IT and productivity growth in the semiconductor sector

SUMMARY

The semiconductor industry experienced one of the highest labor productivity growth rates in the 1990s, averaging more than 35 times the average annual US productivity growth rate of 2 percent from 1993-2000. This sector also experienced an increase in IT intensity[1] in 1995-2000 relative to 1987-1995. During the 1990s, the increase in labor productivity in semiconductors was predominantly driven by changes in output quality as measured by the output deflator. A combination of factors, including high absolute demand (in part from increased penetration of computers) and demand specifically for high-performing chips (in part due to rapid PC upgrade cycles) shifted the output mix toward the cutting-edge, higher-quality products.

Of the various semiconductor subsectors, microcomponents and memory experienced the highest change in output quality[2] and demand. In microcomponents and memory, microprocessors (MPUs) and dynamic random access memory (DRAM) were significant (approximately 50 percent) contributors to the sector revenues. In MPUs and DRAMs, IT played a critical enabling role in driving line width reduction that led to improved functionality and integration – quality changes that were the main drivers of productivity improvements in these subsectors in the 1990s.

The impact and role of key IT systems on the productivity and profitability levers in the sector depended on the subsector characteristics and requirements. All the semiconductor companies (or their partners[3]) in microcomponents and memory invested in the key IT systems, but the level of impact varied based on the institutional knowledge and the effectiveness of companies in leveraging these investments. In spite of these complexities, key IT applications that improved productivity in the sector shared three common characteristics. First, key productivity-enhancing applications in the semiconductor sector – electronic

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1 IT refers to software (prepackaged, own account, and custom software), hardware (PC, mainframes, servers), peripherals (storage devices, printers), and communication equipment; refer to the main section for more details. "IT intensity" refers to real IT capital stock per people employed in production.

2 Microprocessors is a significant part of microcomponents revenues; therefore, it is assumed that the subsector output deflator is equal to that of the MPU output deflator.

3 "Partners" refers to IP houses for core design blocks, ASIC houses for back-end design and wafer fabrication, and foundries for wafer fabrication.

design automation (EDA) tools, manufacturing automation systems, process control systems, and process diagnostic tools – were vertical applications with a focus on key business processes. Second, they helped build business process and technological capabilities in parallel. Third, they were deployed in concert with business process changes and technical innovations.

Horizontal IT applications, on the other hand, have had minimal impact to date on the sector's performance. For example, due to noncustomized products and long implementation schedules, enterprise resource planning (ERP) failed to deliver sector-wide impact, although individual companies have deployed and seen benefits from some components of ERP systems.

Across microcomponents and memory segments, IT investments can be grouped into a four-tier "value stack." The first and second tiers consist of IT investments that help to design complex chips with greater functionality and integration and to manufacture them with reduced throughput times and faster ramp-up rates, thus accelerating the introduction of newer and higher quality products. All semiconductor companies (or their partners) have invested in first-tier systems and have seen benefits from these investments. Investments in the second tier were made by the majority of larger semiconductor companies in their newer design and production facilities. Due to rapid growth in external demand and large across-the-board productivity improvements in the 1990s, semiconductor companies did not need to rely upon IT to differentiate themselves, and hence made few third and fourth tier investments. As a result, these categories represent forward-looking investments that may in the future yield competitive advantages for some firms, while pushing the sector's performance frontier.

Moving forward, with slower demand growth, semiconductor companies should seek to generate further productivity gains by evaluating their performance along the productivity levers, both against the levers already generally employed across the sector, and along those that still remain to be used. In doing so, companies can likely benefit by considering IT investments to increase their "stack height," that is, to differentiate themselves in the subsegment, where valuable.

IT vendors interested in participating in this space can help in two ways: by collaborating with customers to develop IT systems that impact underutilized productivity levers, and by developing applications for the third tier of the value stack to help customers gain a competitive advantage. In doing so they should ensure that IT improvements continue to co-evolve with advances in material science and business innovation.

INTRODUCTION

The electronic machinery sector (of which the semiconductor sector is a part[4]) experienced strong labor productivity and IT intensity growth in the 1990s. The semiconductor sector was the largest contributor to labor productivity growth in the 1990s and experienced more than 35 times the average annual labor productivity growth rate of the US economy. Labor productivity in semiconductors grew at a 72 percent CAGR from 1993-2000 compared to 2 percent for the overall US economy (Exhibit 1).

This sector is one of a few that both consume and create IT, and its products serve as inputs to several industries including computer manufacturing, telecom, and consumer goods. Productivity improvements in semiconductors have a spillover effect throughout the economy as increased output quality of semiconductor chips flows through other sectors. In this case, the McKinsey Global Institute (MGI) found:

¶ The semiconductor sector contributed significantly to economy-wide productivity growth and acceleration.

¶ Productivity improvements in DRAMs and MPUs were driven by increased customer demand and reduced line widths.

¶ IT as an input played an enabling role in the sector; its role was significant but complex.

¶ Key IT applications that impacted performance in the semiconductor sector shared three general characteristics.

¶ Significant opportunities and challenges exist for semiconductor companies and for IT vendors wanting to participate in this space.

Focus of current project

The semiconductor sector experienced labor productivity growth of 71.6 percent per year from 1993-2000. Change in output quality as measured by the output deflator, and hence change in real value added, drove this labor productivity growth (Exhibit 2).[5] The output deflator in semiconductors can be impacted by a

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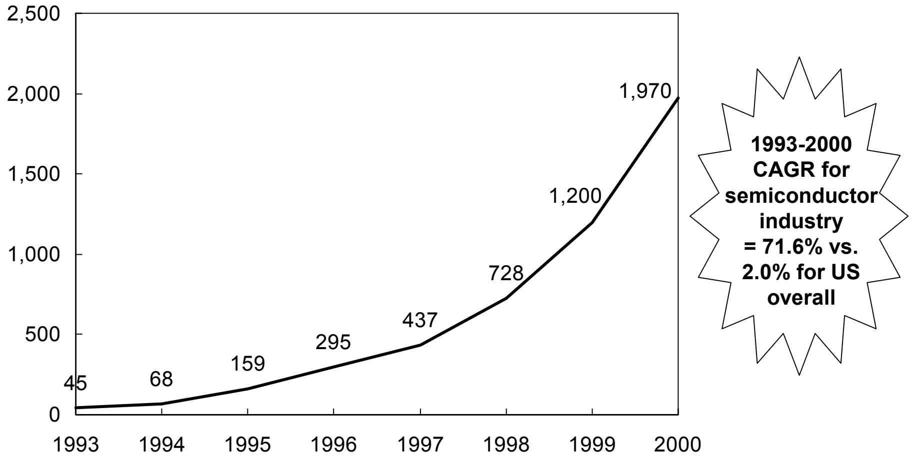
4 MGI's US Productivity Growth report identified semiconductors as a predominant component of electronic machinery. Hence, we interchangeably use electronic machinery and semiconductors, and the current project focuses only on semiconductors. Data for semiconductor productivity was obtained from the National Bureau of Economic Research (NBER) and the US Census; see appendix for further details.

5 It is MGI's estimate that outsourcing/offshoring has had minimal impact on the productivity growth. If it is assumed that all the employees in TSMC, UMC, and Chartered were located in US from 1993-2000, productivity growth would have decreased by only 1.3 percent to 70.3 percent (assuming no change in value added).

Exhibit 1

SEMICONDUCTOR SECTOR EXPERIENCED EXPONENTIAL LABOR PRODUCTIVITY GROWTH IN 1990s

Thousands of chained (1996) dollars per PEP



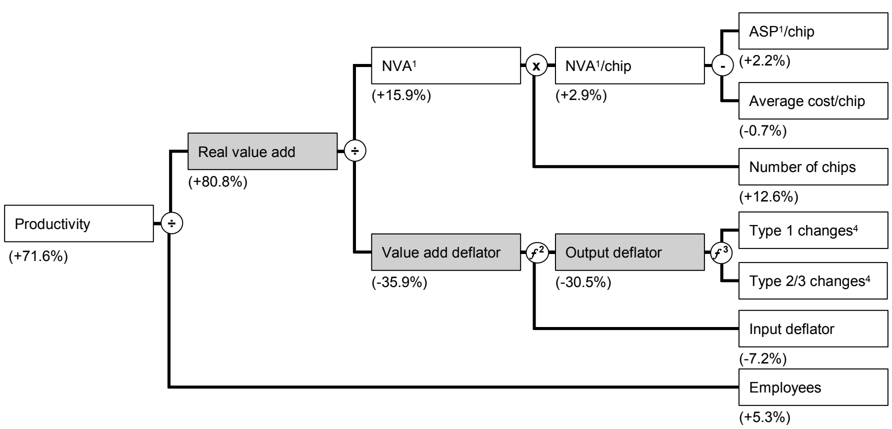
Source: National Bureau of Economic Research; Bureau of Labor Statistics; Census of Manufacturers

Exhibit 2

OUTPUT DEFLATOR WAS MAIN DRIVER OF SEMICONDUCTOR PRODUCTIVITY GROWTH IN 1990s

Main driver

CAGR, percent, 1993-2000



1 ASP = average selling price; NVA = nominal value add
2 Product calculated using Fisher formula (geometric average)
3 Output deflator is function of type 1 and type 2/type 3 changes
4 Type 1, type 2, and type 3 refers to type of quality changes and are semiconductor specific; type 1 changes involve underlying process technology changes, type 2 and 3 changes involve design changes (functional/architectural)

Source: National Bureau of Economic Research; Census of Manufacturing; Bureau of Labor Statistics; IC Insights change in process technology (defined as Type 1 change) and by changes in functionality and architecture (defined as Type 2 and Type 3 changes) in the chip.[6]

Of the various subsectors, microcomponents (of which MPUs are a significant part) and memory (of which DRAMs are a significant part) experienced the highest change in output deflator and demand (Exhibit 3). These two subsectors also accounted for more than half of worldwide semiconductor sales in 2000 (Exhibit 4). Thus, MGI focused on studying MPUs and DRAMs to understand the role of IT in the productivity growth of the semiconductor sector in the 1990s.

Definition and scope of IT for current project

Semiconductors occupy a unique position in the economy. The semiconductor sector (along with computer manufacturing, telecom, and IT services as part of business services) both consumes and produces IT. As an IT producing sector, semiconductors drove, through rapid improvements in product quality, productivity gains in multiple sectors that include them as an intermediate input (e.g., computer manufacturing, telecom, consumer goods, and manufacturing). In other words, increases in the quality of semiconductors affected the quality of the output in other sectors and thus flowed through the various output deflators in the economy.

In addition, IT also played an important role as an input to the semiconductor industry in enhancing labor productivity during the 1990s. This study focuses primarily on the role of IT as an input (e.g., we looked at the extent to which IT as an input helped to drive quality increases in the output).

This study focused on two types of IT inputs – direct and indirect – since both types of IT played a critical enabling role in improving labor productivity (Exhibit 5). “Direct” IT includes hardware (mainframe computers, PCs, storage devices, and peripherals), software (prepackaged, custom, and own-account software), and communication equipment. The study also considered “indirect” IT investments, which include software and hardware that are embedded or bundled as a part of the system (e.g., process control hardware and software in etch equipment in foundries, and inspection hardware and software in AOI). Typically these investments are captured in the BEA instruments category.

SECTOR PRODUCTIVITY

The semiconductor sector was a significant contributor to the US economy’s labor

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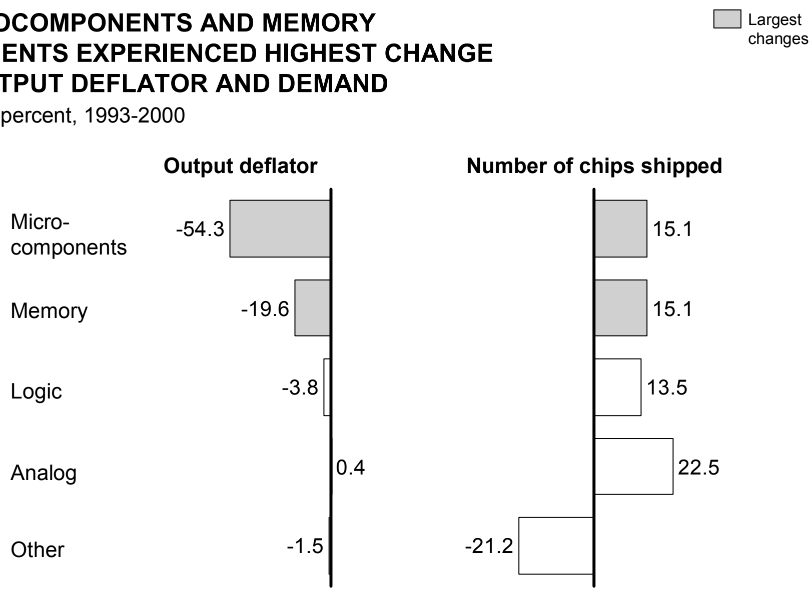
6 Refer to next section for more details.

Exhibit 3

MICROCOMPONENTS AND MEMORY SEGMENTS EXPERIENCED HIGHEST CHANGE IN OUTPUT DEFLATOR AND DEMAND

CAGR, percent, 1993-2000

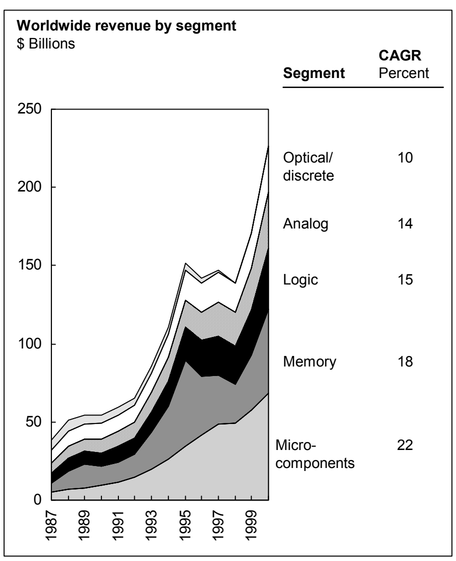


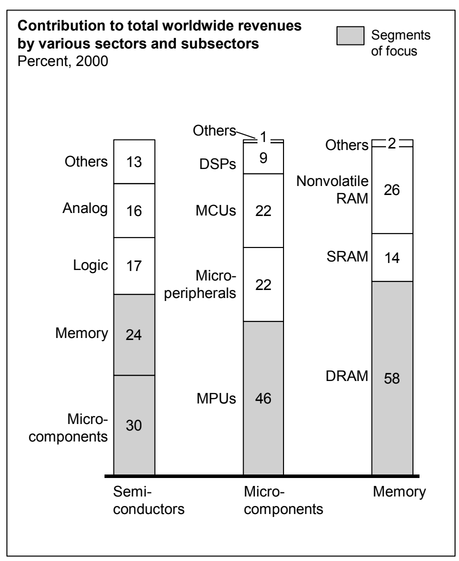
Note: Microprocessor, memory devices, transistors, diodes and rectifiers, and other, deflators from BLS were mapped to the micro-component, memory, logic, analog, and other segments as defined by IC Insights

Source: IC Insights; Bureau of Labor Statistics; MGI analysis

Exhibit 4

MICROCOMPONENTS AND MEMORY SEGMENTS ARE MAJOR CONTRIBUTORS TO SECTOR REVENUES





Source: Bureau of Labor Statistics; Dataquest

Exhibit 5

CURRENT PROJECT CONSIDERED "DIRECT" AND "INDIRECT" IT INVESTMENTS

Focus of study

	"Direct"	"Indirect"
Description	• Computation hardware and related peripherals, software, and data/voice communication spend made as "main focus"/nonbundled, nonembedded investments	• Computation hardware and related peripherals, software, and data/voice communication spend bundled/ embedded in other types of capital spend
Examples	• Personal computers • Mainframe computers • Direct access storage devices • Computer printers • Computer terminals • Computer tape drives • Computer storage devices • Integrated systems • Prepackaged software • Custom software • Own-account software • Communication equipment	• Embedded process control software/hardware in manufacturing equipment • Embedded software, hardware and related peripherals in metrology equipment
Rationale for focus	• Conventional definition of IT	• Embedded software and hardware help leverage improvements in other types of technology, i.e., material science and process technology

Source: MGI analysis

productivity growth and productivity jump[7] in the 1990s. Semiconductors along with wholesale, securities, retail, computer manufacturing, and telecom contributed to more than 75 percent of net US productivity growth and to more than 80 percent of the net jump in the 1990s.

Sector contribution to economy-wide productivity growth in the 1990s

The semiconductor sector, which represented only 0.18 percent of private employment and contributed to 0.48 percent of nominal GDP in 1993, was the biggest contributor to labor productivity growth over the 1990s, accounting for 20[8] percent of the growth (Exhibit 6).

Sector contribution to economy-wide productivity growth acceleration in the late 1990s

In MGI's US Productivity Growth report,[9] semiconductors was one of the six sectors that contributed to 99 percent of the net, economy-wide productivity jump. Productivity acceleration in semiconductors was predominantly driven by output quality as measured by the output deflator. The primary causes of the productivity acceleration in the microprocessors subsegment were twofold: heightened competitive intensity attributable to the "race" between AMD and Intel to have the fastest chip on the market, and technological innovation in process technology, which reduced throughput time for new chips and facilitated the firms' decision to shorten product life cycles (or to release new products more frequently).

The previous report's findings remained unchanged when updated with now-available 2000 data.[10] Electronic machinery continued to be a major contributor to the economy-wide acceleration in productivity growth. While contributing only 3 percent of US nominal GDP in 1995, electronic machinery contributed a full 11 percent of the acceleration in productivity growth in 1995-2000 (Exhibits 7a and 7b). Productivity acceleration in semiconductors also continued to be driven by changes in the value-added deflator. Interestingly, with the release of new economic data, the change in the value-added deflator (and hence real value

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7 "Jump" is defined as the difference between the productivity growth in two time periods.

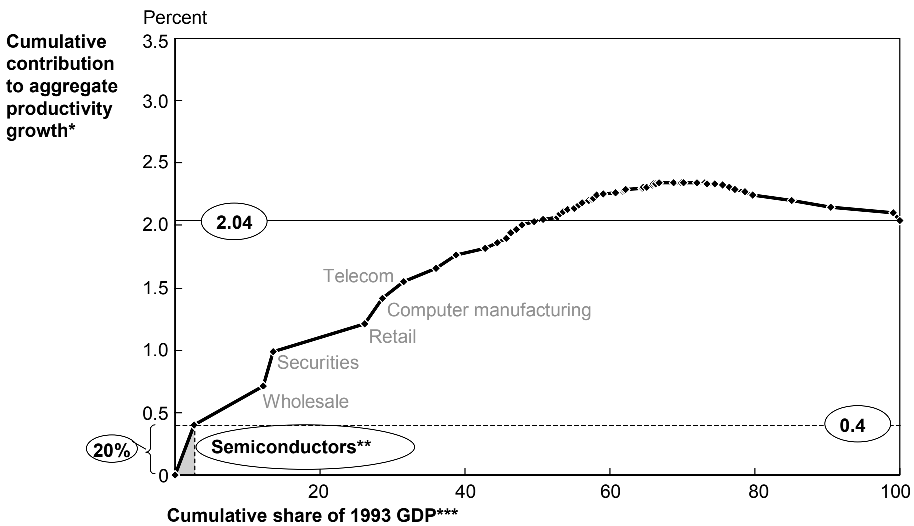
8 Contribution of the electronic machinery sector overall, not semiconductor subsegment alone

9 MGI "US Productivity Growth 1995-2000, Understanding the Contribution of Information Technology Relative to Other Factors," released October 2001.

10 See appendix to this report for details.

Exhibit 6

SEMICONDUCTORS WAS THE BIGGEST CONTRIBUTOR TO US LABOR PRODUCTIVITY GROWTH IN THE 1990s



* CAGR from 1993-2000; does not include farm and government sectors; real estate and holdings contribution evenly divided among sectors excluding top 6

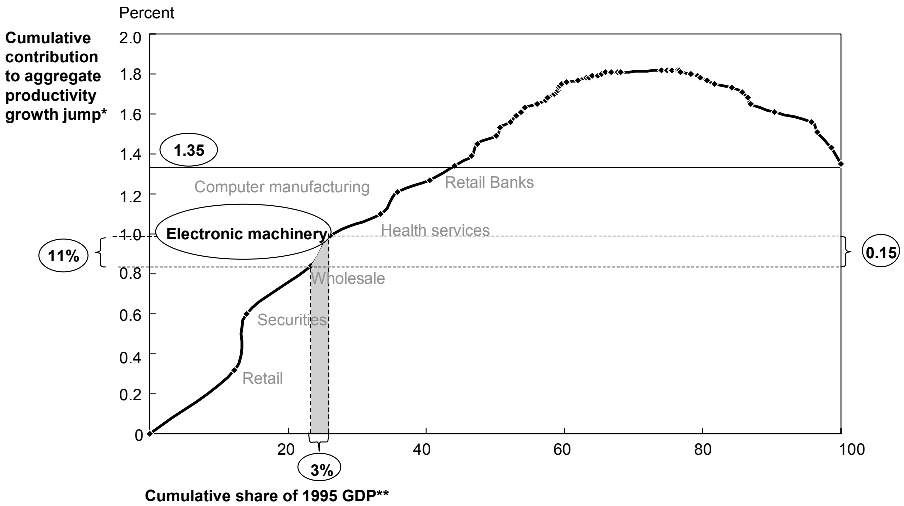
** MGI's US Productivity Growth report identified semiconductors and computer manufacturing as the predominant (by contribution to growth) subsectors of electronic machinery and industrial machinery; thus the sector and the corresponding subsector are used interchangeably in this chart

*** Does not include farm, government, holdings, and real estate sectors

Source: Bureau of Economic Analysis; MGI analysis

Exhibit 7a

ELECTRONIC MACHINERY MADE A DISPROPORTIONATE CONTRIBUTION TO JUMP IN 1995-2000



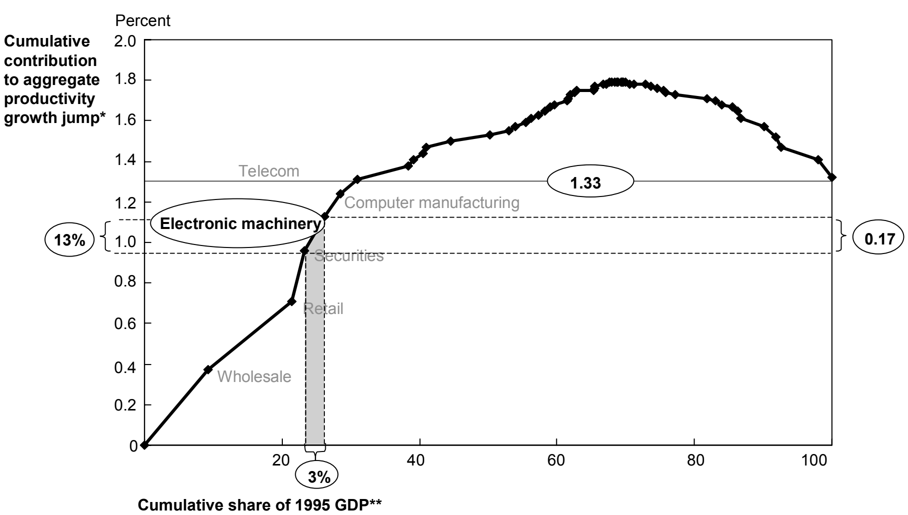
* Jump is defined as difference between 1995-2000 CAGR and 1987-95 CAGR; does not include farm and government sectors; real estate and holdings contribution evenly divided among sectors excluding the top 6

** Does not include farm, government, real estate, and holdings sectors

Source: Bureau of Economic Analysis; MGI analysis

Exhibit 7b

2001 MGI REPORT ALSO SHOWED ELECTRONIC MACHINERY'S DISPROPORTIONATE CONTRIBUTION TO JUMP IN 1995-99



* Jump is defined as difference between 1995-99 CAGR and 1987-95 CAGR; does not include farm and government sectors; real estate and holdings contribution evenly divided among sectors excluding the top 6

** Does not include farm, government, real estate, and holdings sectors

Source: Bureau of Economic Analysis; MGI analysis added) is even more significant than it was in the original report[11] (Exhibits 8a and 8b). The productivity jump in microprocessors can still be attributed to high absolute levels of demand, technological innovations in reducing line widths, and increased competitive intensity between AMD and Intel (Exhibit 9).

PRODUCTIVITY IMPROVEMENTS IN MPUs AND DRAMs

A reinforcing cycle drove productivity improvements in MPUs and DRAMs in the 1990s. This continuous cycle involved external demand for higher-quality chips from the PC market, increased capability to manufacture chips at reduced line widths (leading to better quality), and increased capability to design chips at lower line widths (leading to better functionality and integration) (Exhibit 10). However, it is not possible to name any one of these factors as the initiator of the productivity growth.

¶ **External demand.** Increased demand for PCs, and especially for PCs priced under $1,000 per unit, played a critical role in increasing demand for higher-quality, low-cost chips. In the US, PC penetration per individual increased from about 20 percent in 1990 to approximately 60 percent in 2000, while sub-$1,000 PC penetration went from 0 percent to 20 percent from 1997 to 2001 (Exhibit 11).

¶ **Capability to manufacture at lower line widths**. Advances in material science and process technologies offered manufacturers the capability to produce higher-quality chips at lower unit cost (Moore's law[12]), while cost advantages of lower line widths[13] and competitive dynamics made capital upgrades to lower line widths very compelling. For example, investment in foundries that could manufacture to lower line widths was driven by Intel's desire to have the fastest chip on the market at any given time, and adoption in the DRAM subsector was driven by the desire of DRAM players to become the lowest cost producers and to gain market share in a commodity market.

¶ **Capability to design at lower line widths.** Advances in design tools allowed firms to take advantage of the ability to manufacture at lower

11 The other significant change is the jump in the growth rate of employees; initial indications are that the industry accelerated its hiring significantly in 2000, just at the end of the boom, a common pitfall in cyclical industries. See appendix for details.

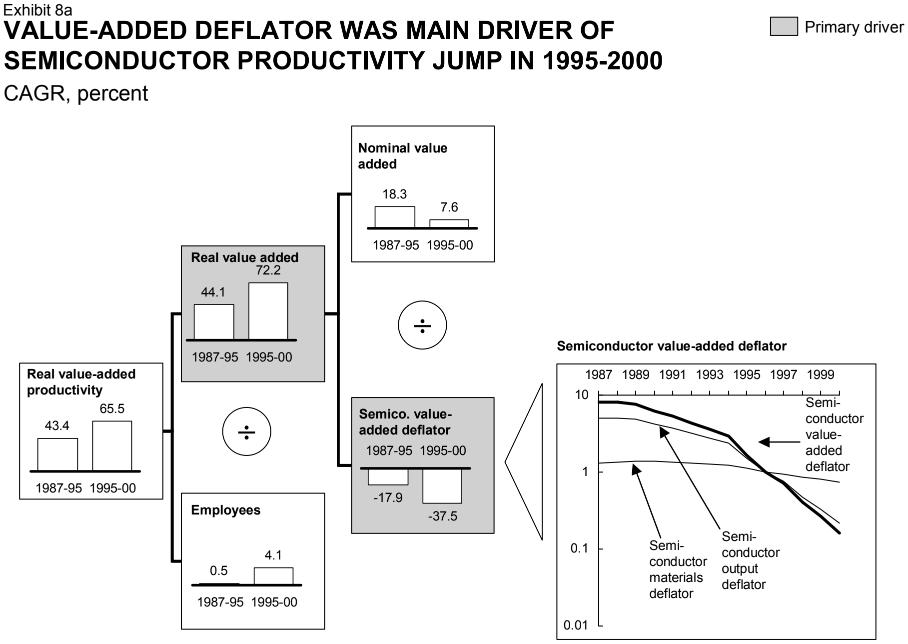
12 Moore's law predicts that the number of transistors per unit area will double approximately every 18 months.

13 Manufacturing chips at lower line widths yields more chips for the same wafer size, thus reducing cost per chip.

Exhibit 8a

VALUE-ADDED DEFLATOR WAS MAIN DRIVER OF SEMICONDUCTOR PRODUCTIVITY JUMP IN 1995-2000

CAGR, percent

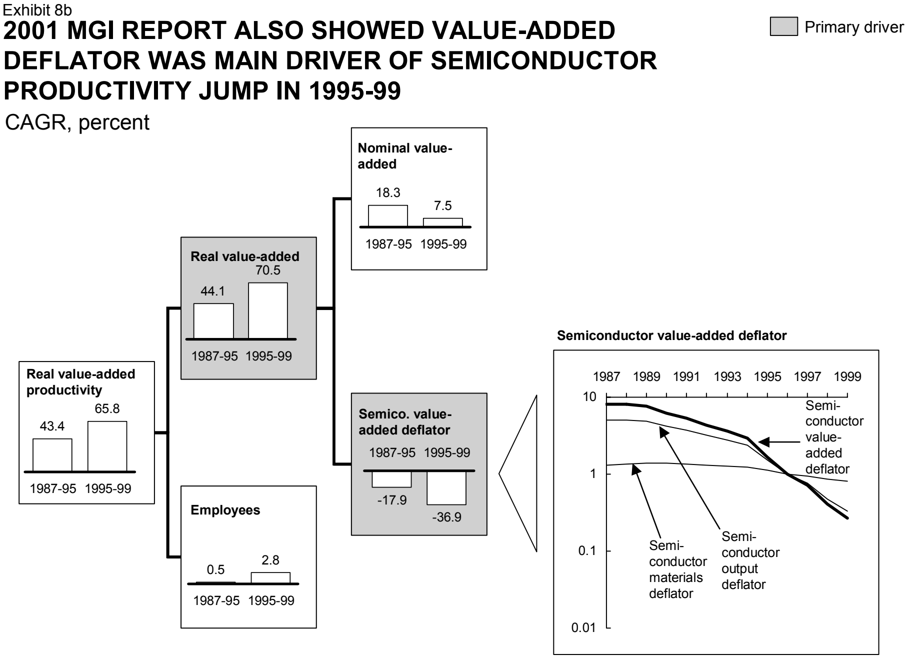


Source: Bureaus of Labor Statistics; Census of Manufacturing; National Bureau of Economic Research; McKinsey analysis

Exhibit 8b

2001 MGI REPORT ALSO SHOWED VALUE-ADDED DEFLATOR WAS MAIN DRIVER OF SEMICONDUCTOR PRODUCTIVITY JUMP IN 1995-99

CAGR, percent

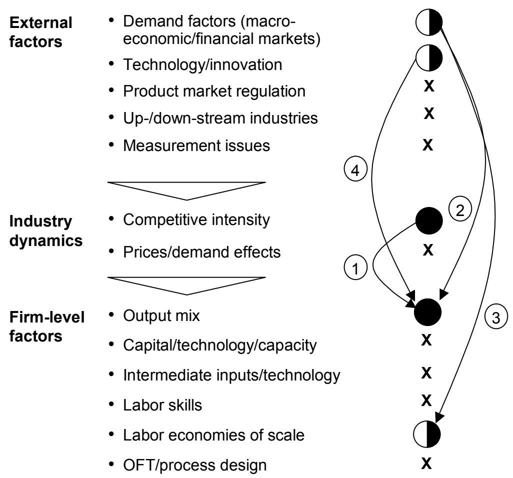


Source: Bureau of Labor Statistics; Census of Manufacturing; National Bureau Economic Research; McKinsey analysis

Exhibit 9

COMPETITIVE INTENSITY AND DEMAND WERE CAUSAL FACTORS FOR SEMICONDUCTOR INDUSTRY PRODUCTIVITY JUMP

- Important (>50% of acceleration)
- Somewhat important (10-50% of acceleration)
- Not important (<10% of acceleration: asterisk to right indicates significant negative)

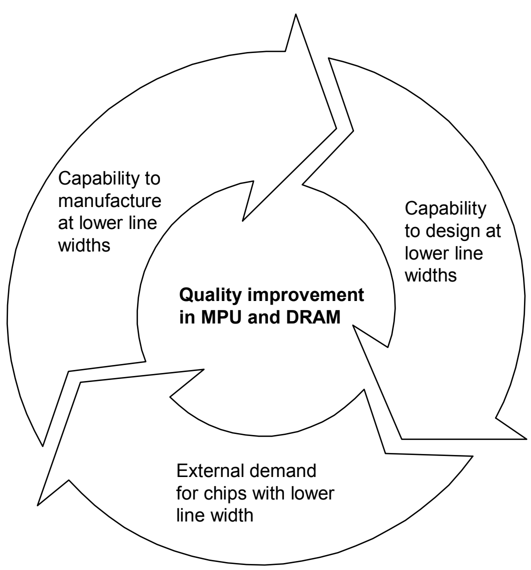


1. A surge in competitive intensity from AMD pushed Intel to more frequently release new chips such that, at any given time, Intel had the highest-performing chip on the market
2. High absolute levels of demand (in part from increased penetration) as well as demand specifically for high-performing chips (in part from upgrading behavior) shifted the output mix toward the "cutting edge"
3. High demand allowed microprocessor manufacturers to amortize R&D and other fixed labor costs more quickly
4. Technological improvements in both the semiconductor manufacturing equipment and in the wafer inspection/yield management industries shortened the time to profitable production yields and facilitated firms' decisions to shorten the product life cycle (or to release new products more frequently)

Source: MGI "US Productivity Growth 1995-2000" report, released October 2001

Exhibit 10

SELF-REINFORCING CYCLE DROVE PRODUCTIVITY IMPROVEMENTS IN DRAMs AND MPUs

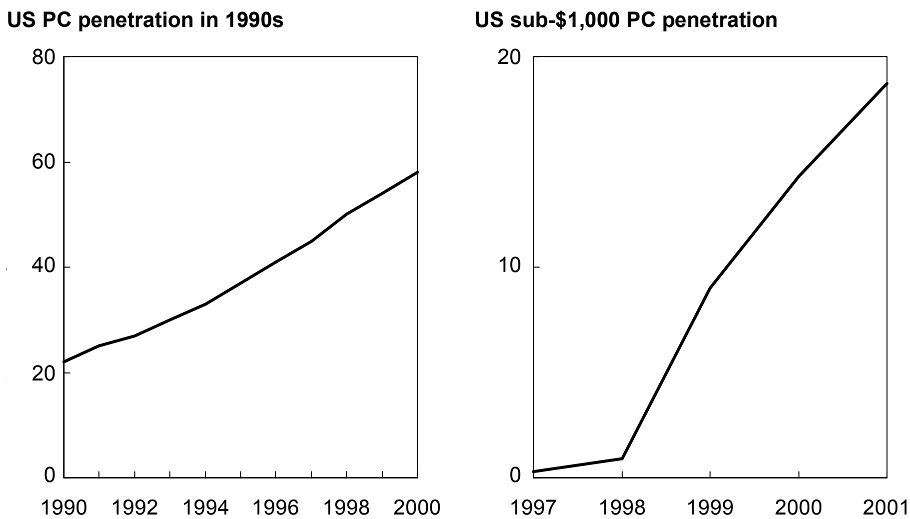


Source: MGI analysis

Exhibit 11

US PC PENETRATION, ESPECIALLY SUB-$1,000 PC PENETRATION, INCREASED SIGNIFICANTLY

Percent



Source: Computer Almanac; IDC; MGI analysis line widths and enabled design of higher-quality chips due to higher availability of gates per unit area.[14]

Drivers of output quality in MPUs and DRAMs

Improvements in output quality can be decomposed into three types of quality changes.[15] The first type, primarily, drove output quality during the 1990s.

- **Type 1 changes.** Type 1 changes are attributable to underlying process technology and not a change in architecture or functionality. This typically results in both lower unit cost and better quality (e.g., better functionality). Line width reduction is a major driver of Type 1 changes.
- **Type 2 changes.** Type 2 changes come from new functionality, not including core logic redesign. For example, the change from Intel Pentium® to the Intel Pentium® MMX would be a Type 2 change. This change typically results in better quality but has only a marginal impact on unit cost.
- **Type 3 changes.** These changes come from a fundamental shift in product architecture or core logic of the chip, typically resulting in better quality but at a higher unit cost relative to the previous generation. For example, the change from the 486 chip to Intel Pentium® would be a Type 3 change. Type 3 changes usually result in a discontinuous advance such as a new platform architecture.The change in the output

deflator cannot be systematically and numerically allocated to Type 1, Type 2, and Type 3 changes because in a concentrated market such as MPUs, nominal prices can drop significantly with no change in quality for competitive and mass market adoption reasons. The lower price would affect the output deflator. This is also true for the DRAM market, which is a commodity market where nominal prices can drop when new capacity comes on-line. However, interviews with industry experts indicated that quality improvements (which were driven by reduction in line widths) were the predominant drivers of the output deflator in the 1990s. Analysis of line width reductions in MPUs and DRAMs indicates that both these subsectors experienced very strong Type 1 change (Exhibit 12). This further supports the conclusion that line width reduction was the major driver of the output deflator in the past decade.

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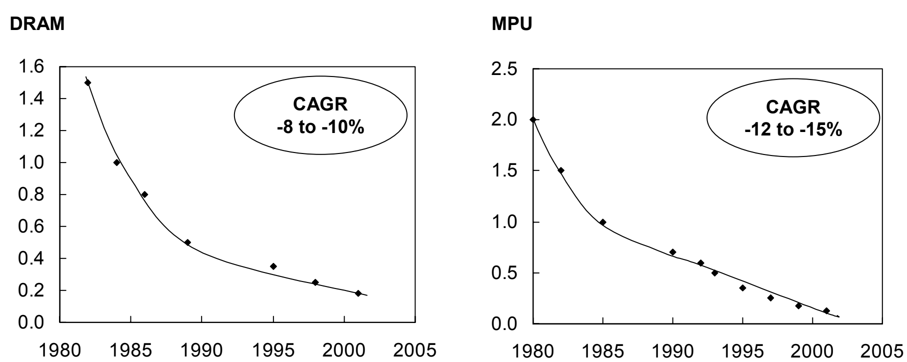
[14] But these advances did not keep pace with process technology advances, causing the "design gap"; see Exhibit 17 in this section for more details.

[15] For more details, see "An alternative methodology: valuing quality change for microprocessors in the PPI," by Mike Holdway of Bureau of Labor Statistics.

Exhibit 12

MPUs AND DRAMs EXPERIENCED EXPONENTIAL REDUCTION IN LINE WIDTHS

Reduction in line width over time
Microns



Source: Merrill Lynch report – Nov 1999; ITRS 1998; IC Insights; MGI analysis

ENABLING ROLE OF IT

The semiconductor sector is one of several sectors (including healthcare, telecom, and aerospace) that experienced constant technological innovation, resulting in improved quality of product offerings in the past decade. Across sectors, IT played a critical enabling role in leveraging and commercializing these technological innovations. For firms, the level of impact from the various IT investments depended on a firm's strategy, its execution, its business processes, and the institutional knowledge within the company required to take advantage of the investments. IT alone did not offer a competitive advantage but, when complemented with good business decisions, IT enabled firms to significantly improve their performance. For example at Intel, IT investments in design and manufacturing complemented their strategy (e.g., the decision to exit the DRAM business to focus on MPUs), execution (excellent marketing has made the Intel® brand the world's fourth most powerful brand[16]), and institutional knowledge to make Intel the world's largest semiconductor company and the world leader in MPUs.

Overview of business processes and key IT components

Critical IT applications enabling reductions in line widths, improvements in functionality and integration, and increases in labor productivity in MPUs and DRAMs were sector-specific and impacted key business processes.

A typical semiconductor company (and its partners) has three business processes (Exhibit 13a):

¶ **Design.** The design process includes all aspects of the chip design such as front-end design (i.e., design specification, logic simulation, and synthesis) and back-end design (place and route, formal verification, and final synthesis).

¶ **Manufacturing.** Manufacturing entails front-end planning (e.g., raw materials procurement and production scheduling), front-end wafer fabrication (e.g., wafer processing,[17] inspection), and back-end wafer fabrication (e.g., dicing, bonding, encapsulation, and testing).

¶ **Central functions.** This includes all functions to ensure continuous, smooth operations of a semiconductor company.

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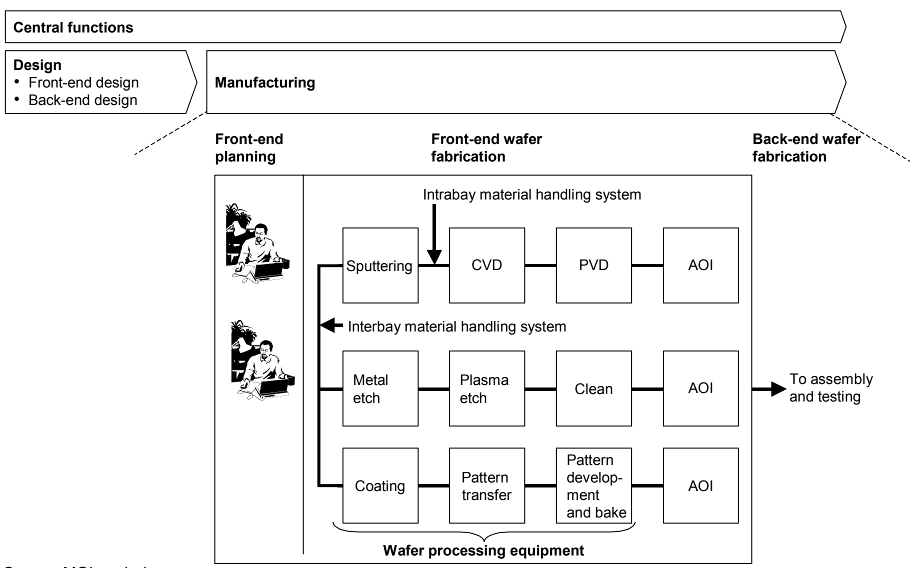
16 Interbrand 2000 ranking.

17 Wafer processing involves several steps such as epitaxial layer formation, chemical-mechanical planarization (CMP), oxidation, chemical vapor deposition (CVD), plasma vapor deposition (PVD), lithography (coating, pattern transfer, pattern development, and bake), etch, and ion implantation.

Exhibit 13a

BUSINESS PROCESSES IN SEMICONDUCTOR SECTOR

ILLUSTRATIVE



Source: MGI analysis

Mapping potential IT investments across these business processes, IT investments can be grouped into five bundles (Exhibit 13b):

1. **Design tools** are software and associated hardware that automate design processes and provide the ability to design complex chips (better functionality and integration) relatively faster.
2. **Manufacturing automation systems** are automated wafer handling systems and flow management software to reduce human handling and to increase operational efficiency in the fab; these systems include both manufacturing execution systems (MES) and manufacturing control systems (MCS)/automatic material handling systems (AMHS).
3. **Process control systems** are software and hardware to control process steps within the wafer processing equipment.
4. **Process diagnostic tools** are test equipment and software to track and respond to defects and problems in the wafer manufacturing production line.
5. **Support IT systems** include central and corporate IT systems to support various activities in the enterprise; they include infrastructure systems (e.g., network management, storage systems, security) and various horizontal applications.

Impact of key IT systems on performance levers

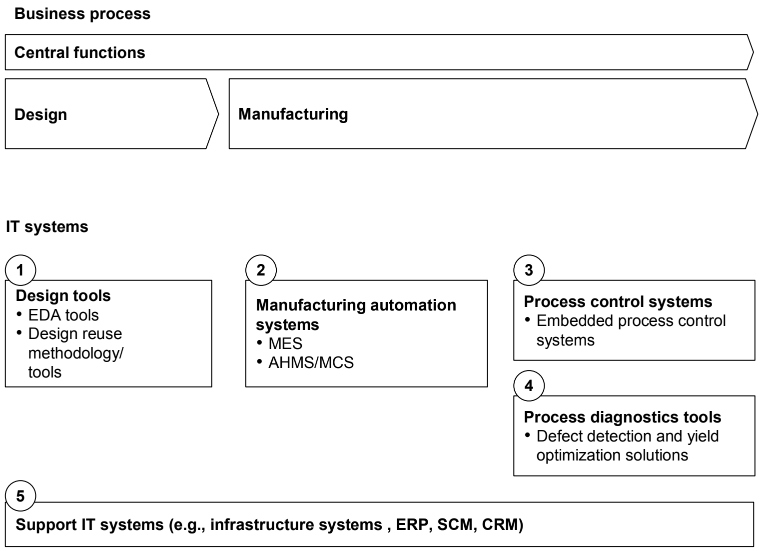
Across both the MPU and DRAM subsectors IT investments helped increase sector asset utilization and sector labor efficiency (Exhibit 14). For example, across subsectors, process control systems played a critical role in realizing improvements in material science and process technology, and MES streamlined material and paper flow within a fab. In MPUs, EDA tools and process diagnostics tools played a key role in reducing the design and production throughput times for new, higher-quality products thus reducing their time to market. Reducing time to market consequently increased the value of the existing portfolio by increasing the fraction of new value-added products.

However, key IT systems impacted different productivity and profitability levers within the subsectors due to the variation in subsector characteristics and requirements. For example in MPUs, where it is important to have the fastest chip in the market and customers are willing to pay a higher price for the "hottest" product, IT helped develop new products to enhance revenue, and they helped reduce time to profitable yield, increasing asset utilization. On the other hand in

Exhibit 13b

IT SYSTEMS IN THESE BUSINESS PROCESSES CAN BE GROUPED INTO 5 BUNDLES

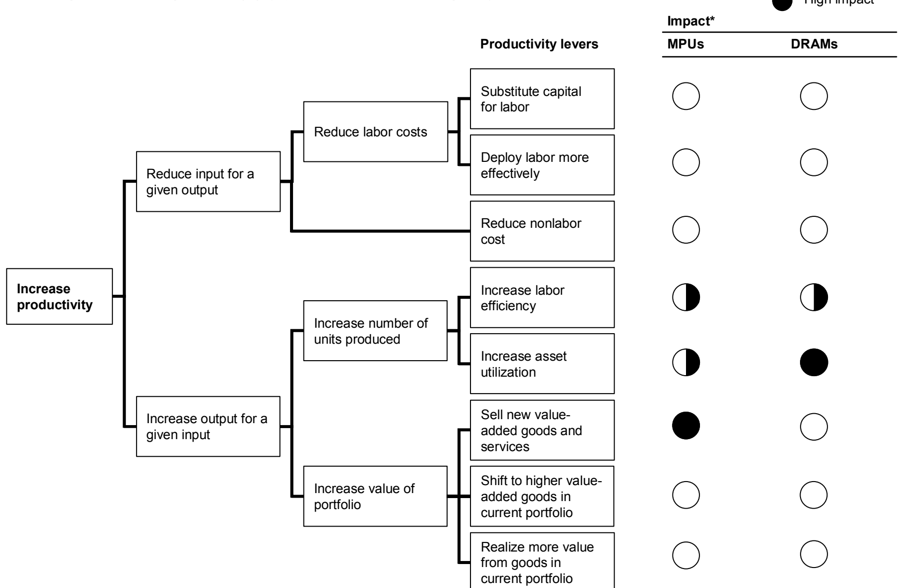
ILLUSTRATIVE



Source: MGI analysis

Exhibit 14

PRODUCTIVITY LEVERS IMPACTED BY KEY IT INVESTMENTS IN 1990s VARIED BY SEGMENT



* Sector average of impact of IT

Source: Interviews; MGI analysis

the cost-conscious DRAM subsector, IT helped increase asset utilization and labor efficiency and thus helped reduce unitized fixed costs.

For the most part, there was a direct relationship between improvements in productivity and profitability. For instance, a decrease in unit fixed costs (creating a decrease in the ratio of manufacturing costs to revenues), was affected to a great extent by better fab utilization in MPUs and DRAMs. Similarly, increasing the value of the existing portfolio in MPUs increased revenues and ratio of revenues to PP&E (plant, property, and equipment) in this subsector (Exhibit 15).

Relationship between critical IT investments and subsector characteristics

The critical business processes vary by subsegment and thus the relative importance and role of each IT "bundle" depends on the subsector requirements and characteristics (Exhibit 16).

- The DRAM subsegment is largely a commoditized market, and firms in this space have huge fixed costs and are price takers. Hence this segment is primarily focused on increasing throughput and on reducing unit costs. Operational effectiveness (and thus process capabilities) is critical in reducing unit fixed costs and maintaining a low cost structure, elements essential to surviving and competing in this market. Consequently, the critical IT investments that drove productivity in this subsector are process control systems, process diagnostics tools, and manufacturing automation solutions.
- The MPU subsegment has differentiated products as well as customers who are willing to pay a premium for new, higher-quality products. Hence this segment is more focused on revenue maximization. In this market, design superiority and enhanced manufacturing capabilities are critical to gaining a first mover's advantage and thus a competitive advantage. The key IT investments are EDA tools, process control systems, process diagnostics tools, and manufacturing automation solutions

IT architecture in semiconductor sector

Semiconductor companies have deployed IT across their value chain. At a sector level, vertical IT investments have played a critical enabling role in design and wafer processing, but horizontal applications have had limited impact to date.

Exhibit 15

IT IMPACTED DIFFERENT PROFITABILITY LEVERS ACROSS SUBSEGMENTS IN THE 1990s

++ High impact
+ Medium impact
0 No impact

* Sector average of impact of IT
Source: Interviews; MGI analysis

Exhibit 16

SUBSECTOR CHARACTERISTICS AND REQUIREMENTS DETERMINE CRITICAL IT INVESTMENTS

	DRAMs	MPUs
Sector characteristics	• Commodity market with no product differentiation • Firms are price takers, and prices drop as more production capacity comes on-line • Competitive advantage gained from improved process capabilities	• Market with perceived differentiated products with accelerated new products introduction • Customers willing to pay for higher quality products and market rewards reduced throughput time for new chips • Competitive advantage gained from improved design capabilities
Sector requirements	• Sector requires low cost structure and operational effectiveness to compete effectively • Sector dynamics demand reducing unitized fixed costs and labor costs by better asset utilization and improved labor efficiency	• Sector values reduced time to market for new products and hence requires faster ramp-up rates • Sector requires exponential quality increase in products
Key IT investments	• Process control systems • Process diagnostic tools • Manufacturing automation systems	• Design reuse methodology/tools • Process control systems • Process diagnostic tools

Source: Interviews; MGI analysis

Role of IT in design

In the past 10 years, process innovations sharply increased the available gate per unit area due to reductions in line widths. This allowed higher quality chips with more functionality and integration (and thus increased performance) to be designed at a constant or lower price. EDA tools have helped increase the number of gates that can be designed per unit area. They have, however, been unable to match improvements in process technology, and thus have not been able to fully utilize the total gates available for design, resulting in a "design gap" (Exhibit 17). Companies such as Cadence, Synopsys/Avant!, and Mentor Graphics offer EDA tools. In spite of this limitation, the design gap would have been much wider if EDA tools had not continued to improve.

In particular, EDA tools helped in three areas. First, they helped in designing semiconductors at an increasing level of abstraction (Exhibit 18).[18] In the early 1990s, semiconductors were designed at the gate level; however, by 1993, register transfer level (RTL) design had become mainstream; now, behavioral design has become mainstream. This higher level of abstraction has improved design productivity by 200 to 750 percent (Exhibit 19). In turn, the increasing level of abstraction played a key role in reducing "real" design time – chip design time adjusted for increasing complexity. "Nominal" time, the actual time it takes to design a chip, has increased due to the increased complexity of chip design, but at a much lower rate than warranted. In a sample ASIC design (Exhibit 20), EDA tools helped to reduce design time by more than 90 percent in design specification, synthesis, and formal verification, and to reduce design time for logic simulation by 69 percent and for place and route by 23 percent. Impact of the EDA tools on the various design steps is uneven because the computing effort for simulation and place and route increases exponentially with gate design, but does so linearly for other steps.

Second, improved accuracy in the design tools reduced the number of prototypes, which reduced overall development costs and time to market for a new design.

Third, EDA tools helped leverage improvements in process innovations that reduced the line widths. The tools were needed for updating libraries and for generating new masks when chips designed for the older line widths needed to be produced in a newer foundry running the new lower line widths.

Role of IT in wafer processing

Improvements in process technology have been a key driver of the exponential reduction in line widths in semiconductors (for example, line widths in DRAMs

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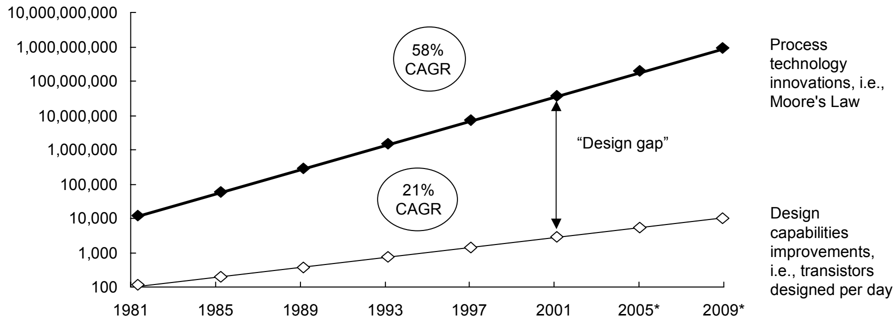
[18] Designing at a higher level of abstraction refers to the ability to design more at a conceptual level.

Exhibit 17

IMPROVEMENTS IN DESIGN CAPABILITIES HAVE NOT KEPT PACE WITH PROCESS TECHNOLOGY INNOVATIONS

ASIC EXAMPLE

ASIC design productivity shortfall
Logic transistors

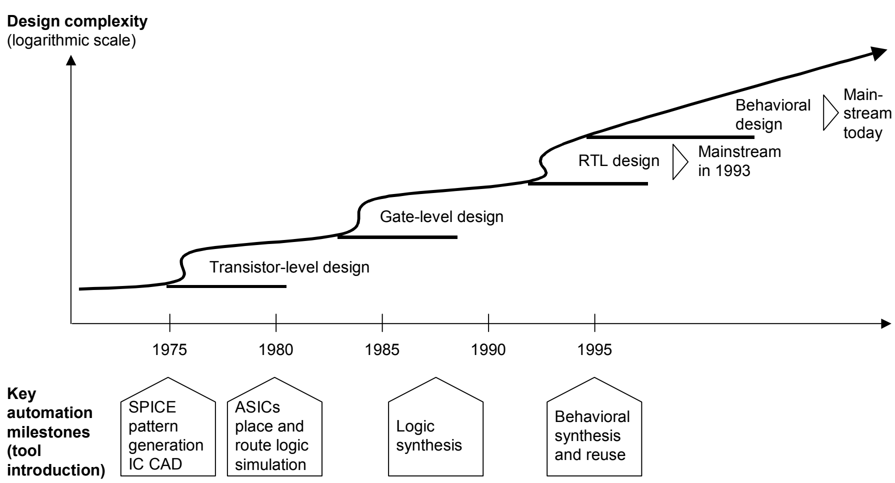


Estimated time taken for design team to complete a design version** Years	1981	1985	1989	1993	1997	2001	2005*	2009*
	0.06	0.16	0.5	1.4	4.0	12.0	34.0	98.0

* Forecast
** Assuming a 6-person design team
Source: Sematech; McClean Report, 2002; MGI analysis

Exhibit 18

EDA ENABLED DESIGN AT AN INCREASING LEVEL OF ABSTRACTION



Source: MGI analysis

Exhibit 19

NEW EDA METHODS IMPROVED DESIGN PRODUCTIVITY BY 200-750%

EXAMPLE

Productivity comparison
Working days

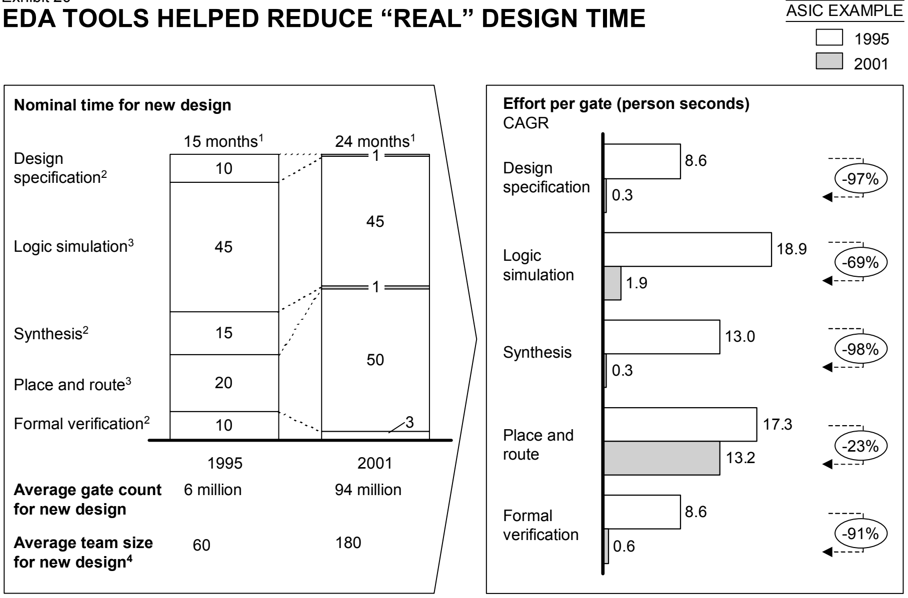
Application	Design methodology: RTL synthesis	Design methodology: Behavioral synthesis	Productivity improvements Percent
• ATM cell scheduler	30	10	300
• Graphics processor	60	15	400
• Satellite DSP	400	180	220
• MPEG 2-color converter	60	10	600
• Disk drive controller	15	2	750

Source: Synopsys; MGI analysis

Exhibit 20

EDA TOOLS HELPED REDUCE "REAL" DESIGN TIME

ASIC EXAMPLE



1 Average time for new design based on prevalent process technology (250 nm in 1995, 130 nm in 2001)
2 Computing effort (e.g., computer time spent to calculate power consumption) scales roughly linearly with gate count
3 Computing effort (e.g., computer time spent in checking for timing violations) scales nonlinearly with gate count
4 Design team sizes have tripled in the past 10 years

Source: MGI interviews; McClean Report

reduced by a factor of eight from 1.5 microns in 1982 to 0.18 microns in 2001), and hence of increased productivity in semiconductors. IT has played an important role in enabling and leveraging these improvements. The critical IT systems in manufacturing are manufacturing automation systems, process control systems, and process diagnostic tools.

Manufacturing automation systems. These systems include manufacturing execution systems (MES) and material control systems/automatic material handling systems (MCS/AHMS). Offerings such as PROMIS and FACTORYworks from Brooks-PRI and WorkStream from Applied Materials are examples of MES available in the market today. Companies such as Brooks-PRI and Asyst offer MCS. In the 1990s, MES played a key role in streamlining material and paper flow and in reducing human handling within a fab. These developments reduced human errors, and equipment and labor idle time, thus increasing the operational efficiency of a fab. MCS, which automated movement of wafers between various processing equipment, provided some incremental benefits in performance, but its effect on sector productivity was moderate. The reasons for the moderate impact are: MCS had not reached 100 percent penetration in the industry; incremental benefits, in addition to MES, were marginal; and wafer processing and variability in the process, not the actual movement of wafers between equipment, were the critical bottlenecks for improved performance.

Going forward, AMHS is expected to be more widely deployed as 300 mm wafers become mainstream. AMHS will be needed given the bigger size of 300 mm wafers; a typical 300 mm wafer carrier can weigh 10 kilograms/22 pounds, and for health and safety reasons cannot be handled manually. In the future, AHMS can be expected to impact performance by increasing foundry utilization and by enhancing labor efficiency in the fabs.

Process control systems. Process control systems include embedded software and hardware in the various wafer-processing equipment (embedded hardware and software in etch equipment from Applied Materials, Lam Research, Tokyo Electron, etc., are examples of process control systems). Indirect IT systems in this equipment were critical to realizing improvements in process technologies by helping maintain tighter process specifications through closed-loop, real-time process control.

Process diagnostics tools. Process diagnostic tools include automatic optical inspection (AOI) equipment for mask, reticle, and wafer inspection, and yield optimization software. Automatic test equipment (ATE) is not considered part of process diagnostics since they test the finished product and are considered necessary investments for quality control in end products.

In the 1990s, indirect IT systems played a critical role in increasing the detection sensitivity of the inspection equipment, while direct IT systems such as improved computation software and faster computers have helped convert inspection data into intelligent and enhanced decision support information. This advancement is of particular importance when newer technologies are introduced. Manufacturing to reduced line widths results in new kinds of defects – imperfections that do not affect the quality of the finished product at a greater line width could become material at reduced line widths, and this requires more sensitive and sophisticated testing and analysis. Also, as process technology continues to mature, these advancements are still critical for maintaining and improving yields. In the 1990s they helped improve time to profitable yield, thereby reducing throughput times. For example, the time for 5,000 wafer starts per week reduced from 36 months for 0.80 microns to less than 12 months for 0.13 microns (Exhibit 21).

Role of horizontal applications

Enterprise resource planning (ERP), supply chain management (SCM), and customer relationship management (CRM) are the three main horizontal applications that were widely deployed in the semiconductor sector in the 1990s. To date, these applications have had relatively little impact on the productivity of the sector as a whole. However, as the sector faces more challenging external demand conditions, and as leading firms continue experimenting with these applications, they may grow in importance and impact.

ERP software that allows enterprises to automate or outsource support and administrative functions has had minimal impact on productivity to date. The sector has not experienced significant reductions in the labor pool of support and administrative staff (Exhibit 22), and semiconductor companies have not reported great improvements[19] in their back-end operations. The lack of impact can be attributed to three causes: lack of customization around basic business processes, late adoption in the sector, and long implementation schedules. Going forward, as the industry faces an economic downturn, ERP could play a role in improving operational effectiveness and in reducing costs by automating support functions and reducing the number of employees.

SCM applications that manage the flow of materials and information between fabs, suppliers, and planners have had minimal impact to date for two reasons. First, semiconductors have a relatively simple supply chain (silicon and a limited number of chemicals for raw materials), and a small number of SKUs, so supply chain management software is not critical. Second, there is little interoperability and collaboration between suppliers and semiconductor companies. Going forward, SCM could play a role in improving productivity due to features such as availability to promise and capacity to promise (ATP/CTP), which can reduce

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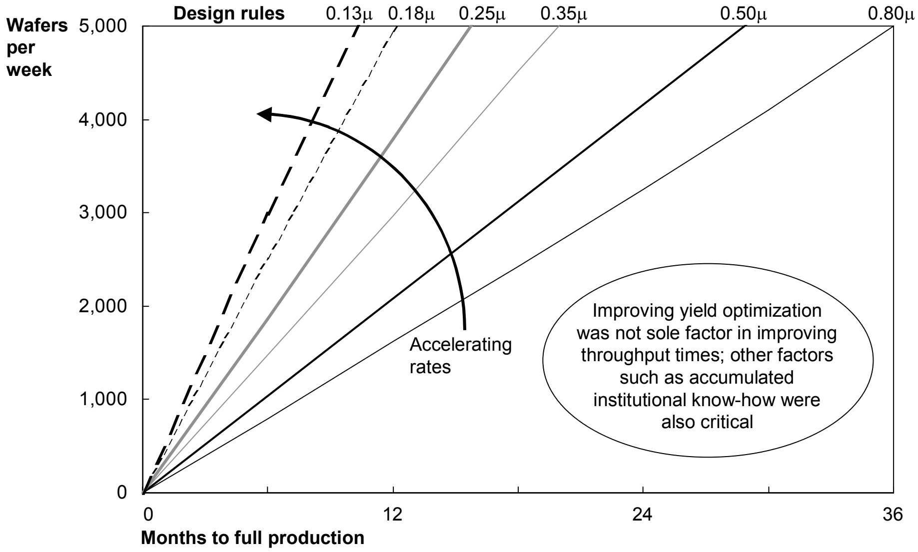
19 Customer interviews.

Exhibit 21

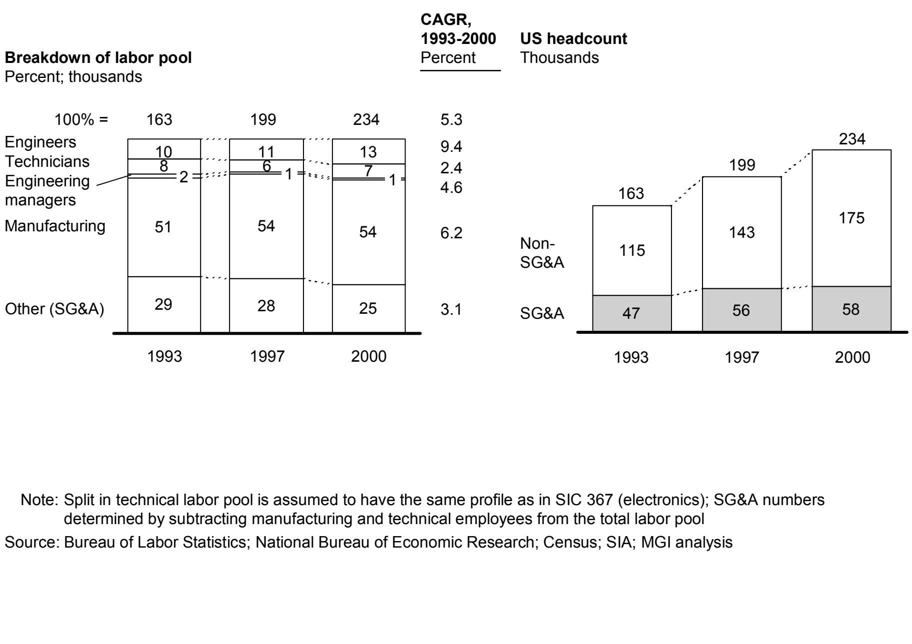
YIELD OPTIMIZATION TOOLS PLAYED CRITICAL ROLE IN ACCELERATING FAB RAMP-UP RATES IN 1990s



Source: Rose Associates; IC insights

Exhibit 22

SEMICONDUCTOR SECTOR DID NOT EXPERIENCE SIGNIFICANT REDUCTION IN SUPPORT LABOR POOL IN THE 1990s



Note: Split in technical labor pool is assumed to have the same profile as in SIC 367 (electronics); SG&A numbers determined by subtracting manufacturing and technical employees from the total labor pool

Source: Bureau of Labor Statistics; National Bureau of Economic Research; Census; SIA; MGI analysis inventory, optimize capacity utilization, and increase revenue per wafer for the foundries.

CRM software that automates account and channel management information has had minimal impact in the sector to date because, historically, semiconductor companies have not needed to focus on specific vertical market solutions, and thus have not required better customer management. Furthermore, semiconductor firms can have varied and atypical relationships with their major customers, ranging anywhere from an "arm's length" commodity relationship to an extensive product design and codevelopment relationship with major customers. Neither of these relationship types is likely to benefit from a standard "off-the-shelf" CRM application (Exhibit 23). Going forward, CRM could play a role in sector performance with changes in industry structure, increased focus on specific customers and vertical market solutions, and increased customer management requirements.

Currently, at a firm level, some companies are reported to have leveraged these horizontal applications to gain some productivity and profitability impact (Exhibit 24a and 24b). The effectiveness of these efforts and the speed with which they diffuse across the industry will determine their sector impact.

IT as a source of competitive advantage

Semiconductor companies (or their partners) in the microcomponents and memory subsectors have invested in most of the IT bundles listed in the previous sections. Therefore, no semiconductor company to date has leveraged its IT investments beyond its competitors to such an extent that it has gained competitive advantage from the IT systems alone.

Across these subsectors, components of the five IT bundles can be segmented into four tiers (Exhibit 25). The first two tiers represent current IT investments in the sector, while the latter two refer to potential investments.

¶ **Basic cost of doing business.** All semiconductor companies in the subsectors studied have invested in these systems and have reached a minimum acceptable threshold of performance. Leading semiconductor companies have seen improved performance not only because they have made these investments but also because they have developed the tacit in-house knowledge to complement and leverage these investments disproportionately. Examples of basic cost-of-doing-business investments include EDA tools, wafer processing equipment, MES, AOI equipment, and yield optimization solutions.

¶ **Extended cost of doing business.** These investments do not have 100 percent penetration in semiconductor companies and are typically seen in

Exhibit 23

SEMICONDUCTOR COMPANIES HAVE VARIED RELATIONSHIPS WITH THEIR MAJOR CUSTOMERS

Low — **Level of cooperation with customers** — **High**

"Take or pay" contracts

- Common in standardized, commodity products (e.g., DRAMs, flash memory)
- Typically multiple suppliers exist for same product line
- "Arm's-length" relationship exists between semiconductor company and customers
- Medium-term contracts are common (2-3 years)
  - Lock-in capacity and assured sales volume
  - Facilitate risk-sharing between semiconductor and next level manufacturers
- Examples
  - AMD's contract with Alcatel to supply flash memory products
  - Nokia's contract to buy DRAMs from Samsung
  - Intel's contract to sell flash memory products to Cisco

"Design win" contracts

- Prevalent in specialized components and subsystems
- Semiconductor supplier works closely with next level customers to develop the needed IP
- After successful design, semiconductor manufacturer is exclusive supplier
- Examples
  - Dialog will supply mixed signal ASIC for Ericsson 3G systems
  - TI supplies DSP to Nokia
  - Celeritek will supply handset GaA semiconductor components and subsystems to a US company

Source: Industry press; MGI analysis

Exhibit 24a

INDIVIDUAL COMPANIES ARE REPORTED TO HAVE LEVERAGED CERTAIN HORIZONTAL APPLICATIONS

Intel

- In 1998, started SCM initiative to have access to vendors' MRP systems to synchronize output with OEM demand; this investment helped reduce costs
- In 1998, took half of its orders on-line at a rate of $1 billion per month, reducing order handling costs
- By end of 1998, 100% of Taiwanese customers were doing business on-line; more than 90% were very satisfied with experience, and 15% of worldwide orders were placed after regular business hours, instead of waiting for next business day
- E-commerce initiative helped SME customers who did not have EDI; orders which initially were handled through faxes and telephones were handled through extranet, reducing order handling costs
- Extranet provided information on Intel products and offered on-line support to reduce expensive and traditional method of supporting customers
- Order tracking service allowed customers to check order status on-line and eliminated need to call customer service representatives
- Extranet eliminated 45,000 faxes per month from Taiwanese customers in 1998
- By May 2000, 100% of customers ordered product on-line

Source: Literature search

Exhibit 24b

INDIVIDUAL COMPANIES ARE REPORTED TO HAVE LEVERAGED CERTAIN HORIZONTAL APPLICATIONS (CONTINUED)

AMD

- In 1999, e-MRO solution was expected to generate annual savings of $15 million-37 million
- In May 2000, announced plans to join B2B exchange for SCM. Initiative was expected to help increase supply chain efficiency and improve delivery of products and services, thus increasing customer satisfaction
- In February 2001, company started implementing ERP to increase customers' real-time visibility into AMD's production and supply chain; this was expected to help AMD deal with component shortages that plagued high-tech manufacturers and help it enter the business PC market
- In 2001, expected Web-based procurement applications to reduce procurement and related costs by 30-40%
- Currently expecting ERP to help the goal of closing books at end of every business day

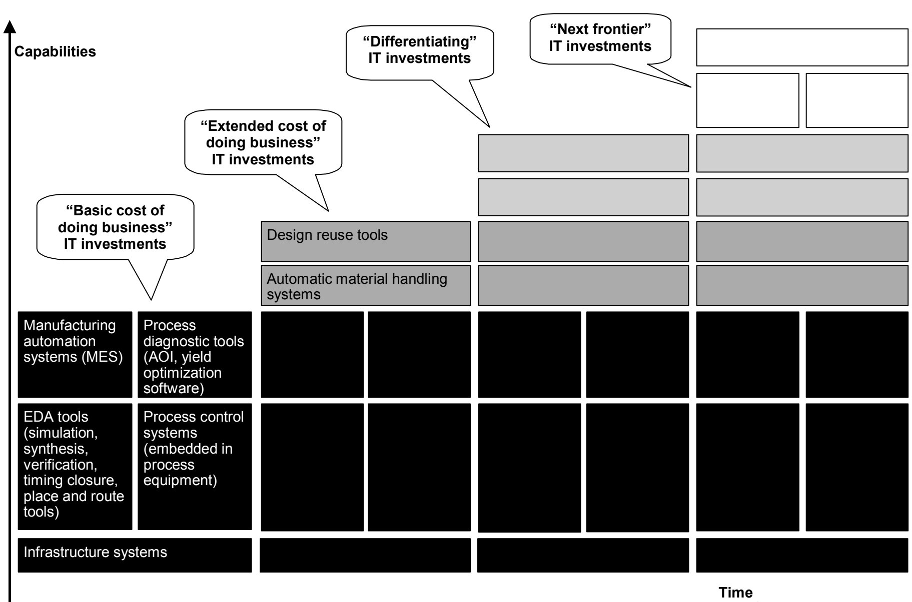
Micron

- Embraced RosettaNet aggressively to increase communication among engineers, buyers, and sellers to achieve time and costs savings in conducting business transactions

Source: Literature search

Exhibit 25

IT INVESTMENTS CAN BE SEGMENTED INTO 4 TIERS



Source: Interviews; MGI analysis

newer foundries and for newer products. Examples include MCS/AMHS in foundries, and design reuse in engineering.

¶ **Differentiating.** This segment, along with the next tier of investment, represents a set of forward-looking investments. Currently no player has leveraged IT alone to significantly differentiate itself. As mentioned above, some companies are beginning to employ horizontal applications that may provide incremental economic benefits to those firms, but are unlikely to yield distinctive competitive advantage. Going forward, with demand less buoyant, players may deepen and tailor their investments in this tier in hopes of differentiating themselves. The likely differentiating IT investments will include design tools for simultaneous hardware/software co-verification, enhanced timing closure engines, and cost and throughput time-reducing process control and enhanced process diagnostics systems for 300 mm wafers and copper interconnects.

¶ **Next frontier.** These are the investments that will push the performance frontiers of the leading semiconductor companies and of the overall semiconductor sector. These might include new lithography options as a replacement for photolithography.[20]

These four categories of investment together form the value stack. Currently, all semiconductor companies in the microcomponents and memory segments have two components of the value stack and are at similar levels. The leading players in the sector have the institutional knowledge to better leverage existing IT investments, and may capture more value in the future as they increase their stack height, that is, as they invest in differentiating and next frontier investments to jump ahead of the competition.

Parallel capability building in semiconductors

IT and business capabilities in the semiconductor sector were built by firms with a focus on their specific position in the value chain, such that the sector as a whole was building its IT and business capabilities through the parallel efforts of multiple firms. This trend co-evolved and was reinforced as firms focused on specific parts of the value chain (resulting in the atomization of the industry) and on rapidly building process and technological capabilities to complement their choice and to compete successfully.

Initially, companies adopted an integrated device manufacturer (IDM) model, where the front- and back-end design, wafer fabrication, and assembly and testing were done internally (Intel and Micron Semiconductors are IDMs). In the 1980s,

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20 As line width reduces significantly below the wavelength of light, visible light cannot be used for transferring patterns from mask to the die and options such as X-rays are currently being considered as a replacement.

the market transitioned to a customer-owns-tools (COT) and ASIC business model, where the semiconductor company did the front-end design and outsourced the back-end design, wafer fabrication, and assembly and testing to an ASIC house. For example, for AMCC products, AMCC did the front-end chip design, and IBM did the back-end design and fabrication of the chip. In the early 1990s, the market transitioned to a fabless or fab-light COT and foundry model – the semiconductor companies performed the front-end and back-end design and predominantly outsourced wafer fabrication and assembly and testing to a foundry (TSMC, UMC, and Chartered dominate the foundry space). To illustrate, Broadcom does the chip design (both front-end and back-end) and outsources the chip manufacturing to TSMC. Currently, companies are buying certain design modules from IP houses (e.g., ARM, MIPS) (Exhibit 26).

The transition from an IDM to a COT/ASIC to a fabless COT/IP and foundry business model has helped companies focus on a single part of the value chain, and has played a part in enabling firms to build capabilities in parallel. Atomization of the value chain and the build-up of specialized technological capabilities in parallel reinforced each other to continue the trend. In some cases these capabilities have created an effective barrier to entry in certain parts of the value chain. For example, tacit knowledge creates an effective barrier to entry in wafer fabrication; a new company must make huge capital investments and recruit multiple key experienced individuals to start a foundry. In other cases, atomization has reduced barriers to entry. In design, companies with innovative design/IP can focus on design and outsource all other aspects of production or sell design elements to other players.

SUMMARY OF RELATIONSHIP BETWEEN KEY IT APPLICATIONS AND PERFORMANCE

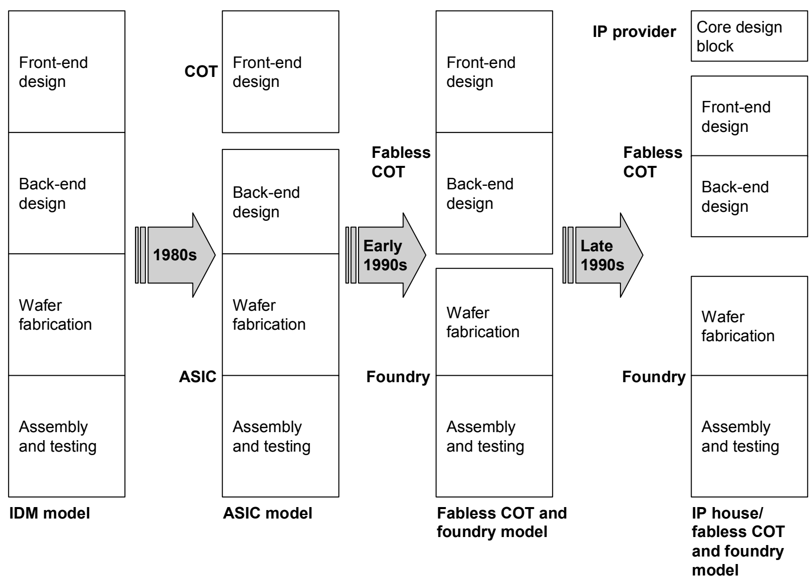
As discussed in the previous section, much of the richness in trying to understand the role of IT in enabling productivity gains in the semiconductor sector lies in understanding the business processes, performance levers, and the IT architecture specific not only to the sector as a whole but also to the different subsectors. In summary, we found that key productivity-enhancing applications in this sector shared three general characteristics:

1. They were vertical applications with a focus on key business processes, and they impacted critical performance levers.

Across the microcomponents and memory segments, vertical IT investments targeting important business processes delivered the highest impact. For example,

Exhibit 26

INDUSTRY VALUE CHAIN ATOMIZED OVER TIME



Source: Interviews, MGI analysis

as line widths reduced from 0.80 microns in the late 1980s to 0.18 microns today, the photolithography[21] process experienced significant technological improvements[22] to etch narrower line widths. Embedded hardware and software in the steppers (i.e., photolithography equipment) played a critical role in leveraging these process improvements by enabling a real-time feedback loop and by maintaining tight process control.

Key technology investments played an enabling role in positively impacting the subsector-specific performance (productivity and profitability) levers. For example at Intel, third-party and in-house developed EDA tools as well as process control systems in manufacturing helped to accelerate the introduction of new products to maximize revenues. Similarly, in the DRAM subsector, process control systems and process diagnostic tools played a core role in reducing throughput times (thus increasing fab utilization) and thereby reducing unitized fixed costs.

2. Key IT investments helped build capabilities in parallel

The semiconductor sector has been characterized by a growing atomization of the value chain from an IDM to a COT/ASIC to a COT/foundry model. Firms in the sector used IT to build technological/process capabilities with a focus on their specific position in their value chain, such that the sector as a whole was building its IT and business capabilities through the parallel efforts of multiple firms. This trend co-evolved and was reinforced as the industry atomized, with firms rapidly building a narrow set of technology and IT capabilities in parallel to achieve excellence in their part of the value chain.

3. They were deployed in concert with business process changes and technological innovations

Across the sector, significant technology investments codeveloped with changes in the business processes. For example, as line widths reduced, the number of gates per unit area available for design increased, and the need for more stringent process control and process diagnostics became critical. This led to investments in EDA tools that could enable design at a higher level of abstraction and in more sophisticated wafer process equipment and process diagnostics tools to take advantage of these technological innovations.

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21 Process of transferring the patterns from the mask to the wafer.

22 The wavelength of light used for transferring patterns from mask to die transitioned from 436 nm (G-Line) in 1986 to 365 nm (I-line) to 248 nm (DUV) in 2001.

FUTURE OUTLOOK FOR IT INVESTMENTS

The semiconductor sector has seen productivity benefits from existing vertical IT investments. However, horizontal applications have not significantly impacted the sector's performance to date. As this sector struggles to emerge from a trough of weak demand, companies may benefit from leveraging their existing horizontal IT investments to improve their operational effectiveness and to reduce their cost structure. In particular, some firms may achieve gains by making incremental IT investments to better tailor existing investments in various horizontal IT applications, including SCM, ERP, and CRM, to business process requirements and link them to performance metrics.

Going forward, as the sector makes the transition to 300 mm wafers and copper interconnects, the sector will most likely see additional IT investments in manufacturing (e.g., investments in automated material handling systems and in inspection and test equipment) due to the added complexity of bigger wafer size and new interconnect material. These investments will be on top of the regular capital investments made by the sector to keep up with Moore's law. Intel, for instance, plans to spend $12.5 billion over the next two years on new manufacturing technology[23].

OPPORTUNITIES AND CHALLENGES FOR USERS AND VENDORS

MGI's findings have implications for both semiconductor companies and IT vendors interested in participating in this space. As the economy slows down and as the sector struggles to cope with reduced demand, individual semiconductor companies need to identify and evaluate options to maximize impact from all performance levers. They can use IT along with other investments to differentiate and gain competitive advantage. IT vendors can help by developing solutions to leverage underutilized performance levers through work with companies to increase their "stack height," and by providing technology solutions to maintain strong productivity growth.

Implications for semiconductor companies

In the 1990s, increased customer demand, the upbeat US economy, and the continued effects of Moore's law helped semiconductor companies maintain strong performance growth. IT vendors also benefited from the boom as companies invested not only in IT to design faster chips and build new fabs, but also in applications designed to improve other types of operations, such as

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[23] Wall Street Journal, August 13, 2002

customer order management, procurement, and ERP. However, during the current downturn, the strategic focus of semiconductor companies is shifting from ramping up to meet demand to optimizing operations to maximize productivity. In this environment, MGI's findings have three significant implications for semiconductor companies:

1. Employ additional productivity levers. The semiconductor sector saw an exponential productivity improvement in the 1990s, but the increase was primarily driven by only three of the eight productivity levers in MPUs and by only two of the eight productivity levers in DRAMs. Going forward, as the economy slows and the sector struggles to find additional sources of productivity besides growth, individual companies need to evaluate options to employ the remaining levers.

- In MPUs and DRAMs, companies can increase the emphasis on the "substitute capital for labor" lever by fine tuning their business processes, training their personnel, and making incremental IT investments to fully take advantage of their existing ERP investments and automating their back-end operations.
- In the commodity DRAM market, individual companies could consider investing in additional EDA tools to increase functionality and integration in memory chips and employ the "offer new value-added goods and services" lever.

The nature of the sector prevents certain levers from having significant impact on productivity, and companies should consider employing these levers only after they have utilized the higher-priority levers. For example, in both MPUs and DRAMs, labor efficiency is not a critical lever since labor is a small portion of the cost structure; thus, companies should not initially focus their efforts on pulling the "employ labor more efficiently" lever. Similarly, individual companies in DRAMs are price takers and should not initially target the "realize more value from goods in current portfolio" lever.

2. Identify differentiating IT investments. To date, semiconductor companies have had limited success in using IT to differentiate themselves from one another. This is somewhat ironic for an IT-producing sector, and points to a future agenda for firms. Going forward, individual semiconductor companies in both the MPU and DRAM subsectors may benefit, as firms in other sectors have, from identifying differentiating IT investments, aligning their business processes and organizational structure behind these IT investments, and leveraging the investments to move up the value stack. For example, design complexity, atomization of the industry structure, and cost considerations have driven design teams to be dispersed across national and company boundaries, a trend that will continue to accelerate in the future. Consequently, one of the differentiating investments in the future could be IT systems that provide the ability to successfully perform collaborative design and thus reduce the time to market for new design and increase the functionality and integration per chip.

3. Maximize impact from current investments. As the semiconductor sector is a relatively high spender on direct and indirect IT, individual companies need to consider options to maximize impact from their existing IT investments. One such option would be for individual companies to form a shared utility group with other companies for IT investments in business processes that do not offer a competitive advantage. For example, a DRAM company could form a shared utility with other semiconductor companies for their order receiving and order processing operations, instead of each company investing in back-office automation. Similarly as line widths shrink every 18 months and semiconductor companies invest in new capital equipment for the next generation wafer processing, companies could use their existing capital equipment to act as a contract manufacturer and/or outsourcee for market segments that need products two to three generations behind.

Implications for IT vendors

The findings also have two implications for IT vendors wanting to participate in this space:

1. Help customers pull levers. As the semiconductor industry struggles to recover from the trough, its IT vendors can "ease the pain" for their semiconductor customers by helping them achieve high impact from appropriate productivity and profitability levers. For example, design tool vendors need to evaluate options to close the design gap. In particular, EDA vendors have opportunities to improve in the logic simulation and place and route portion of the design. Improvements in these areas have lagged those seen in other design areas such as design specification, synthesis, and formal verification. These efforts could enable DRAM companies to employ the "sell new value-added goods and services" lever and help MPU companies to continue to pull this lever effectively.

2. Build collaborative customer relationships. Independent software vendors (ISVs) can collaborate with individual semiconductor companies to develop customized offerings based on their strategy and business processes to help the semiconductor company achieve its IT-enabled differentiation. For example, an ISV developing a collaborative product design suite can work with a semiconductor company that has multiple design teams at various geographic locations to help it design chips in parallel in the various locations, in a relatively shorter period of time, with more functionality and integration. This would enable the semiconductor company to use IT as a differentiator.

Glossary of terms used in semiconductor sector case

Term	Definition
AMHS	Automatic material handling system; includes interbay and intrabay wafer handling system in foundries.
CAGR	Cumulative annual growth rate.
Chip	Autonym for semiconductors.
COT	Customer owns tools; refers to companies doing back-end and/or front-end chip design in-house.
CRM	Customer relationship management; refers to tools and software for automating and improving effectiveness of sales, marketing and customer service functions.
Deflator	A price index; used to convert nominal numbers to quality-adjusted output measures.
DRAM	Dynamic random access memory; stores data which are needed for application processing.
Design gap	Difference between gates designed and gates available for design per unit area.
Design specification	Step in chip design.
Die	Autonym for semiconductors.
Direct IT	Includes hardware (mainframe computers, PCs, storage devices, and peripherals), software (prepackaged, custom, and own account software), and communication equipment.
EDA	Electronic design automation; tools for chip design.
ERP	Enterprise resource planning; applications to automate back-end office processes.
Fabs	Refer to foundry.
Final synthesis	Process in chip design.

Term	Definition
Foundry	Manufacturing facility for semiconductors, also known as fabs.
Formal verification	Process in chip design.
IDM	Integrated device manufacturer; refers to chip companies performing all the required processes from chip design to chip manufacturing in-house.
Indirect IT	Includes software and hardware that are embedded or bundled as a part of the system (e.g., process control hardware and software in etch equipment in foundries and inspection hardware and software in AOI). Typically these investments are captured in the BEA instruments category.
IT intensity	Real IT capital stock per person engaged in production.
Line width	Distance between the source and the drain in a transistor; determines the number of transistors that can be placed per unit area.
Logic simulation	Process in chip design.
MCS	Material control system; also known as AMHS.
MES	Manufacturing execution system; application to automate several processes in the foundry.
Microns	Unit of measurement; 10^{-6} meters.
Moore's law	Predicts that the number of transistors per unit area will double approximately every 18 months.
MPUs	Microprocessors.
Photolithography	Manufacturing process in wafer fabrication.
Place and route	Process in chip design.
SCM	Supply chain management; applications to manage flow of data and material among fabs, suppliers, and planners/customer service providers.
Synthesis	Process in chip design.
Wafer	Unit of production in front-end manufacturing; one wafer yields several chips.