing to provide, including the percent margin that a distributor will receive for demand creation and fulfillment.

- *Appropriate organizational and IT systems.* Manufacturers should reexamine their organizational structures when determining how they can improve distributor relationships. For instance, they may need to create new roles or hire additional personnel to manage the distribution channel. All IT systems should be easy for both end customers and distributors to use, and they should be capable of handling a large volume of transactions.

- *A willingness to assist with marketing.* The best sales efforts will involve marketing from both sides, with the distributor interacting directly with customers to push sales and manufacturers attempting to stimulate general demand through various measures, including social media. Texas Instruments, for instance, has a variety of blogs on its website. Each contains articles that discuss technical topics and provide links to matching products. Whenever marketing, manufacturers should be careful to ensure that they are supporting distributors, rather than circumventing them by directing customers to other purchasing options.

In combination with other improvement levers, manufacturers can significantly increase margins by providing distributors with the type of support described above. Consider the results obtained by a midsize manufacturer that closely examined its distribution channel. For each product, it analyzed market size, growth trends, customer needs, relative market share, and other important metrics. The manufacturer also assessed the capabilities and track records of all distributors. Based on this information, it adjusted distributor margins and made other changes. One important shift involved increasing marketing support for some products and regions. Together, the strategic shifts allowed the manufacturer to increase its gross margins for the distribution channel by nearly 6 percent without hurting sales. Meanwhile, distributors received higher revenues because their sales efforts were more effective.

As the semiconductor industry matures, manufacturers can no longer maintain a business-as-usual posture about distribution. If they do not reexamine all aspects of their relationships through an objective, fact-based analysis, they could lose value and miss important

opportunities. The most successful manufacturers will consider exactly what they want from a partnership, which distributors are best positioned to provide it, and how such arrangements can benefit both parties. And once a partnership is established, manufacturers must remain fully committed and lend their full support to distributors. This means sharing product knowledge, providing advice, and helping the sales force reach its full potential—efforts that go far beyond signing a contract and providing financial compensation. ■

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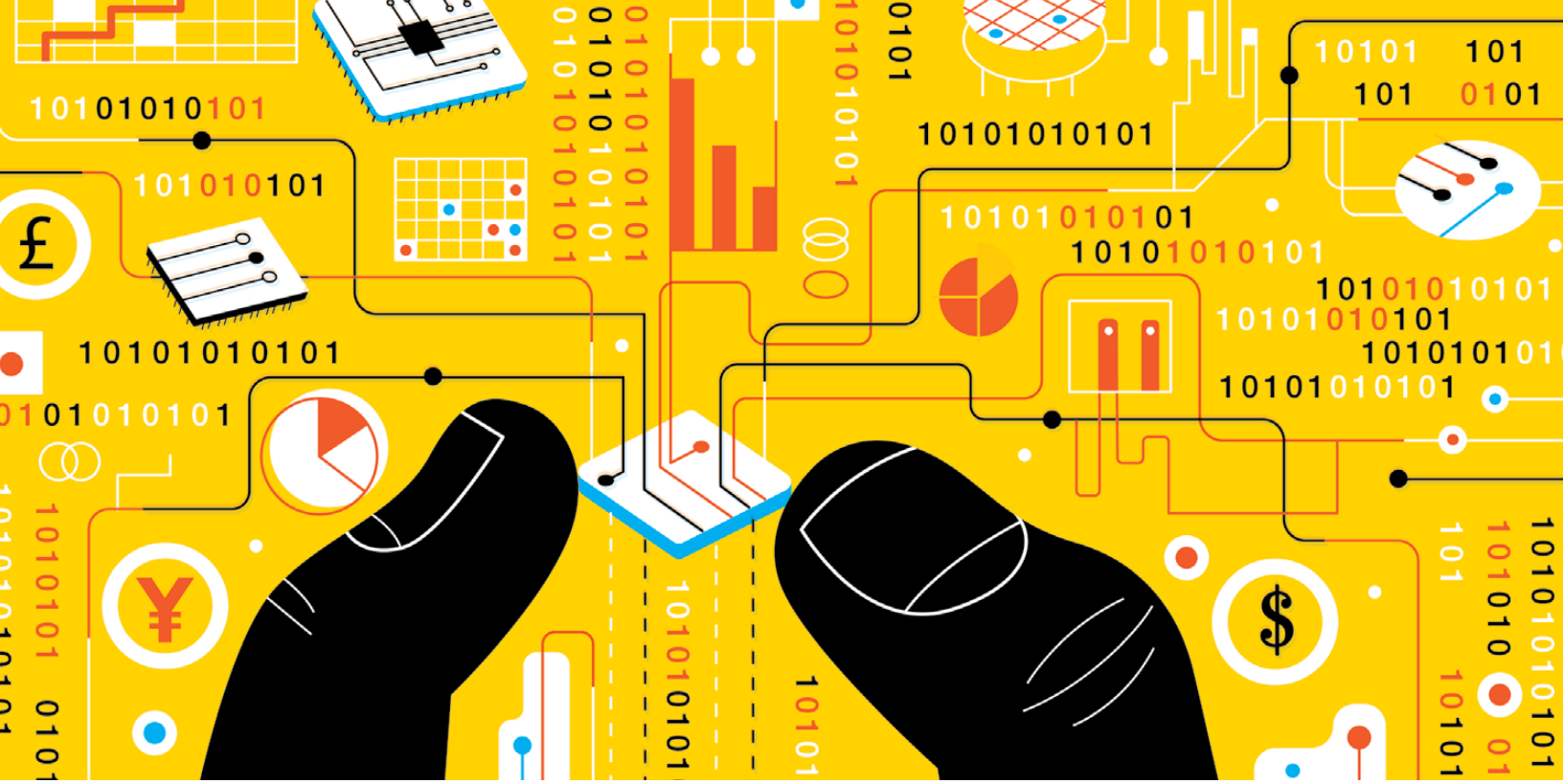


Using the power of advanced analytics to improve manufacturing, R&D, and sales

New techniques can help companies make better decisions by using accurate, reliable, and scientific information to analyze risk, optimize processes, and predict failure.

Gaurav Batra, Zach Jacobson, and Nick Santhanam

When used effectively, advanced analytics can not only significantly improve operations and margins but also spur growth. Yet many companies, including several semiconductor players, have been slow to embrace these techniques. According to the International Data Corporation, the global pool of data is more than 2.8 zettabytes and growing, but companies generally use only about 0.5 percent of that ocean of information to make decisions. Businesses—usually consumer-facing ones—that do collect and analyze a broad range of data achieve many benefits. Banks, insurers, and retailers, for example, have used insights from advanced analytics to build sustained competitive advantages, including stronger customer relationships and greater operational efficiency.

Semiconductor companies have been leaders in generating and analyzing data. But few have effectively applied advanced analytics to fab operations, where they could improve predictive maintenance and yield, or to R&D and sales, for enhanced pricing, market-entry strategies, sales-force effectiveness, cross-selling, portfolio optimization, and other tasks.

But we may soon see the more widespread adoption of advanced analytics in semiconductors. First, computing power and storage infrastructure have become markedly easier to deploy with the advent of cloud computing. Second, there has been a step change in the power of the tools used to extract, aggregate, manage, analyze, and display data, as well as in techniques to incorporate data into actionable

models. Hadoop applications, for example, have made it possible to extract insights from unstructured data by simplifying the integration of disparate data sources.[1] Finally, slower industry growth is prompting semiconductor companies to look for operational efficiencies, including some that may be more easily identified and deployed with advanced analytics.

In this article, we provide a high-level overview of advanced-analytics strategies to illustrate how they can help companies transform their manufacturing, R&D, and sales functions. We include several examples of companies that have used these methods to optimize productivity, time to market, and other important metrics. Our objective is not to assess, compare, or evaluate different analytical tools or techniques or specific capabilities in detail. Rather, we wish to show the overall value of advanced analytics and the importance of improving these capabilities.

A new mind-set

Advanced analytics can provide a framework to unlock insights about where to invest and how to improve the performance of manufacturing, R&D, and sales. The engineers who handle these tasks should increasingly consider themselves data scientists—people mining information that can be used to improve business functions.

The methodologies of advanced analytics are quite different from those used in traditional empirical analysis (Exhibit 1). To put it simply, traditional data analysis is based on what information you have, advanced analytics on what information you need. The traditional approach usually starts with available data and focuses on the information they reveal and the insights they provide. Project and executive teams then determine how these insights might help them make specific decisions.

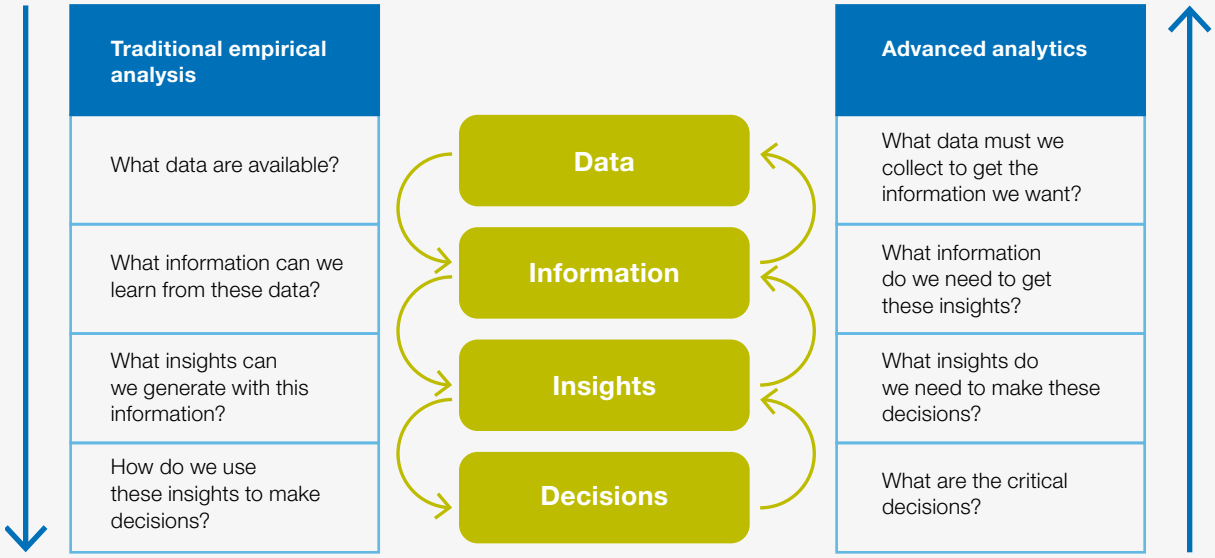
With advanced analytics, by contrast, teams begin by asking what business problems they are trying to solve and which critical decisions a company must make. They then identify the insights that will help clarify those decisions, the type of information that might produce the required insights, and, finally, the data sources the organization needs to obtain this information. In a properly designed program, advanced analytics offers not only accurate, reliable, and timely information on past and present operations but also invaluable predictive insights to guide decision making (see sidebar, "Getting more from R&D and sales," for an example of how advanced analytics can assist with these functions). Companies can use advanced analytics, for example, to create models anticipating future developments, such as R&D bottlenecks that could delay production. With this information, they can make better decisions to direct the business.

Applying advanced analytics in manufacturing

In chip manufacturing, the volume of data generated on the fab floor has continued to expand exponentially with each new node dimension. Leading-edge tools have so many measuring instruments that each one routinely identifies and gathers over 300 sensor inputs. In consequence, all information collected throughout the fab—including metrics for processes, products, and machine state—will quickly exceed terabytes of data. Fabs also gather extensive in-line, end-of-line inspection, and metrology data. Few, however, combine and apply advanced analytics to all these production data, even though that could improve many important manufacturing dimensions, including yield, throughput, equipment availability, and operating costs.

Consider, for example, a fab that wants to decrease equipment downtime. The fab could conduct a multivariate analysis to enhance condition-based monitoring—a maintenance strategy that involves examining certain indicators to determine if equipment performance is decreasing. Among other benefits, the analysis would help the fab to predict more accurately when parts or consumables will fail.

Exhibit 1 **Advanced analytics requires an approach completely different from that of traditional empirical analysis.**



Source: McKinsey analysis

With this information, the fab can optimize the planned maintenance schedule, which will reduce downtime, as well as costs for parts and labor.

In addition to preventing equipment failures, fabs can use advanced analytics for more complex purposes. For instance, they could link equipment and process-level data to inspection and metrology data to make more accurate predictions about yield failures or yield degradation. Predictive modeling is difficult, since it requires multiple steps. Fabs must first gather complete data sets and then apply algorithmic approaches to identify patterns in the data before building any models. However, the payoffs can be great. Take the case of a company that recently used advanced analytics to predict process failure in a production step that involved depositing material on a wafer. The company was able to make the prediction with a confidence interval of about 70 percent—a level that might seem low but is comparable to the results obtained when oil, gas, or mining companies apply advanced analytics to their processes. By identifying the factors responsible for failure, the analysis helped prevent significant yield loss early in the production process.

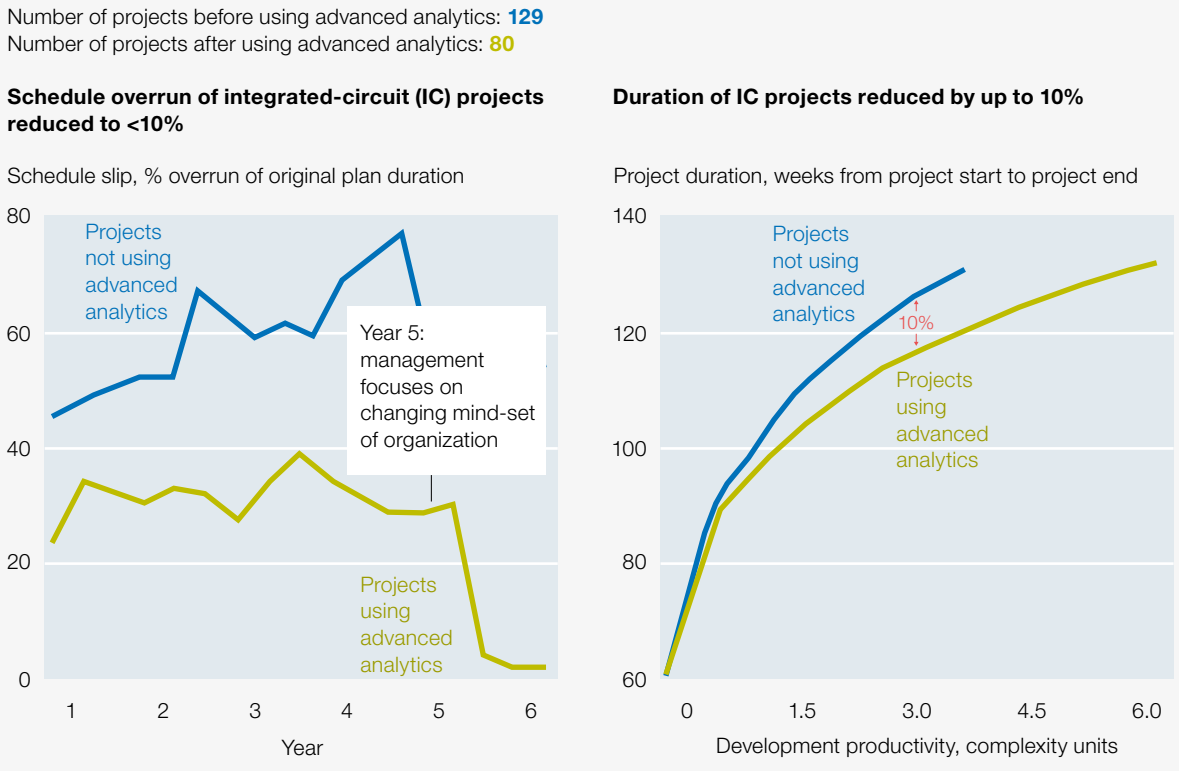
Applying advanced analytics to R&D

Our experience suggests that most semiconductor companies have inefficient R&D operations. Some 80 percent of development projects do not meet their initial schedules, often because teams overestimate their productivity and underestimate the complexity of their projects—the level of effort and resources required.[2] Our study of more than 2,000 integrated-circuit (IC) projects, for instance, showed that companies often drastically underestimated staffing requirements in the early and late stages but over-staffed in the middle of the cycle in reaction to the previous dearth of resources. Partly because of such inaccurate estimates, IC projects frequently struggle to meet their budget and time-to-market targets.

R&D's inefficiency may also result from an absence of rigor when companies assess their performance or measure their success. Semiconductor companies, for example, have few reliable metrics for gauging complexity or evaluating productivity (of individual project teams or the research effort as a whole). Similarly, they lack an adequate framework for assessing new market developments and estimating the needs of projects, so they base their allocation of R&D resources on instinct and history. But our research shows that this method is problematic: companies usually underestimate the time needed for completion by at least 15 percent and sometimes by as much as 400 percent.

Advanced analytics can make R&D more efficient by replacing instinct and guesswork with a fact base for decision making, thus ensuring that resources are deployed to the right projects and used optimally throughout the project life cycle. Companies can, for example, improve R&D's effectiveness and efficiency by statistically modeling the complexity of projects (such as the impact of adding a certain type of resource) and determining the best staffing levels. In fact, our research shows that semiconductor companies can reduce the time to market of their IC projects by up to 10 percent (Exhibit 2). Advanced analytics also plays an important role in streamlining R&D processes, optimizing product portfolios, and helping business leaders reduce costs.

Exhibit 2 **Using advanced analytics in R&D decision making can lead to many improvements.**



Note: All 209 projects finished and released to volume production.

Source: McKinsey analysis

Moving from seat-of-the-pants decision making to rigorous analytics

In the absence of analytics, R&D staffers at semiconductor companies sometimes make poor investment decisions. Design engineers, for example, might focus on incremental improvements to existing products, since they are inclined to believe that such changes will increase sales, rather than on developing new solutions. But in many cases, relatively small upgrades produce few returns. To counter such personal biases, advanced analytics offers a range of data-based tools that can examine customer and product segments at a detailed level, sharply improving the cost-effectiveness and returns of investments. The resulting insights also help companies to assess the risks of various investments and to balance their research portfolios.

In one case, a semiconductor company used advanced-analytics tools to conduct a segment-specific analysis of two important areas: market opportunity (such as potential market size, projected growth rate, and margin) and competitiveness (including the number of companies in the market, the level of differentiation among product offerings, and the customer's willingness to change suppliers). In addition to uncovering hidden opportunities for growth, the assessment transformed the company's R&D portfolio strategy from a reactive, seat-of-the-pants process into a far more insightful, objective, and predictive one based on solid numbers.

Improving R&D processes to increase efficiency

Advanced analytics can also improve many R&D processes, including some cumbersome, time-consuming, or error-prone tasks. A large chip manufacturer, for example, wanted to improve its time to market by at least three months and to stabilize development costs, which had been increasing at over 25 percent annually. Problems often arose because the company had not automated the process for comparing the results of large simulations. It also had difficulty assessing the quality of its test inputs. To address these issues, the manufacturer used advanced-analytics tools to automate its design-verification process, with the goal of reducing the number of iterations for regression testing and improving the quality of the test. Automation helped the company shorten the product-development cycle by one to three months, thus generating an additional $100 million in revenue. The company also eliminated many development costs, saving over $3 million annually.

Optimizing resources throughout the project life cycle

Companies can create predictive models for R&D projects by employing proprietary advanced-analytics tools that use chip- and block-level parameters (for instance, node, power, transistor count, and memory) as proxies for design complexity. The models can determine how each parameter correlates with the completion of projects on time and on budget. They also allow companies to gain an objective view of their R&D performance compared with best-in-class benchmarks—a straightforward definition of what outstanding productivity looks like. Such root-cause analyses can help to explain the gap between current and best-in-class performance and to identify specific drivers for efficiency and productivity.

Predictive R&D models provide rapid insights that let companies adjust a project's staffing or make other changes in real time, thereby increasing the efficiency of R&D investments. For instance, while projects are under way, companies can use advanced-analytics tools to simulate realistic scenarios—such as altering the number of sites or the size of teams—and thus predict their impact on time to market and other important variables. Again, advanced-analytics tools help minimize risk, since they allow companies to see the potential implications (including the costs) of new strategies before they are implemented.

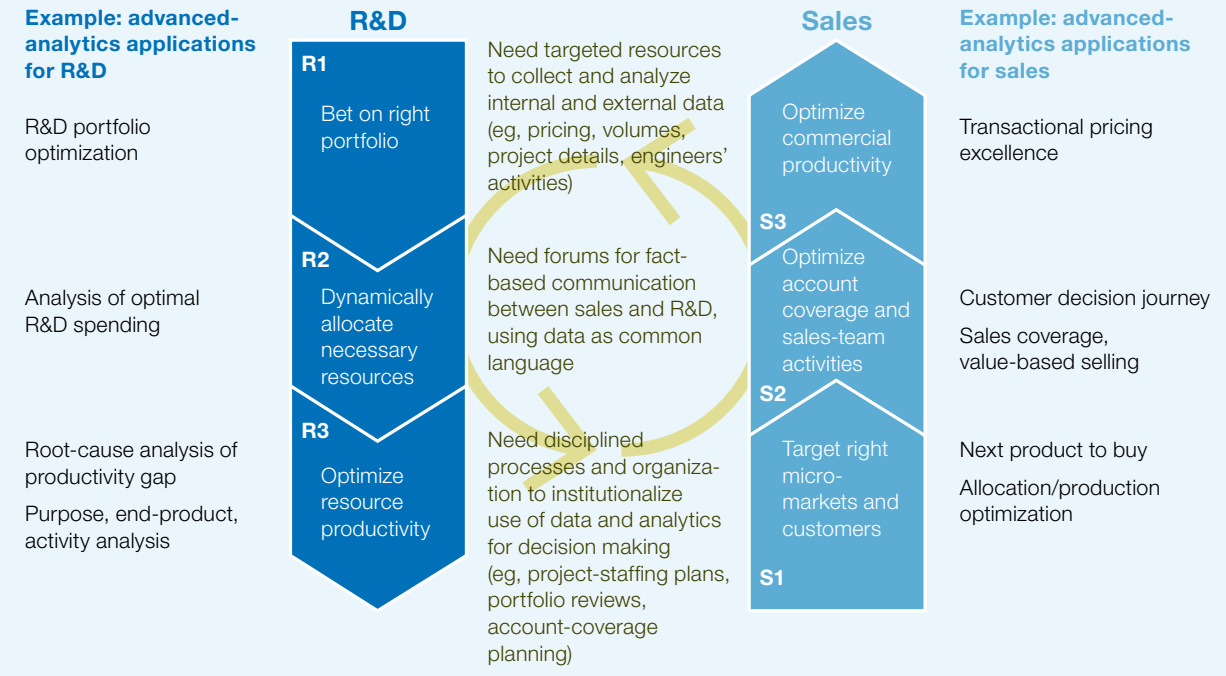
Consider the results obtained when a company in the advanced-manufacturing industry used an advanced-analytics tool to improve the productivity of over 7,000 engineering personnel responsible for designing and implementing complex electro-mechanical projects. The tool analyzed internal data at all levels—for instance, information on the project itself, team collaboration, and personnel—and determined which factors led to the best outcomes for the business in multiple areas, from team resourcing to communication frequency to project management. Among other findings, the tool revealed that productivity was lagging because the company often pulled engineers away from their projects when unexpected problems arose. This practice alone created a 7 percent net productivity drag (as measured by the number of engineering hours needed to complete a project) for the entire engineering department. In addition, the tool showed that large teams (of more than seven people)

Getting more from R&D and sales

In our experience, most semiconductor companies struggle to make R&D and sales truly complementary functions and coordinate them only about half of the time. Better integration can keep companies ahead of evolving markets and the competition, as well as provide a 7 to 14 percent revenue uptick within 12 to 18 months—potentially with more to follow. The exhibit shows advanced-analytics strategies that can not only improve R&D and sales but also assist with integration by providing objective data. It also outlines the requirements for optimal implementation.

Exhibit

Some best-in-class semiconductor companies leverage advanced analytics to drive organic growth.



Source: McKinsey analysis

were associated with diminishing returns and that global teams working around the clock could actually be counterproductive. By making some organizational and operational changes, the company identified improvement opportunities that could increase productivity by 27 percent.

Applying advanced analytics in sales

As with R&D, semiconductor companies frequently lack analytical rigor when they make investment decisions in two other important areas: pricing and sales coverage.

Pricing: From intuition to data

Sales teams often ignore or don't have critical pricing data, including historical information on each customer and market segment. They typically treat markets as whole entities rather than examining specific customer relationships or trends related to product demand. Sales teams may, for example, pursue opportunities in the automotive or consumer-electronics industries instead of identifying potential high-margin microsegments within these markets or the portfolios of individual customers. The lack of a numbers-based framework also encourages companies to rely solely on their executives' instincts to set prices. That often leads to inconsistent or ineffective discount policies and to an overreliance on poorly targeted cost-plus strategies.

Advanced analytics can help semiconductor companies bring new rigor to pricing. For instance, one player discovered through advanced analytics that it had set its list prices so low that customers rarely attempted to negotiate. By adopting a detailed analytics-based approach, combined with new statistical-analysis tools that can clean up and analyze volumes of transaction data, it optimized its pricing and its customers' willingness to pay. In this way, it captured more revenue with no loss in sales volumes. In another case, advanced analytics showed a semiconductor company that it was offering different discounts for deals of similar size and setting minimum prices regardless of sales volumes. The company then created a more rational and profitable discount program—again, with no loss in sales volumes.

A number of advanced-analytics tools, some shown in Exhibit 3, can help semiconductor makers analyze pricing. In addition to proprietary analytics programs, they can use algorithms, heuristics, web crawlers, and scientific data-collection surveys to amass, sort, clean up, and normalize different kinds of information into actionable insights. To fill in gaps in data on the competition, for example, they can take advantage of web-crawling tools that collect publicly available pricing data for more than 100,000 components. Clustering algorithms can segment customers and markets in objectively meaningful ways. The systematic use of these and other analytical approaches can increase a company's return on sales by up to seven percentage points.

Account management: A detailed look at the customer base

Many industry players base their key-account-management strategies on current revenues. That sometimes leads them to overinvest in existing customer relationships and underfund high-potential prospects. Advanced analytics could help these companies make more rational, well-considered decisions about sales coverage. For instance, advanced analytics showed one chip maker that it was devoting only 45 percent of its sales team's resources to a customer segment that produced 50 percent of its revenues. Meanwhile, 30 percent of the resources went to a less promising segment that generated only 20 percent of its sales. The company also determined that 70 to 80 percent of its average salesperson's time was devoted to tending accounts it had already penetrated and only 20 to 30 percent to winning new business.

Exhibit 3

Advanced-analytics tools can assist with various sales tasks, including transaction pricing.

Barriers to value capture	Mitigating advanced-analytics tools/techniques
Unclean data	Cleansing heuristics to eliminate fuzzy logic Clean-up algorithms for transaction data
Lack of updated competitor data	Web-crawl tool to collect publicly available competitive pricing data for >100,000 parts
Limited transaction data with respect to large, complex part portfolio	Multivariate regression algorithms to identify and quantify statistically significant influencers of price
Subjective customer and part segments	Clustering algorithms to segment customers and parts into objective, homogeneous segments
Lack of availability of timely and relevant data at time of decision	Web-based/mobile-based tool to provide real-time pricing guidance

Source: McKinsey analysis

Another component manufacturer used data mining and analysis to assess the attractiveness of its products against those of competitors. The company found that customers regarded roughly half of the 5,000 products it examined as leading edge, 35 percent as generic, and 15 percent as pure commodities. It combined this information with pricing and share-of-wallet data to create an index of product strength and to deploy its sales force more effectively.

Advanced analytics can also improve account management by pinpointing a company's top customers, as opposed to more routine transactional ones or targets that turn out to be unattainable. By combining these customer analyses with product analyses, semiconductor companies can get a clearer view of how and where they need to compete.

How to make this happen

Companies can increase the likelihood that advanced analytics will gain traction by ensuring that all programs have four core elements: robust and actionable data, enterprise-wide support, well-trained analytics teams, and a suitable IT infrastructure.

Ensuring robust and actionable data

Our experience with clients has demonstrated that any solid advanced-analytics effort must start with the creation of a robust data set that encompasses all necessary inputs, can be stored effectively, and allows for easy retrieval. While this may sound simple, it can be extremely challenging. For example, in manufacturing, most leading-edge fabs have well-defined data models for individual tools. Each model can require sorting through 300 or more individual variables per tool or process step (repre-

Whenever possible, companies should compile their own information instead of relying on possibly incomplete data from outside sources.

senting such diverse inputs as electrical current, resistance, temperature, pressure, and robot location). Some of these variables may be collected every few seconds or milliseconds, resulting in large volumes of data. In addition, inputs for each model may differ, depending on what equipment or sensors are in use or whether data are being analyzed while a process is under way or after it is completed.

Many companies also have difficulty aligning data sets or making comparisons. Information is typically generated and stored in different formats, and much of the data are "noisy"—they cannot be understood and interpreted correctly by machines, because they include unstructured text or have other limitations. Overcoming these challenges requires companies to go back to the original data and ensure that they are aggregated in a consistent way. This may require companies to work with vendors, to invest in additional tools, and to build internal data-collection and management capabilities.

To ensure robust data and facilitate analytics, companies must carefully extract, validate, and visualize information before creating any models. They should also ensure that they examine complete information rather than relying on aggregate data sets that capture averages or on a sampling of inputs, since such methods can lead to false positives or missed patterns. Manufacturers, for instance, would need to compile all sensor, process, inspection, and metrology data.

Whenever possible, companies should compile their own information instead of relying on possibly incomplete data from outside sources. For instance, equipment vendors often gather and manage data and then provide fabs with a summary analysis and statistics, rather than supplying full data sets along with process and outcome data. If companies rely solely on this partial information when they conduct analytics, their results may not be accurate.

Companies must also ensure that their data are gathered and stored effectively, so they cannot take common shortcuts. When data are lost, for example, many companies just replace the missing information with averages or extrapolated data points. While that approach might save time, it reduces the quality of the analytics, so companies should identify and fill any gaps.

Building support at all levels

Across industries, companies have made large investments in advanced-analytics initiatives only to receive little in return. All too often, the problem is that the top leadership views advanced analytics as a tactical responsibility for midlevel managers rather than a strategic priority for the entire company. In the absence of a corporate directive, some business units embrace advanced analytics, while others treat it as an afterthought because they question its worth. Companies can avoid such situations if their boards have one or more members who actively advocate advanced analytics. Management tactics that may help build support include the following:

- newsletters that describe interesting advanced-analytics findings and show how they improved revenues and other metrics
- routine meetings where data scientists ask for input from all stakeholders, including frontline employees—information that is then used to develop customized approaches
- dashboards that show preliminary results from recent analyses; companies can then ask employees if the information would help them improve performance
- quick wins gained by applying advanced analytics to areas that do not require a large-scale transformation, such as pricing or customer acquisition

Training, staffing, and supporting analytics teams

Companies usually need new staff to handle advanced analytics, especially an experienced leader who can help define the strategy. Every analytics team should also include the following roles:

- data engineers responsible for managing data and preparing data for analysis
- people who create models to predict business outcomes, optimize processes, segment customers, and accomplish other important tasks
- business liaisons who serve as a bridge between the modelers and the decision makers on the business side; for instance, they may work with the leadership to identify important business problems that models should address

Although many companies now situate analytics teams within IT, this placement may be problematic because all advanced analyses should focus on solving important business issues and changing employee behavior. Data engineers and modelers, especially those who are just out of school and have little workplace experience, may not be able to identify the most important business problems. Placing advanced-analytics teams within business units, where they can serve as internal consulting groups and interact closely with business liaisons who understand operational issues, may be preferable.

Creating the right IT infrastructure

Some companies already collect the internal information necessary for advanced analytics but do not organize it well or make it readily accessible. They can address these problems by creating data marts and related support teams. While companies may be tempted to include all easily accessible information in the data marts, it is better to restrict them to data that will help address pressing business needs. Such a data mart will need extraction, transformation, and loading (ETL) routings that continuously pull information from different sources and link it together using common identifiers. Companies must establish a rigorous process to ensure the data's quality, since even a single error in the ETL may decrease confidence in the data mart.

Analyzing external data may pose a greater challenge, since many businesses capture incomplete information on the activities of their competitors or the behavior of their customers. To close this gap, companies could consider establishing a market-research team specifically to scan public sources for competitive insights. If such teams feel that public sources are inadequate, they can work with third-party aggregators to gain more insights.

In certain cases, companies may need to seek assistance from data experts to manage information. The point when they do will vary greatly, depending on their technological capabilities and the type of

data under analysis. For instance, most businesses can manage structured (usually SQL-based) databases effectively, but they may have more difficulty working with unstructured data, such as text, images, and videos.

The payoff from advanced analytics is a more aggressive, alert, and competitive enterprise that makes better decisions and uses more accurate and reliable information to analyze risk. Once the infrastructure is in place, fabs can create better predictive models to enhance manufacturing. Meanwhile, sales and marketing teams can more efficiently sell what R&D teams and design engineers create. ■

[1] Hadoop is an open-source software framework for the distributed storage and distributed processing of very large data sets.

[2] See Aaron Aboagye, Dorian Pyle, and Alexander Silbey, "By the numbers: R&D productivity in the semiconductor industry," *McKinsey on Semiconductors*, Autumn 2014, mckinsey.com.

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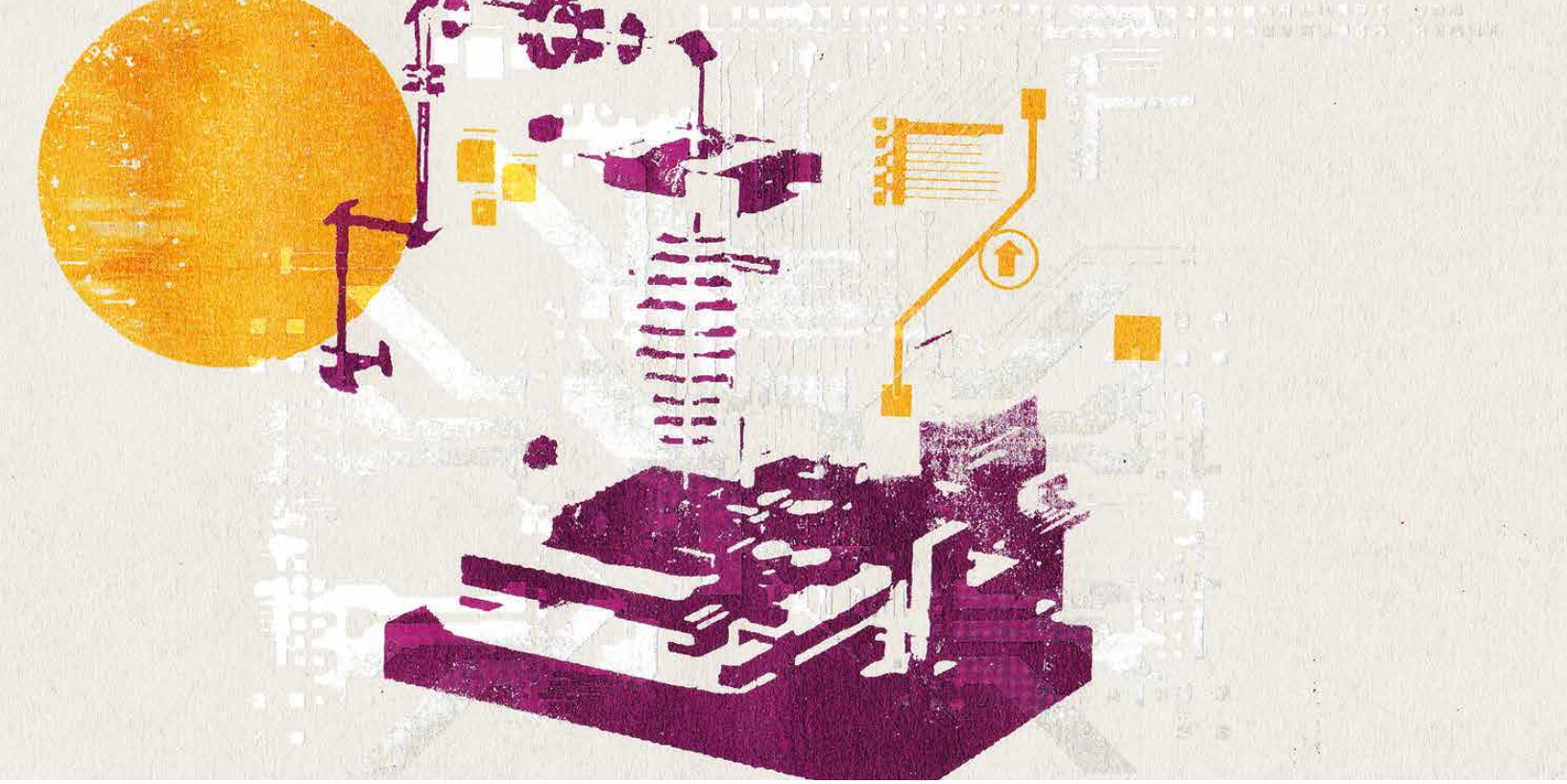


Capital equipment: Will further shrink bring growth?

The midterm outlook for the capital-equipment industry is positive, but companies need to prepare for the slowdown of Moore's law.

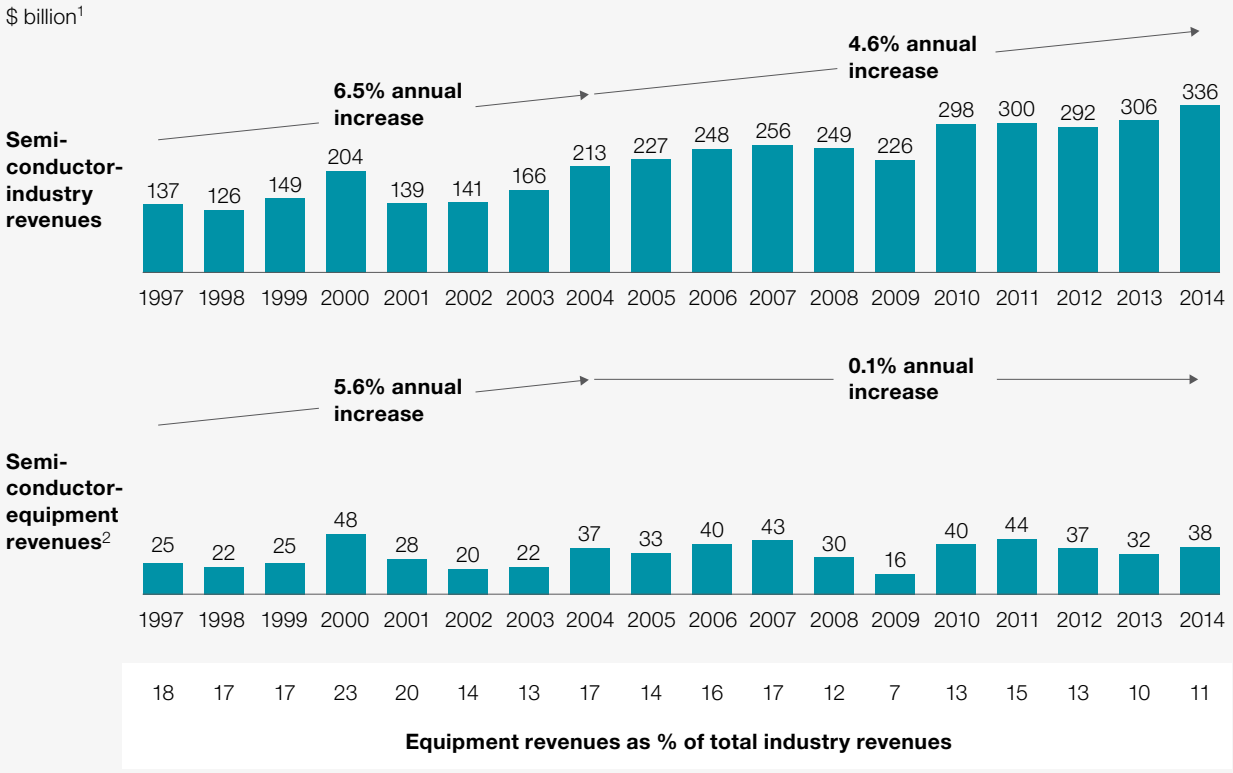
Marc de Jong, Hubert Heersche, Freek Kelkensberg, and Hiroaki Ohta

The semiconductor market has grown by 4.6 percent annually over the past decade, with revenues rising from $213 billion in 2004 to $336 billion in 2014. This increase results from greater demand, primarily in the mobile segment, that is fueled by "shrink"—the ongoing decrease in the size of electronic components on silicon realized through continued process-node progression. Shrink enables both improved performance and reduced costs for end users.

Notably, one group of players has received limited benefits from the semiconductor industry's gains: the capital-equipment companies that supply chip makers with machines for deposition, etching, lithography, metrology, assembly and testing, and other steps in the manufacturing process. Their revenues were volatile and only rose from $37 billion in 2004 to $38 billion in 2014—an increase of 0.1 percent annually. This is in contrast to the period from 1997 through 2004, when growth was 5.6 percent annually. While the semiconductor industry also saw lower growth over the past decade, its decline from preceding years was not as great. The steadily increasing growth discrepancy between chip makers and their suppliers is apparent when we make revenue comparisons. Revenues for equipment players were equal to about 18 percent of semiconductor-industry revenues in 1997; that figure fell to 11 percent in 2014 (Exhibit 1).

Despite these numbers, we see strong indications that the next decade will be more attractive for capital-equipment players. Growth in semiconductor demand is expected to remain steady, with device

Exhibit 1 **Semiconductor-equipment revenues have not kept pace with industry growth and represent a smaller share of overall revenues.**



[1]Figures may not sum, because of rounding.
[2]Semiconductor-equipment revenues are not included in the semiconductor-industry revenues shown in the top half of this chart.

Source: SEMI; WSTS; McKinsey analysis

manufacturers and end customers continuing to favor leading-edge chips. Furthermore, the manufacture of these chips is rapidly becoming more advanced, and the number of fabrication layers is increasing. Semiconductor equipment plays a pivotal role in enabling the next generation of chips, providing new opportunities for capital-equipment manufacturers.

To increase the likelihood of success, equipment companies should build strong relationships with their customers, jointly working with them to solve technical challenges and promote innovation. In addition, they would benefit from defining a long-term strategy for dealing with one of the most important changes that will ever affect the semiconductor industry: the inevitable slowdown of Moore's law. In a mature industry, semiconductor players will look for other means for continuing cost reduction and improving performance besides shrink and rapid time to market for new nodes, forcing equipment manufacturers to seek other forms of revenue and margin.

Growth drivers: The outlook for the equipment industry

Three forces will promote the capital-equipment sector's growth over the next decade:

- megatrends that will continue to generate consumer demand for products containing leading-edge semiconductors, encouraging semiconductor players to invest in new fabrication capacity and equipment

- the increased determination of leading semiconductor giants to focus on innovation and develop cutting-edge products in response to intensifying competition and increased customer buying power

- a stronger role for equipment players as the process for moving to subsequent nodes becomes more complex, requiring both more equipment per wafer (due to an increasing number of process steps per wafer) and more expensive equipment (due to the increasing complexity of the equipment required to progress to subsequent nodes)

The first two forces—steady demand and a focus on innovation—have been present, to some degree, for many years, and they will continue to have a positive effect. But it is the stronger role for equipment players in the value chain that will open the most revenue opportunities in equipment sales and servicing in the next decade.

Megatrends may promote demand for leading-edge semiconductor products

A large ecosystem of companies with annual earnings before interest and taxes of more than $250 billion—both in the semiconductor industry and related sectors—is dependent on a continuous stream of new devices with increased performance, lower power consumption, and lower costs (Exhibit 2). We see several megatrends that could drive these companies to seek leading-edge chips:

- *The mobile revolution.* Smartphone penetration in developing markets is still at an early stage, and demand is expected to increase. Simultaneously, the creation of new mobile innovations, such as payment systems, will also lead to new demand in developed markets.

- *The Internet of Things, connected cars, and advanced security.* Several interrelated—some would say overlapping—areas could generate additional demand. Although the "things" will mostly be connected with chips based on mature nodes, the associated data and Internet connectivity will increase requirements for processing and storage capacity.

- *Big data.* Companies are increasingly analyzing the large stores of data that they accumulate to derive insights—for instance, greater knowledge of customer behavior. In consequence, data-processing and storage requirements are rising.

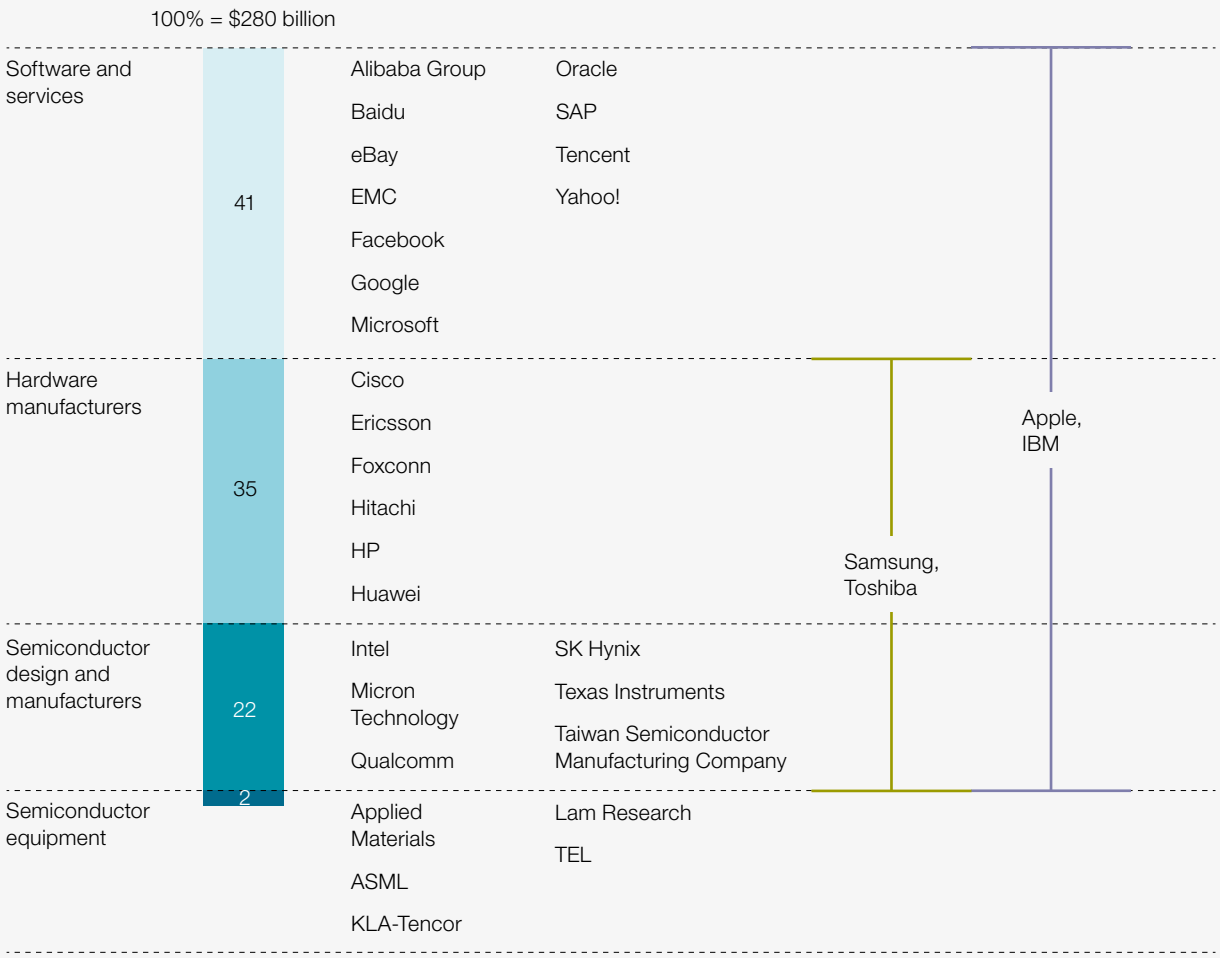
Together, these trends will continue to spur demand for leading-edge semiconductors. Equipment players like Applied Materials, ASML, KLA-Tencor, Lam Research, and others are well positioned to benefit from the increased demand.

Innovation will remain at the forefront of the semiconductor industry

Several forces are prompting semiconductor companies to remain at the forefront of innovation. First, leading high-tech players such as Apple have increasing influence over the semiconductor industry because of the scale of their orders. Semiconductor companies try to win their business by offering advanced technology, which increases the focus on innovation. Second, the semiconductor industry has been consolidating, and the remaining players are all determined to increase their market share. Traditional boundaries are also fading—for instance, microprocessor and logic segments are merging—so many companies are investigating new segments, as seen with Intel's entry into the foundry market.

Exhibit 2 **The semiconductor ecosystem will provide momentum for equipment growth.**

Top technology companies, EBIT,[1] 2014, by segment, %[2]



[1]Earnings before interest and taxes.
[2]Allocation of EBIT across segments indicative; companies displayed in their core segment.
Source: McKinsey analysis

Such moves also increase competition, making it more important for semiconductor players to create technologically advanced products that will win market share.

Recognizing the importance of innovation, chip manufacturers will continue to invest heavily in R&D. We believe the economics of these investments are fundamentally sound, with the payback time for chip manufacturers remaining close to 24 months for nodes beyond 20 nanometers/16 nanometers (Exhibit 3). Equipment players may benefit from their customers' focus on leading-edge technologies, as this will translate into demand for upgraded manufacturing technologies. Since these machines are more complex than those used over the past decade, equipment manufacturers will likely see increased sales.

A stronger role for equipment players

With shrink nearing its physical limits, technology road maps for reaching the next node are more complex and difficult than ever before. In consequence, we expect equipment players to have an even more pivotal role in the value chain as the key enablers of shrink, allowing them to increase their relative revenues in the semiconductor ecosystem.

First, the number of process steps per wafer is increasing, requiring more equipment, but the throughput of machinery is no longer increasing rapidly enough to compensate for this. Furthermore, a shift to 450-millimeter wafers, which would result in a step change in productivity for semiconductor manufacturers, is likely to occur later than expected or not at all, since cost advantages are declining for smaller nodes and required investments are enormous.

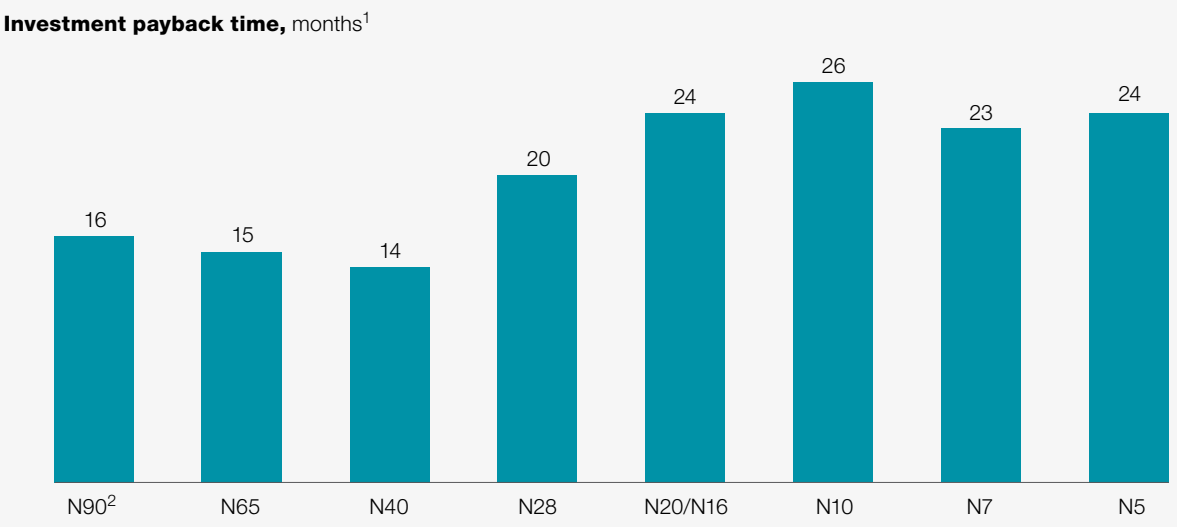
Second, the business model of equipment players is gradually shifting from selling hardware to selling a certain level of performance. Various equipment players are already offering different pay-per-usage models—for instance, by wafer or minute. Through these models, equipment players can extend their role in the fab and help semiconductor players optimize equipment performance for their specific processes and requirements.

The challenges ahead

Although the next decade opens opportunities for equipment manufacturers, we also see issues ahead. Consider some of the challenges that equipment players face:

- Competition is intense in each subsegment of the equipment market, with only the winners creating economic profit.

Exhibit 3 **Payback time for foundries will be close to 24 months for nodes smaller than 20 nanometers/16 nanometers.**



[1]Includes fab capital expenditures and R&D.
[2]N = node.

Source: McKinsey analysis

- The creation of more advanced technologies necessitates greater R&D costs for equipment, raising the stakes.

- Device architecture is less certain than it was in the past, with no clear winner among various design options. For instance, chip makers are investigating many new memory solutions for PC storage, such as 3-D NAND, HDD, MRAM, PRAM, and ReRAM. It is therefore often difficult to predict what equipment a semiconductor company will request.

- Chip makers tend to investigate several manufacturing options for every product, each with different implications for equipment manufacturers. They do not select the winning strategy until shortly before large-scale production begins, and their hesitation makes it difficult for equipment manufacturers to anticipate future demand, prepare their supply chain, and make their own technology-roadmap choices.

- Equipment manufacturers must expand into new areas because of rapid advances in semiconductor components and production complexity—particularly the transition from 2-D to 3-D structure. For example, they need to create new equipment features to handle the increased atomic-layer deposition (ALD) and etching (ALE) that 3-D fabrication requires. Greater use of ALD and ALE will also require companies to hire more material scientists, because many new materials, such as silicon germanium and titanium, are now being used to advance semiconductor technology.

- With industry consolidation, many small semiconductor players have vanished, and the remaining larger players typically have more professional procurement operations with better negotiating skills. About 60 percent of equipment demand will come from six major semiconductor players, including Intel and Samsung. The scale of the remaining chip manufacturers will work in their favor, since equipment players eager to win large deals are often tempted to offer more beneficial terms.

Beyond these immediate problems, the slowdown of Moore's law also presents challenges. There are indications that players are still striving for innovation, such as IBM's recent surprise announcement of a 7-nanometer chip. Such developments make us believe that shrink will continue until at least 2025, as players strive toward 7-nanometer to 5-nanometer technology. That said, signs of a slowdown are already apparent and may become more pronounced over the next decade. For instance, Intel recently announced a delay in the development of its 10-nanometer node, which suggests that the company's traditional two-year cadence for shrink has increased by at least six months. In a mature industry where the slowdown continues, semiconductor players will start to seek alternatives to both shrink and rapid time to market for reducing costs, forcing equipment manufacturers to search for other forms of revenue and margin.

Strategies for success

Given the shifts ahead, winning equipment players will employ a two-part approach: short-term strategies to promote innovation, handle complexity, and minimize risks, as well as long-term strategies to address the eventual slowdown of Moore's law.

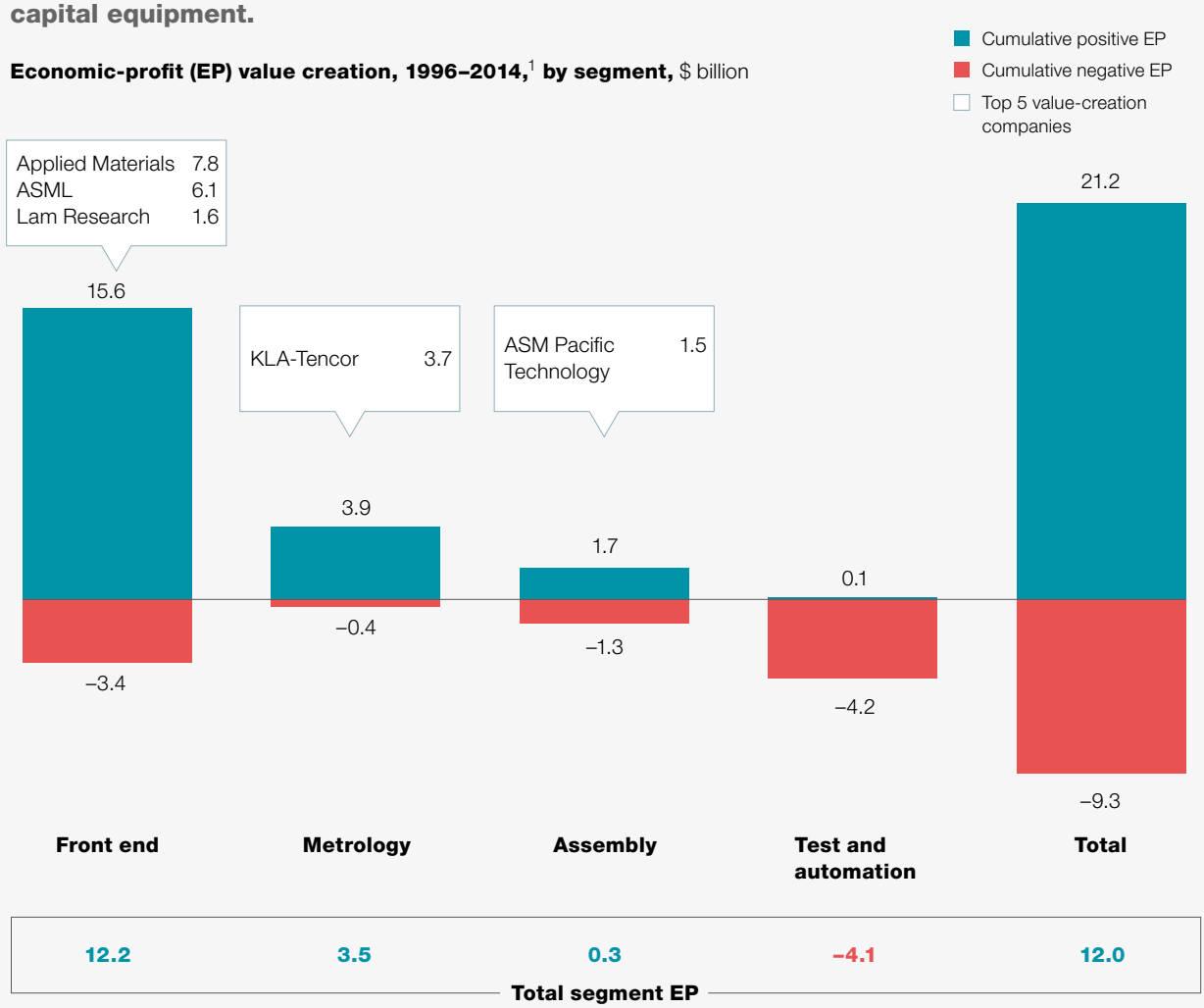
Winning in equipment over the next decade

Historically, only one or two equipment players has been successful in specific segments, and this trend continues. Today, a handful of companies—Applied Materials, ASM Pacific Technology, ASML, KLA-Tencor, and Lam Research—account for about 99 percent of all economic profit generated

Exhibit 4

The top one to three companies create the bulk of economic profit in each segment in capital equipment.

Economic-profit (EP) value creation, 1996–2014,[1] by segment, $ billion



[1]Economic profit is calculated as net operating profit less adjusted taxes – (capital charge, where capital charge is invested capital at previous year end x weighted average cost of capital); figures may not sum, because of rounding.

Source: Bloomberg; Capital IQ; McKinsey analysis

in the capital-equipment space (Exhibit 4). In this competitive market, the most successful players will focus on product excellence, develop innovative offerings, and collaborate with customers.

Product excellence. As technology challenges increase and R&D investments rise, the semiconductor industry's winner-takes-all nature—which is already more pronounced than in other sectors—will become more intense. To succeed, equipment players should consider focusing on subsegments where they have established a leading position or can achieve one because their technology gives them an edge. We believe that expansions or acquisitions purely to increase scale or reduce cost are less likely to be successful in the current market. Players should consider entering other segments if this would reduce time to market or improve the

value of their product offering. For instance, equipment players might gain an edge by collaborating with suppliers in related fields or acquiring them, since this will help them create an integrated supply chain. Such partnerships and acquisitions can help reduce lead times, which are increasing because of production complexity and uncertainty about when demand will accelerate.

Innovative offerings. Equipment players may also want to distinguish themselves from competitors through unique offerings. This strategy might involve several elements:

- providing integrated solutions and services, such as assisting with large-scale data analysis or software applications
- creating customer-specific solutions; since semiconductor players have their own unique manufacturing processes, there is an opportunity to tailor equipment to meet specific process requirements
- collaborating with other players to optimize the overall fab process; as one example, data exchange among equipment from different companies could promote improvement

Such efforts may require partnerships or M&A with other equipment players, since few companies will have all the skills needed to create these offerings.

Customer collaboration. Closer collaboration with customers may be beneficial, since it otherwise would be difficult to develop solutions targeted to their specific needs. As an added benefit, customer collaboration could give equipment manufacturers more insight into any decisions made about device architecture or manufacturing processes.

Strategic partnerships with customers could also be important for certain equipment players, especially with R&D costs rising. For instance, equipment players could shift to a business model in which their customers provide sales guarantees, agree to a pay-per-use system, or cofund R&D projects related to equipment development, as Intel, Samsung, and Taiwan Semiconductor Manufacturing Company did with ASML. This strategy can increase the likelihood that an equipment player's large investment in new technology will pay off.

The slowdown of Moore's law will require a substantial strategic shift

When Moore's law slows down significantly, demand for leading-edge equipment is predicted to drop precipitously. Since this change could present the greatest disruption that equipment manufacturers will ever face, they should begin preparing now, even though it is likely at least ten years away. For instance, equipment players could adopt a new business model in which more revenue comes from maintaining the installed base and optimizing its performance, rather than from selling new equipment. The transformation of pure hardware-oriented companies into those that are more service oriented has been observed in other maturing industries. Some companies have shifted from only creating parts—such as engines or wind turbines—to providing routine maintenance, repairs, and other services for existing equipment.

A new attitude toward cost reduction may also be beneficial as Moore's law slows down. Traditionally, semiconductor companies have focused on reducing costs through shrink. Therefore, they prioritized decreasing time to market for the next node over the price of equipment. As the industry matures, however, fab costs will emerge as the main differentiator among semiconductor players. Equipment manufacturers may appeal to them by creating equipment that will help their customers minimize production costs.

Another strategy for securing long-term growth involves exploring opportunities to promote innovation in adjacent industries. This strategy will sometimes necessitate partnerships or M&A to gain market access. While a few equipment players have already begun exploring adjacent industries, results have been mixed. One success story involves Canon and Nikon, which drew on their knowledge of lithography for semiconductors to create lithography equipment for the manufacture of flat-panel displays used in various consumer goods, such as mobile phones, PCs, and televisions. Equipment players may be more likely to win in adjacent industries if they can leverage existing strengths, as companies in other sectors have done. For example, Fujifilm realized that it had to expand its core offerings as digital photography began to rise. Although the company began investing in digital technologies, it also started exploring other businesses where its thin-film and material capabilities would be useful. In one new business line, Fujifilm used its knowledge of photographic chemicals to create other chemical offerings, which it now supplies to multiple industries. Similarly, the company applied its knowledge of photographic technology to create medical-imaging equipment, such as endoscopes and ultrasound machines. Meanwhile, Eastman Kodak, Fujifilm's main rival before the digital era, maintained its focus on the photography business and filed for bankruptcy in 2012.

Over the next decade, the end market for leading-edge devices containing semiconductors will continue to grow. To meet the demands of their customers for innovative products, semiconductor players will continue to strive for shrink. But they will face more challenges when attempting to realize their technology road maps, and the production process will become more complex. All of these trends could benefit capital-equipment manufacturers, provided that they focus on innovation, develop new strategies for sharing risk, improve supply chains, explore integrated solutions, and upgrade their sales capabilities. In addition to these strategies for short-term success, equipment players should also prepare for the eventual slowdown of Moore's law and a mature industry by servicing the installed base, helping fabs reduce production costs, and exploring adjacent industries. ■

The authors wish to thank Rebecca Doherty for her contributions to this article.

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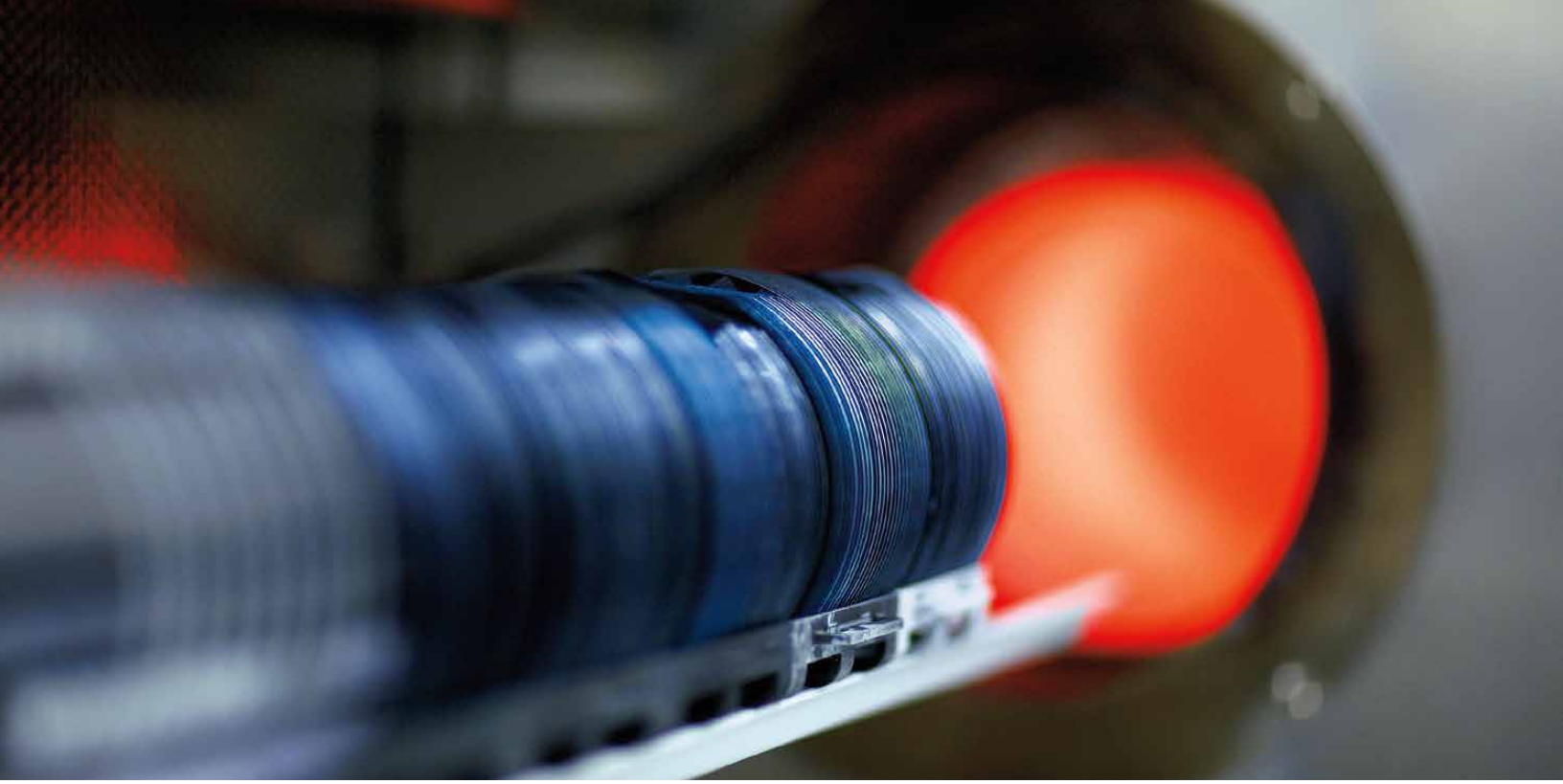


Ramping up at warp speed

Fabs can reduce expansion costs and streamline ramps through a new approach that emphasizes data-driven decision making and better communication.

Mark Patel, John Saunders, Nicholas Sergeant, and Tilia Wong

Semiconductor manufacturers are in an aggressive race to win major new designs and meet their customers' demands for rapid time to market. This has led them to accelerate ramps—the process of bringing a new technology from development to full-scale production—with increasing frequency. To facilitate these efforts, leading companies are developing more sophisticated capabilities in their fabrication plants, allowing them to streamline manufacturing, increase wafer size, and shrink nodes.

Fab construction costs have soared over the past few years, and further increases are expected. According to Gartner, total industry outlays for expansion—retrofitting, upgrades, and new facilities—could rise to as much as $75 billion by 2018, up from an estimated $66 billion in 2015. Despite these high capital outlays, ramps are frequently plagued with problems that put them behind schedule or over budget. In addition to raising capital costs, such issues may interfere with a fab's commercial prospects, since manufacturers that are first to market with an innovative technology gain a lasting commercial advantage. Additionally, a leading-edge fab that produces nodes at high volume can lose tens of millions of dollars in revenue for each week of delay.

Many serious ramp problems can be overcome or mitigated through a strong management approach that emphasizes fact-based decision making and increased communication in three critical areas: project planning, performance management, and capability building (Exhibit 1). While the new approach requires intense management attention, the rewards are substantial. Better planning and tracking could reduce ramp durations by 20 percent and overall capital spending by 15 to 20 percent. Contractor expenses alone could fall by as much as 30 percent. After a ramp is complete, managers may be able to accelerate future projects by codifying best practices and developing strategies to transfer knowledge to new teams.

This article focuses on applying the new approach in fabs, but it is also applicable to any large-scale manufacturing ramp requiring coordination of numerous stakeholders and careful sequencing of all activities, including those for production of cutting-edge advanced-material, energy, and electronic components.

A complicated process

Every ramp is unique, but they all require certain tasks, including accurate capacity forecasting, seamless tool handoffs, and timely ordering and delivery of equipment. To manage the complexity, leaders must create detailed schedules, establish performance goals, and constantly manage performance. Since ramps require great precision and thousands of process tools, a single misstep or process change can cause delays. The personnel challenges are also daunting because each group—engineers, construction workers, and others—has different incentives and goals.

Faced with such an overwhelming number of details, fab managers may inadvertently omit some critical specifics from ramp plans, such as handoff procedures on equipment installation. Adding to

Exhibit 1

Fab leaders can improve ramp management by creating detailed plans, maintaining a central control tower, and bringing best practices to new ramps.

1 Get everyone on the same page

Plan well from project outset:

- Create detailed end-to-end plans for tool installation
- Make fact-based assessments about time lines, risks, and other important factors
- Appoint owners for each tool

2 Keep the ramp on course

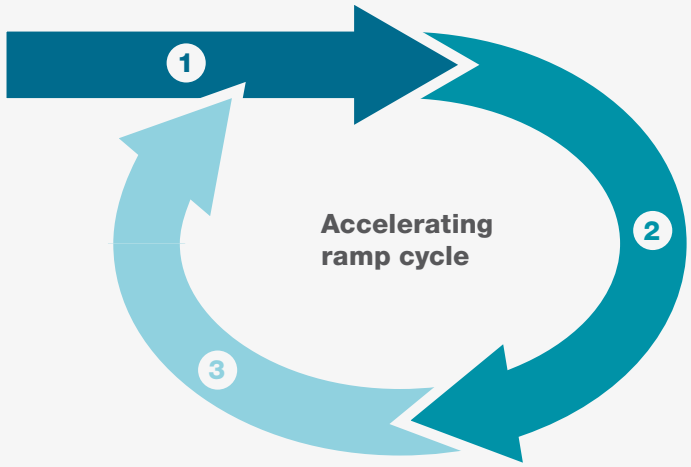
Maintain a central control tower:

- Set up a rigorous management system
- Maintain a central program-management database to facilitate communication

3 Maintain momentum

Bring the best to new ramps:

- Codify and share best practices
- Carry ramp talent forward



Source: McKinsey analysis

the confusion, many fabs lack the necessary benchmarks and metrics for ramp activities or do not record them for future reference. Without this information, team leaders may have difficulty spotting potential problems early, including those resulting from interdependencies or a change in plans.

Other ramp problems arise from inadequate communication, with teams and individuals making decisions in isolation because they lack established processes for sharing information. Manufacturing engineers, for instance, may not communicate important details about equipment throughput and capabilities to the capacity-forecasting experts who determine the number of production lines needed to meet volume requirements. If the experts base their decisions on incomplete information, they could underestimate the capacity needed, potentially delaying the entire project.

Project planning: Getting everyone on the same page

Fab leaders often struggle with ramp execution because they do not align on responsibilities, time lines, and goals. But they can potentially mitigate this problem by creating a detailed, end-to-end project plan that describes important milestones and activities. Important elements of the plan include the following:

- the sequence for installing tools
- major milestones and handoff points when responsibility for a tool transfers from one group to another
- required resources, including personnel, equipment, and materials
- productivity-rate assumptions
- lead times needed for the procurement or delivery of supplies, as well as the time needed to prepare for implementing various processes
- a time line that includes buffers to account for unexpected events

With this information, managers can see their next steps, understand if they are about to miss a deadline, and create a recovery plan. To manage change, project plans should discuss potential problems that could cause delays, such as a break in the gas line for a critical-path tool, and include contingency plans for managing these events.

Project plans should also include performance goals and related metrics that specify the expected duration of various tasks and weekly completion rates. These metrics will be most accurate if they are based on historical benchmarks for similar tools from prior installations or from partner fabs (either within the company or with technology partners). If this information is not available internally, tool vendors may be able to estimate the time needed to install a tool and undertake the qualification process.

Once managers have metrics—such as productivity rates and time lines for completing tasks—they will be able to identify areas of weakness throughout the entire project. Managers should inform all relevant contractors, vendors, and internal groups about project metrics, allowing them to follow a common strategy.

Creating an appropriate management structure

Ramps are so complex that they generally require oversight from the following three management teams, beginning with the planning stage:

- *An executive committee.* This group includes the fab manager and project lead. It makes all major decisions related to the project scope, schedule, and budget with input from leaders of relevant groups, such as finance, industrial engineering, equipment engineering, and construction. The executive committee also monitors performance and assigns accountability for various goals to specific groups.

- *A project-execution team.* This group includes functional teams, such as those from procurement or utilities, and tool-specific teams.

- *A tool team.* Each fab should appoint a single coordinator for every tool family to serve on this team. Tool owners are responsible for ensuring that handoffs between ramp teams are complete.

The tool team reports to the project-execution team, which, in turn, reports to the executive committee. Under this management structure, a single person on the executive committee has responsibility for coordinating all functions, with input and advice from frontline managers who are directly involved with execution or tool implementation. The frontline managers also escalate problems, as needed, and help resolve them.

Performance management: Keeping the ramp on course

Even if managers create a solid project plan, unforeseen events may cause delays or require a shift in strategy. But these problems can be mitigated by establishing better performance-management processes and establishing a central performance-tracking tool.

A better approach to performance management

The new, three-tiered management structure is critical to better performance management, as are the metrics that teams should create during the planning stage. Together, they can facilitate two important tasks: progress assessment and change management.

Assessing progress. While most fab managers now attempt to review performance during ramps, they generally do not compile detailed information for each tool and function. Since the managers rely on incomplete information when assessing progress, they may inadvertently overlook potential issues. To avoid such problems, fab managers should convene and chair weekly reviews that include the ramp leaders, all executive-committee members, and leaders of the functional and tool-execution teams. By creating a shared understanding of ramp progress, these reviews will help fab managers identify areas for improvement.

At the beginning of each review, ramp leaders should receive updates about tool-installation progress, allowing them to estimate changes in future capacity. The project-execution team should announce any major project changes and their implications. The functional leaders on that team should then provide a progress update that includes important performance metrics such as the number of tools that have been installed or the percent of installations that were completed on schedule. The meeting should close with a discussion of important issues the executive committee will need to address.

Additional meetings are needed at the functional level to assess progress. These 15- to 30-minute stand-up meetings, which include members of the project-execution and tool teams, should occur daily and focus on the scope of work that must be completed over the following 24 hours, including deliverables, handoffs, and production time lines for all tools. For best results, functional managers should review the daily execution plan with the floor crew, highlighting the tools that could create bottlenecks or decrease capacity if problems occur.

If leaders detect performance gaps, during either the fabwide review or functional meetings, they should set ambitious yet realistic goals for resolving them. Meanwhile, leaders may need to adjust the schedule, always considering the complexity of the tasks involved, crew capability, and the availability of necessary resources.

Managing change. Even minor changes to the project plan can affect multiple ramp tasks, potentially causing delays. For example, a process-flow update might necessitate use of a different corrosive gas for

etching, a change that could require procurement of new chemical cabinets, construction of additional infrastructure, or development of different product-validation tests. To prevent major delays, fabs should convene a multidisciplinary forum to discuss any unexpected developments. This will help keep all functions aware of plan updates and give them an opportunity to discuss their impact.

Any team members who are requesting changes should supply forum members with relevant information well before the meeting. This prework will allow the forums to make immediate decisions or approve the resources needed to conduct further analyses, preventing bottlenecks. Ideally, the multidisciplinary forum will be led by select executive-committee members who rigorously assess the impact of any changes across the entire fab, lead the decision-making process, and propose appropriate mitigations.

An emphasis on accurate and accessible tracking data

To improve performance management, fab leaders should establish a central, easily accessible program-management tool that allows all stakeholders to view ramp information and input their latest data. Among other information, the system will contain the following:

- agreed-upon performance metrics
- a searchable database of past projects that allows managers to make benchmark comparisons and identify teams that could serve as models for others
- the latest milestone dates for tool installation
- tool-performance parameters, such as throughput
- the owner for each stage and tool

The program-management tool will facilitate communication and provide staff at all levels with a detailed snapshot of their tools' status, project time lines (including missed milestones), and next steps. For example, the capacity-forecasting group will be able to access up-to-date information when making decisions about production, rather than rely on data that was collected a few days before. It will then be able to route wafers to the tools that have the most spare capacity, mitigating the chance of bottlenecks.

By making it easier to see potential problems, managers may be more likely to work with the appropriate tool owners to resolve them. The program-management tool may also help prevent costly oversights at all stages, such as the failure to get timely bids for a critical-path tool, resulting in additional fees to expedite work.

For best results, fab leaders should incorporate the program-management tool into their standard management practices, primarily leveraging it to make data-driven decisions. They should also ensure that the tool has an easy-to-use interface and keep data-collection requirements to a minimum. For instance, leaders should ensure that information only needs to be entered into the tool once, after which it will be shared across the organization. When deciding what data should be collected, leaders should focus on important metrics that are necessary for making decisions or identifying deviations from the project plan.

In one recent ramp, a fab developed a program-management tool that could integrate large volumes of data. All stakeholders contributed content, and they could easily create and update performance dashboards. Since all relevant managers used the tool, it served as the single source of information for fab leaders who needed a comprehensive view of the project's status. To ensure that the tool captured all appropriate information, it directly connected

to multiple project-related databases at vendor and contractor sites and the fab itself. Among other benefits, the tool helped the ramp team quickly identify and resolve bottlenecks in the installation and qualification processes, accelerating the project time line. Exhibit 2 shows how a strong analytics tool can help eliminate some common ramp problems.

Capability building: Preparing for the next ramp

Teams may be tempted to sit back and celebrate their success after completing a ramp, rather than prepare for the next one, but this would squander their momentum. Instead, we recommend that fab leaders immediately codify all best practices and lessons learned about ramp management, tool templates, and communication strategies. To facilitate future projects, the information should be added to a continuously updated "ramp in a box" that can be used to educate new teams and facilitate communication processes from day one.

Fab managers can also maintain momentum by having experienced staff serve as champions on new ramps, rather than appointing a fresh team for every project. These champions should have a broad set of capabilities, including knowledge of procurement, contractor-relationship management, equipment-supplier management, and end-to-end project planning. During a project's early stages, champions can direct initial planning while also launching capability-building programs to help managers get up to speed quickly. Typically, they will first train a few people to serve as ramp leaders. This small cohort will then provide training to other staff, following a field-and-forum approach in which participants attend short boot camps and

Exhibit 2 **Strong analytics tools can eliminate five common problems in generating performance metrics.**

From	To
Model is difficult to share across organizations	Represents model logic **graphically**
Assumptions behind metrics not transparent	**Consistently tags data filters** to metrics generated
Low data integrity due to source-integration errors	**Directly connects** databases and blends data into an **integrated data set**
Short historical view due to Excel file-size limits	Supports **terabytes of data** from weekly exports of existing project-management schedules
Long lead time to update visuals	**Prebuilt dashboards** for every organizational layer **customized** for semiconductor ramp milestones

Source: McKinsey analysis

then apply what they have learned in the workplace before returning for more instruction. For example, trainers could provide instruction on creating a day-to-day deliverables plan for a critical tool and then help participants troubleshoot any problems that arise when participants attempt to apply this knowledge in the field. Trainer support, combined with the ramp in a box, will allow managers to deploy resources and equipment rapidly during new projects.

Because there are so many moving parts, problems are almost inevitable during a ramp, ranging from tools that fail to work as planned to slower-than-expected execution speed. What can be managed, however, is the frequency and magnitude of these problems. By following a data-driven approach to planning and central communication, teams can avoid many issues and spot the rest early enough to diminish their impact. And by ensuring that project knowledge and leadership flow from ramp to ramp, fab leaders can ensure that new teams learn from past experiences and that future projects reflect best practices.

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