A Strategic Analysis of the DRAM Industry After the Year 2000

By

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Submitted to the MIT Sloan School of Management on May 10, 2013 in partial fulfillment of the requirements for the degree of Master of Science in Management Studies

Abstract

The DRAM industry has been growing in line with the development of information technology since the 1970's. However, the industry has become commoditized and is well known for its recurring cycle of upturns and downturns, resulting in a number of bankruptcies, mergers and acquisitions. Specifically, the years following 2000 became increasing challenging for the key DRAM producers that remained in the market. The combination of demand shifts to consumer oriented electronics and rising manufacturing costs reduced profitability across the industry. As these conditions persist, DRAM producers need to find a way to generate sustainable profit and to create buffers against imminent downturns. This thesis details the industry level problems DRAM vendors have faced in the past, the dynamics that have caused recurring industry cycles and commoditization, and how those dynamics affect the industry. In this context, the thesis concludes with two suggestions for potential strategies for market differentiation. First, DRAM producers should strengthen services that provide opportunities to differentiate their value proposition to customers while simultaneously generating new sources of profit. Second, DRAM market leaders should continue to focus heavily on R&D of high performance products while carefully managing the timing of new product launches to maximize profits.

Thesis supervisor: Michael A. Cusumano
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Introduction

During my professional experience in DRAM industry for over eight years, I had struggled to find my company a way out from the strong momentum of commoditization of the industry so that the firm manages its business with a sustainable growth in revenue and profit. However, it was not easy to find how DRAM market has formed its commoditized structure and repeatedly has cycles of upturns and downturns. This paper focuses on describing the major market dynamics that have affected DRAM business and also the interrelationship of those dynamics to explain how the industry has its characteristics. And I suggest two strategic options for DRAM vendors to beat the commoditization. Those who have interest in market dynamics and business strategy in highly commoditized technology industry will be the target readers of this paper.

The first chapter describes basic DRAM industry characteristics with recently updated data and the second chapter analyzes the dynamics that make DRAM producers hard to maintain sustainable profitability: what limits DRAM vendors' profitability, how the market becomes commoditized, how the market brings out recurring cycles of upturns and downturns, and how the industry has been concentrated by letting most of the firms fall into consolidation or bankruptcy. The methodologies used to analyze these dynamics are: System Dynamic modeling on a conceptual level to explain the progression of each market characteristics by adopting the work of Henry Weil. The practical data by market research firms, such as Gartner, iSupply, DRAMeXchange and IDC, are used to describe market dynamics. For the strategy suggestions, I have referred to Michael Cusumano and other authors' work on services and Richard D'Aveni's book, 'Beating the commoditization'.

Chapter 1: DRAM Industry Analysis

1.1 DRAM industry

Today, we cannot describe our daily life without information technology (IT), which also accelerates other industries' development such as manufacturing, media and finance by helping information be produced, stored, and transferred more efficiently. Semiconductors are a core element in IT because they are components giving the power of processing or storage in electronic devices. There are several kinds of semiconductors including major ones such as Logic, Microcomponent, Memory, and Analog as well as other small sized ones - Sensors, Optical, Discrete.

DRAM is the abbreviation of dynamic random access memory, and a kind of memory semiconductor. There are two major kinds of memory conductors: the one is volatile and the other is non-

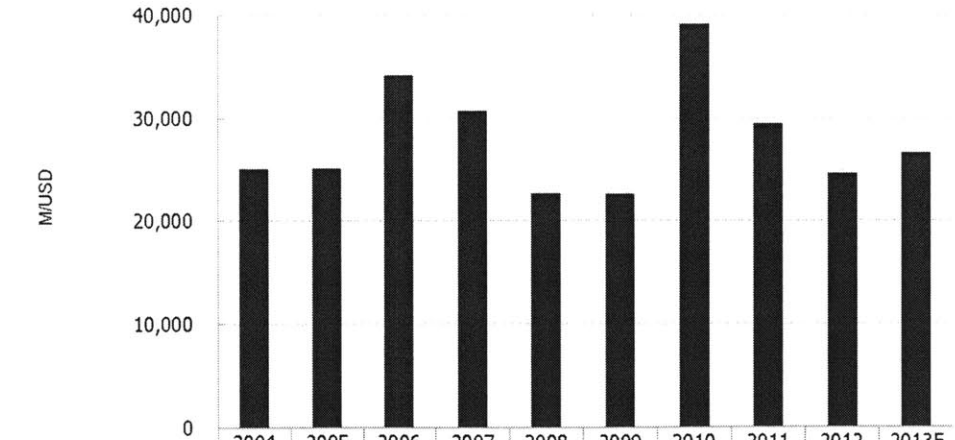
volatile. DRAM is a volatile memory used in the procedures of data processing in most of the IT devices; it cannot keep its data when electricity is off. On the other hand, FLASH memory keeps its data when a device is turned off; NAND flash is used to store data and its major applications are SD cards, SSD, and any other mobile devices that store data such as mobile phones and tablet PCs.

In 1966, DRAM was invented by Dr. Robert Dennard at the IBM Thomas J. Watson Research Center. He was granted U.S. patent number 3,387,286 in 1968.[1] DRAM has been developed to be faster in processing speed and to have greater capacity in line with the developments of IT devices; especially computers and mainframes have led the progress until the early 2000's. DRAM is now used in most of IT devices including servers, main frames, PCs, mobile phones, game consoles, digital TVs, mobile phones, and etc.

1.2 Market size

The total DRAM market in 2012 recorded US$24.6 billion, decreased by 16.5 percent from the 2011. According to DRAMeXchange, a market research firm specialized in memory semiconductor market; the market size in 2013 will be US$ 26.6 billion with the growth rate of 8.1percent. DRAM market size has been on a typical cycle of which length is from four to five years, and the cycle is clearly shown in the both periods of 2006-2009 and 2010-2013, where the market reaches the peak and shrinks for about three years. This recurring industry cycle will be explained further in the Chapter 2.

Figure 1-1 Worldwide DRAM Revenue

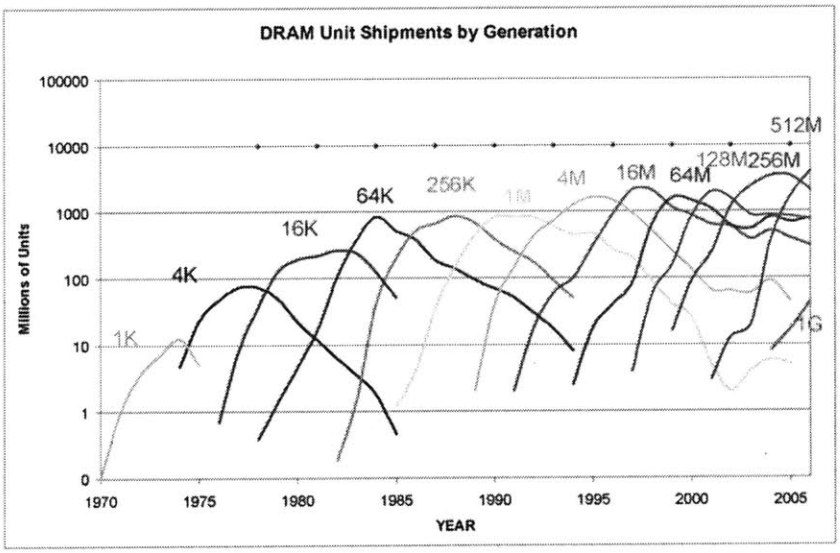


Source: DRAMeXchange's Platinum data sheet, Jan 2013.

[1] http://en.wikipedia.org/wiki/Dynamic_random-access_memory

DRAM is a semiconductor chip of which capacity is measured by bit, a unit of data that DRAM can contain when it operates on an electric device. DRAM products are typically identified by the number of bits per chip, sometimes called its "granularity." Intel produced the first commercialized DRAM in 1970 with the capacity of 1,024 bits of storage, dubbed 1K DRAM's. DRAM has been developed to have higher capacity up to 4Gb (Giga bit) in 2013; the granularity of DRAM had grown by a factor of four until 128Mb DRAM was developed in the mid-1990's and it has grown by a factor of two afterwards.

Figure 1-2 Volume of DRAM bits shipped per year by chip granularity.



Source: The Remarkable Story of The DRAM Industry, Randy Isaac, IEEE SSCS NEWS, 2008

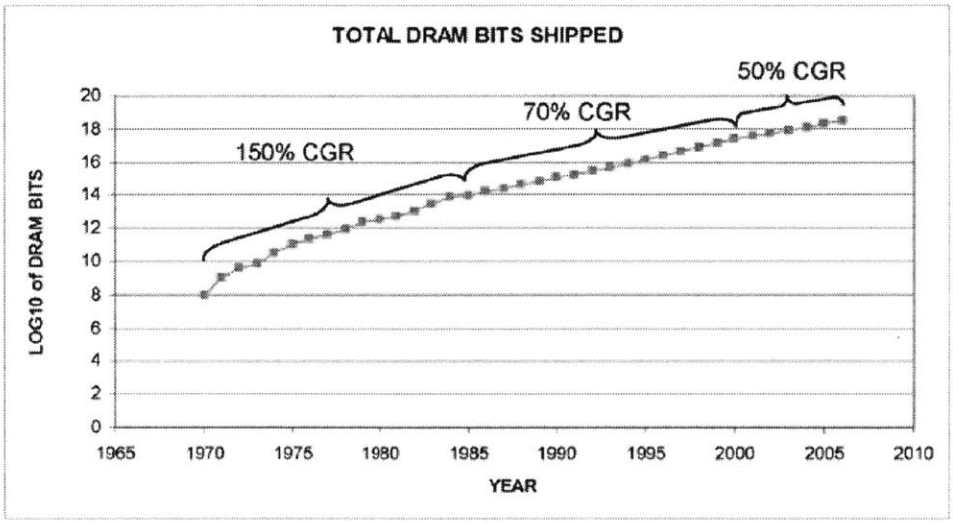
Figure 1-3 shows that the number of total DRAM bits shipped per year from 1970, and the number of total bits has greater than the previous year; there was no downturns in terms of volume in this market: The annual growth rate of the bits of DRAM was an incredible 150 percent in the first 15 years of the industry, an impressive 70 percent in the next 15 years and a still respectable 50 percent since then.[2] There are some reasons on this constant growth in the industry: at first IT industry has been growing in the last four decade faster than most of the other industries so that the demand from information processing devices such as servers, PCs, and smart phones gave constant momentum for this growth. Second, a semiconductor industry has been regarded as strategic industry by most of the governments and those governments subsidized the firms in the industry. The third background is that semiconductor business is one of those industries that need huge capital at initial investment to build fab[3] so that any idle

[2] Isaac, R. (2008) The Remarkable Story of The DRAM Industry, Solid-State Circuits Society Newsletter, IEEE, Retrieved from http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4785692

[3] Fab is a semiconductor manufacturing site.

capacity in this high fixed cost structure business makes unit cost of a chip higher, which eventually makes chip companies fall into deficit.

Figure 1-3 Volume of DRAM bits shipped per year.



Source: The Remarkable Story of The DRAM Industry, Randy Isaac, IEEE SSCS NEWS, 2008

1.3 Pricing

The DRAM price is famous for its volatility, for example, according to the recent news, the price of a commodity DRAM for PC, 2Gb DDR3, rose 14 percent in February from the second half of January.[4] This dramatically fluctuated price gives a clue that a DRAM business has already fallen into commoditization. Because DRAM is a standardized product in its specifications led by JEDEC[5], it has been hard for DRAM manufacturers to make and promote performance differentiation, especially DRAMs for PCs. Those PC DRAMs are called commodity DRAMs and the price of PC DRAM has been mainly affected by demand and supply ratio in the industry, even regardless going under the manufacturing costs. Historically, DRAM price has decreased by 27 percent every year.[6] However, DRAM price has been more fluctuating recently: the yearly price drop rate has been varied from 55.6 percent to 8.1 percent between 2008 and 2009; moreover, the price even rose by 8.9 percent compared to that of the previous year.

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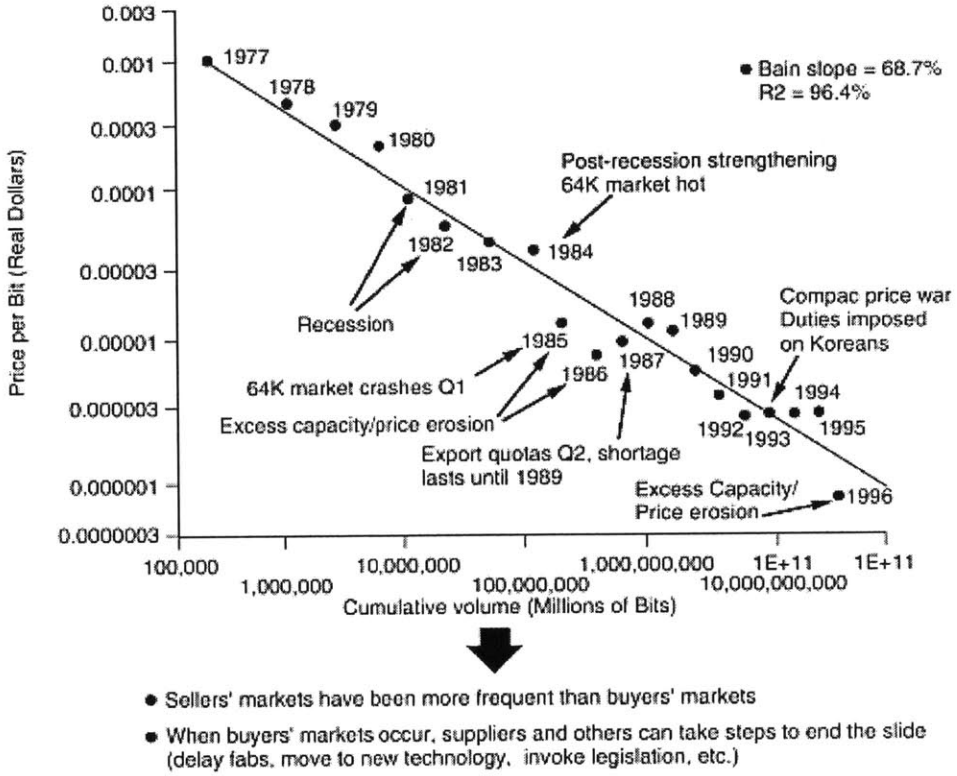
[4] The China Post, DRAM contract prices up sharply in Feb, (Mar. 3, 2013), Retrieved from http://www.chinapost.com.tw/taiwan-business/2013/03/03/371928/DRAM-contract.htm

[5] Joint Electron Devices Engineering Council (JEDEC), is an independent semiconductor engineering trade organization and standardization body. http://en.wikipedia.org/wiki/JEDEC

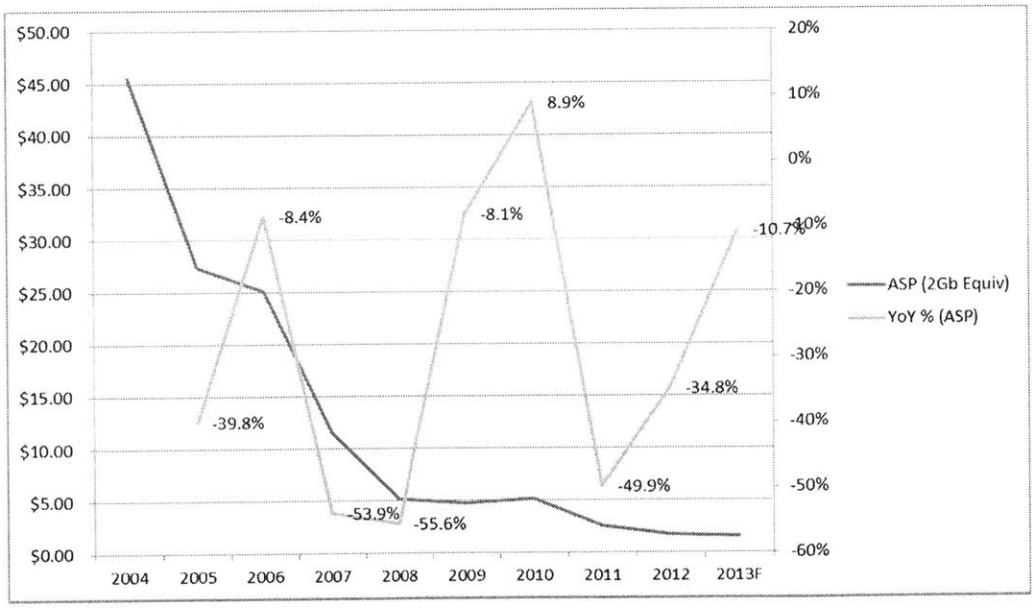
[6] Isaac, R. (2008) The Remarkable Story of The DRAM Industry, Solid-State Circuits Society Newsletter, IEEE, Retrieved from http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4785692

Figure 1-4 Historical DRAM Price per bit



Source: Measuring and Sustaining the New Economy: Report of a Workshop (2002), National Academy of Science,

Figure 1-5 Historical DRAM Price from 2004 to 2012



Source: DRAMeXchange's Platinum data sheet, Jan 2013.

1.4 Manufacturers

There have been dozens of DRAM producers, and all of them have owned their manufacturing fabs. The number of DRAM vendors has been decreasing when there were market downturns; Qimonda, the last European firm spun off from Infineon was bankrupt in 2006, and recently the last Japanese company, Elpida is under The Reorganization Plan asked by the Tokyo District Court. It is natural to observe industry consolidation when there is recession or any kind of severe downturn in the industry. DRAM industry has strictly followed this rule and now the number of DRAM manufacturers is around ten. However, the four mainstream vendors account for 95 percent of output in the industry – Samsung, Hynix, Micron and Elpida.

From 1970's and 1980's, following Intel, US companies such as Advanced Micro Devices (AMD), Motorola, and Texas Instruments (TI) joined the DRAM industry; US companies dominated with almost 90 percent of market share of 4K DRAM. From 1980's concentrating their R&D capacity into developing higher yield, Japanese companies gained competitive advantages in costs due to the gap in yields: US companies' yield was around 50 percent to 60 percent but Japanese ones' were over 70 percent.[7] The Japanese conglomerates including Hitachi, Matsushita, NEC, Toshiba, Mitsubishi and Fujitsu, aggressively came into the market with the government's support and ample capital from banks and their related companies. As a result in late 1980's majority of top DRAM vendors were Japanese – seven out of top ten companies in 1987. Korean companies, also conglomerates such as Samsung, LG, and Hyundai, invested billions of US dollars from mid-1980's and started to gain their leading positions from 1990's. Samsung finally became the biggest DRAM vendor in 1992 and still holds the position. Taiwanese firms including Nanya, Promos, Powerchip and Winbond, also copied the former entries done by Japanese and Korean firms, but have minor shares in the market and finally are leaving the industry in 2010's.

When there were the industry downturns – decrease in total revenue, some firms were merged with the others or the others exited the industry by selling their facilities to other semiconductor manufacturers. There were seven downturns in the industry as shown on the Figure 1-5; during the downturns, the DRAM market size in revenue decreased by from 36 percent to 79 percent and durations of downturns varied from three quarters to eleven. Each downturn brought about industry consolidations and now the number of commodity DRAM vendors is basically three: Samsung, SK Hynix, and Micron, since the Elpida, the last Japanese firm filed the bankruptcy in 2012 and will be merged with Micron in 2013. The industry concentration is now highest ever in history.

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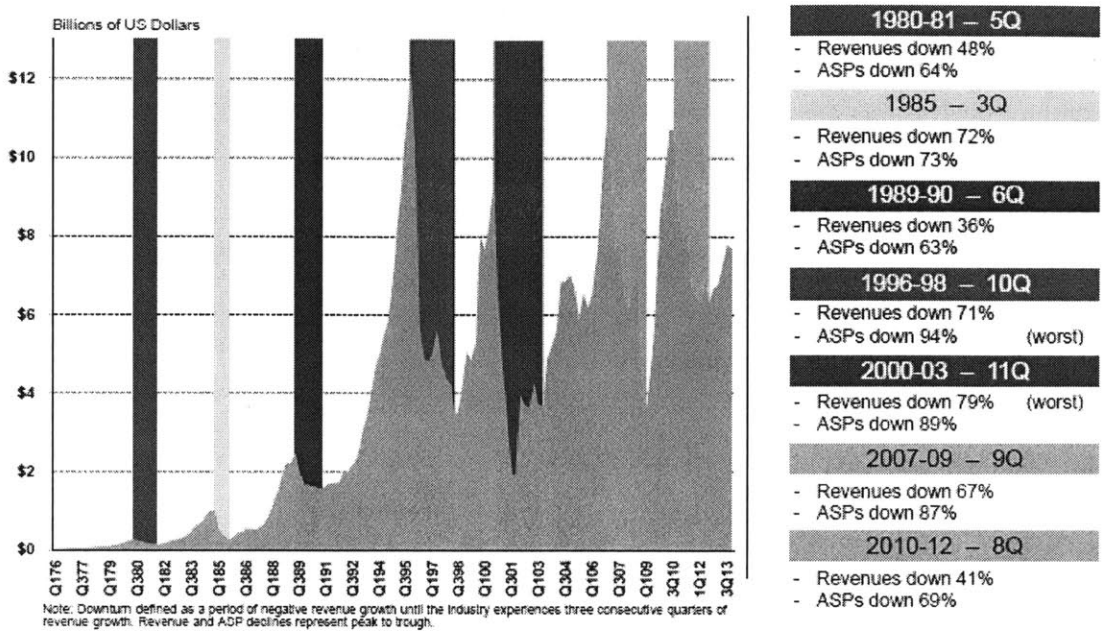
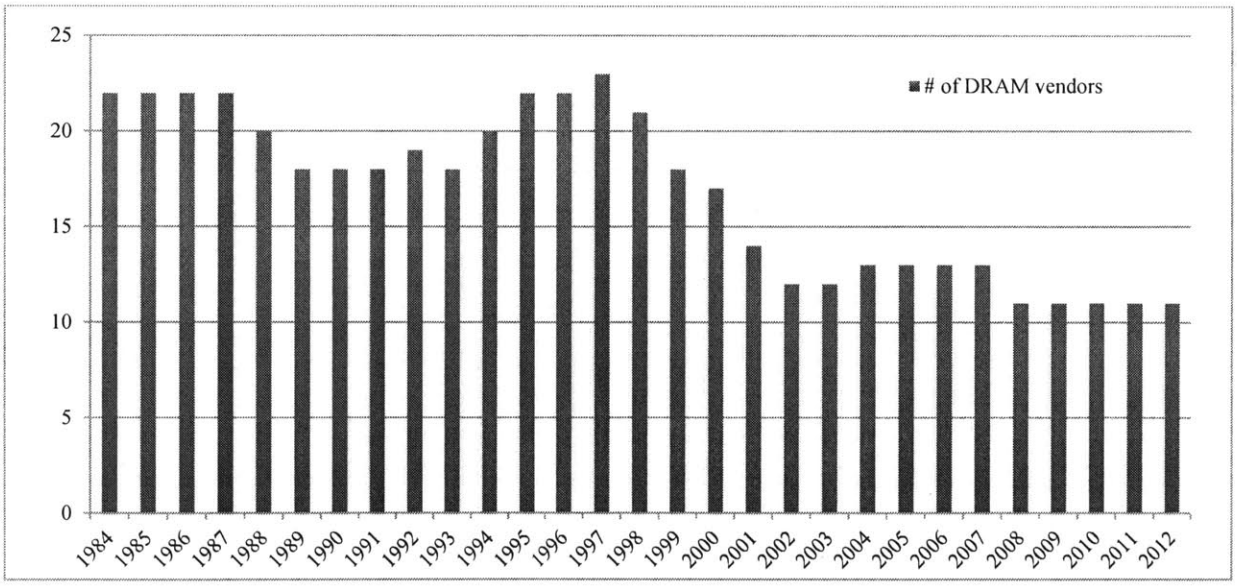
[7] Brown, C & Linden, G, (2009), Chips and Change, The MIT Press, page 17

Figure 1-5 DRAM Silicon Cycle Seven Major Downturns



Source: Gartner, DRAM Forecast, 1Q13 Update

Figure 1-6 Number of DRAM vendors

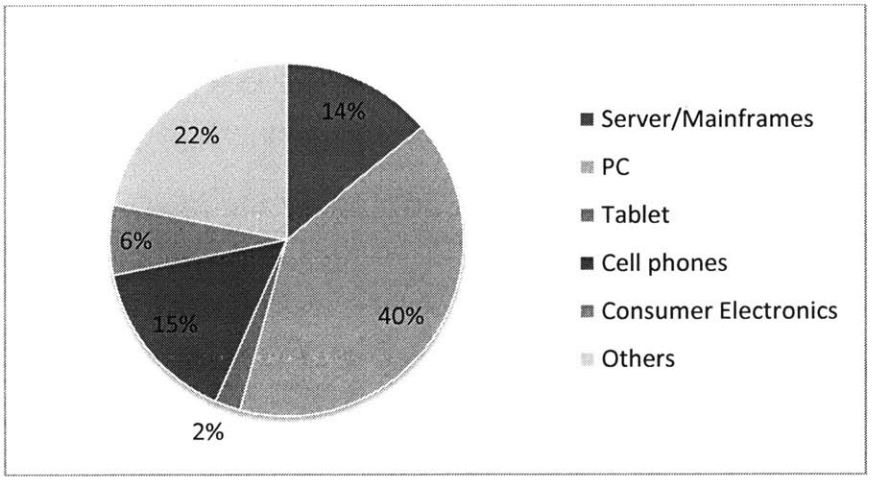


Source: WSTS, IDC, HANADAETOO Securities

1.5 Applications

DRAM is an electronic component used in various data processing devices including computers, mobile phones, servers, TV's, and other electronic goods. Major dram consumption has been linked to those electronic devices processing more data and the number of those devices. For example, until 1980's mainframes were the biggest applications for DRAMs and from 1990's PCs were the biggest pie in terms of DRAM bit consumption. On the press release by HIS iSuppli, a research firm, in 2012, PC share of DRAM consumption went down below 50 percent due to fast growth of tablets and cell phones.[8] As shown in Figure 1- 7, Electronic data processing still accounts for 57 percent including PC, Server, tablet PCs and mobile device including conventional cell phones and smart phones have 15 percent of DRAM consumption in 2012 and this portion has been growing rapidly from 2000's. In addition, consumer electronics and the others have static portion and LCD TVs or Smart TVs, which also process data and are connected to the internet, have the biggest portion in the consumer pie.

Figure 1-7 DRAM application portion in 2012



Source: Gartner, 2013, Forecast: DRAM Supply and Demand, Worldwide, 1Q11-4Q13, 3Q12 Update

In terms of DRAM types, PCs and Servers use so called commodity DRAMs or normal type of DRAMs; tablets and cell phones as mobile devices use low power DRAMs, which help batteries last longer than commodity DRAMs. Consumer electronics except digital TVs use legacy type of DRAMs. For example, PCs and Servers now use mostly 2Gb or 4Gb DDR3, mobile phones and tablets use low power DDR2 or DDR3, and consumer electronics mostly use DDR2 or DDR1.

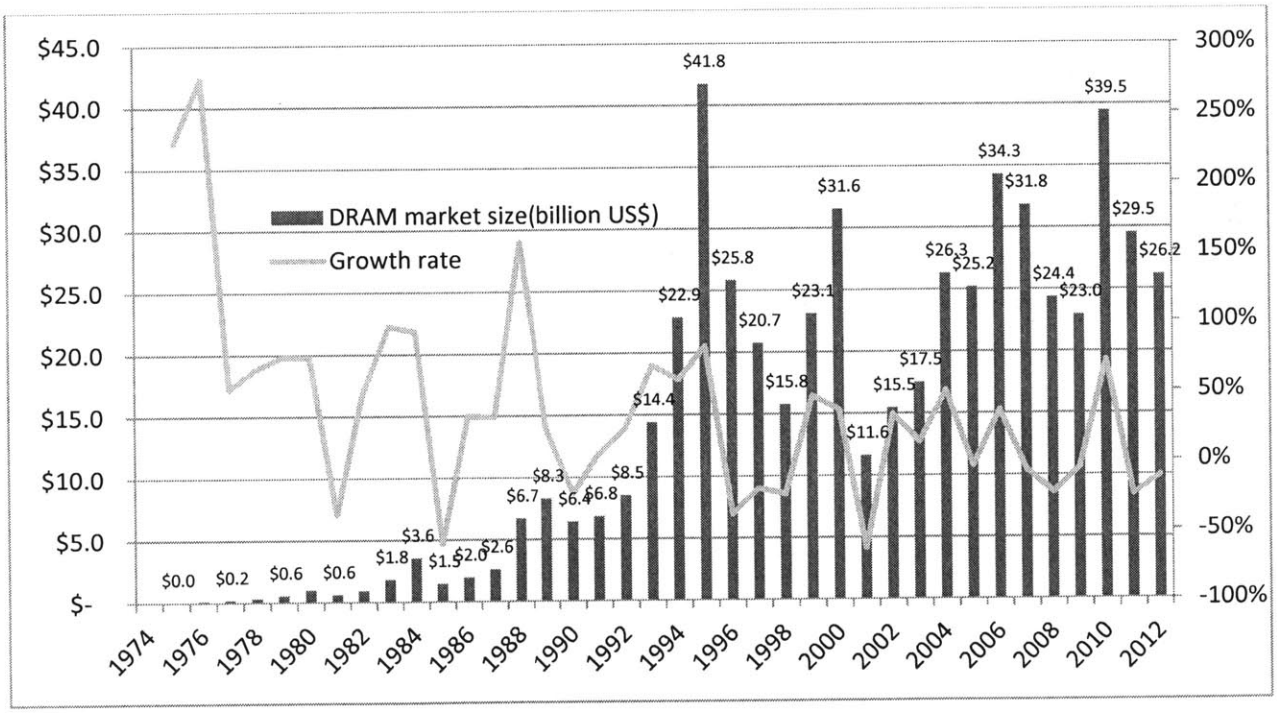
[8] Leimbach C. (Sep. 10, 2012), PC Share of DRAM Market Dips Below 50 Percent for First Time, IHS iSuppli Market Research, Retrieved from: http://www.isuppli.com/Memory-and-Storage/MarketWatch/Pages/PC-Share-of-DRAM-Market-Dips-Below-50-Percent-for-First-Time.aspx

Chapter 2: Market Dynamics Analysis

2-1 Stagnant market growth

This chapter analyzes the dynamics that have brought about challenges for the remaining DRAM vendors and also will explain why some firms had to leave the market after 2000. There are two critical characteristics in DRAM industry: the first one is that the market had been growing faster than any other industry until 1990's, in other words, it is harder for DRAM manufacturers to make as much as profit as before. The total market revenue exceeded US$ 20 billion and recorded US$ 22.8 billion in 1994, but the market size in 2012 was US$ 26.2 billion; between those years, there were five years exceeding US$ 30 billion but compound annual growth rate (CAGR) has decreased every decade: CAGR in 1980's was 26.4 percent, but it has decreased as 16.5 percent in 1990's and 8.5 percent in 2000's. This trend also limited DRAM vendors' profitability and eventually made some firms fall into bankrupt.

Figure 2-1 DRAM Revenue history (1974-2012)



Source: Gartner

Table 2-1 DRAM Revenue history CAGR by decade

Periods	CAGR
1981-1990	26.4%
1991-2000	16.5%
2001-2010	8.5%

Source: Gartner

The reason why the DRAM market size growth has been decelerated can be mainly explained by consumer side changes. Additionally, what make DRAM vendors hard to make profit can be explained in their increased costs on R&D and manufacturing. Lastly, the reason why DRAM is the most commoditized semiconductor with its recurring cycles will be analyzed with System Dynamics perspective in this chapter.

2-2 Demand shifts

2-2-1 Shift from PCs to mobile devices

Conventional PCs consist of desktops and notebooks, and these devices have dominated the DRAM consumption by having more than 50 percent until 2012. To define DRAM demand in PC markets, both of shipment and average content of DRAM have to be considered. PC shipment has steadily growing with around 10 percent of yearly growth rate until 2010 except 2009; this growth has been caused by improved affordability at the low-end market driven by emerging markets. However, conventional PCs growth rate after 2010 is limited to less than 2 percent per year until 2012, forecasted by Gartner.[9]

Table 2-2 PC shipment by form factor from 2005 to 2010 (thousand units)

	2005	2006	2007	2008	2009	2010	CAGR (05'-00')
Desktop	148,119	150,090	156,564	150,374	138,441	146,457	-0.2%
Notebook	63,470	80,866	107,504	133,404	138,861	170,756	21.9%
Netbook				8,450	31,050	33,683	N/A
Total	211,589	230,956	264,068	292,228	308,352	350,896	10.6%
YoY(%)	15.4%	9.2%	14.3%	10.7%	5.5%	13.8%	

Source: Credit Suisse, March 2011, IT Hardware

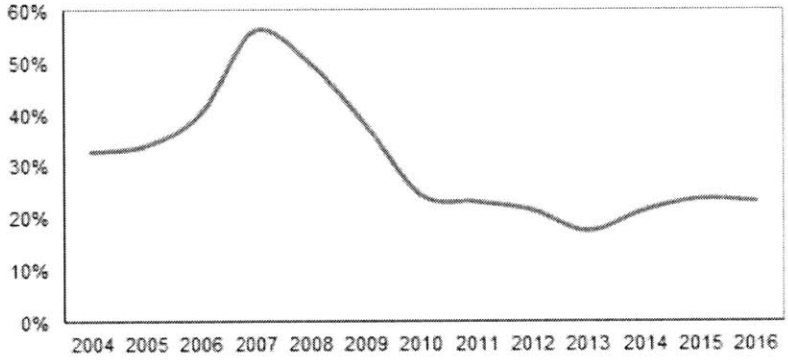
Another critical factor for DRAM demand is average DRAM content per PC and the growth of DRAM content per PC has been sluggish since mid-2000. Historically, steady development in PC

[9] Norwood, A, (2012), Forecast: DRAM Supply and Demand, Worldwide, 1Q11-4Q13, 3Q12 Update

capabilities, along with the PC upgrade cycle and new operating system release, has fueled DRAM content growth; however, the annual growth in the average DRAM usage per shipped PC has been slowing dramatically since the peak in 2007 as shown on the Figure 2-2. Clifford Leimbach, memory analyst at IHS said, "This slowdown reflects the maturity of the PC platform as well as a change in the nature of notebook computers as OEMs adjust to the rise of alternative systems—namely smartphones and media tablets."[10]

In 2012, the average DRAM content of PC including desktops and notebooks was higher by six times as that of media tablet or tablet PCs, by fourteen times as that of cell phones, and by five times as that of premium smart phones. Even though PC shipment is substituted by those mobile devices, this huge gap in DRAM content size hinders the market growth.

Figure 2-2 PC DRAM loading growth rate (Annual percentage increase in average PC DRAM)



Source: IHS iSupply Research, March 2013

Table 2-2 Average DRAM content in major applications (Megabytes)

	2006	2007	2008	2009	2010	2011	2012	CAGR 2006-2011	CAGR 2011-2016
Server, Midrange	11,101	16,082	26,914	31,952	53,566	106,748	134,000	57.3%	45.1%
PCs	664	1,302	1,998	2,465	2,824	3,533	4,337	39.7%	21.8%
Desktop PCs	665	1,292	2,009	2,510	2,835	3,404	4,274	38.6%	21.5%
Mobile PCs	662	1,319	2,106	2,785	3,173	3,950	4,652	42.9%	19.9%
Mini-notebook PCs	N/A	567	864	918	1,050	1,195	1,244	-	13.0%
Media Tablets	N/A	N/A	N/A	N/A	266	483	759	-	44.7%
Digital Cellular Handsets	12	24	36	50	68	133	315	60.8%	63.4%
Traditional	8	12	21	31	35	50	67	44.9%	27.6%
Basic Smartphone	37	41	46	53	61	104	191	23.3%	59.0%
Premium Smartphone	64	134	171	203	252	456	940	48.0%	46.4%

[10] Leimbach, C., (Mar, 12, 2013), DRAM Content Growth in PCs Slows, in Another Sign of Shifting Technology Markets, IHS iSuppli Market Research, Retrieved from: http://www.isuppli.com/Memory-and-Storage/News/Pages/DRAM-Content-Growth-in-PCs-Slows-in-Another-Sign-of-Shifting-Technology-Markets.aspx

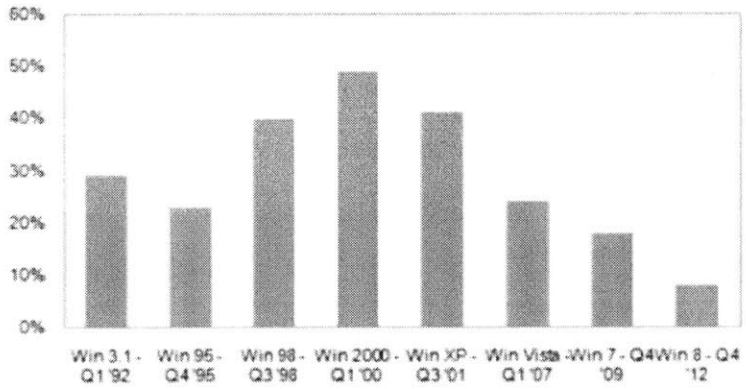
TV, LCD	89	202	320	378	426	493	646	40.7%	30.1%
Video Games Machines	102	146	152	165	207	223	359	16.9%	55.9%

Source: Gartner, 2012, Forecast: DRAM Supply and Demand, Worldwide, 1Q11-4Q13, 3Q12 Update

Another factor deteriorating the DRAM content growth is that now consumers prefer slim design, fueled by MacBook Air made by Apple from 2008 and also led by Intel with its notebook platform, Ultrabook. To compete against tablet PCs, those notebooks need to extend battery life time and be designed as less than 2Kg. As a result, DRAM chips must share limited space on the PC motherboard with other semiconductors that control a notebook's other functions.[11] This slim design basically makes PC makers use less content of DRAM and let them use on-board design rather than DRAM modules so that consumers cannot easily upgrade DRAM, also lowering upgrade DRAM market, that consumers buy DRAM modules for their PCs from retail shops and put them into their PCs for higher performance.

The reason of deceasing DRAM content per PC can be explained by three major factors: the first one is that current PC platform has matured enough to handle most of software. Operating system (OS) has been the biggest software booming PC hardware upgrade or repurchase, however, Microsoft's Windows, of which OS market share is around 90 percent in conventional PCs, has not required higher content as much as before, so the growth of DRAM following the releases of Windows has been decreased.

Figure 2-3 Historical DRAM bit shipment growth followed by Windows release



Source: IHS iSupply Research

The other factor can be found on the composition of PC demand, which is driven by low-end, relatively cheaper price with lower DRAM contents and sold in emerging markets. This segment is the main growth segment in PCs and with the bigger portion of this low-end Pcs, the average DRAM content

[11] Mearian, L. (Mar 12, 2013), DRAM trends herald a slowdown in PC uptake, Computerworld.com, Retrieved from: http://www.computerworld.com/s/article/9237524/DRAM_trends_herald_a_slowdown_in_PC_uptake

grows in the slower pace. Moreover, this low-end portion makes the average PC price decrease quickly, that makes eventually DRAM vendors squeeze their profit.

2-2-2 Consumerization

Another economic challenge to DRAM vendors is change in end users; DRAM applications are more sold by price sensitive or frugal consumers rather than by performance-minded corporate purchasers.[12] For example, consumer accounted for around 30 percent until mid-1990's and gained its share to 50 percent in 2005 and the shares of government and corporate have been deceased during that time.[13] This trend continues in the 2000's in electronics industries: in PCs market, there are more PCs sold by consumers than by corporates; in 2005 the corporate PCs accounted for 37 percent of the total PC shipments and the consumer portion has increased every year and exceeded commercial PC's, having 52 percent of the total shipment. Moreover PC price has been decreasing along with the consumerization; for instance, PC price decreased by 6.5 percent in compound annual rate from 2005 to 2010.

Table 2-3 PC shipment by consumer groups (Thousand units)

	2005	2006	2007	2008	2009	2010	CAGR(05'-00')
Consumer	78,714	89,387	104,721	123,041	147,704	190,112	19.3%
Commercial	132,874	141,569	159,348	169,187	160,648	177,984	6.0%
Total	211,588	230,956	264,069	292,228	308,352	368,096	11.7%
Consumer portion (%)	37.2%	38.7%	39.7%	42.1%	47.9%	51.6%	

Source: Credit Suisse, March 2011, IT Hardware

Table 2-4 PC price by form factor

	2005	2006	2007	2008	2009	2010	CAGR(05'-00')
Desktop	$ 805	$ 726	$ 727	$ 692	$ 615	$ 605	-5.6%
Notebook	$ 1,292	$ 1,174	$ 1,111	$ 1,008	$ 872	$ 803	-9.1%
Netbook				$ 457	$ 415	$ 373	N/A
Average	$ 951	$ 883	$ 883	$ 829	$ 711	$ 679	-6.5%

Source: Credit Suisse, March 2011, IT Hardware

In addition, the other applications rather than PC, including mobile phones and digital TVs started to use more and more DRAMs from 2000's with the digital data processing functions and the most of these applications' end users are also consumers. TVs started to have more DRAMs for two major reasons; the one is that TVs are now using digital signals rather than analog ones and with enhanced resolution, such as HD TVs, which need more DRAMs for motion picture processing. The other factor is

[12] Brown, C & Linden, G, (2009), Chips and Change, The MIT Press, page 77
[13] Brown, C & Linden, G, (2009), Chips and Change, The MIT Press, page 78

that TVs with additional data processing functions, so called smart TVs need DRAMs to process information data through internet connection, for example, internet browsing, streaming TV programs, and other information services. The same trend affected the mobile phone industry, and now smart phones with nearly same capabilities as those of basic PCs show the biggest growth in 2000's among major DRAM applications in shipment by substituting the conventional mobile phone, and will keep this position, and with the nearly same functions as smart phones, tablet PCs will be growing as well. For example, the compound annual growth rate in shipment of smart phones are over 30 percent between 2006 and 2011, and will be over 20 percent in the next five years; the rate of tablet PCs will be also over 30 percent from 2011 to 2016; the digital TVs or LCD TVs' growth rate from 2006 to 2011 is also over 30 percent. This strong consumerization trend of major DRAM applications will keep on affecting the DRAM industry.

Table 2-5 Major DRAM applications shipment forecast (Thousand units)

	2006	2011	2016	CAGR 2006-2011	CAGR 2011-2016
Server, Midrange	538	603	824	2.3%	6.5%
PCs	231,489	365,084	524,124	9.5%	7.5%
Desktop PCs	150,326	155,636	151,135	0.7%	-0.6%
Mobile PCs	81,164	185,018	367,801	17.9%	14.7%
Mini-notebook PCs	-	24,430	5,188	-	-26.7%
Media Tablets	-	67,320	312,706	-	36.0%
Digital Cellular Handsets	997,090	1,835,200	2,301,002	13.0%	4.6%
Traditional Mobile Phone	913,004	1,346,860	935,177	8.1%	-7.0%
Utility/Basic Smartphone	6,323	130,387	394,248	83.2%	24.8%
Premium Smartphone	77,763	357,953	971,577	35.7%	22.1%
DVD Blue and Red Laser Players & Recorders	92,980	82,750	51,370	-2.3%	-9.1%
TV, LCD	41,646	196,433	225,108	36.4%	2.8%
Digital Set-Top Boxes	83,198	172,035	349,658	15.6%	15.2%
Video Games Machines	63,850	71,930	63,400	2.4%	-2.5%
Digital Still Camera	87,120	128,100	120,800	8.0%	-1.2%

Source: Gartner, 2012, Forecast: DRAM Supply and Demand, Worldwide, 1Q11-4Q13, 3Q12 Update

Consumer market gives three major challenges to semiconductor manufacturers; consumers are more price sensitive than corporate buyers, they are more prone to trends that appear and vanish with equal rapidity, and consumer markets are more fragmented than corporate markets.[14] Consumers as price takers, with the much enhanced price comparison environment on the internet, eventually affect semiconductor firms' profit level by boosting electronics companies price competitions. The faster trend and more fragmented in consumer markets shorten product life cycles and increase the risk that a type of

[14] Brown, C & Linden, G, (2009), Chips and Change, The MIT Press, page 81

DRAM will not sell in sufficient volume to cover its fixed development costs.[15] In addition, short product life cycle in consumer electronics also pushes the development cycles of DRAMs.

2-3 Increasing Costs

2-3-1 Cost factors and Moore's law

In a semiconductor value chain, there are four steps: design, fabrication, assembly, and test. Among those steps, design needs a highly intelligent human resources and fabrication needs huge capital investment for building a fab and installing equipment as well as human resources for process development. It is critical for DRAM vendors' sustainability to keep their cost down at least by 27 percent every year - the historical DRAM price decrease rate per year, to be more specific, they have to produce make the same bits of DRAMs with at least 27 percent less cost as that of previous year; in other words, DRAM vendors need to sell higher number of DRAM chips or chips with the more capacity. To do so, DRAM vendors have to increase output of chips, develop a chip with more capacity or bits. DRAM vendors have to develop or design a new DRAM chip with higher density or capacity and the historical cycle of DRAM density change has been around four years. DRAM vendors keep investing on R&D to upgrade chip's capacity.

There are fundamentally three ways to increase output: to increase yield by enhancing current manufacturing process, to increase manufacturing capacity by extending or building a fab, and to use better manufacturing technology, designing more chips on a single wafer. The first factor is mainly dependent on the learning curve; as time goes by, DRAM vendors typically raise a product's yield level from around 40 to 50 percent to 80 to 90 percent since the beginning of a mass production of a DRAM product. A critical issue for DRAM manufacturers is that, to achieve the second or the third methods, DRAM vendors have to invest huge capital into its manufacturing sites either to increase capacity or to reduce cost per chip.

DRAM industry has been the best example following the Moore's law, which is coined in 1965 by Gordon Moore as "the number of transistors on a computer chip will double in every two years." And the time term has been modified to 18 months by Dave House.[16] DRAM has been the best case following this law as shown in Figure 2-7 –DRAM bit per chip has increased by four times every three years.

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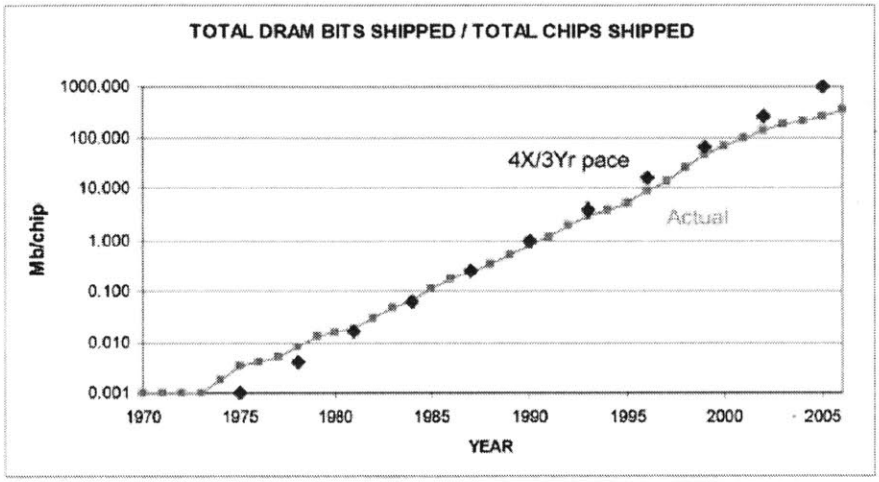
[15] Brown, C & Linden, G, (2009), Chips and Change, The MIT Press, page 82

[16] Transcript,(2005), Intel Corporation, Excerpts from A Conversation with Gordon Moore: Moore's Law, Retrieved from: http://download.intel.com/museum/Moores_law/Video-transcripts/excepts_a_Conversation_with_gordon_Moore.pdf

Figure 2-7 Average DRAM bits per chip shipped per year



Source: The Remarkable Story of The DRAM Industry, Randy Isaac, IEEE SSCS NEWS, 2008

In his paper in 1975, Moore picked out three major factors that made this steady growth in the number of transistors on a chip: Improvements in manufacturability leading to larger die sizes; innovation in semiconductor design efficiency; and higher resolution lithography. In DRAM's case, lithography is the key factor, accounting for 50 percent of this growth as described on the earlier part. And the other two factors account for 25 percent respectively.[17]

However, there are two major limits in the larger die sizes: the first limit is a basically economic reason – die size is the key cost factor for a DRAM chip, namely, the more dies on a wafer, the less manufacturing cost per chip. DRAM vendors cannot increase a die size sacrificing profitability. The second reason is from demand side; the standardized modules are the way DRAM is consumed on PC including desktops and notebooks and there is always a size limit of PCB[18] of modules. Additionally, the demand of mobile devices is sharply increasing and the physical limits of those devices including mobile phones and tablet PCs are even smaller and thinner than the conventional limit of PC modules. The other factor of innovation in semiconductor design efficiency has been also stuck with some cell size limit from mid-1990's, since DRAM design approaches reached a limit in area of approximately 6-8F2 where F is the smallest lithographic feature size. A physical area of 6F2 is regarded as some limit of memory cells without going to multiple bit-per-cell technologies, inevitably making access speed slower. As a result,

[17] Isaac, R. (2008) The Remarkable Story of The DRAM Industry, Solid-State Circuits Society Newsletter, IEEE, Retrieved from http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4785692

[18] printed circuit board

cell size innovation became an ineffective factor.[19] Ultimately, lithography becomes the most effective and nearly the sole solution for DRAM vendors to follow Moore's law or economic growth of their business.

2-3-2 Increasing manufacturing cost

One of the most important economic factor affecting DRAM vendors is the rising cost in manufacturing equipment. The DRAM fab costs have been dramatically increased for the last decades and this trend has squeezed the profitability of DRAM vendors.

DRAM manufacturers have to upgrade their process or node, at the pace of every two or three years to keep up with increasing demand and also to reduce cost per bit, by using advanced lithography. In this key semiconductor manufacturing process called lithography, a wafer – a thin slice of silicon - is covered with light-sensitive liquid material called photoresist and light streams are emitted onto this photoresist through an opaque mask which have holes that let light through to form a pattern of microchip patterns – in this case, DRAM. The exposed areas of the photoresist are weakened when the light hits them, and then corrosive plasma etches the pattern into the silicon, then the leftover photoresist is washed away, leaving the photoresist pattern engraved as DRAM chip structure. Lithography toolmakers have developed their tools to reduce the wavelengths of light and to find advanced optical tricks to finesse the light into depositing patterns smaller than the wavelengths themselves because the shorter the wavelength or the finer the resolution of the features is printed on the chips and the more transistors can be put onto a chip. The first commercial lithography tools were manufactured in the early 1980s with the visible light at a wavelength of 436 nm. And the wavelength has been shrunk, in 2001, to the 193-nm light, derived from an argon-fluoride laser used today to create patterns with feature sizes down to 38 nm. Today, the features of complementary metal-oxide-semiconductor (CMOS) silicon transistors will continue scaling to below 20 nm with extreme ultraviolet (EUV) lithography. ASML Holding, one of the leading lithography technology firms, introduced an EUV lithography system in 2009 that can produce chips with features smaller than 30 nm. Nikon, Japanese lithography firm reportedly has a similar tool in development.[20] This lithography tool has been the biggest cost driver of fabs, which typically accounts for from 20 percent to one third of the total costs for a new fab.[21] And the cost of this tool has continuously increased as a technology breakthrough needed for each upgrade – scaling down. Apart from this core tool, the costs for

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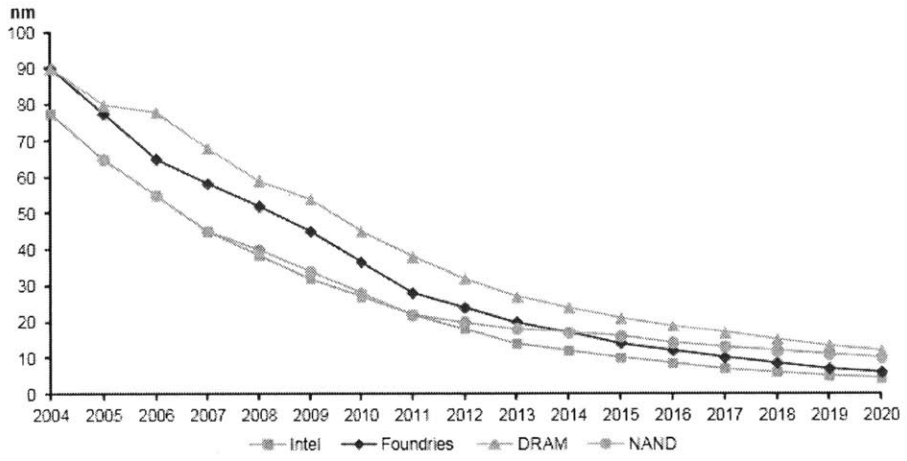
[19] Isaac, R. (2008) The Remarkable Story of The DRAM Industry, Solid-State Circuits Society Newsletter, IEEE, Retrieved from http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4785692

[20] Arnold, B. (Apr 1, 2009), Shrinking Possibilities, http://spectrum.ieee.org, Retrieved from http://spectrum.ieee.org/semiconductors/design/shrinking-possibilities/3

[21] Robertson, J. (Sep 9, 1999), Chip makers gripe bitterly, but litho costs keep soaring, http://www.eetimes.com, Retrieved from: http://www.eetimes.com/electronics-news/4116925/Chip-makers-gripe-bitterly-but-litho-costs-keep-soaring

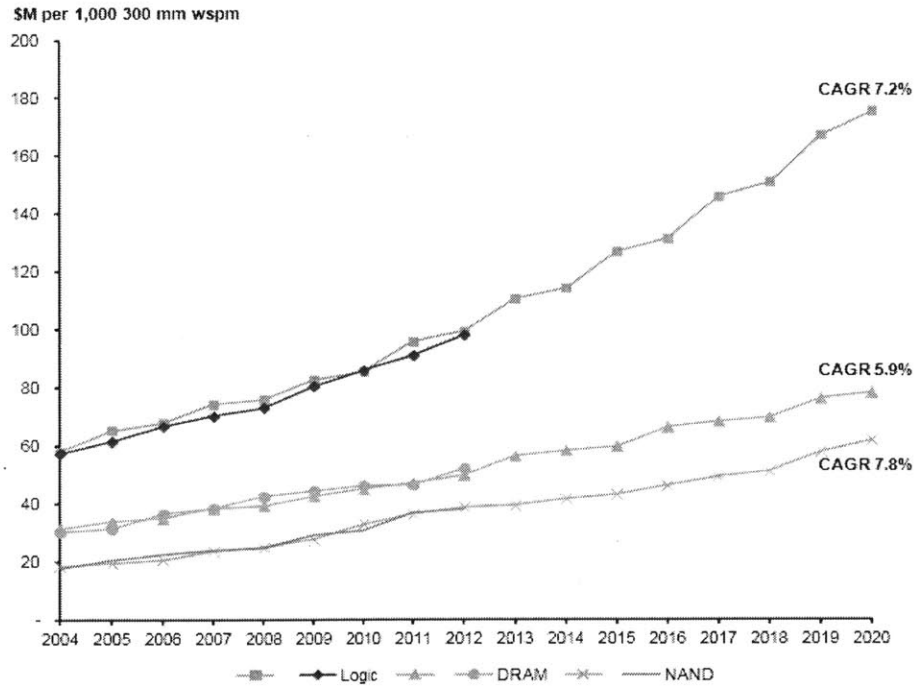
the other tools have also increased as they have been needed to modified and advanced as manufacturing process develops. Moreover, as the lithography develops, new materials have been needed for advanced nodes – a semiconductor manufacturing process with thinner wavelength.

Figure 2-4 Minimum Feature Sizes for Leading-Edge Semiconductor Manufacturing



Source: Gartner (Sep, 2012)

Figure 2-5 300 mm Average Wafer Fab Equipment Cost Projections (wspm=wafer start per month)



Source: Gartner (Sep, 2012)

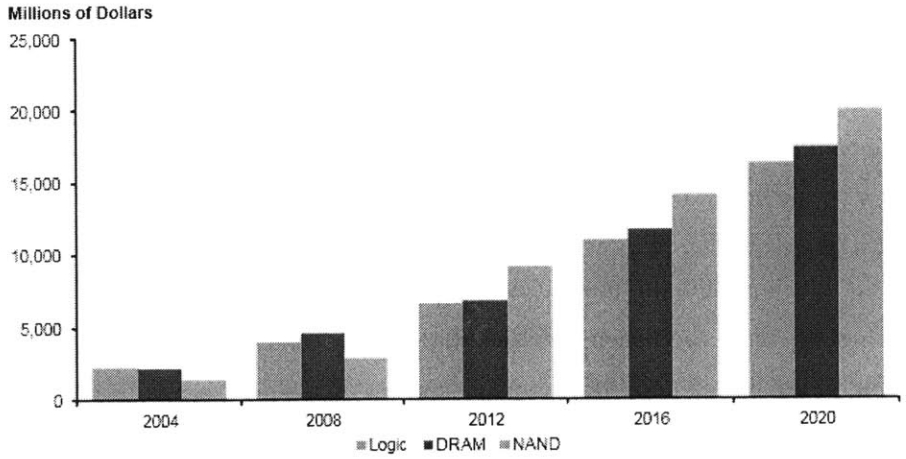
Table 2-6 300 mm Equipment Costs per Node (Millions of Dollars per 1,000 wspm)

Node	90nm	65nm	45nm	32/28nm	22/20nm	14nm	10nm
Logic	60-70	65-85	70-90	85-115	105-125	120-140	135-155
DRAM	30-40	35-45	45-55	55-65	65-75	75-85	85-95
NAND	14-22	15-25	20-25	30-40	35-45	45-55	55-65

Source: Gartner (Sep, 2012)

As DRAM vendors use the more advanced process or node, the equipment cost for a new fab is also increase: in the DRAM industry's case, about ten million US dollars increases for each phase of node. Another reason of increasing fab cost is increased fab space, the initial 300mm wafer fab was much smaller than those new leading edge fabs built recently and the capacity of a fab – wspm (wafer start per month) has also increased. For example, DRAM fabs in 2004 were running 50,000 wspm, while today some new fabs have capacity of more than 200,000 wspm. With more expensive equipment and increased capacity, the fab cost has been and will be rising fast, according to the Gartner's report, "Market Trends: Rising Costs of Production Limit Availability of Leading-Edge Fabs", cost of building a leading edge fab was about US$5 billion in 2008, now is about US$7 billion and will be over US$10 billion in 2016[22].

Figure 2-6 Historical and Projected Fab Costs for different semiconductor industry



Source: Gartner (Sep, 2012)

[22] Johnson, B. Freeman, D, Christensen, D, Wang S.T.,(Sep 17, 2012), Gartner, Market Trends: Rising Costs of Production Limit Availability of Leading-Edge Fabs

2-4 DRAM market cycle in System Dynamics perspective

2-4-1 DRAM industry cycle

DRAM industry has been well known for its strong industry cycle that makes upturns and downturns making the companies' revenue and profit severely fluctuating. An industry expert, Jim Handy said on Forbes's website recently, "It is impossible for DRAMs and semiconductors to get away from industry cycles. Cycles are inevitable in any capital-intensive business with undifferentiated products."[23] As shown on the Figure 2-1, there have been, in the DRAM industry history, strong evidences showing the industry cycle with the peak years having higher revenue in every four or five consecutive years. For example, there were peaks in the years of 1995, 2000, 2006, and 2010 and, after those peaks the total market size of DRAM industry continuously decreased for three or four years. Each of those downturns has made most of the DRAM manufacturers undergoing operational losses in their business, and some of the companies had to leave the industry by being merged with another one or by selling their facilities to semiconductor firms making another types as shown on the Figure 1-5. On the other hand, those companies survived the downturns usually have enjoyed the industry upturns, increasing their market shares and profits. Therefore, it is significant for DRAM vendors to have a long term business strategy to make its operation sustainable by knowing when this industry cycle comes, how it affects their profitability, and eventually how they deal with it. On this part, System dynamics modeling is used to explain the causes and effects of the DRAM industry cycle.

System dynamics modeling is a powerful and also useful tool to understand a market's dynamics, a structure of them by understanding how each variable affects one another. DRAM industry cycle can be explained as why it inherently happens, what cause it and finally how it can be treated by DRAM manufacturers.

2-4-2 DRAM industry cycle variables

There are direct factors causing DRAM industry cycle on both sides of demand and supply. On the demand side, the direct demand comes from IT devices shipment, of which affecting elements are macro economy, product life cycle, technology trend, price drops, and etc. For example, there has been typically a four years replacement cycle in corporate PC market related to Microsoft's OS upgrade term. But these demand side variables have been receded after 2000; the PC upgrade or replacement did not come out as much as before with the Windows 7, released in 2009 or with the Windows 8 released in 2012.

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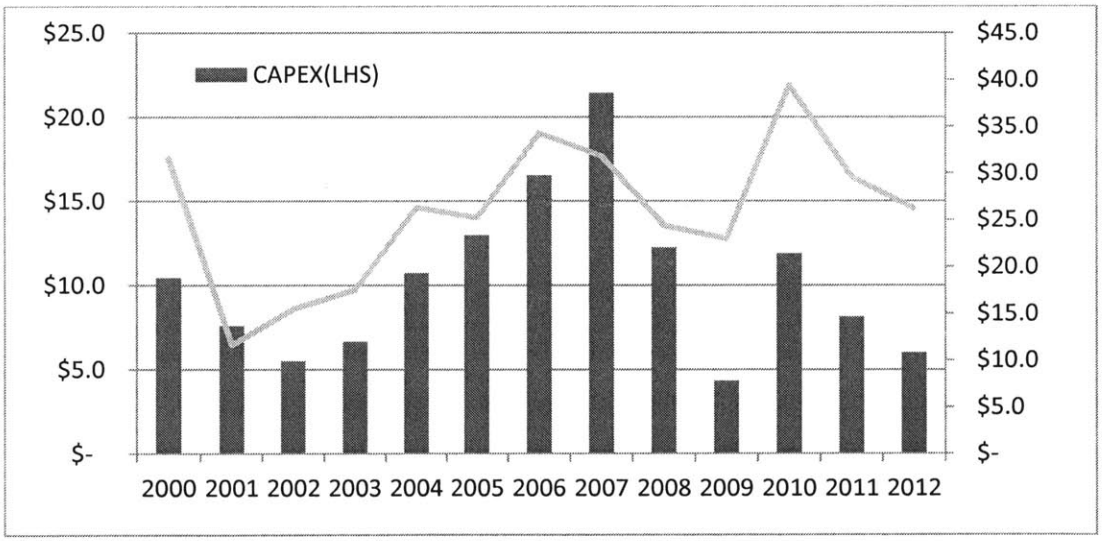
[23] Hardy, J. (Mar 22, 2013), Is the Semiconductor Cycle Dead?, ww.forbes.com, Retrieved from: http://www.forbes.com/sites/jimhandy/2013/03/22/is-the-semiconductor-cycle-dead/

On the other side, supply has more effective power causing the industry cycle. As described above, to upgrade or build a fab needs a large amount of capital, multi-billion US dollars, now. DRAM companies spend significant effort and long time to plan and execute their capacity expansion by forecasting future demand. Moreover, it takes months or even over a year to get that equipment from the time they actually make orders to equipment suppliers. For example, a lithography machine has from one year to two years of lead time because optical lenses are mostly hand crafted, making them extremely expensive so that equipment suppliers do not usually keep inventory of lenses rather have make-to-order process. The critical supply side reason of DRAM industry cycle is that it makes the industry easily fall into over-supply status by building and running another fab because a new fab is usually of leading edge technology with higher capacity than existing ones in the industry, its output is significantly enough to turn the market's demand and supply balance into over-supply. This magnitude of investment on capacity gets even bigger when most of the companies have enough capital to expand capacity with the profit from the peak years – the lemming effect. As shown on the Figure 2-7, after bigger capital spending, the market size tends to drop as shown in 2008 and 2011.

Figure 2-7 DRAM industry's capital spending and total revenue (billion US$)



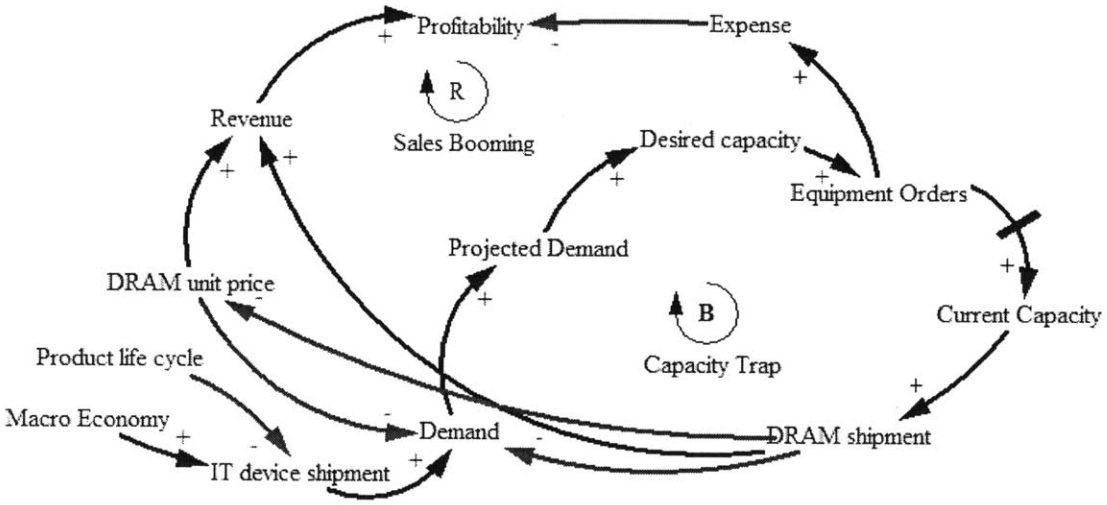
Source: Gartner, DRAMeXchange

2-4-3 System Dynamics modeling: DRAM industry cycle

DRAM industry cycle that has a fluctuation in revenue and also profit can be modeled as Figure 2-8. There are two major loops: the left one is named as Sales Booming and another one is called Capacity Trap. The Sales Booming is a reinforcing loop that makes each variable increase affecting one another: when DRAM manufacturers' revenue grows profitability grows, expense, equipment order,

current capacity, and DRAM shipment also increase. And with the increased DRAM shipment, revenue also grows or increased DRAM shipment decreases demand and decreased demand raise DRAM unit price and it also increases revenue. This loop explains how DRAM industry total revenue grows in the booming years. However another loop called Capacity Trap has a strong effect on this loop as a balancing loop by reducing the reinforcing effect of the Sales Booming loop. Capacity Trap can be explained as following: if demand increases, projected demand, desired capacity, and equipment orders increase and then there is a time delay of several months or even one or two years to increase current capacity. During this time delay, the reinforcing loop of Sales Booming continuously works, adding revenues and profits to DRAM vendors but when the delay goes away and finally current capacity grows, as explained above, with significant magnitude of escalation, and it suddenly lowers DRAM unit price and eventually decreases revenue.

Figure 2-8 System Dynamics model of DRAM industry cycle



One way to decrease this supply side effect is to have a flexible and gradually expandable capacity plan. For example, Samsung, the industry leader with over 40 percent of market share in the industry since 2011 has built a new fab of which area is double as former ones of the firm and filled with equipment on the half of the building first and later the company wait and see how the industry cycle goes on, then plan to decide to extend the building's manufacturing capacity. However, it is not a small financial burden for the other DRAM manufacturers to build a fab building first and let it vacant for over a year since the depreciation normally accounts for 30 percent to 60 percent depending on the maturity of fabs – in average 45 percent.[24]

[24] Wang, B. & Norwood, A. (2013), Gartner, Market Statistics: DRAM Manufacturing Cost Model, 2013

The other approach to reduce its cyclical industry feature is to have convertible fabs, which can produce DRAM, other types of memory or semiconductors. There has been a flexible capacity when NAND flash– non-volatile memory used for data storage in IT devices – memory market had a rapid growth in the late 2000's. For instance, Samsung had one fab line producing both DRAM and NAND flash, but this approach also brings about another shortcoming that it takes two months or even longer to convert the line from one to another; during the time, a firm has to sacrifice output and also it gets harder to maintain the defect level of the production line, namely yield level, since each manufacturing step of semiconductor is so sensitive that a number of engineers have to stay and control equipment, coping with real time data; there is a learning curve effect on each process step but converting one product to another stops this learning curve effect of each production step, making lower output compared to fabs continuously producing one type of product. Additionally, even though DRAM and NAND flash are the same memory semiconductor, the material such as gas or metal used for those memory semiconductors are different, which makes this convertible line have more production facilities such as pipes, safety equipment, etc.

2-5 Commoditization in System Dynamics perspective

2-5-1 Commoditization features

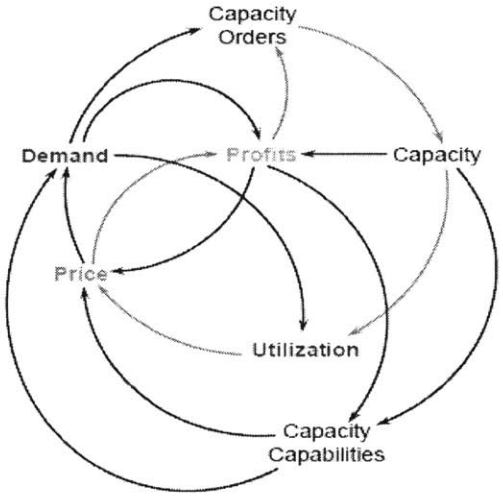
Commoditized industry is defined as a competitive environment of which characteristics are as following: product or service differentiation is difficult to achieve, customer loyalty or brand value is low, price competition is severe so that cost leadership is regarded as sustainable advantage, and recurring cycles in investment, capacity utilization, prices, margins and return on capital.[25] DRAM market shows most of the commoditized market's features because DRAM products are standardized by JEDEC so that it is hard to make performance differentiations; brand value exists weak as only a few customers tend to source DRAM products with less quality dysfunctional parts; price competition is so severe that monthly price change varies up to double digit percent; DRAM vendors' operational margin has been so hard to get, making the number of firms leave the industry; as explained above DRAM industry cycle is a typical industry cycle that has been repeated and shows fluctuations in investment, price, capacity utilization, and return. Therefore, DRAM industry is a typical example of commoditized market.

[25]Weil, H. B.,(2007), System Dynamics Review, 23, 2-3, 137-156, Application of system dynamics to corporate strategy: an evolution of issues and frameworks

2-5-2 System Dynamics modeling: Commoditization

A simplified System Dynamics model on commoditization formulated by Henry B. Weil, a senior lecturer at MIT Sloan School of management is shown on the Figure 2-9. This model has a few basic economic variables. At first, increased capacity leads price drop and demand growth, leading to another capacity expansion. This reinforcing loop often makes market grow, often exceeding exogenous drivers' growth e.g. GDP or population. However, there is a delay in capacity growth, as shown on the DRAM industry cycle model that accelerates the excess capacity.

Figure 2-9 A general System Dynamics model of commoditization



Source: Henry Birdseye Weil, 2007

In his research, Weil explains that a key cause of commoditization is persistent excess capacity typically driven by over-estimated demand, proliferation of players, amplification of planning errors, lapse of financial constraints, dysfunctional regulation, or impact of market liberalization. For example, proliferation of competitive players in an industry drives each one's market share aspiration; new entrants usually sacrifice profit to gain market share, over-optimism of players bring about planning errors; some resellers enter into an industry with different price/cost structures. Each of those cases makes excess capacity in the industry and drives it commoditized.[26]

2-5-3 Commoditized DRAM market

DRAM market has been inherently commoditized with such features as standardization of specification, and recurring capacity expansion. As market becomes more commoditized, it gets more

[26] Weil, H. B.,(2007), System Dynamics Review, 23, 2-3, 137-156, Application of system dynamics to corporate strategy: an evolution of issues and frameworks

difficult for DRAM manufacturers to make profit or even to survive during the downturn seasons. The impact of technology in DRAM industry is significant because it is directly related to unit cost; therefore, it becomes a firm's critical competitiveness to make profit. However, in such industries requiring huge capital for capacity, in DRAM industry's case, the required capital gets even greater; firms are dominated by fixed cost, making margins highly sensitive to capacity utilization, and hence increasingly volatile. This phenomenon is exactly seen in the DRAM industry. "There are powerful incentives in a commoditized industry to stretch asset lives and invest as little as possible. Significant 'barrier to exit' which make it more difficult and/or costly to eliminate capacity (e.g., governmental support of national champions, protection by bankruptcy courts, or environmental regulations which impose large clean-up obligations) exacerbate those dynamics"[27] This can explain why a number of companies have left the market almost when they went into bankruptcy except the case of Intel, of which long term business strategy was intentional.[28]

2-6 Market concentration vs. DRAM cycle

2-6-1 Market concentration (HHI)

As DRAM market accelerates its commoditization, the number of DRAM vendors has decreased as shown on the Figure 1-6, the data shows the number of players in the industry toped 23 in the late 1990's but after then it kept falling down to eleven in 2012. Moreover, the market concentration has been continuously increased, in other words, leading companies in the industry have gained more market share.

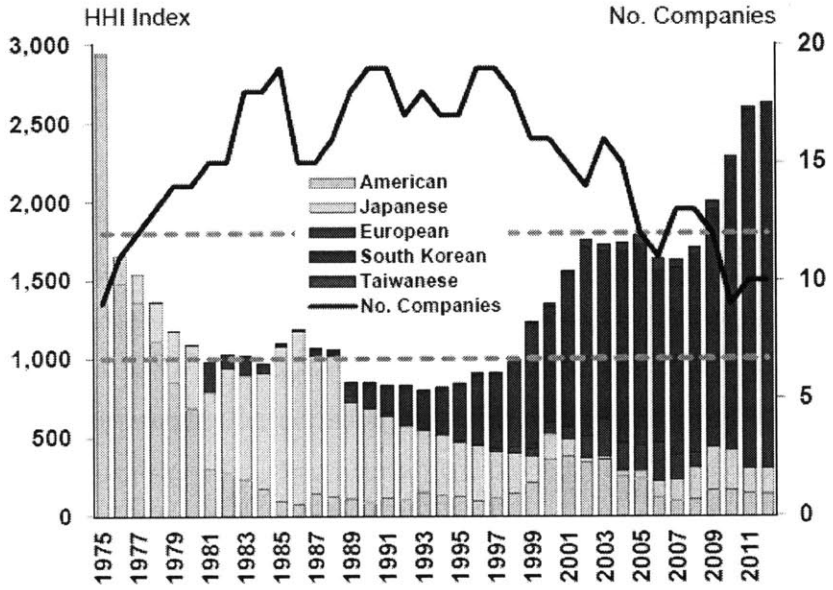
As a market concentrated, a smaller number of vendors account for a large proportion of market revenue. Herfindahl-Hirschman Index (HHI) is a widely used measure of market concentration of which range from near to zero to 10,000. The HHI for an industry is calculated by summing the squares of each market share of all the market participants. Almost zero value of HII means that there are countless firms - each having fractional market share, meaning perfect competition; monopoly has the value of 10,000, if one firm has 100 percent of market share. The U.S. Department of Justice and the Federal Trade Commission use the HHI to guide merger policy, based on three types of market: when the value of HHI is higher than 1,800, the industry is regarded as highly concentrated , the value between 1,000 and 1,800 means moderately concentrated and the value below 1,000 is referred to not concentrated. As a market consolidates, it tends to be stabilized, meaning price of product or service, revenue growth of the market,

[27] Weil, H. B.,(2007), System Dynamics Review, 23, 2-3, 137-156, Application of system dynamics to corporate strategy: an evolution of issues and frameworks

[28] Burgelman, R. A, (1996), Strategic Manage.J., 17, S1, 193-214, A process model of strategic business exit: Implications for an evolutionary perspective on strategy

and profitability of firms become less volatile than when market is not concentrated. DRAM market's HHI has been steadily growing up to 2,633 in 2012 as shown on the Figure 2-10, and when Elpida, just went bankrupt, is merged by Micron, HHI will rise sharply.

Figure 2-10 HHI of DRAM industry



Source: Gartner (March, 2013)

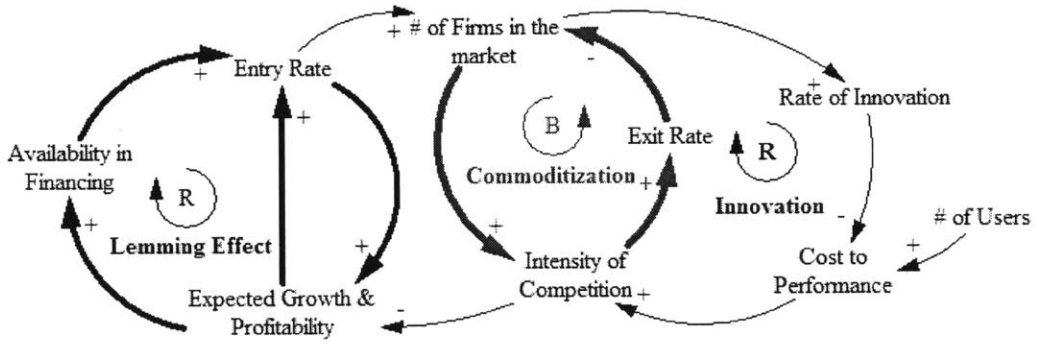
However, DRAM industry gets more and more concentrated, the volatility of economic factors: DRAM price, market revenue, manufacturers' profitability has not been less volatile compared to the time when the industry was not as concentrated as now. For example, the market size severely dropped from US$39.5 billion to US$29.5 billion in 2011. This tells the market concentration has less influence due to the strong commoditization effect in DRAM industry.

2-6-2 System Dynamics modeling: market concentration

The reason why DRAM companies have left the industry can be also explained with a System Dynamics model as shown on the Figure 2-11. There are two reinforcing loops – Lemming effect and Innovation; each one accelerates Commoditization by increasing the two variables in the Commoditization loop – number of firms and Intensity of competition. As described above, technology or innovation drives cost to performance, in DRAM's case, mostly cost reduction, and this eventually, increases intensity of competition. In addition, wherever expected growth in the market is discovered or the market shows steady growth such as booming years in the DRAM industry cycles, a number of firms tend to enter the industry and it increases the number of firms in the industry and also raises the

competition intensity. The both reinforcing loops at the end accelerate Commoditization loop, eventually making exit rate higher and higher.

Figure 2-11 A System Dynamics model of commoditization, lemming effect, and innovation



Source: Henry Birdseye Weil

Many firms have left the market as shown on the Table 2-7, some of them once had around 20 percent of market share at their heyday, meaning they were at that time leading companies in the industry but had to leave in a few years. Most of them had to be merged by the other companies, some of the merged firms were organized by governments' reorganizational plan such as Hyundai and LG had to merged as Hynix by the order of Korean government; the others were by fully economical reason. Some of the firms that went bankrupt or fell into financially severe status had to sell their capacity namely fabs to other semiconductor industry – Qimonda, and Powerchip.

Table 2-7 significant market departures in DRAM industry

Exit Year	Company	Prior Year's Share & Share of Overall	Peak Share and Year	Notes
1995	Intel	0.3% (0.5%)	82.9%, 1974	Exited the mainstream business in early 1980s and slowly phased out of the DRAM business.
1998	Texas Instruments	6.2% (17.5%)	25.7%, 1976	Sold its DRAM operations to Micron Technology.
1998	Motorola	0.6% (1.5%)	8.9%, 1982	Sold its DRAM operations to Infineon (then Siemens) after the downturn in 1996.
1999	LG Semicon	7.9% (78.2%)	7.9%, 1998	Taken over by Hyundai Electronics Industries, creating Hynix.
2000	NEC	8.8% (19.9%)	17.1%, 1986	Merged its DRAM operations with to form Elpida Memory.
2000	Hitachi	4.8% (16.9%)	19.0%, 1985	Merged its DRAM operations with NEC to form Elpida Memory.
2001	Toshiba	6.4% (11.7%)	19.3%, 1988	Sold its commodity DRAM operations to Micron, still retaining some specialty DRAM production.
2002	IBM	0.6% (0.3%)	7.8%, 1993	Originally a supplier to IBM's captive market, the company saw a slow exit from the industry.
2002	Mitsubishi	1.8% (8.3%)	13.9%, 1986	Merged DRAM business into Elpida.
2004	Mosel Vitelic	2.9% (100%)	2.9%, 2003	Withdrew from the market while its previous foundry partner ProMOS picked up its sales.
2009	Qimonda	9.5% (27%)	15.4%, 2003	Qimonda moves into bankruptcy, fabs sold
2011	Powerchip	1.5% (89%)	4.3%, 2006	Withdrew from the branded market. sold fab in 2013
2012	ProMOS	1.2% (100%)	4.3%, 2006	Withdrew from the DRAM market to focus on design activity
2013	Elpida	12.7% (99/9%)	16.4%, 2009	Taken over by Micron

Source: Gartner, June 2012

Chapter 3: Strategic suggestions

3-1 Service strengthening

3-1-1 Role of service in technology industry

Services in product industry have been defined as following: what "(a) can be sold or given away separately from the industry's "physical" products; (b) relate directly to the industry's products and may even be necessary to use those products, but; (c) are not part of the production process of the physical goods themselves." (Cusumano, Kahl, Suarz, 2008) As an industry gets more commoditized, companies in the industry tend to compete with minor differentiations of their products or services related to them. During this process, Service has a significant role in manufacturing industries, especially if products of those industries are of complexity or uncertainty in terms of technology; such services as consulting, customization, installation, technical support, maintenance, repair and training are typical way of differentiating from competitors marketing activities. What is more important is that those service activities can create new business models or opportunities to generate more profits; for example, in mainframe business manufacturers make a lot of money through their maintenance or upgrade of the systems, training of customers' employees, and customization of the products fitting customers use. What is well-known is that services can be more profitable than commoditized physical products. In addition, these service activities become another competitiveness of a firm by differentiating their values to customers. Because services are generally more labor intensive and time consuming to achieve a higher level of quality than mass production products, they often become a source of competitive advantage for a firm that cannot be easily copied by its competitors.

Even though most firms have realized the significance of service in manufacturing business as services can be another profit generator or differentiation method, it is hard to find a long list of successful manufacturing companies in service strategy. There are three hurdles hindering service strategy: (1) Manufacturing firms' management might not believe in the economic potential of service components for their product or business. (2) Although firms know the importance of service in their business, they think service is beyond their business scope. (3) Firms trying to strength their service components fail to deploy their service strategies. [29]

[29] Olivia, R. & Kallenberg, R. (2003), International Journal of Service Industry Management, 2003, 14, 2, 160-172, Managing the transition from products to services

3-1-2 Services in DRAM industry

According to a thesis, "A theory of services in products industries", the authors insist that significance of service grows as level of technology, use complexity, or market uncertainty increases. And the level of customized as opposed to standardized services also increases as those elements grow; however, manufacturers are likely to provide a smaller share of product specific services when there is industry wide product platforms and higher degrees of product modularity.[30]

DRAM industry has been following strictly this assertion. Even though there are a lot of opportunities in service in DRAM industry, DRAM vendors have not made any services as their business model that can be sold to the component buyers. In a DRAM sales process, there are several steps that DRAM manufacturers and customers make: when a new DRAM product is launched, DRAM vendors send sample products for qualification process of customers' IT devices. This qualification process is the procedure that manufacturers - producing servers, PCs, mobile phones, or any other electronics devices - precede by optimizing a component to their product design to achieve expected performance, to prevent operational failures, or to improve manufacturing efficiency. During this process of qualification, DRAM customers need a whole set of data from DRAM vendors to make sure a new DRAM fits their system and also to optimize system performance and they test their system with the new DRAM samples installed under various conditions including different temperature, voltage, and so forth, by working with engineers from DRAM firms; this qualification process takes from a couple of months to six months, depending on technical complexity or required reliability of customer's system. After the qualification process, DRAM manufacturers deliver mass products of a new product and customers use them for their products. However, when there is a quality issue on a customer's product related to DRAM, DRAM vendors have to work closely to resolve any quality issues by testing the DRAM products with customers' equipment or devices and finally to find a solution that will make the failure not to happen again. DRAM vendors deliver a report of modifications on DRAM products with data and test results.

Although DRAM manufacturers are taking part in various activities during the sales process as described above, especially in design and quality process with their customers, they do not charge any of those activities yet but just give those services away when they do business so far. There are a few reasons why they cannot regard service as their part of business model generating profit but as complementary one to sell physical products. At first, DRAM business is a kind of a standardized electronic component business that makes a strong product-centered organization; namely, it tend to be an

[30] Suarez, F., Cusumano, M., & Kahl, S., (2008), MIT Sloan School of Management, Services and the business models of product firms: an empirical analysis of the software industry

organization pursuing technologic advance, cost reduction, and manufacturing process improvement. The second reason is that because DRAM vendors have concentrate on technology advance and cost reduction activities, there are a number of third party distributors providing various service in the industry – such services as inventory keeping, technology consulting, and even qualification support. Although those firms have medium or small end customers but they sometimes work with industry leaders including Dell, one of the leading PC makers.

3-1-3 Service strengthening strategy

There are still opportunities for DRAM companies to commercialize their services; I will focus on knowledge transfer in two segmentations. Most forms of services including consulting, customization, installation, technical support, maintenance, repair, and training, are transference of knowledge about products and their use between producers and customers. In DRAM industry, current services of qualification and failure analysis are also a form of knowledge transference, because DRAM vendors analyze DRAM test data and deliver it to customers in those cases, on the other hand, DRAM vendors also learn how customers optimize DRAM and other electronic components in their systems, and what customers need in terms of DRAM performance or specification. DRAM vendors must have accumulated such knowledge about designing and optimizing the electronic devices as well as about DRAM itself. And I believe sharing this knowledge with customers through consulting and technical supports from customers' design procedure will be another opportunity of service that will make a DRAM manufacturer differentiated from its competitors and also have longer business relationships with customers.

At first, I suggest DRAM vendors employ their knowledge about heat efficiency control in servers, main frames, and mobile devices. When the customers producing those devices, energy efficiency is one of the most critical factor that differentiate from their competitors' products, because energy efficient servers reduce operating cost of end users, such as data centers or research centers, and mobile phone producers can design phones having longer operating hours. In addition, when it comes to mobile phones, safety related to heat is also critical issue in designing phones since mobile phones are mostly carried by people attached to their bodies; reliability issues such as explosion of phones due to over-heated system can be fatal safety accident for mobile phone producers. DRAM is one of the priority components consuming electricity in devices; for example, in servers or main frames DRAM is the second energy consuming component next to CPU. DRAM producers have accumulated knowledge and skills that is necessary for system designing and optimizing in different IT device manufacturers by working with different electronics producers by sharing experiences, quality data. They can work with

their current customers from the initial design step of customers' products by helping them to optimize electricity efficiency related to DRAM.

My second suggestion is a reliability issue for servers or main frames. In the server industry, today, virtualization is a dominating trend that makes one physical machine of server works as a multiple ones by using software. Virtualization has many benefits, however it raises DRAM contents and DRAM reliability becomes more important for end customers, who have thousands of servers in data centers. Following this trend server producers now promote their server DRAM quality by assuring the reliability through their own test procedures and some of the procedures are done with DRAM vendors. It is well-known that server producers add high premium on those DRAM modules when they sell them as upgrade parts. I believe that DRAM venders can enter this maintenance or upgrade service market by assuring the compatibility and reliability of DRAM for any kinds of servers with their own DRAM modules. Even though this approach will cannibalize their server business with server producers, however there is a new trend that some of the major end customers such as Facebook, Google and Amazon, which have the biggest data center capacity in IT industry, purchase their upgrade DRAM modules directly from DRAM vendors. Whoever strengthens this server upgrade service market will seize the opportunity of fast growing market because the other end customers will follow the trend of building or upgrading their own server systems.

The third opportunity for DRAM vendors is that they can help mobile phone companies design not only with energy efficiently with high performance DRAM technology, but also with thinner design both by support with thinner multi-layered memory and by support design knowhow from DRAM vendors' knowledge and skills that has been built from long experience of working with various mobile phone producers. It is needless to say consumers prefer slimmer or thinner designs for their mobile phones and each electronic component has to squeeze its size to meet mobile phone producers' requirement of performance and sizes. DRAM vendors especially help on designing DRAM related parts but this process will help mobile phone producers know how to squeeze the sizes of components on their phones circuits, by learning from DRAM vendor's technologic consulting on DRAM designing.

It will not be easy for DRAM producers to commercialize services they can provide, because DRAM producers have been concentrating on cost reduction as their competitive advantage but overlooked the significance of services as core element of competitiveness. For DRAM vendors conventional point of view, the main goal of service activities it either preventing from any quality failures or pulling the sales schedule by finishing customer qualification as soon as possible; under this situation, DRAM vendors have minimized inputs including human resource and research and

development budget into their current service activities. What I can suggest is that DRAM vendors have to organize a new team in charge of these advanced service activities separately, in other words, new place with new assigned jobs under their own reporting channel to top managements. This method of building an independent team will give the team members think of services as their products to sell, and make them have a new vision of their current activities.

Strengthening services for DRAM manufacturers will at first give them a powerful differentiated strategy by giving additional values to their customers; secondly, through service activities they will also reinforce their relationship with customers so that they gain opportunities of understanding customers' needs more concretely; they can gain more market share or even strengthen customer relationships, not losing customers through lower price approach from competitors. Finally, and most importantly, DRAM producers will find a business model of those upgraded services, directly contributing their business performance with higher profit level.

3-2 Beating the escalation trap

3-2-1 The escalation trap

DRAM pricing has been mainly affected by demand and supply ratio so far. DRAM producers regularly have meetings, negotiating sales price and quantity with customers – mostly monthly; DRAM price has been set under the market situation, depending on whether it is under oversupply or shortage. DRAM price has been historically dropping by around 30 percent every year, so that DRAM vendors have had to either reduce their cost by 30 percent or increase production by 30 percent every year with huge capital spending on their R&D, equipment and capacity. However, price drop line has been extremely fluctuating, for example in 2007 and 2008, DRAM price dropped by over 50 percent but in 2009 and 2010 it dropped by less than ten percent. DRAM producers have fought against this severe volatility with dynamic pricing – different prices or different pricing contracts for different customers. However the inherent DRAM dynamics of commoditization cycle has overruled their attempts.

According to the book, "Beating the commodity trap" written by Richard A. D'aventi, this commoditization driver of DRAM industry is defined as 'escalation trap', caused by rising benefits for the same or lower price, namely the trend that DRAM content size grows but price decreases. In this market, competition is costly but no company can afford to be the first to stop and end the game of one-upmanship; in other words, one competitor is making money – in DRAM industry, it is Samsung – by leading the escalation of benefits and lowering its costs ahead of price decreases, while the others are trapped in a game of non-profitable, playing catch-up; competitiveness advantage in the past is today's

entry stakes; customers demand higher quality of products but are willing to pay less. Even an industry leader, as Samsung in DRAM industry with biggest margin and highest market share, is under the risk of this escalation trap by being threatened by a new competitor entering the market with lower priced products with the same or even higher benefits and a leading company can fall into the catch-up trap. In DRAM industry, whenever a new product is introduced, the other competitors have caught up with the new product within a year or two, and the price of the new product has been falling so quickly – typically within a year – eventually falling into commoditized cycle.

3-2-2 Beating the escalation trap

The escalation trap accelerates commoditization and is threatening most of companies in the industry, however this trap can be an opportunity for a leading company; a leading company with higher market share and more advanced technology can seize the chance to control and manage the momentum of escalation and finally to manage or reshape the escalation, in other words, it can enjoy margins with more advanced products and introduce another products with better quality when the other competitors are about to catch up with the leading company's product level by providing similar quality of the leader's current products'.

An industry leader in DRAM market, Samsung, can set a new pace of escalation trap. Samsung tends to be the only company generating profit when market falls into downturns. However, the current strategy of Samsung is still remained as keeping lower costs with similar products to its competitors. DRAM producers generally have a dynamic pricing model by having different pricing for different customers; it sells DRAM products in the lower price to customers with higher order quantity. However, they tend to put fixed premium, from five percent to twenty percent, on high performance products such as lower power, higher speed, or more reliable DRAM chips. Those different levels of premium are usually set by the additional manufacturing cost to produce high performance DRAMs: extra tests, lower level of yield, etc. Considering industry's trend that consumer electronics more value design, mobility, and efficiency, DRAM vendors must promote their premium products that can give better energy efficiency or higher performance and they have to change the pricing methodology from cost based one to customer value based approach. Following the trend, Samsung has promoted its energy efficient DRAM products for servers or main frames on its website and through the events called CIO forums to server producers and data center companies, assuring its low power product can save energy costs.

Samsung can manage the pace of escalation trap, by developing and promoting higher performance DRAMs by occupying premium segments. Even though it will take some time to make customer generally use premium products, namely, to redefine a primary benefit to customers. However,

it will give Samsung an opportunity of finding a way out of the trap by pushing down the competitors into a low end and lower margin corner so that they cannot escape from the escalating trap. This can put some growth limit to the leading company temporarily because it will take some time and financial capital to develop more advanced products and promote them but this can help slow down the severe commoditization making the volatility in the industry. What is more important is that pricing strategy of mixing various premium products with different prices will help the company avoid being benchmarked and give more opportunities to have stable prices.

Another way to beat the escalation trap is to freeze the escalation by locking customers with long term business contracts. And most DRAM firms have already adopted this strategy with major IT device producers. However this approach has a limit that each time a contract closes to the end competitors can offer lower price deals to large customers and most of the contracts are based on quarter or year.

Conclusion

This paper explains how DRAM industry has become commoditized and how it has come with the recurring cycles of upturns and downturns; both characteristics of the industry have hindered DRAM vendors from maintaining stable business performance. I have used System Dynamics modeling on a conceptual level by explaining how economic variables affect one another in the industry and how those relationships have influence on the DRAM producers' business.

It is always hard to find a way out from commoditized market and also differentiate a firm's products or business models in the market. However, I suggest two strategic options to get away from the commoditization trap in DRAM market. The first option is to make service as a DRAM firm's differentiated and also profitable strategy by giving extra value to customers – knowledge transfer. And the second suggestion is to lead the market's performance products with strategic pace management so that a leading firm can maximize its profit and also avoid its cutting edge products from falling into commoditization. I believe Samsung as an industry leader can employ the both strategies to protect and to enhance its dominant position. However, the second tier followers including Hynix, and Micron can also adopt the first strategy of enhancing services when the market reaches peak seasons. They need to focus on niche segment to adopt the second strategy, since Samsung has led the technology advances in the most of the major segments.

One of the significant industry issues such as 400mm wafer fabs has not been covered on this thesis, because that technology is at least five years away from now and it is not sure that DRAM vendors

can move to the next generation fab. To build a 400mm wafer fab will be extremely costly because equipment for each manufacturing step has to change in terms of size, reliability, and so forth. However, this new level of manufacturing technology can bring about significant cost reduction as 300mm fabs that currently appear as cutting edge technology manufacturing facilities in the industry. And there will be a technology breakthroughs in DRAM design called a three-dimensional integrated circuit (3D IC), which can make DRAM vendors effectively reduce cost per chip, however, this technology still remains in R&D status. Those new dynamics will bring impacts to the commoditized DRAM market, however, DRAM firms will have to spend immense capital on R&D and new facilities and also have to find a way to decouple price drop from cost reduction from those new technology advances.

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