Computer Processing

Case Studies

Donald P. Greenberg

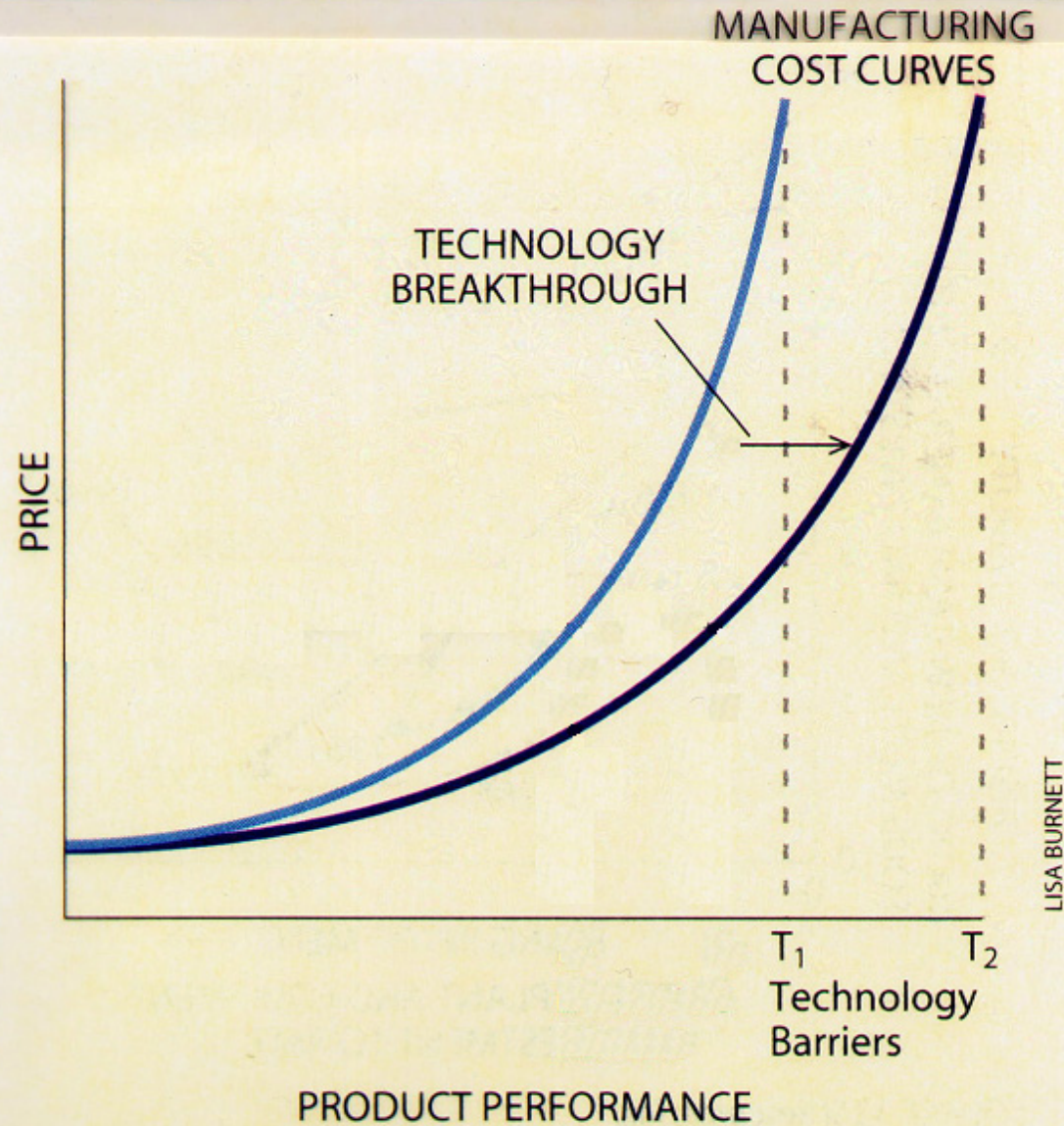September 2, 2015

Lecture #3

Required Reading

- G. Dan Hutcheson and Jerry D. Hutcheson. Technology & Economics in the Semiconductor Industry, <u>Scientific American</u>, January 1996.

- Shimpi, Anand Lal. "The ARM Diaries, Part 1: How ARM's Business Model Works." *Anand Tech*. N.p., 28 June 2013. Web. 31 Aug. 2015.

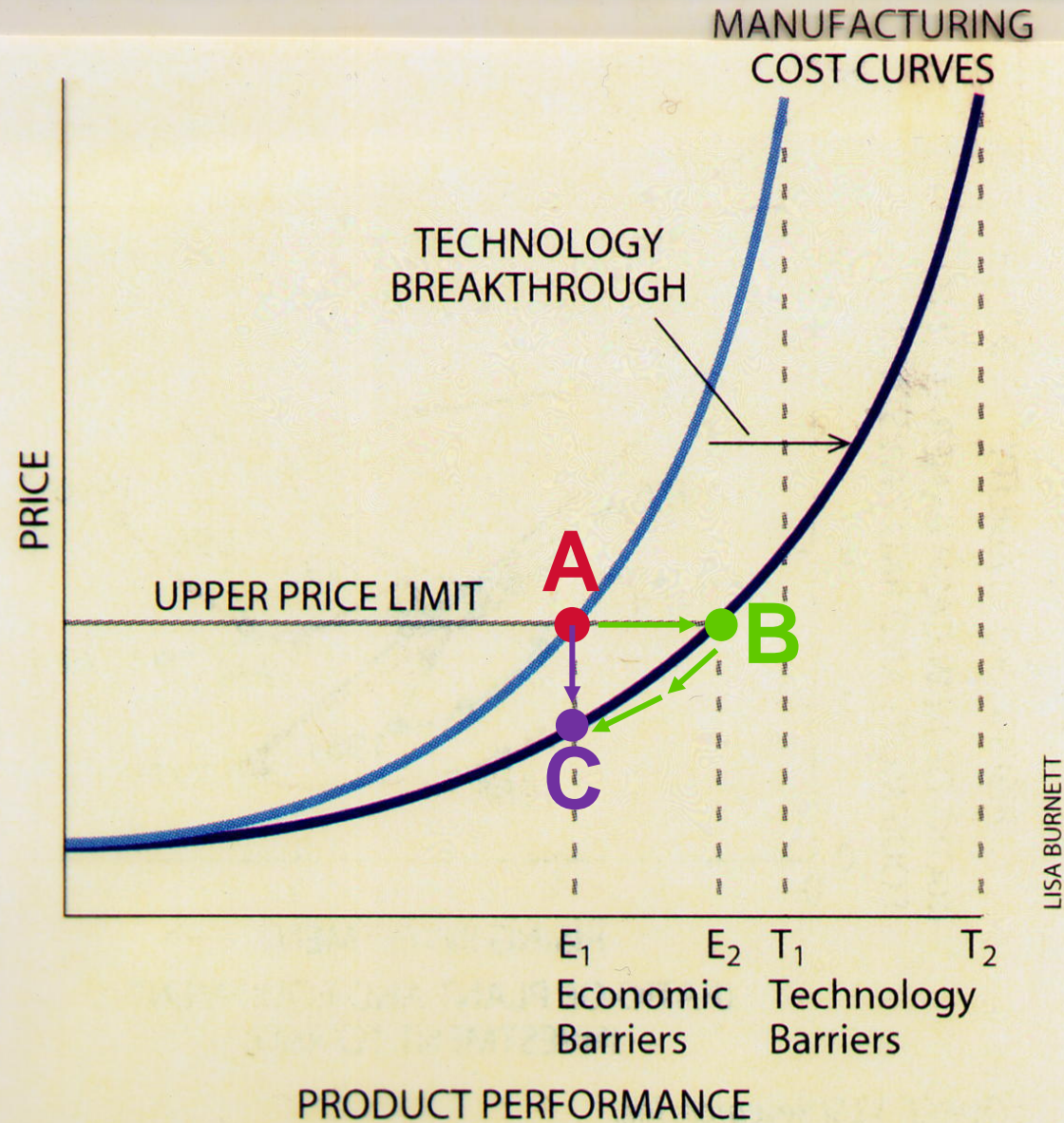# Economics of the Semiconductor Industry

- **G. Dan Hutcheson and Jerry D. Hutcheson. Technology & Economics in the Semiconductor Industry, <u>Scientific American</u>, January 1996.**

PRICE VERSUS PERFORMANCE

MANUFACTURING
COST CURVES

TECHNOLOGY
BREAKTHROUGH

PRICE

PRODUCT PERFORMANCE

T_1 T_2
Technology
Barriers

LISA BURNETT

SOURCE: VLSI Research, Inc.

PRICE VERSUS PERFORMANCE

Return on Investment (ROI)

Assumptions:

Payback period (time)

Net Present Value
Value of future benefits in today's money

Internal Rate of Return

How do you predict what the technology, manufacturing cost, market demand, market supply, and competition will be five years in the future?

Return on Investment (ROI) Model does not work well

Difficulties:

- **How long does the product last?**

- **What is the price (revenue)/unit?**

- **Exponential change**

- **Non-linear pricing behavior**

- **Competition (monopoly pricing)**

- **Prediction of demand**

- **Technical obstacles**

Profitability vs. Investment in the Computer Industry
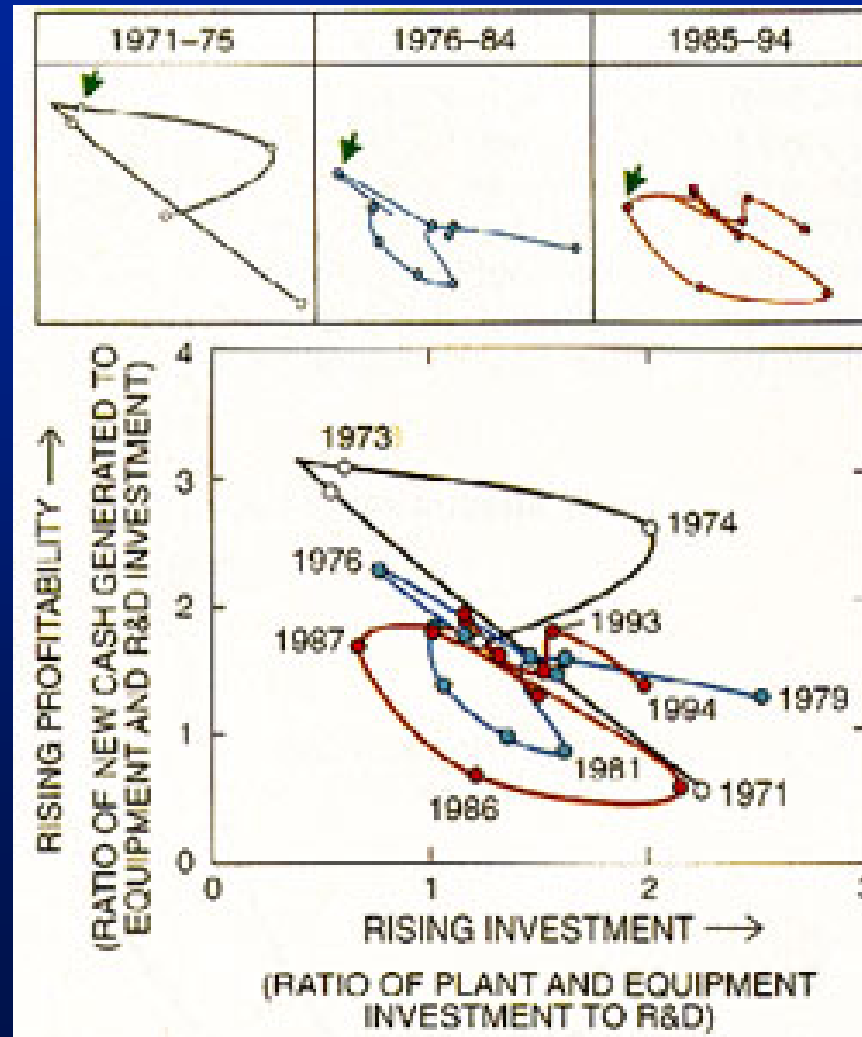
Profitability vs. Investment in the Computer Industry

Rising Profitability

$$\text{Measured by ratio} = \frac{\text{cash generated during year}}{\text{investments made in new technology previous year}}$$
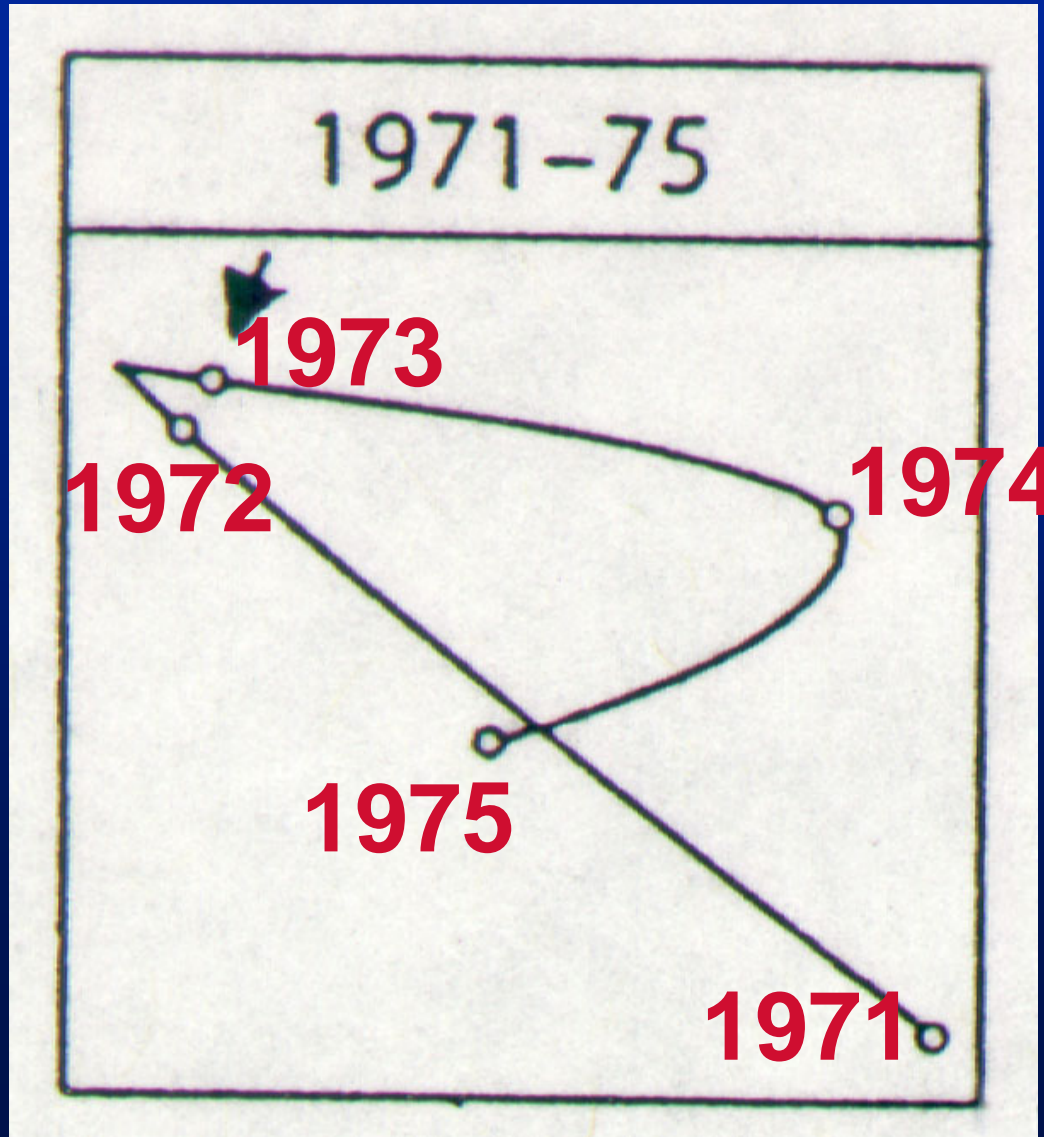
$$\text{where new technology} = \text{new equipment} + \text{R \& D}$$

$$\text{cash} = \text{gross profit (including R \& D)}$$

Rising Investment

$$\text{Measured by ratio} = \frac{\text{plant \& equipment investment}}{\text{R \& D}}$$
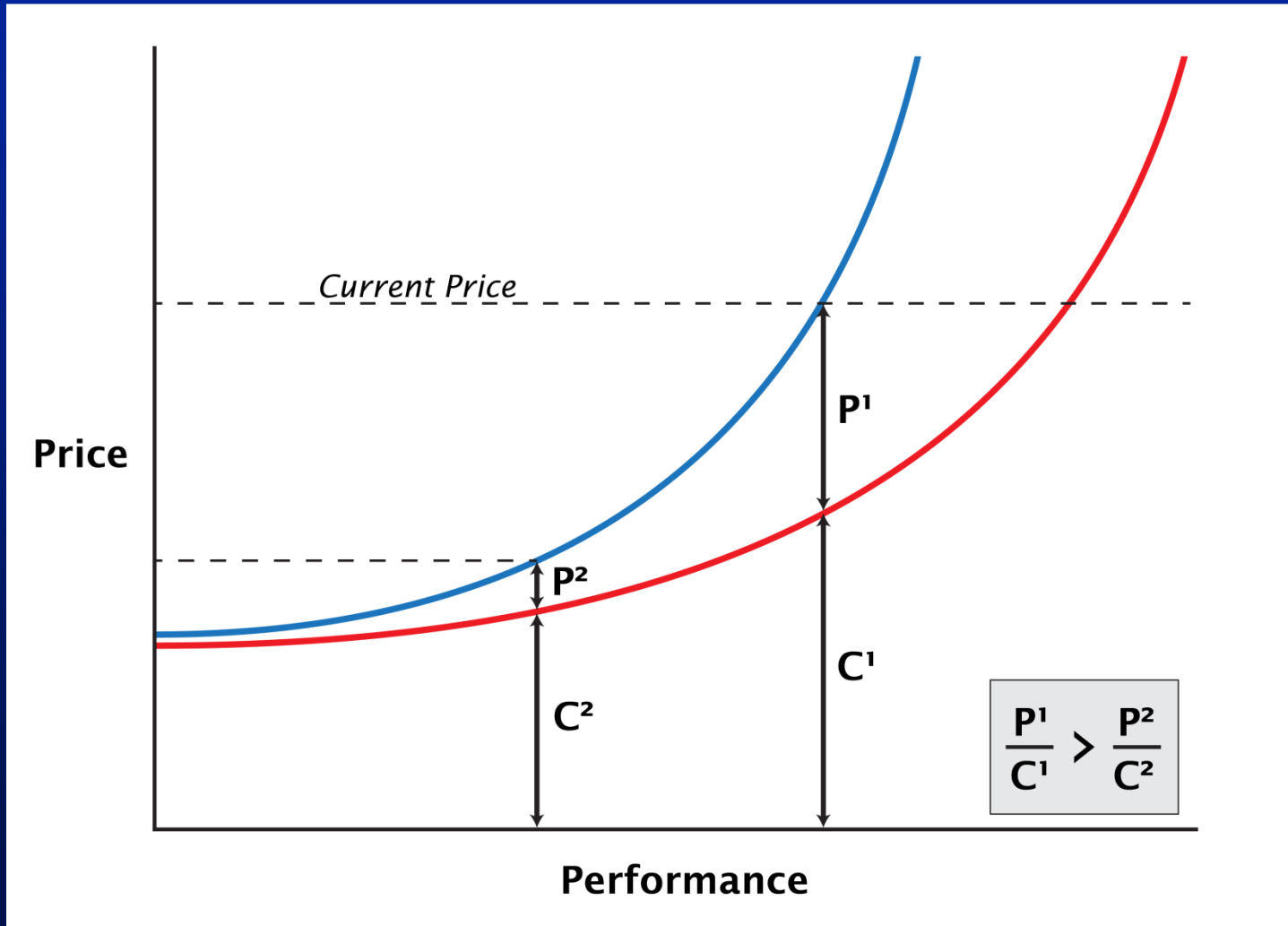
Profitability vs. Investment

Profitability vs. Investment in the Computer Industry

- It is obvious that with the shrinking technology, it is getting more expensive to move to the next generation process technology.

- It is also obvious that the manufacturing cost as well as the sales price of processing chips is decreasing rapidly.

Price vs. Performance

New Gross National Product Accounting

- On July 31, 2013, the U.S. Bureau of Economic Analysis restated the size & composition of the GNP

- R&D will no longer be treated as an expense (original work of art, film, music & books will also be treated as "long-lived assets"

- U.S. Gross National Product will get an immediate 2.7% boost

New Gross National Product Accounting

- Intangible investment is not a faddish new idea

- In the 1930's & 1940's economist Joseph Schumpeter made intangibles the centerpiece of his theory that economies grow through innovation

- Ben Bernanke in a 2011 speech also promoted this idea to stimulate innovation
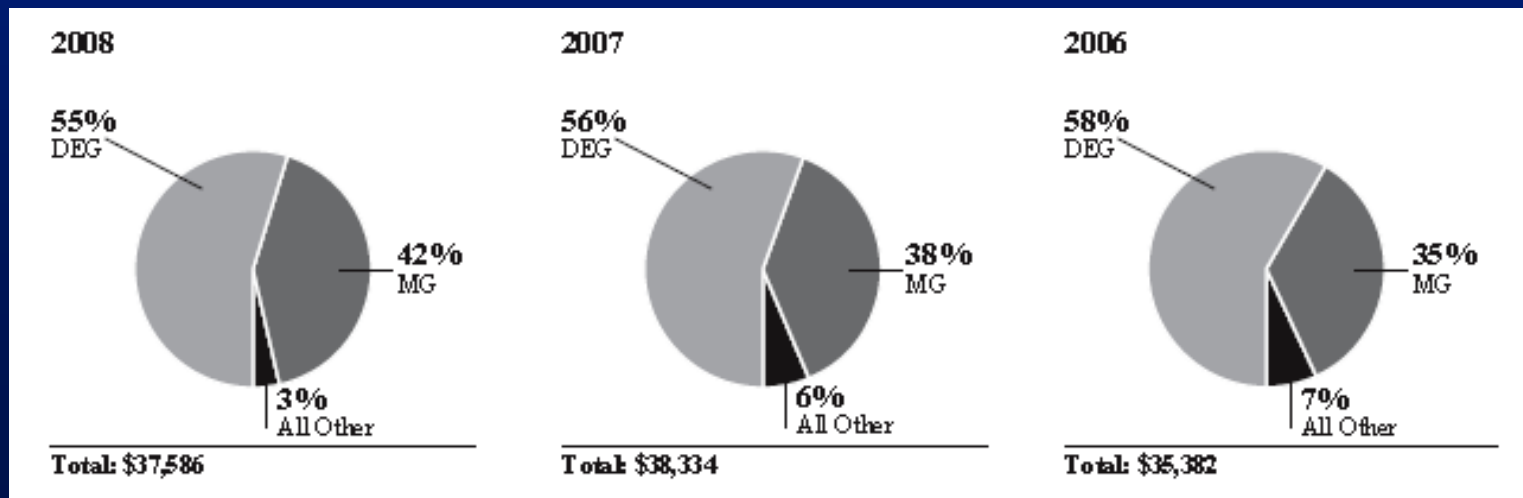
Intel 2007

- The growth in mobile microprocessors outpaced the growth in desktop microprocessors.

- Systems price points have migrated to lower levels and average selling prices indicate continued erosion.
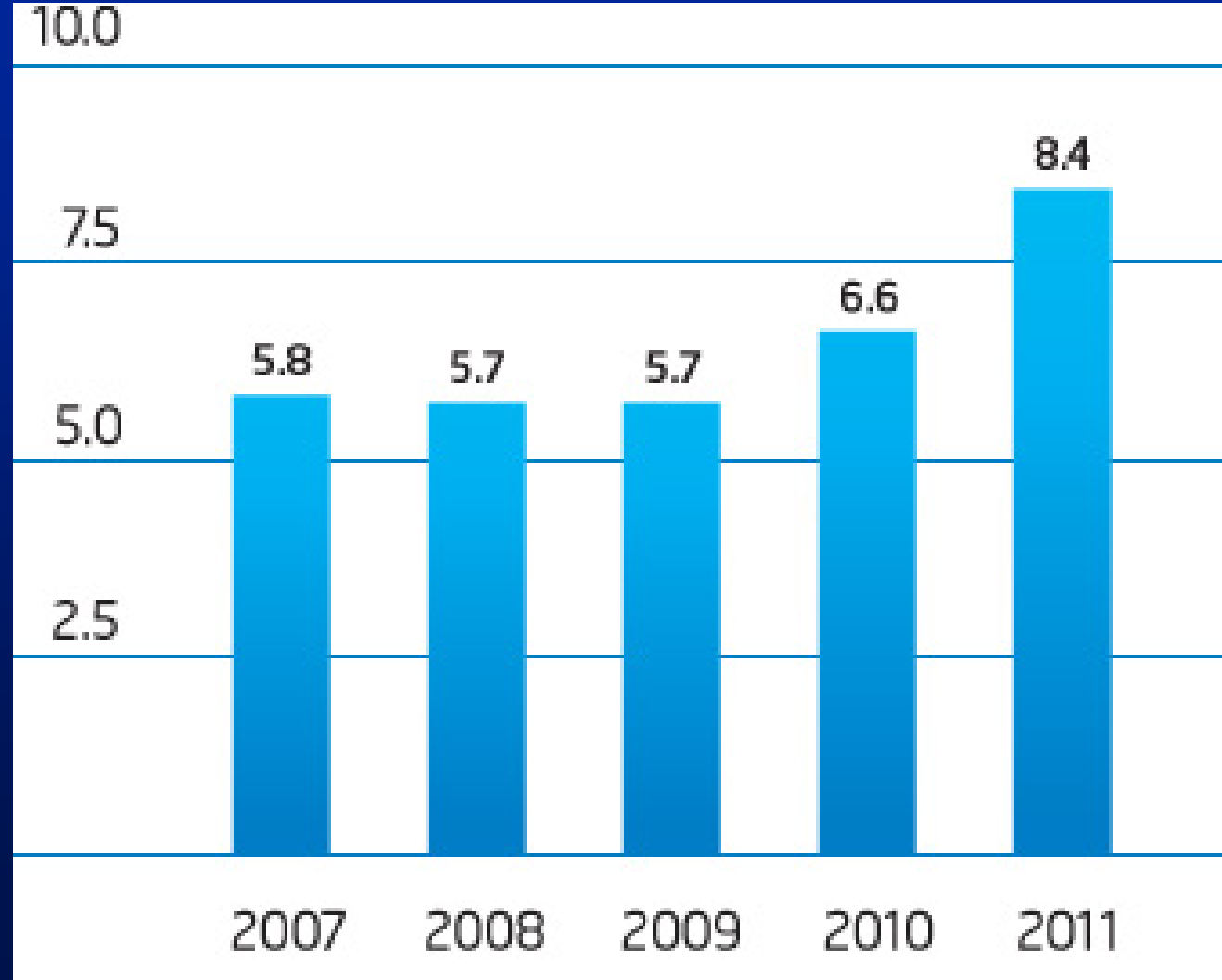
Intel 2007

- Mobile microprocessors ASP's are less than desktop microprocessor ASP's.

- In 2007 gross margins were negatively impacted by declining ASP's and higher start-up costs for the new 45nm process technology.

- At the end of 2007, Intel had roughly $20B cash.

Intel   2008

- In 2008 the average selling price for all products continued to decline

- The revenues for the mobility group as contrasted to the digital enterprise group continued to increase

Percentage of Revenue (Dollars in Millions)

2008
55% DEG
42% MG
3% All Other
Total: $37,586

2007
56% DEG
38% MG
6% All Other
Total $38,334

2006
58% DEG
35% MG
7% All Other
Total: $35,382

Intel Research and Development

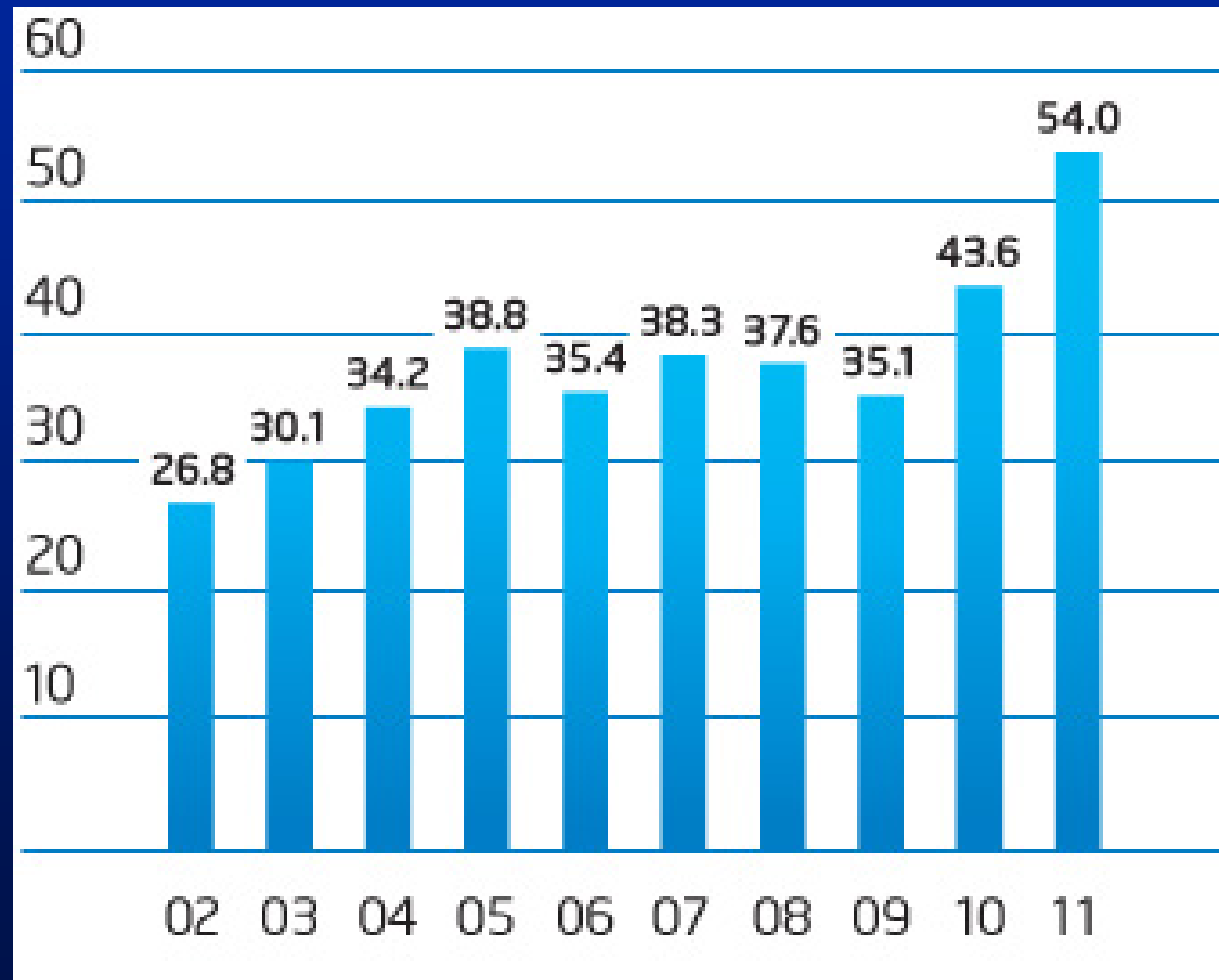# Intel Capital Additions to Property, Plant and Equipment
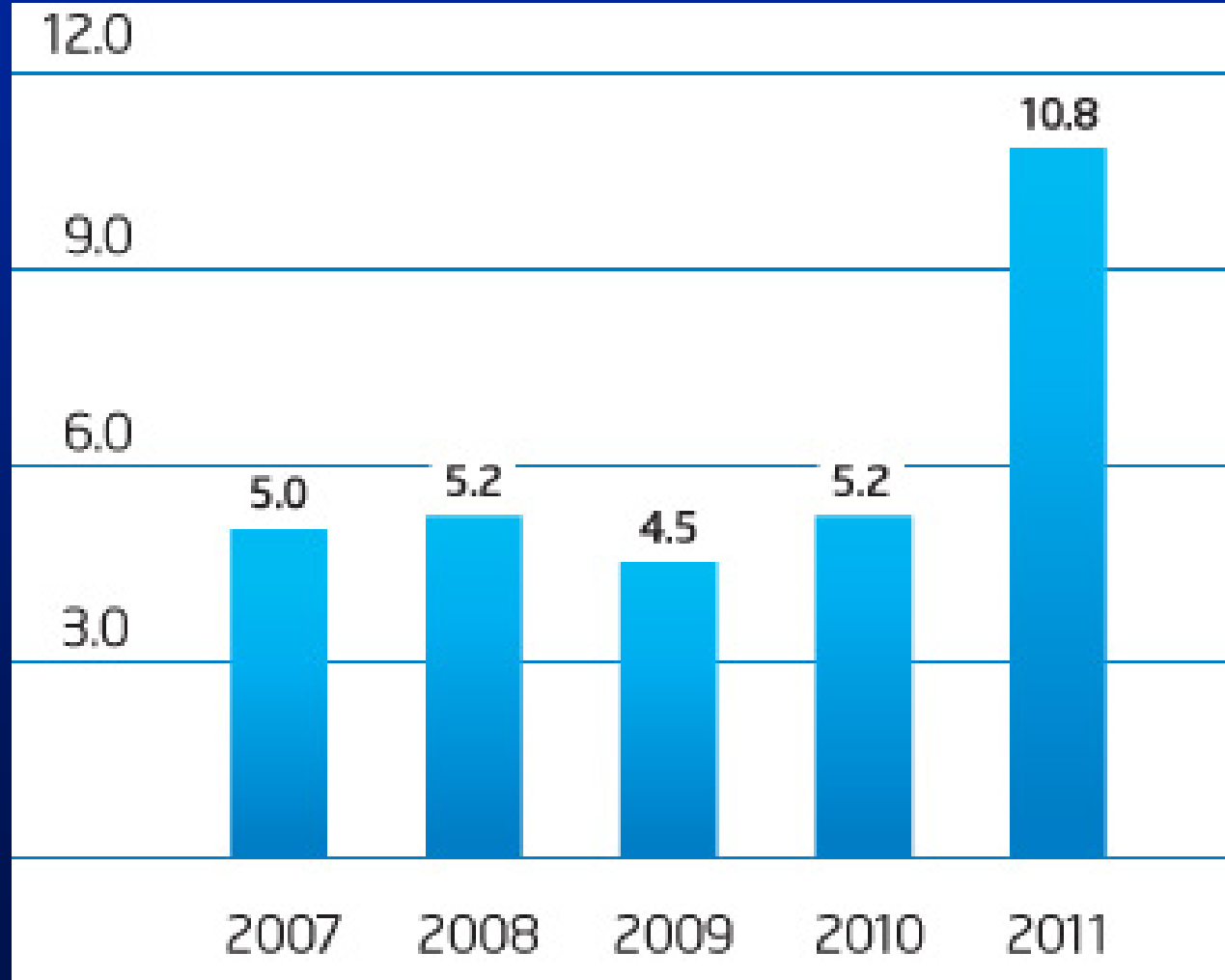
Intel's In a Sweet Spot 2011

- Having invested in its 32nm fab, Intel achieved higher than expected efficiencies and introduced new chips faster than expected.

- Sandy Bridge, their latest microprocessors was introduced in 2011.

- AMD, even if it designed better chips, was stuck with its 45nm production and couldn't compete. Their chips were more expensive to produce.

- Intel's new chips possibly eroded the graphics market for competitors (nVidia & AMD) as PC makers no longer needed stand-alone graphics processors.

Intel Net Revenue   2011

Intel 2011

- A new fab costs approximately $3-4B or more

- Should Intel Continue to Invest In Creating New Fabrication Facilities?

Intel Net Revenue   2012
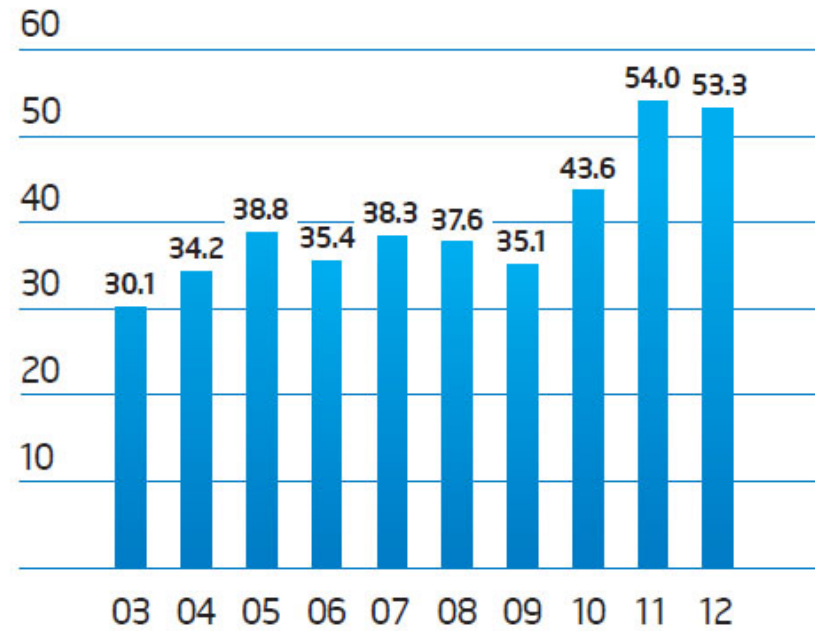
Capital Additions to Property, Plant and Equipment
Dollars in billions
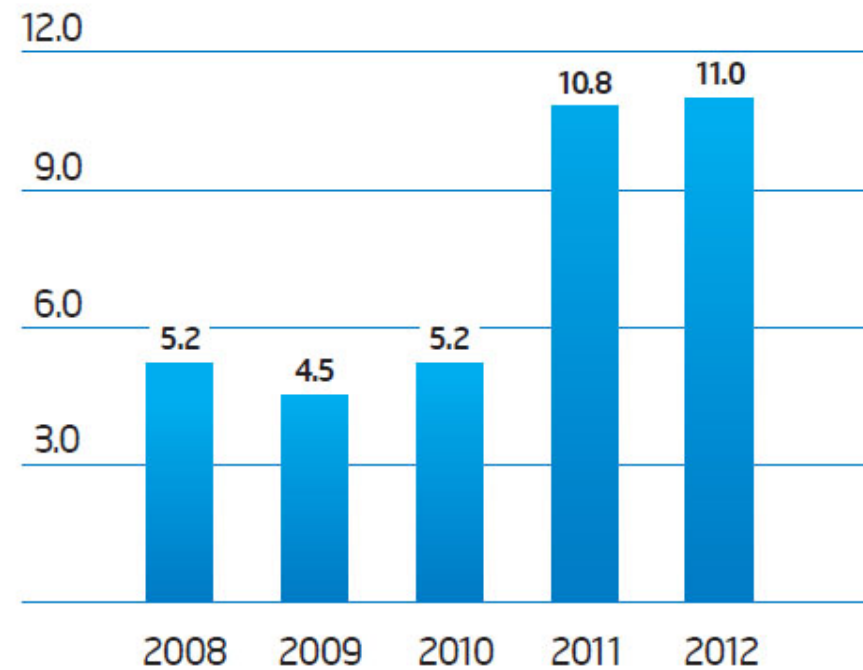
Intel Research & Development   2012

Intel 2012
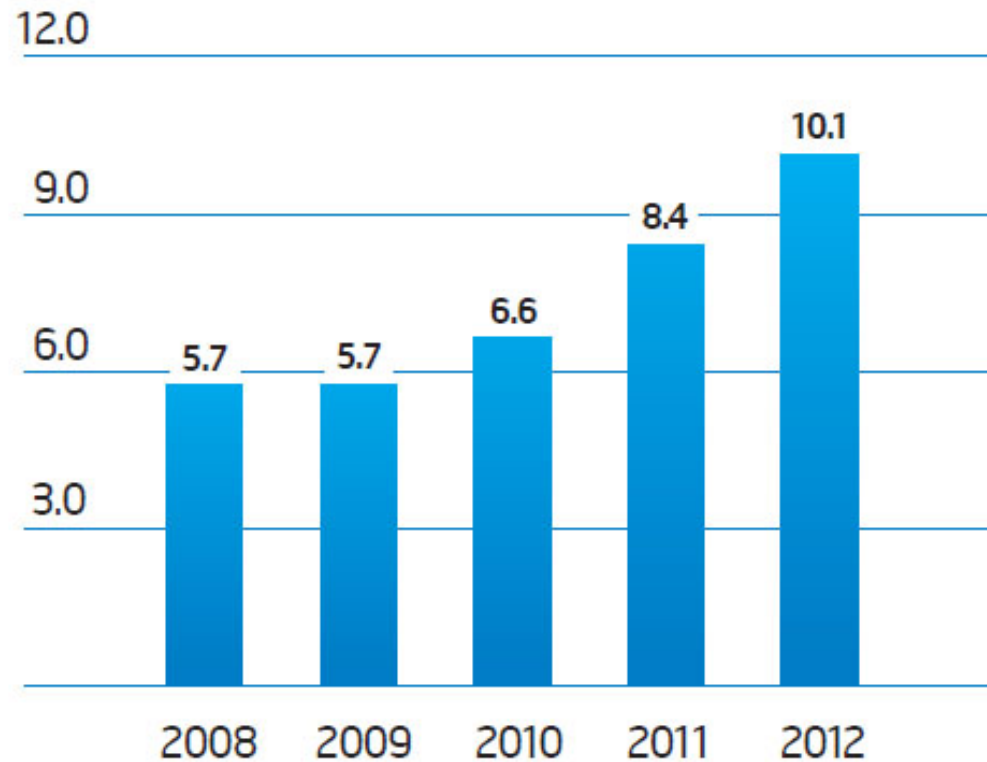
- Intel announced that it would spend $9B to upgrade four fabrication plants to move to 22nm technology (one in Israel).

- ARM and IBM announced a joint agreement to move to 14nm technology.

Computer Industry Problem   2013

- The high price servers are representing a much smaller percentage of revenue stream

- The prices of laptops and netbook computers are continuing to decrease

- Competition and price wars in the mobile computing segments (mobile phones, smart devices, tablets) are fierce

Intel   2014

- In 2011 Intel had announced it would build a $5B high-tech manufacturing plant, Fab 42, in Arizona.

- 2012 President Obama visited the plant and mentioned Fab 42 in his State of the Union Address.

- January 14, 2014, Intel puts the new Arizona chip factory on back burner.

- Why did Intel PAUSE?

Intel   2015

- Intel again delays 10nm technology. It will depend on revenue increase from Windows 10 and its new Skylake processor.

- The second generation of 14nm production technology had significant yield improvements.

- At the same time, Intel moved to purchase Altera so it could shift from PC's to mobile devices.

Intel's Hillsboro   2015
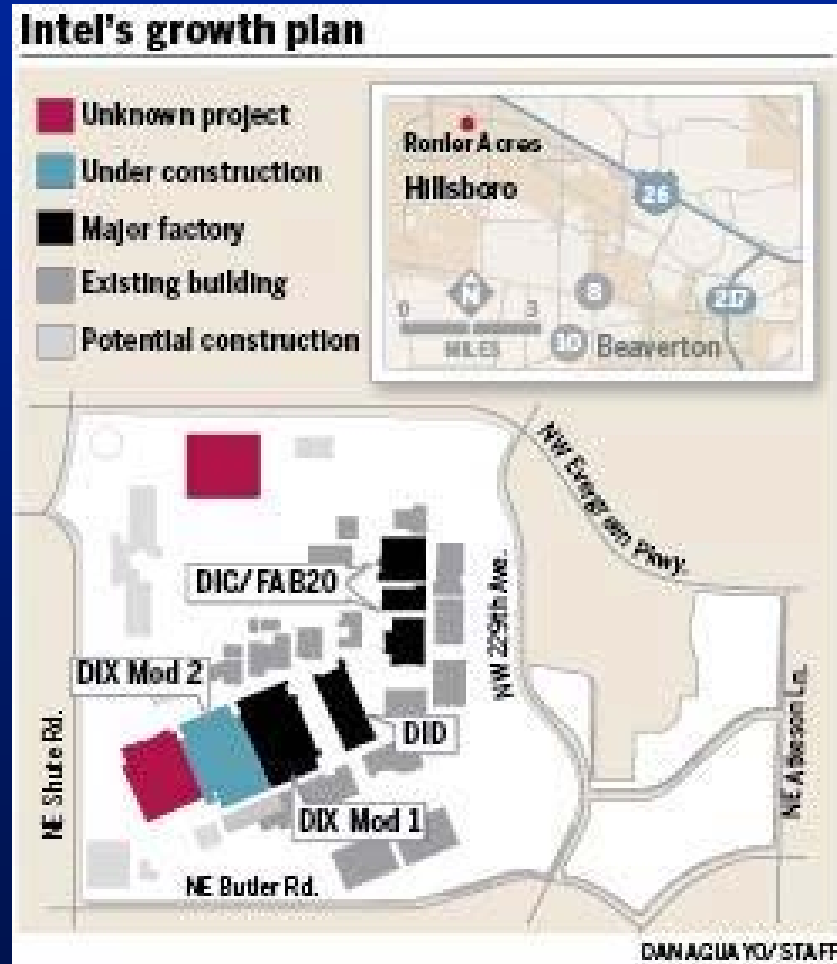
Foundry Model

- Many companies (Integrated Device Manufacturers, IDMs) design and manufacture integrated circuits (efficiency through vertical integration)

- Today, there are many companies that:

  - only design devices (fabless semiconductor companies),
  - as well as *merchant foundries* that only manufacture devices.

- The *foundry model* is a business vision that seeks to optimize productivity.

- In 1987, the world's first dedicated merchant foundry opened its doors: Taiwan Semiconductor Manufacturing Company (TSMC)

source: https://en.wikipedia.org/wiki/Foundry_model

TSMC's Customers

- Manufacture's chips for

  - Qualcomm

  - Nvidia

  - Advanced Micro Devices (AMD)

  - Broadcom, Altera

    > (even some for Intel & Texas Instruments)

  - Apple's A5, A6 for iPad & iPhone

  - Apple's new A8

source: https://en.wikipedia.org/wiki/TSMC

TSMC's Revenue 2014

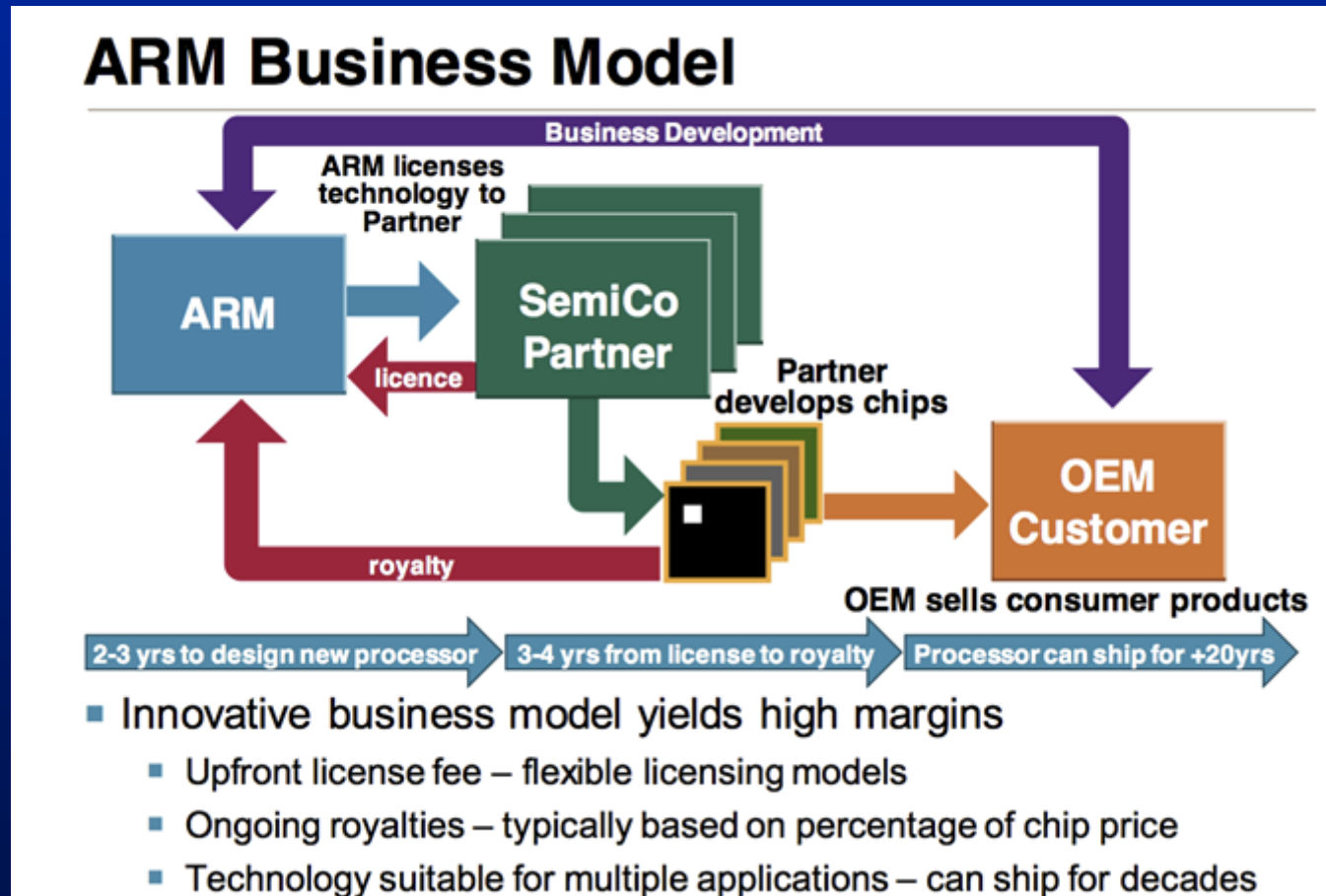- In 2014 TSMC's Revenue reached 25 Billion USD.

- They are particularly at producing low power mobile devices at 28nm.

- They capital spending was between 10.5 – 11 Billion USD.

TSMC's Fabrication Plants   2014

- TSMC had four 300mm wafer plants in Taiwan

- TSMC had four 200mm wafer plants in Taiwan

- TSMC had one 200mm wafer plant in Shanghai, Washington State, Singapore, and other smaller plants.

ARM Holdings - Business Model

ARM Business Model

Business Development

ARM licenses technology to Partner

ARM → SemiCo Partner

licence

Partner develops chips

royalty

OEM Customer

OEM sells consumer products

2-3 yrs to design new processor | 3-4 yrs from license to royalty | Processor can ship for +20yrs

- Innovative business model yields high margins
  - Upfront license fee – flexible licensing models
  - Ongoing royalties – typically based on percentage of chip price
  - Technology suitable for multiple applications – can ship for decades

Shimpi, Anand Lal. "The ARM Diaries, Part 1: How ARM's Business Model Works." *Anand Tech*. N.p., 28 June 2013. Web. 31 Aug. 2015.

ARM Holdings

- Original name was Acorn Computers

- In 1990 a new customer arrived, Apple: and company was renamed Advanced RISC Machines (ARM)

ARM Holdings   2014

- By 2014, ARM dominated the smartphone market and had the following market share

    - 95% smartphone market

    - 10% mobile market

    - 35% digital TV's

    - 23% PC's

- In 2014 ARM cores were licensed for 12 Billion chips

ARM's Customers

- Apple (iPhone 5, iPad, iPhone 5s, iPhone 6, etc.)

- Samsung (Galaxy S4, S5, etc.)

- Qualcomm (Snapdragon)

Will the cost of new fabrication plants lead to an oligopoly in this industry?

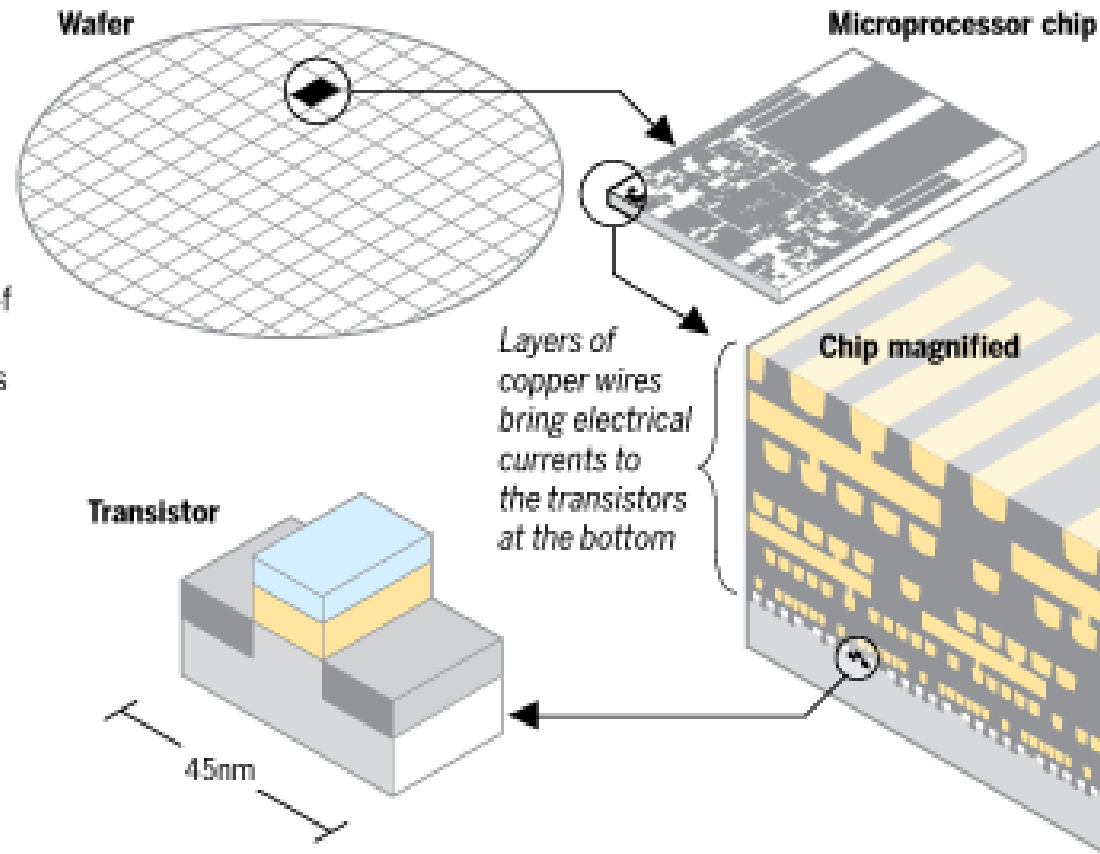# Fewer companies can deliver smaller and more powerful chips (July 20, 2009)

Fewer companies can deliver smaller and more powerful chips

Microprocessor
The 'brain' of a computer. Contains hundreds of millions of transistors interconnected by fine wires made of copper. Each transistor acts as an on/off switch, controlling the flow of electricity through the chip to send, receive, and process information up to 300bn times a second
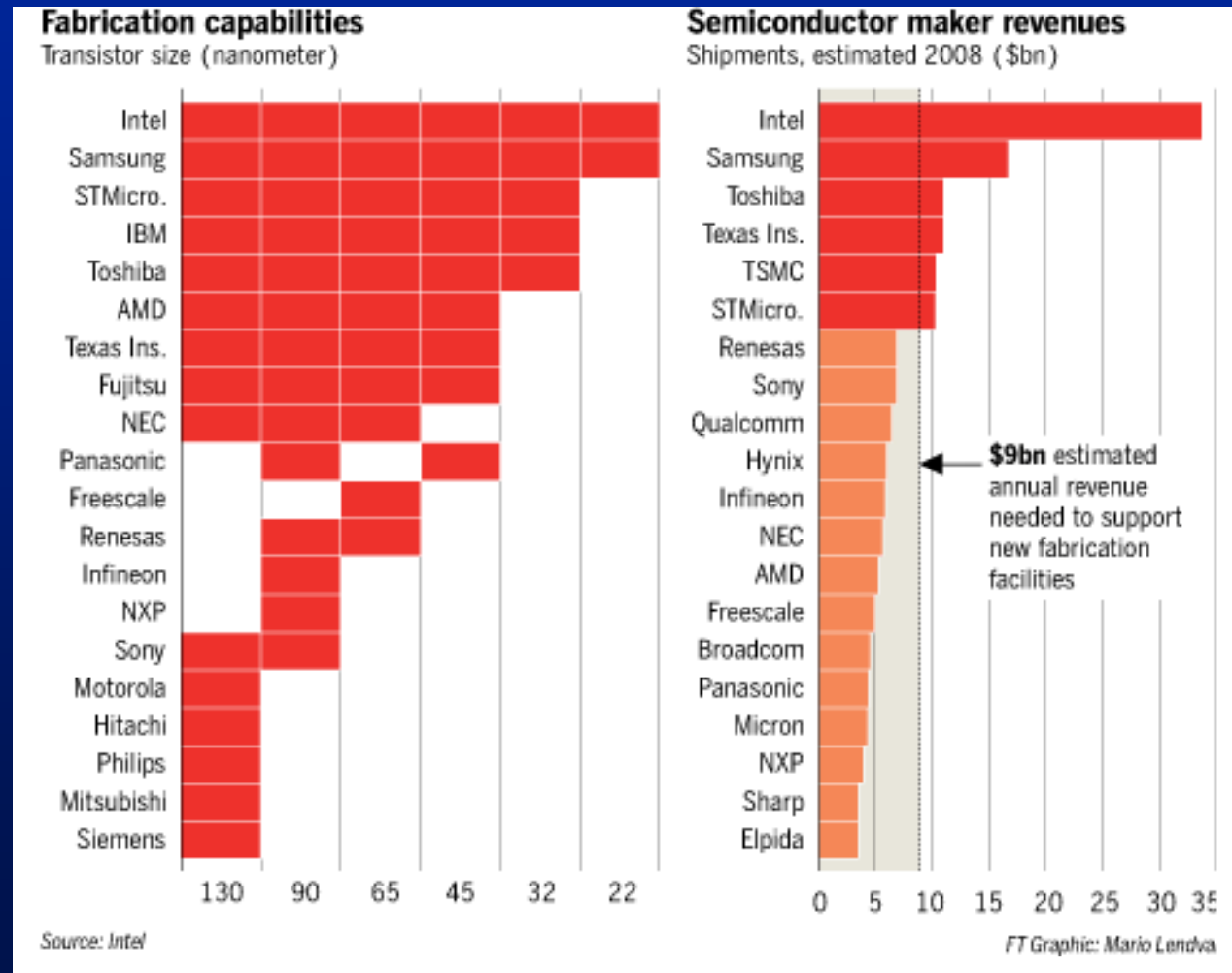
2,000
45 nanometer (nm) transistors can fit across the width of a human hair

Wafer

Microprocessor chip

Layers of copper wires bring electrical currents to the transistors at the bottom

Chip magnified

Transistor

45nm

Fewer companies can deliver smaller and more powerful chips   July 20, 2009

Fabrication capabilities
Transistor size (nanometer)

Intel
Samsung
STMicro.
IBM
Toshiba
AMD
Texas Ins.
Fujitsu
NEC
Panasonic
Freescale
Renesas
Infineon
NXP
Sony
Motorola
Hitachi
Philips
Mitsubishi
Siemens

130 90 65 45 32 22

Source: Intel

Semiconductor maker revenues
Shipments, estimated 2008 ($bn)

Intel
Samsung
Toshiba
Texas Ins.
TSMC
STMicro.
Renesas
Sony
Qualcomm
Hynix
Infineon
NEC
AMD
Freescale
Broadcom
Panasonic
Micron
NXP
Sharp
Elpida

$9bn estimated annual revenue needed to support new fabrication facilities

0 5 10 15 20 25 30 35

FT Graphic: Mario Lendva

How do you predict what the technology, manufacturing cost, market demand, market supply, and competition will be five years in the future?

CASE STUDY 1:
The Great Chip Glut: Economist August 11, 2001

- **East Asia did not understand the industry's woes**

  - **Oversupply**
  - **Taiwan's "foundries"**
  - **TSMC**
  - **UMC** $\Longrightarrow$ **Operating at 30% of capacity (from 70%)**
  - **Singapore – Charted Semiconductor**
  - **Korea's Hynix (Hyundai) - $1B loss in 2Q01**
  - **Malaysia – new fab, 1st Silicon + 2 more**
  - **China – Shanghai alone, 2 fabs under construction**
    - **2 more on drawing board**
    - **12 more planned**

Case Study #2
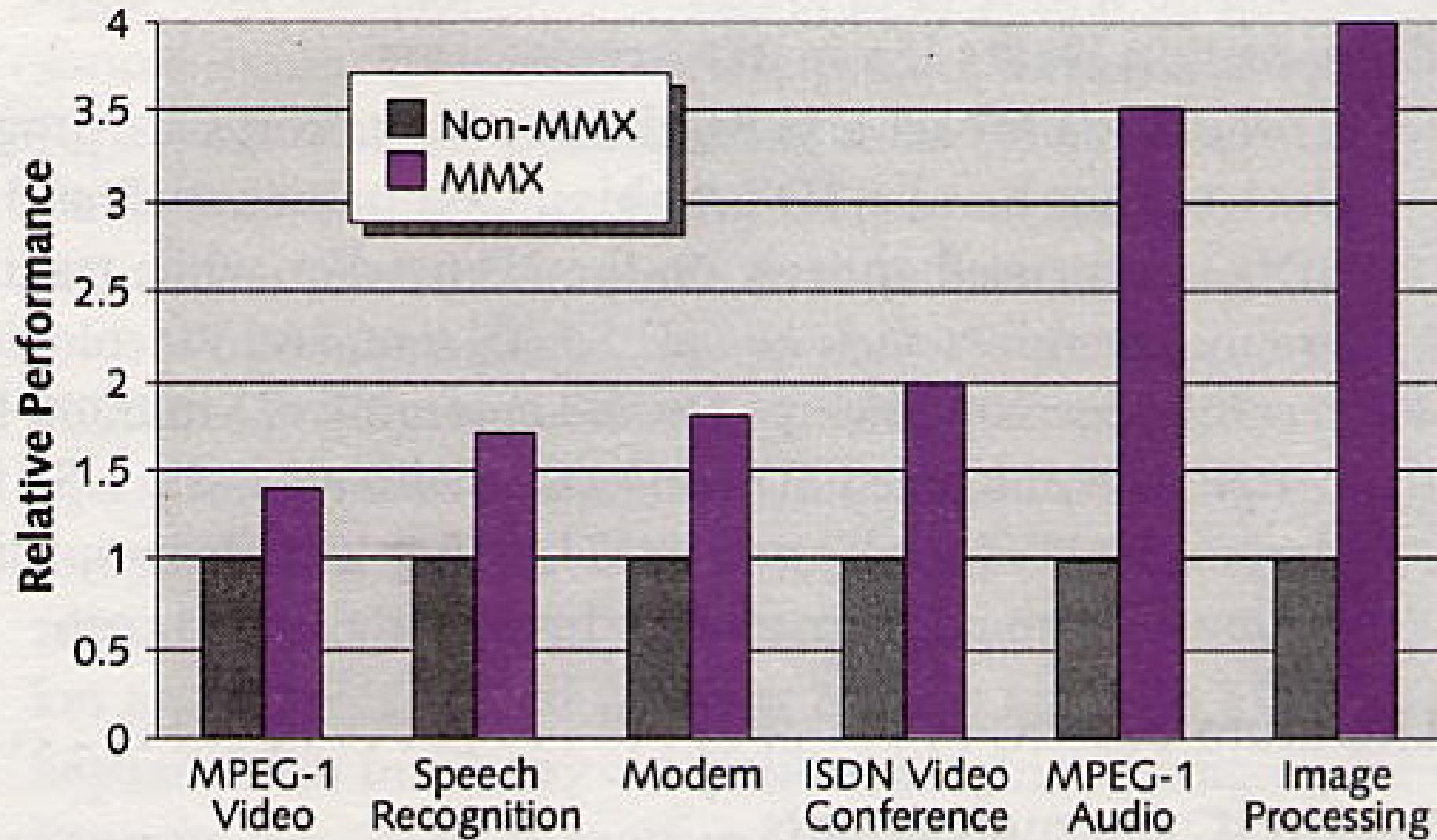
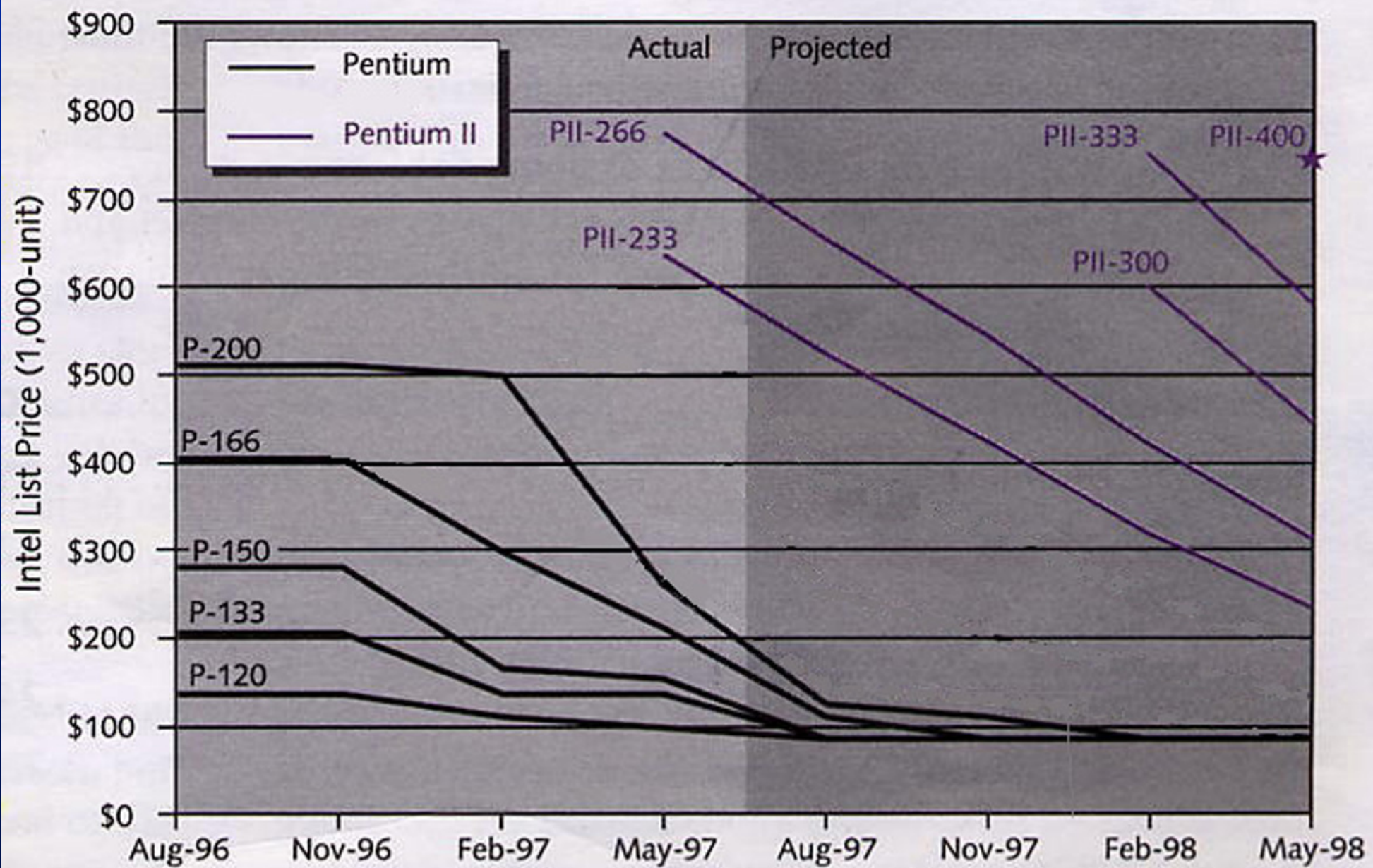Intel's MMX Introduction

Microprocessor Report, July 1997

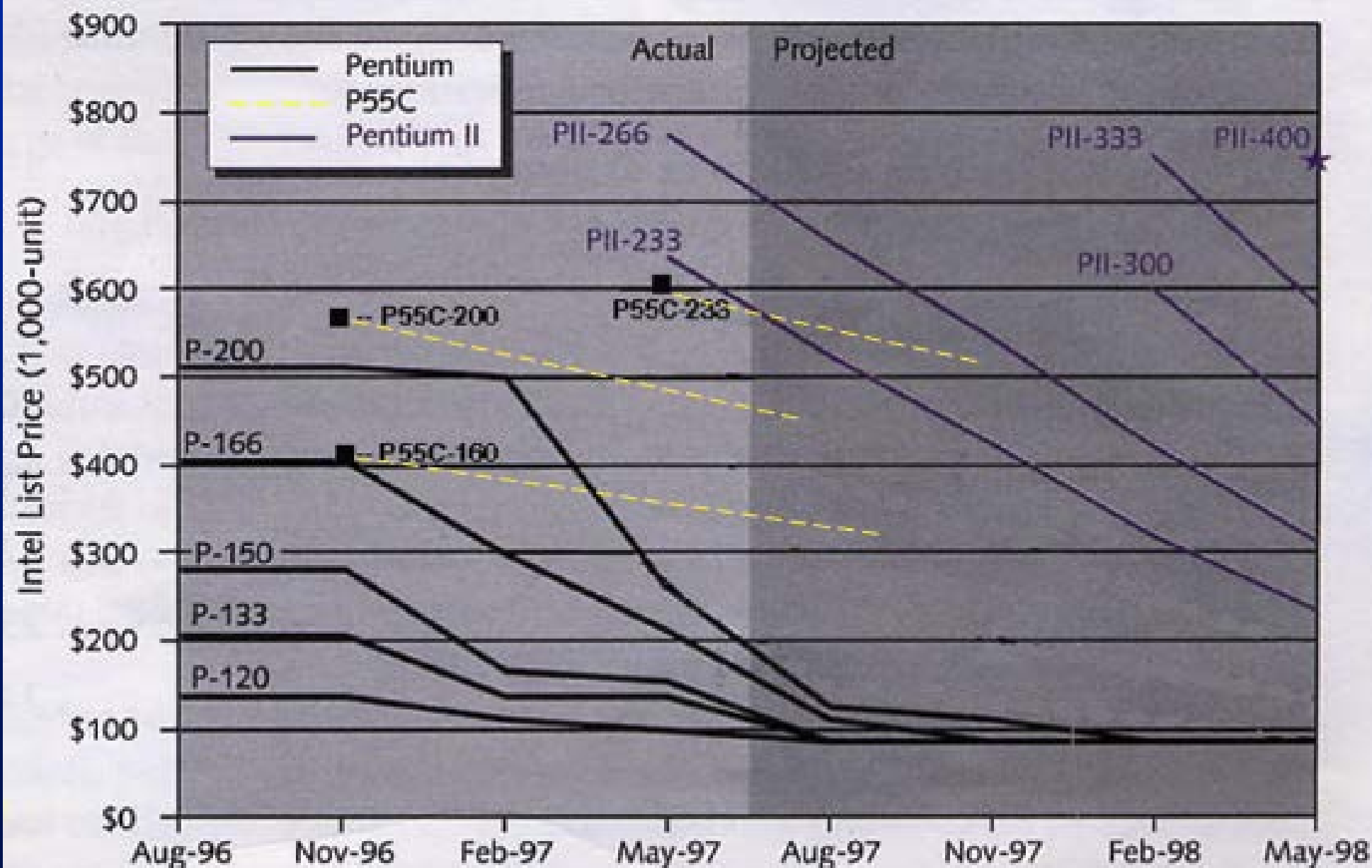# Marketing & Advertising Strategies in the Computer Industry

> *In a fast moving technology, how do you market your product?*

> *How do you get brand name recognition?*
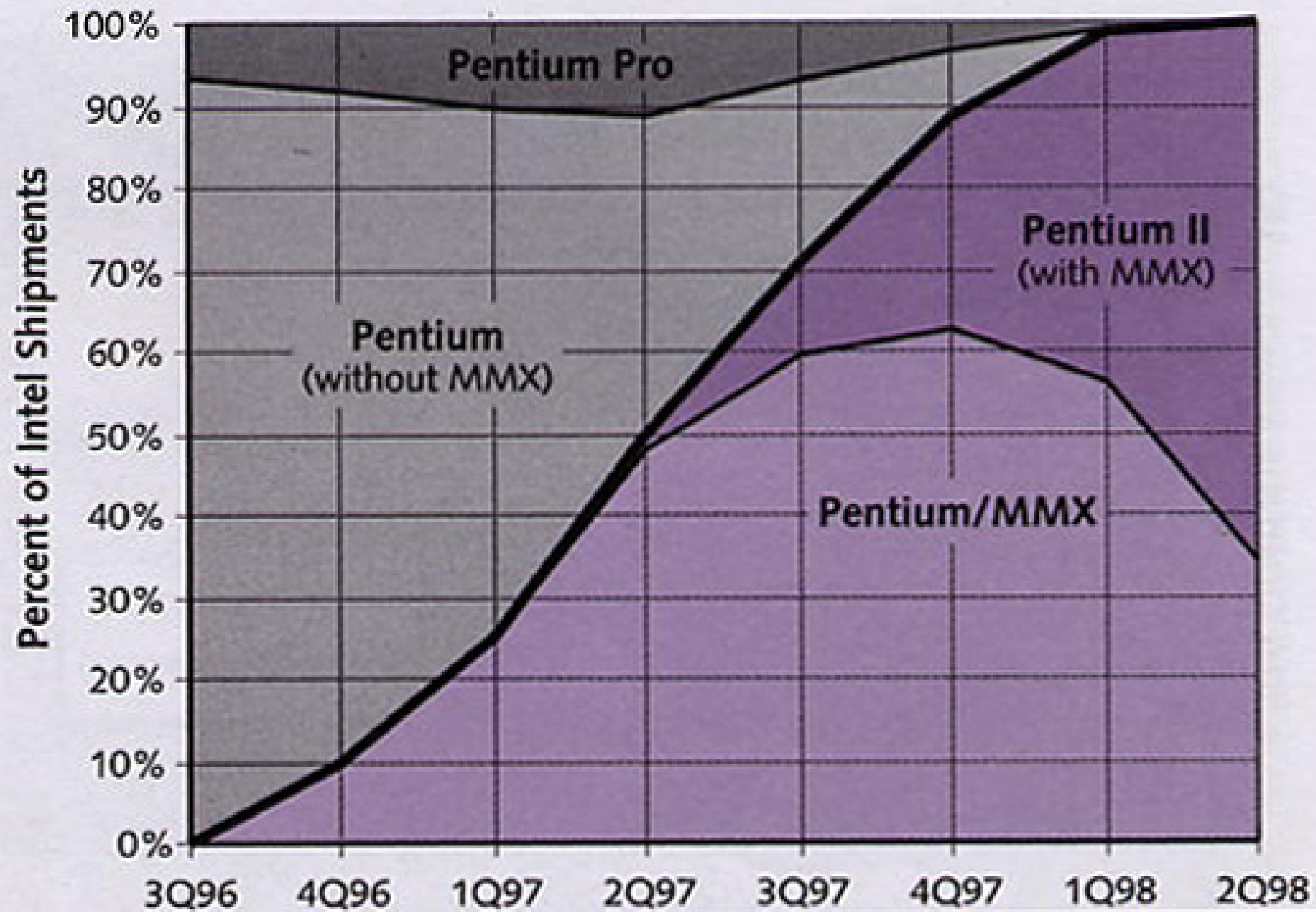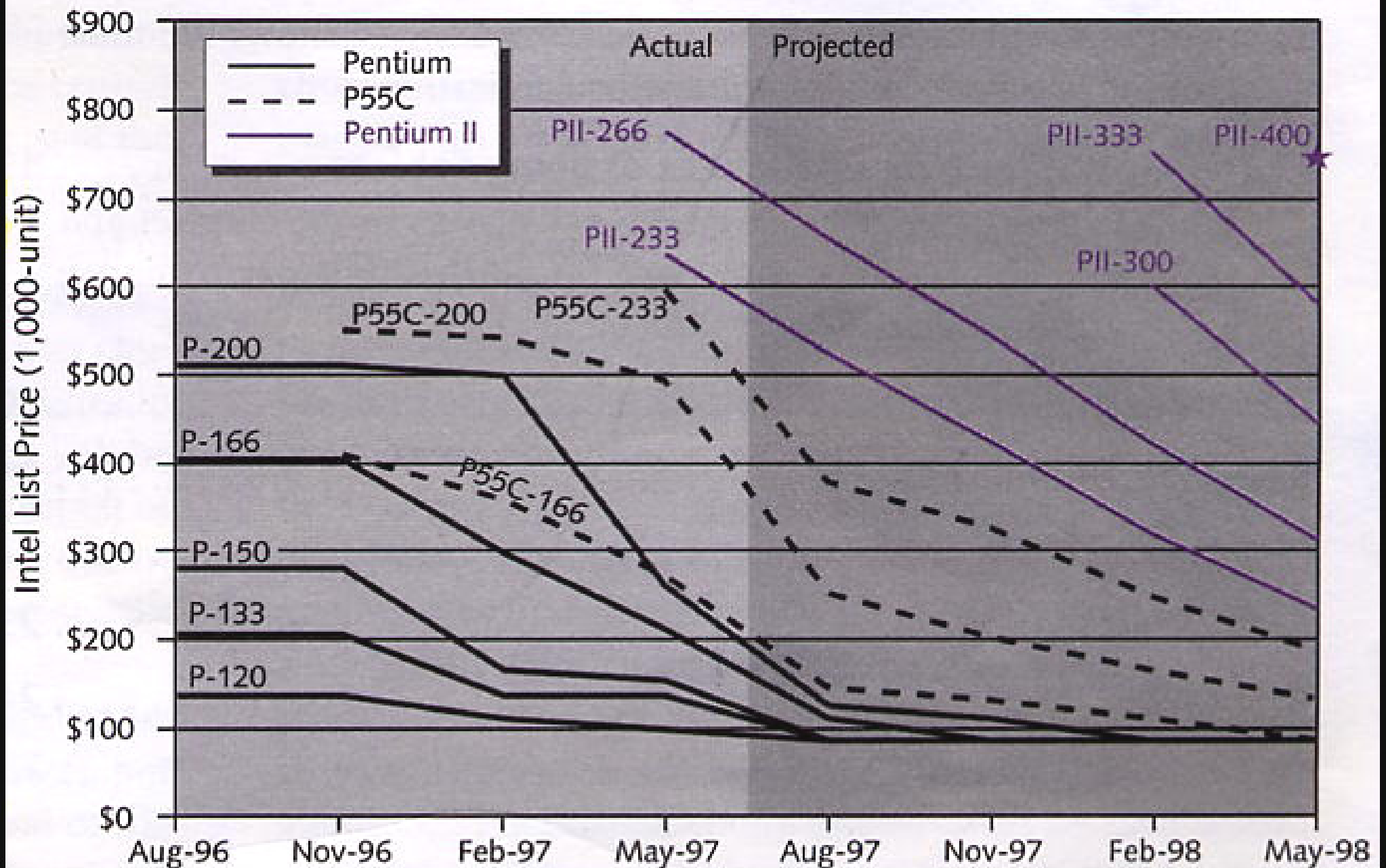
> *When do you start advertising?*

What is MMX?

- First major extension to x86 instruction set since 1985

- 57 new instructions to accelerate:

  2D & 3D graphics

  Video

  Speech synthesis and recognition

Chart — Intel List Price (1,000-unit) vs. time (Aug-96 through May-98)

Legend:
- Pentium
- Pentium II

Vertical axis: Intel List Price (1,000-unit), $0 to $900
Horizontal axis: Aug-96, Nov-96, Feb-97, May-97, Aug-97, Nov-97, Feb-98, May-98

Regions: Actual | Projected

Pentium lines: P-200, P-166, P-150, P-133, P-120

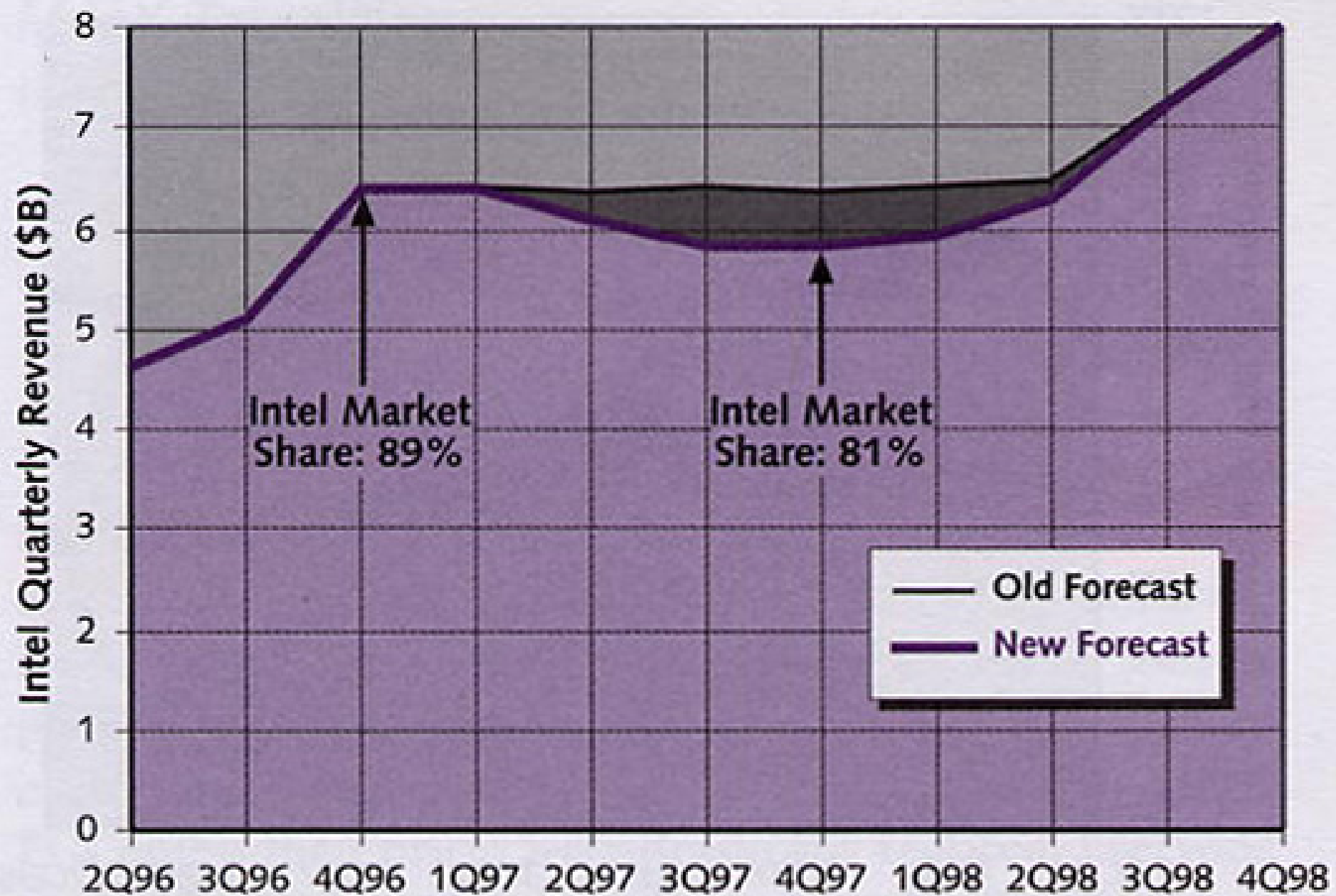Pentium II lines: PII-266, PII-233, PII-333, PII-400, PII-300
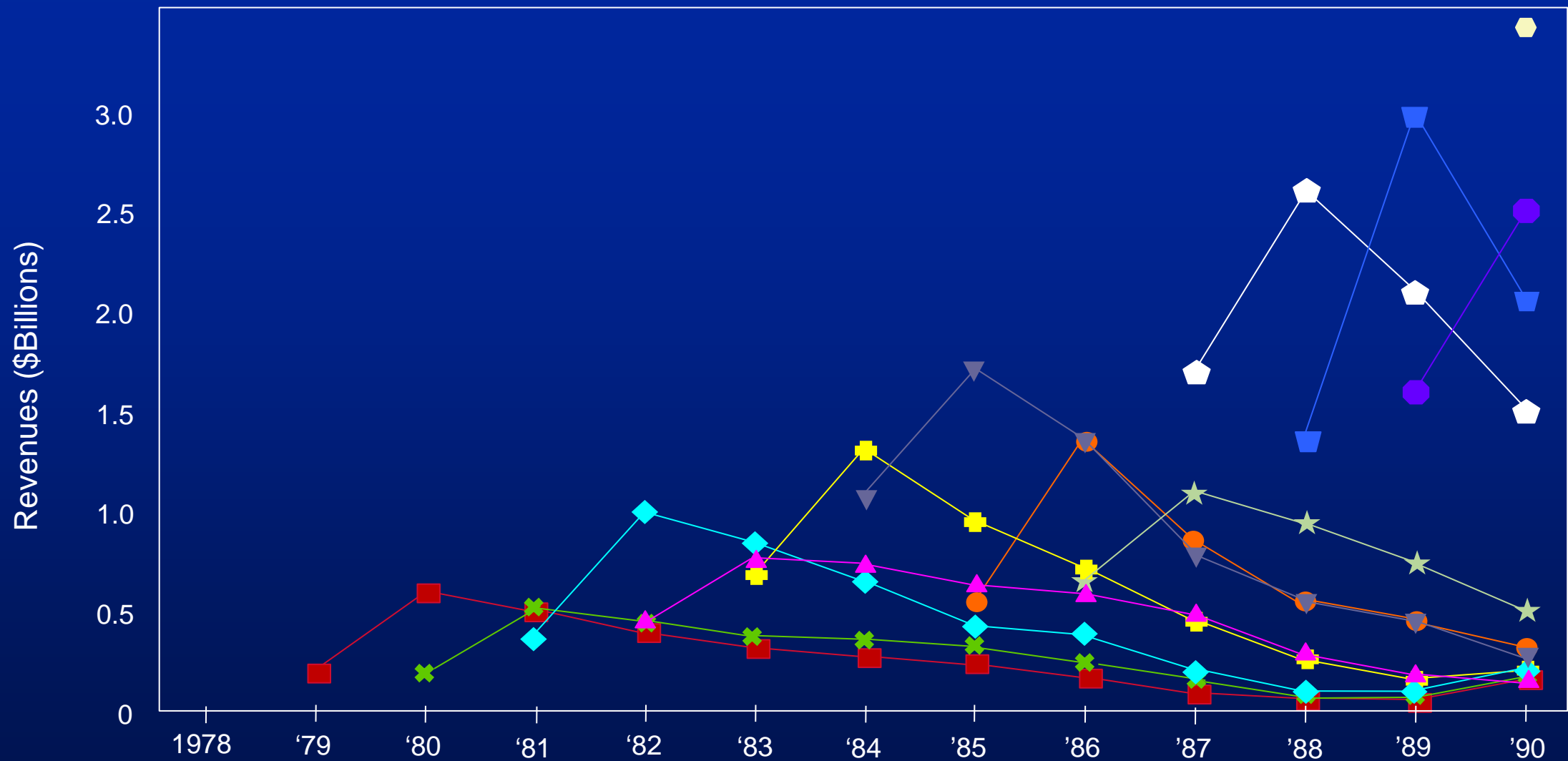
Lessons Learned?

- Need to completely integrate new product development, production capacity, advertising and marketing

- New products need to be introduced frequently to keep ASP constant or at high levels

- Case explains the drive for continually shrinking technology

Case Study #3   Product Shelf Life

- In a rapidly changing technology, the product shelf life can exacerbate the problem.
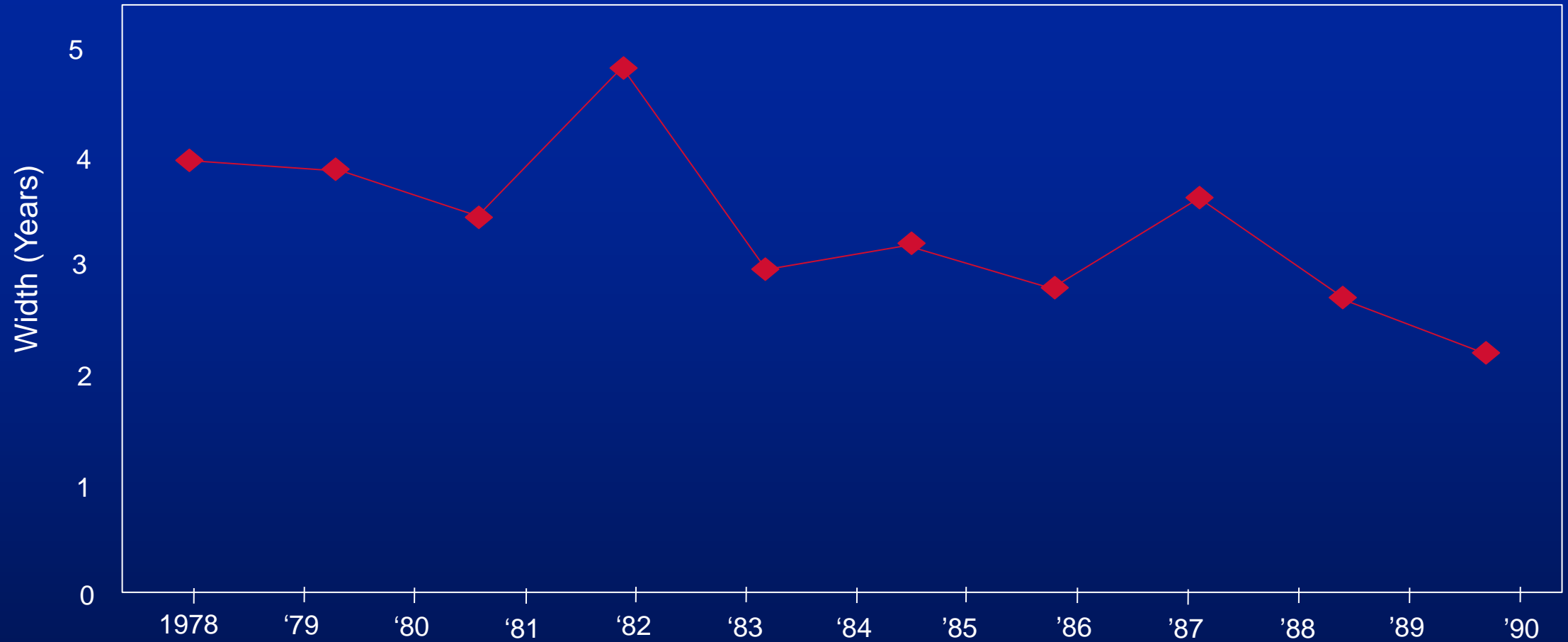
Product Shelf Life Time Is Decreasing

Revenues ($Billions)

1978 '79 '80 '81 '82 '83 '84 '85 '86 '87 '88 '89 '90

Product Selling Price Is Also Decreasing Faster

Source: Hewlett-Packard

Note: Each point on the graph indicates the number of years between (1) the year that sales of a particular cohort of products first reached one-half their subsequent sales peak and (2) the year when sales again fell to that one-half peak level.

Case Study # 4

- **Intel's Weak Celeron Offerings**

Intel's Weak Celeron Offerings

- In late 1998 Intel's weak Celeron offering were being hammered by low-end chips from AMD and Cyrix.

- AMD was suffering at the time with an operating loss of $173M in the second quarter and a 26% decline CPU revenues.

- Intel was also feeling the pain, second quarter revenues and ASP were also down.

- **What should Intel have done?**

Intel's Weak Celeron Offerings

- On the first business day of 1999, Intel cut it's Celeron prices in half and introduced two new speed grades at the same time.

- A result of the aggressive campaign was Intel's market share soared to 81%. AMD lost share and could not sell 2.3 million processors.

- Intel's strategy was to use revenues from its high priced server products to offset declining prices in PC processors.

Case Study #5   2005

- One Laptop Per Child (OLPC)

- (The predecessor to Notebooks and Netbooks)

OLPC

Manufacturer: Quanta Computers

Connectivity: Wireless LAN

Media: 1 GB flash memory

Operating system: Linux

Input: Keyboard, Touchpad, Microphone, Camera

Camera: Built –in video camera (640x480; 30 FPS)

Power: Battery removable pack

CPU: AMD

Memory: 256 MB DRAM

Display: Dual-mode 19.1 cm/7.5'' diagonal TFT LCD 1200x900

Cost: $188

OLPC

Displays

- Traditional barrier to building cheap laptops

- Need to be readable in bright sunlight and low lighting conditions

- Need power efficiency

OLPC

$100 Laptop Display

- Can be mass produced

- Resolution: 95% of the laptops at that time

- Uses 1/7 the power consumption

- Costs 1/3 price

- Can be read in bright sunlight or room light w/o backlighting

OLPC

- Was this a threat from below?

- Will the entry of low-cost laptops reduce Intel's margins?

- Is this a disruptive technology?

Intel's Classmate   2006

A rugged laptop based on Intel's 900Mhz Celeron with 256MB RAM and 2GB of flash memory, WiFi , Ethernet, and Linux O/S

HP's Mini-Note   2006

A Via processor with a 1280 v 768 screen resolution, windows XP or Vista or either a hard drive or a 64GB solid state device.

ASUS's Low Cost Solution   2006

A Linux operating system with 4GB solid state drive, a built in DVD, and a suite of software to replace Microsoft Office.

Budget Laptops of 2015

- http://www.cnet.com/topics/laptops/best-laptops/budget-laptops/

Microsoft Surface 3
$499.00

- 10.8" 1,920 x 1,080 touchscreen
- 1.6 GHz Quad-Core Intel Processor
- 2 GB RAM
- 64 GB SSD

Hisense Chromebook
$149.00

- 11" 1,366x768 touchscreen
- 1.8 GHz Rockchip Processor
- 2 GB RAM
- 16 GB SSD

Toshiba Chromebook 2
$299.00 - $320.09

- 13.3" 1,920 x 1,080 LED display
- 2.16 GHz Dual-Core Intel Processor
- 4 GB RAM
- 16 GB SSD

Acer Chromebook 15
$305.11 - $327.93

- 15.6" 1,920 x 1080 LED display
- 1.5 GHz Dual-Core Intel Processor
- 4 GB RAM
- 16 GB SSD

HP Stream 11.6
$199.00

- 11.6" 1,366 x 768 WLED display
- 2.16 GHz Processor
- 2 GB RAM
- 32 GB SSD

Budget Tablets of 2015

- http://www.cnet.com/topics/laptops/best-tablets/budget-tablets/

Amazon Kindle Fire HDX 7
$235.49

- 7" 1,920 x 1,080 Multi-Touch Display
- 2.2 GHz Quad-Core ARM Processor
- 2 GB RAM
- 16 GB Integrated Storage

Samsung Galaxy Tab A (8-inch)
$179.00 - $ 229.99

- 8" 1,024 x 768 Multi-Touch Display
- 1.2 GHz Quad-Core Qualcomm Processor
- 2 GB RAM
- 16 GB SSD

Dell Venue 7
$129.96

- 7" 1,280 x 800 Multi-Touch Display
- 1.6 GHz Dual-Core Intel Atom Processor
- LPDDR3 SDRAM
- 16 GB Integrated Memory Storage

Amazon Fire HD 6
$99.00

- 6" 1,280 x 800 Multi-Touch Display
- 1.5 GHz Quad-Core ARM Processor
- 2 GB RAM
- 16 GB SSD

Apple iPad Mini 3*
$399.00

- 7.9" 2,048 x 1,536 Retina Multi-Touch
- 1.3 GHz Dual-Core (ARM) Apple A7
- 1 GB RAM – A7
- 16 GB Integrated Storage

Disruptive Technologies?

- Flash memory vs. spinning hard drive

  It uses little power and doesn't break when dropped. Consumer price is 2MB for 1 penny.

- Ingenious LCD panel that detects when onscreen images are static and tells the CPU to shut down

DATATECTURE

Flickr. MySpace. iTunes. Gmail.

In our hyperconnected, superfast age, how can the Internet data centers we've built keep up?

→

Quincy, Wash., home to rows of servers in a 500,000-square-foot data center that Microsoft built in 2006.

(Tom Vanderbilt. "Datatecture," The New York Magazine, 6.14.09)

Water-Powered Computers

*"**Every economic era is based on a key <u>abundance</u> and a <u>key</u> scarcity.**"*

George Gilder,
Forbes ASAP, 1992

Four Commandments

1. Moore's Law
2. Rock's Law
3. Metcalfe's Law
4. Wirth's Law

Moore's Law

1965 "Cramming More Components onto Integrated Circuits"

(anniversary issue of Electronics, April 1965)

- Predicted an annual doubling of components which could be fabricated on a semiconductor chip.

- Also included a cartoon with a sales booth for "home computers" – another prescient insight

Actually, by 1975, doubling period was 17 months

1985, doubling period was 22 months

1995, doubling period was 32 months

today, doubling period is 23 months

Moore's Law *(continued)*

- Original paper noted that the cost per electronic component was inversely proportional to the number of components/chip

- In 1988 Erich Bloch (then head of IBM's research division), later Chairman of NSF Board, & sponsor for Cornell's Theory Center

  "Moore's law won't work at feature sizes less than a quarter of a micron (250 nanometers)"

- Moore, underestimated the staying power of photolithography, "No exponential trend lasts forever, but forever can be postponed"
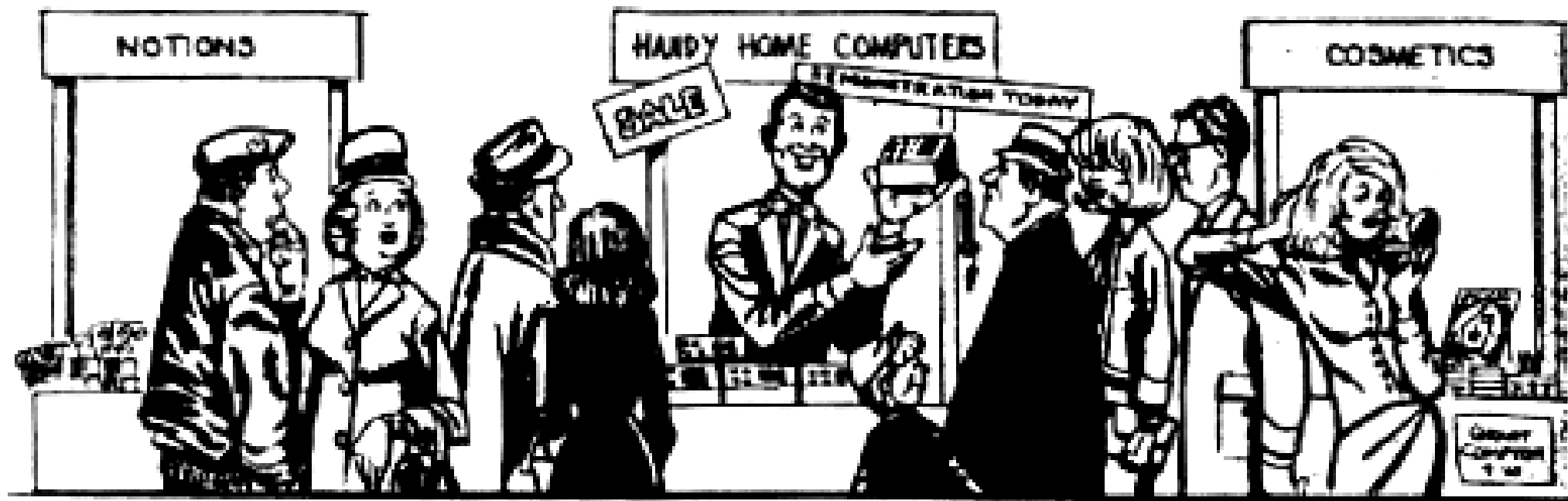
Rock's* Law

"The cost of semiconductor tools will double every four years"

Actually this was not true and current cost is $3 – 4B (slightly more than in the1990's)

What actually happened was:

    1980's. . .increase in yield
    1990's. . .increase in throughput
        (from 20 wafers/hr. $\rightarrow$50 wafers/hr.)
    Now, reduced size with 193μm stepper and larger wafers (300mm)

Rock was an initial investor in Intel

Metcalfe's* Law

"The value of a network grows as the square of the number of users"

≈ 1980 - later in "There Oughta be a Law," NY Times 1996

- Unlike the previous laws, this can't be quantified because value (what economists call utility) can't be measured.

- However, note the impact of search engines, and the business model of Google, Yahoo, etc.

Inventor of the Internet standard

Wirth's* Law

"Software is slowing faster than hardware is accelerating"

IEEE Computer 1995

"Were it not for a thousand times faster hardware, modern software would be utter unusable"

- Most of the features that bloated the programs were superfluous for most of the users most of the time

* Niklaus Wirth, Professor of ETH, Zurich and inventor of Pascal

END. . .