15.351 Managing Innovation and Entrepreneurship
Spring 2008

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Class One – Technology Dynamics

AGENDA

- Motivation for today’s material: Why it is important to assess technology-driven dynamics & why it is hard.

- S-Curves
  - Defining technology dynamics
  - Mapping technology dynamics
  - Managing technology dynamics

Typical definition of an opportunity/threat

- *In a business plan*
- *In a project proposal*

OPPORTUNITY

What is the problem you propose to solve?

How do you propose to solve it?

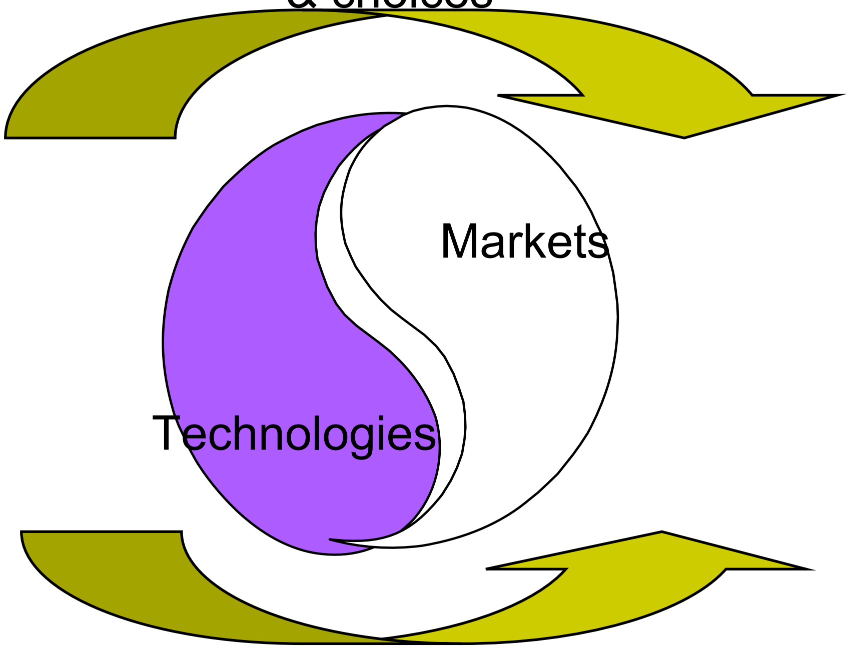
What is the potential market impact?

What is the customer "pain" that you are attempting to address?

What is the market doing now to address the problem?

When the opportunity is driven by a new technological innovation, analysis <u>should</u> integrate technology & market factors

Technology assessment & choices



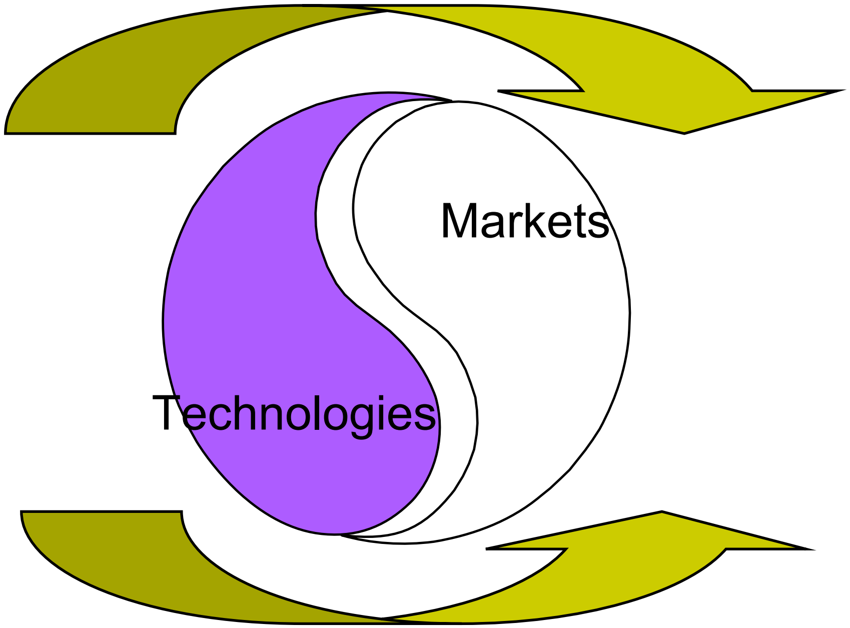
Market assessment & marketing choices

Together technical choices & market assumptions lead to the opportunity – the **concept design** that drives the business "model"

What is wrong with this…?

Typical analyses fail to examine the ***dynamics*** of technology & market factors

Technology assessment, dynamics & choices



Market assessment , dynamics & choices

A more robust opportunity assessment is clear about the ***dynamics*** of the proposed technology & that of competitors & the proposed market & that of competitors

THIS IS HARD – WHY?

Can we forecast the dynamics of technological change?

- Hard because:
  - Predicting the future
  - Hard to get data
  - Requires expert knowledge (across domains)
  - Blind spots when considering others’ technology

But….

- Wealth of historical data
- Trend extrapolation
- Robust heuristics – S curve

Early developments in Artificial Hearts

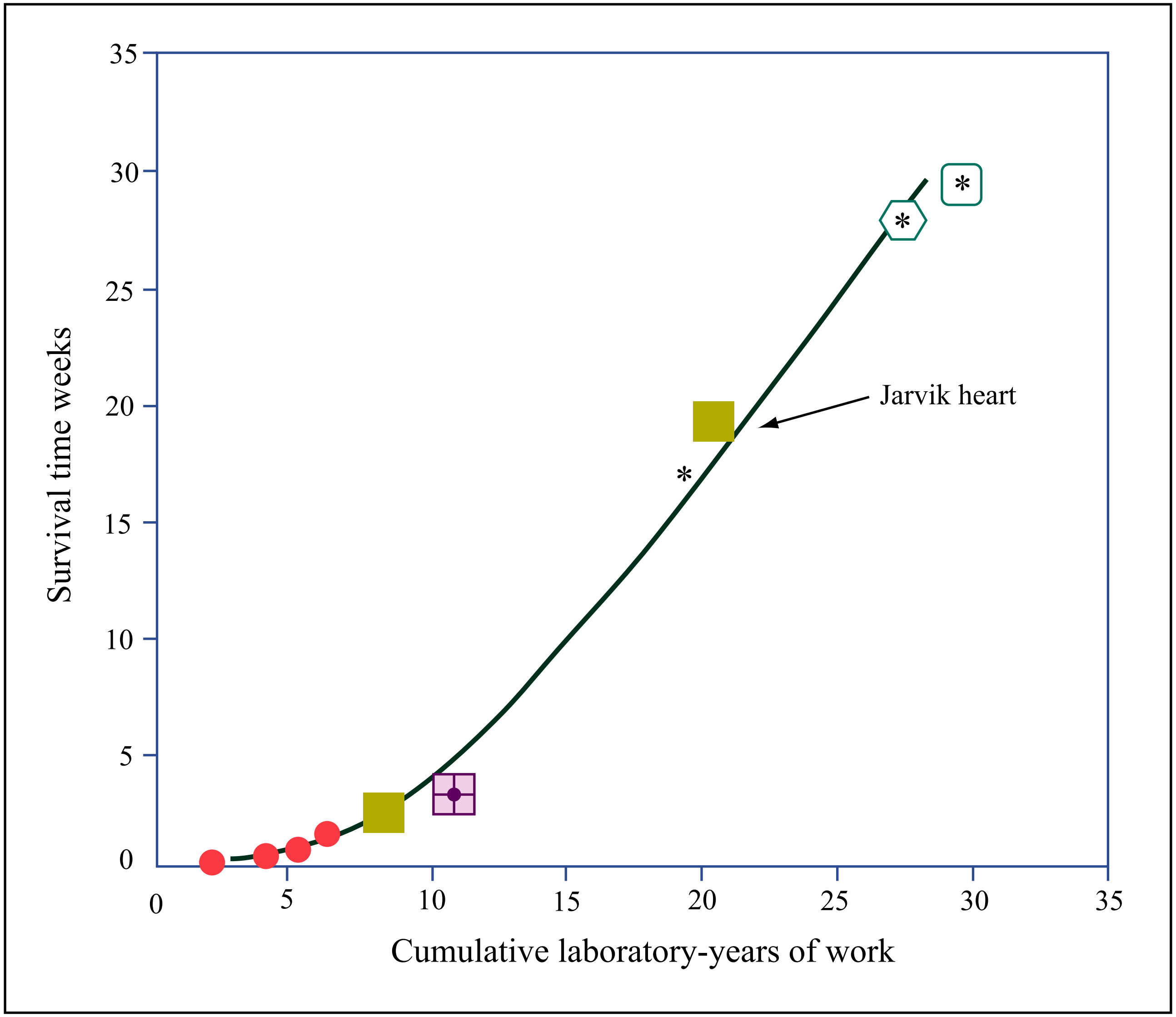
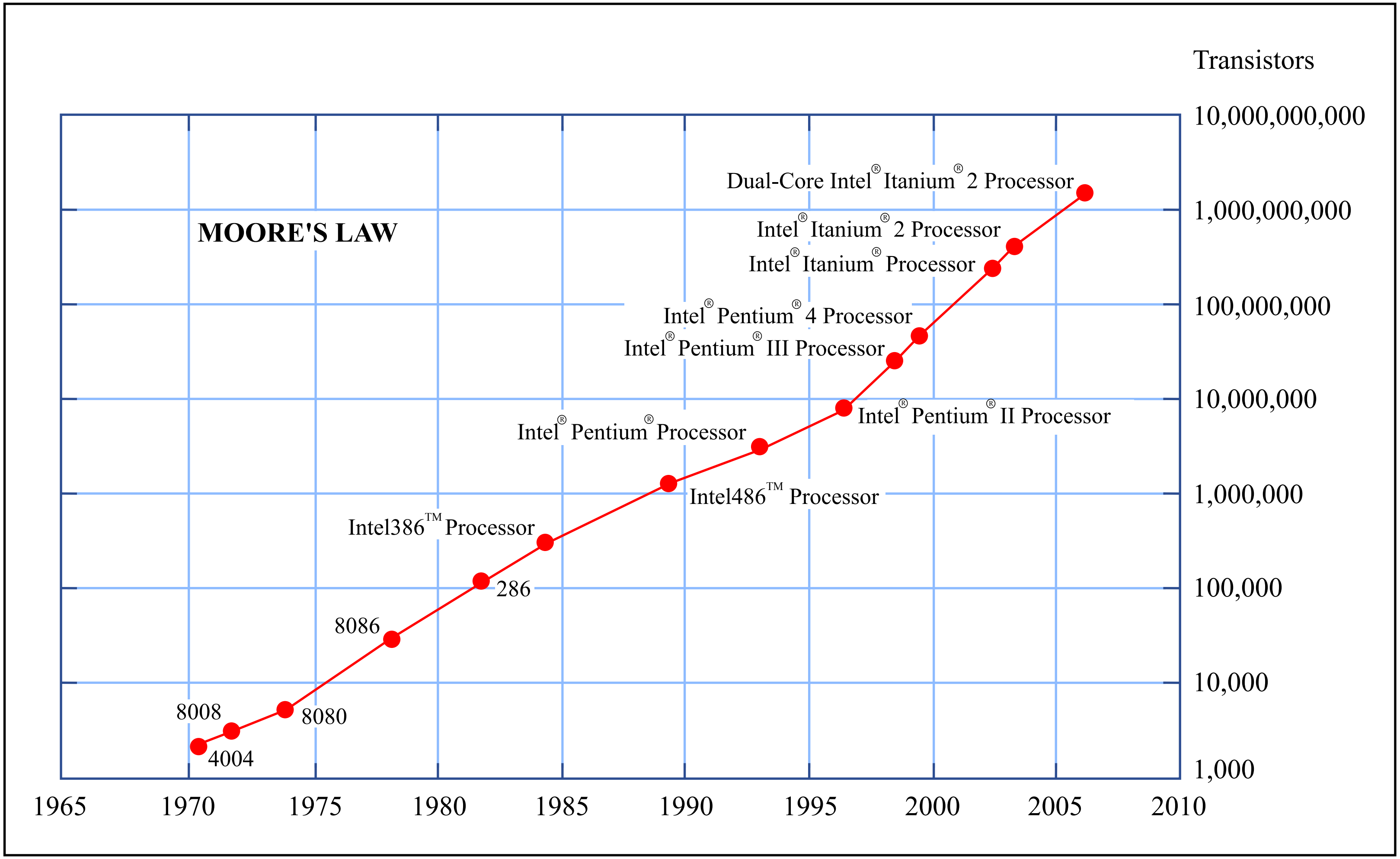


Image by MIT OpenCourseWare.

Moore's Law at Work

In 1965, Intel co-founder Gordon Moore saw the future. His prediction, now popularly known as Moore's Law, states that the number of transistors on a chip doubles about every two years.



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Declining Yield Improvements for Phthalic Anhydride Production

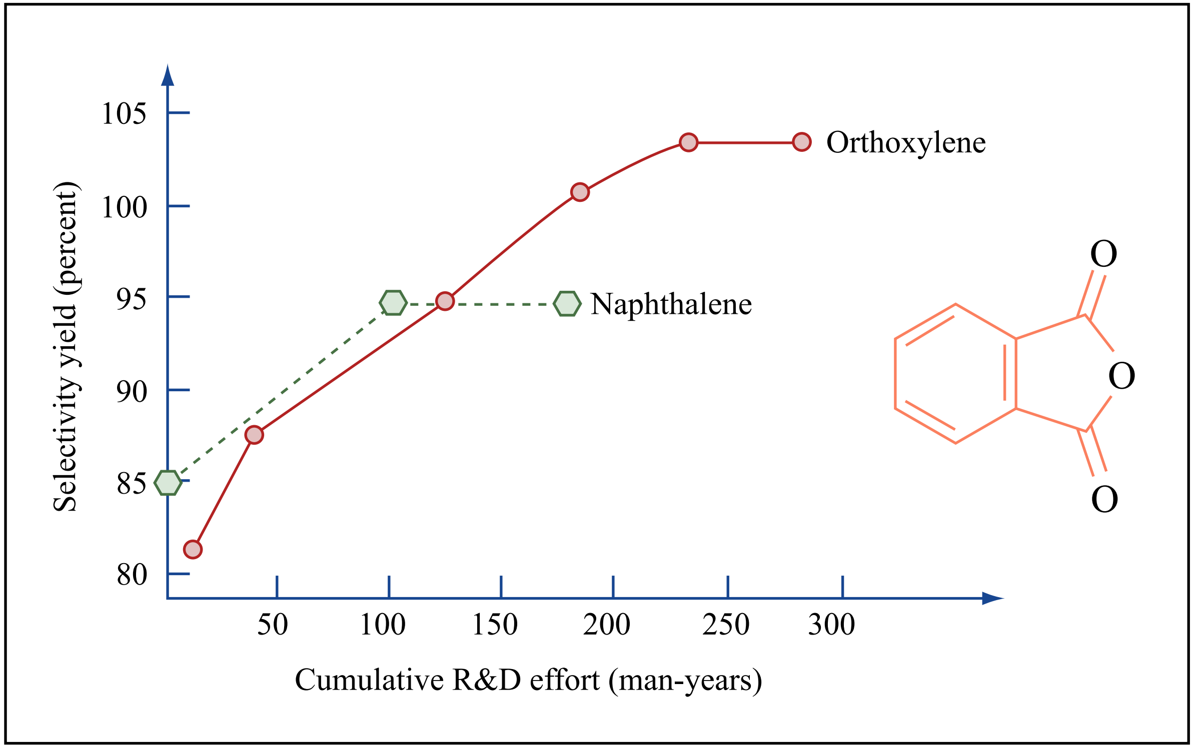
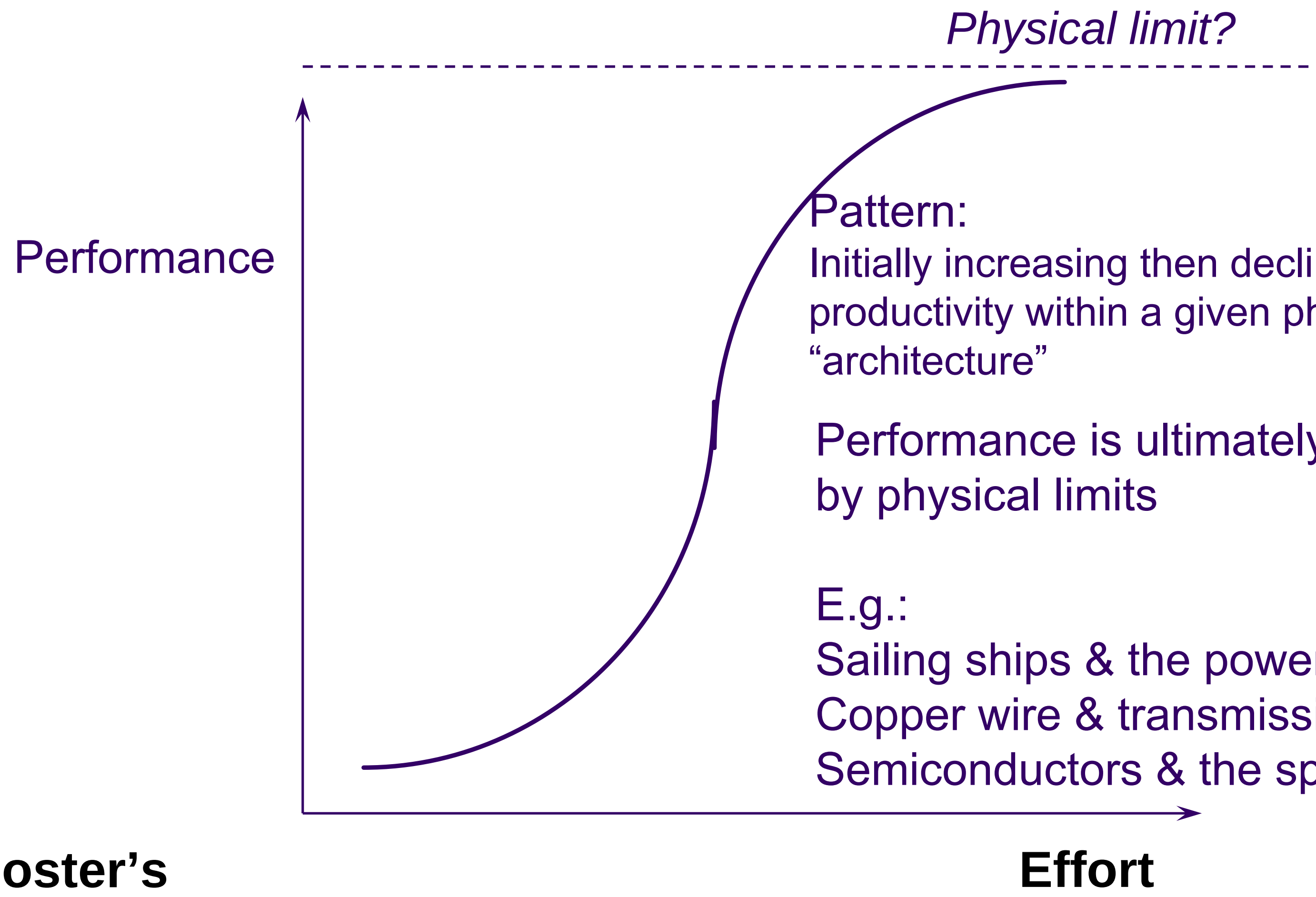


Image by MIT OpenCourseWare.

Declining Yield Improvements for Phthalic Anhydride Production

- PA is an organic chemical molecule, a building block in processes that result in paint thickeners and softer plastic luggage or auto upholstery. It is an important industrial chemical now and may become more so in the future.
- Raw materials: Naphthalene has more carbon in it than required, but lacks oxygen. Orthoxylene looks like Naphthalene except that it has less carbon. A pound of Orthoxylene gives you 1.4 pound of PA, vs. 1.2 pound for Naphthalene. 20% improvement. Worth a lot, margins in the chemical industry are often 10-15%. This does not mean that Orthoxylene-based PA will be cheaper. What if Orthoxylene's price was 20% more expensive than Naphthalene? That was the case until early 1960s when more ortho became available as a result of advances in oil refining. That's when ortho caught up with naphthalene.
- Allied Chemical pursued Naphthalene in its mature stage. Scientists working for Allied, Monsanto, Chevron, and others spent some 100 man-years of effort between 1940 and 1958 seeking more efficient ways of making PA from naphthalene. During that period, performance improved steadily. But from 1958 to 1972, scientists exerted an additional 70 man-years of effort and achieved only limited progress. Eventually, progress on PA from Naphthalene stopped completely.

S Curve – Proposed model for dynamics of technological change



Pattern:
Initially increasing then declining R&D productivity within a given physical "architecture"

Performance is ultimately constrained by physical limits

E.g.:
Sailing ships & the power of the wind
Copper wire & transmission capability
Semiconductors & the speed of the electron

Foster's S Curve

The S-Curve

All it says is: things are going very, very slow in the beginning, the pace quickens in the middle, and then decelerates in the end. That’s all it says. It’s a tool for thinking where you are strategically, it’s a tool for asking questions, like *”what performance measure should I plot?”* It is not a magic forecasting tool.

Breaking Down the Technology S-Curve

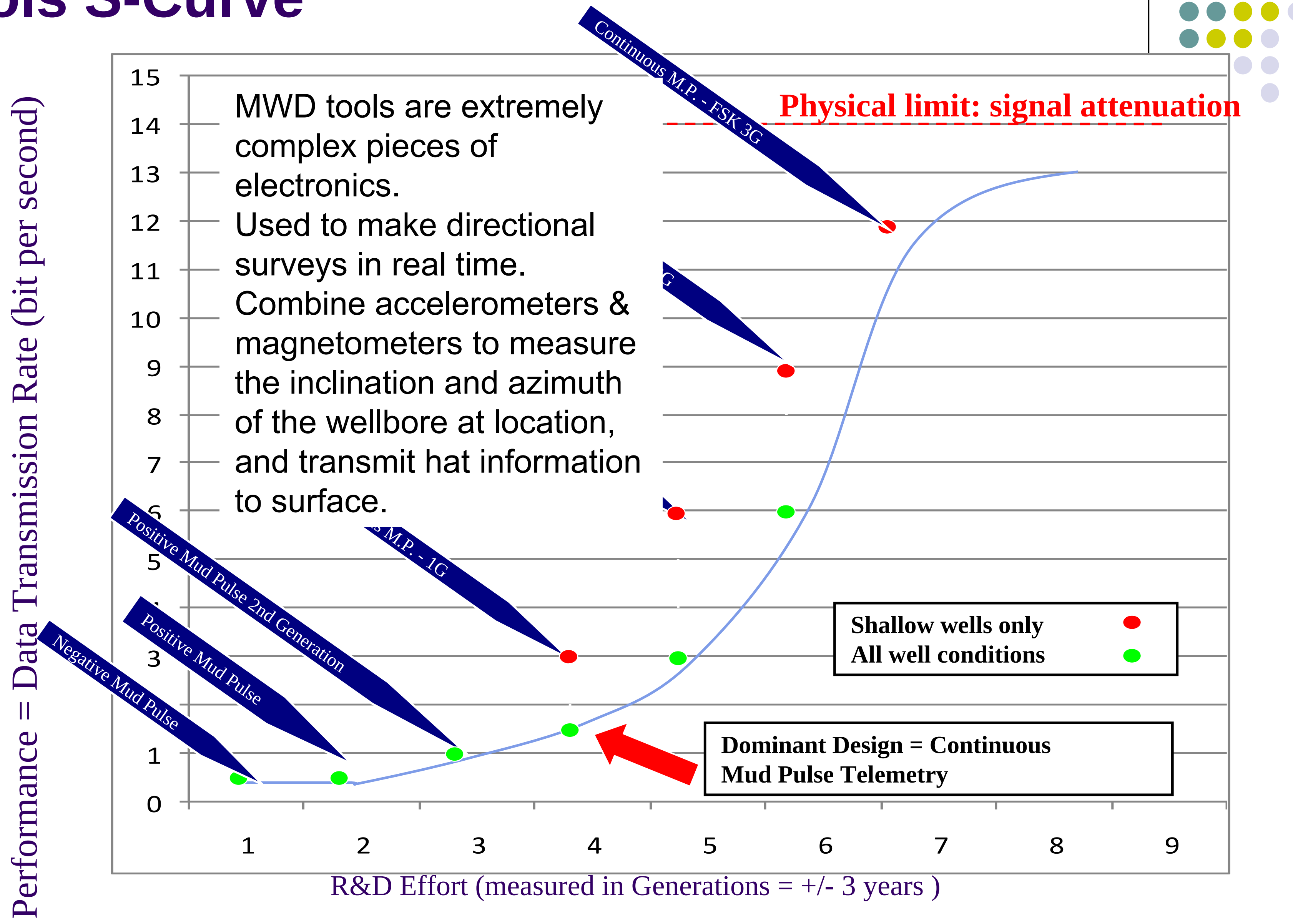
Position	Why?
Early-stage, Low R&D productivity	Need to Experiment; Lots of Early Failures; Building up Knowledge about the Area; Bringing Together the "right" capabilities and knowledge
"Riding Up" the S-Curve	Focusing on an overall "architecture"; focusing on narrower and more well-defined technical challenges; organizational commitment and incentives; leveraging prior experience
Hitting Natural Limits	Key physical limits determined by broad technical choices (e.g., speed of sound; analog versus digital). The constraints result from key architectural choices.

The Evolution of Palomar's Products: Laser Based Skin Treatment

Images removed due to copyright restrictions.

Product	Price	Material Cost	Year
EpiLaser™	$150K	$80K	1996
E2000™	$130K	$60K	1997
LightSheer™	$100K	$40K	1998
SLP1000™	$65K	$25K	2000
EsteLux™	$40K	$ 4K	2001
MediLux™	$50K	$ 4K	2003
NeoLux™	$30K	$ 4K	2003
StarLux™	$80K	$ 5K	2004
Lux Handpieces	$10K	$ 1K	2002-4
Home Devices	?	?	?

Evolution of Measurement-While-Drilling Tools S-Curve

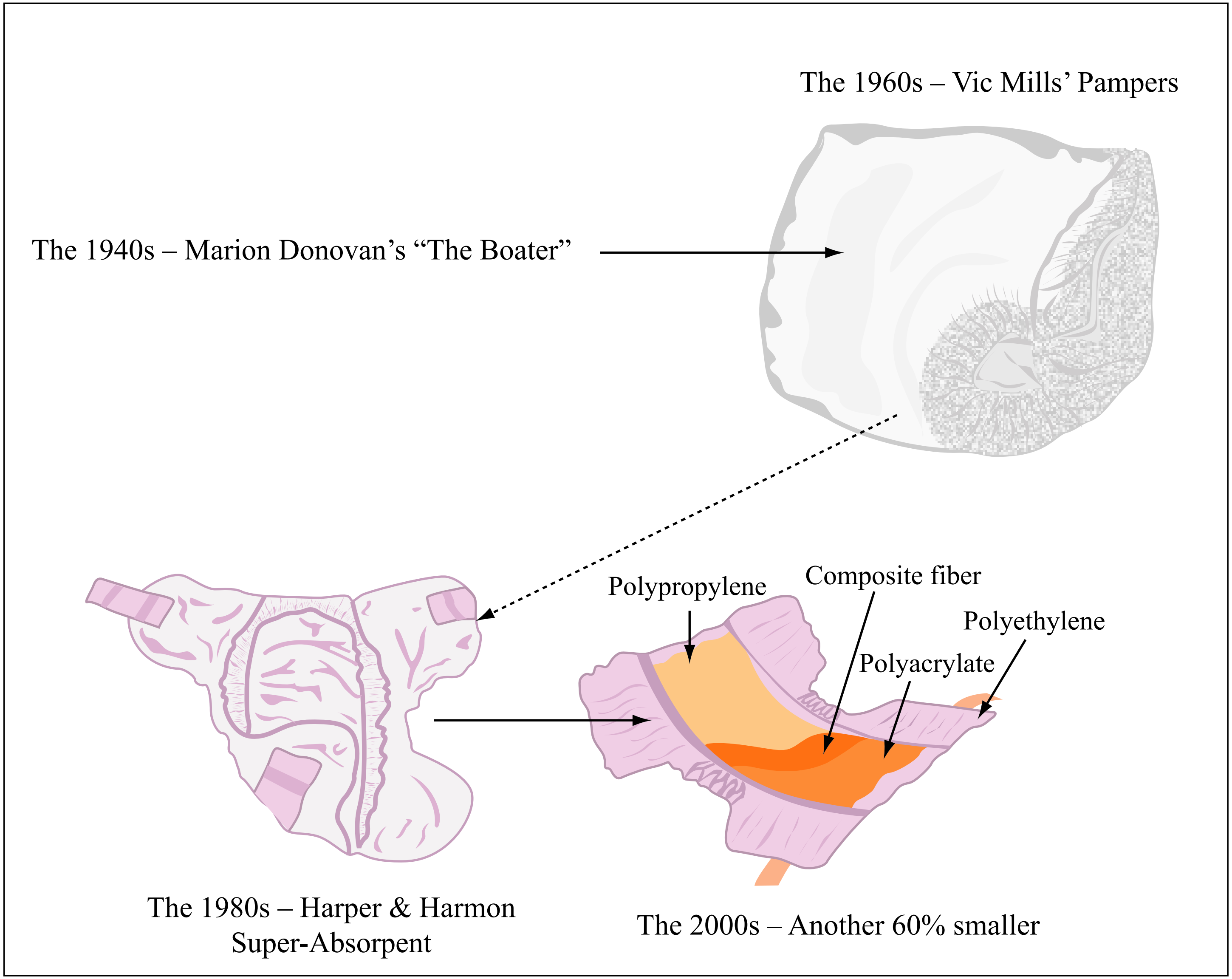


Example – Smaller Diapers

EXERCISE

- Sketch the relevant S curves.
  - What are the appropriate (technical) measures of performance? Are there more than one?
  - Where is this industry now? Are there major growth areas or discontinuities on the horizon?

Evolution of the Disposable Diaper highlights Dynamics of Technology S-Curve



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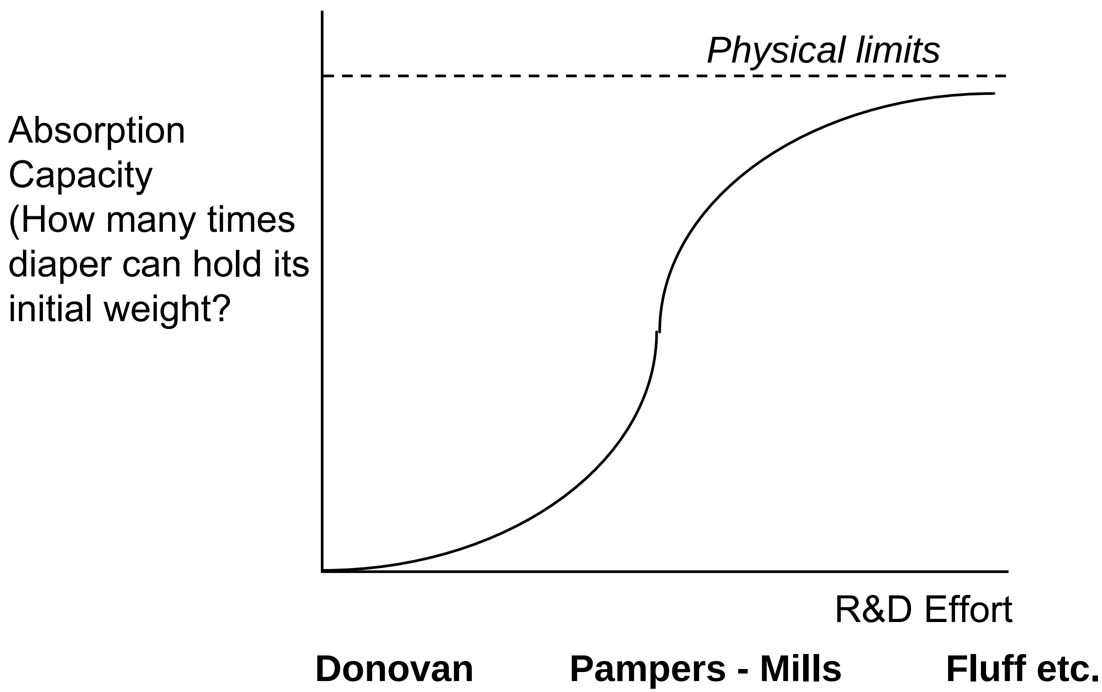
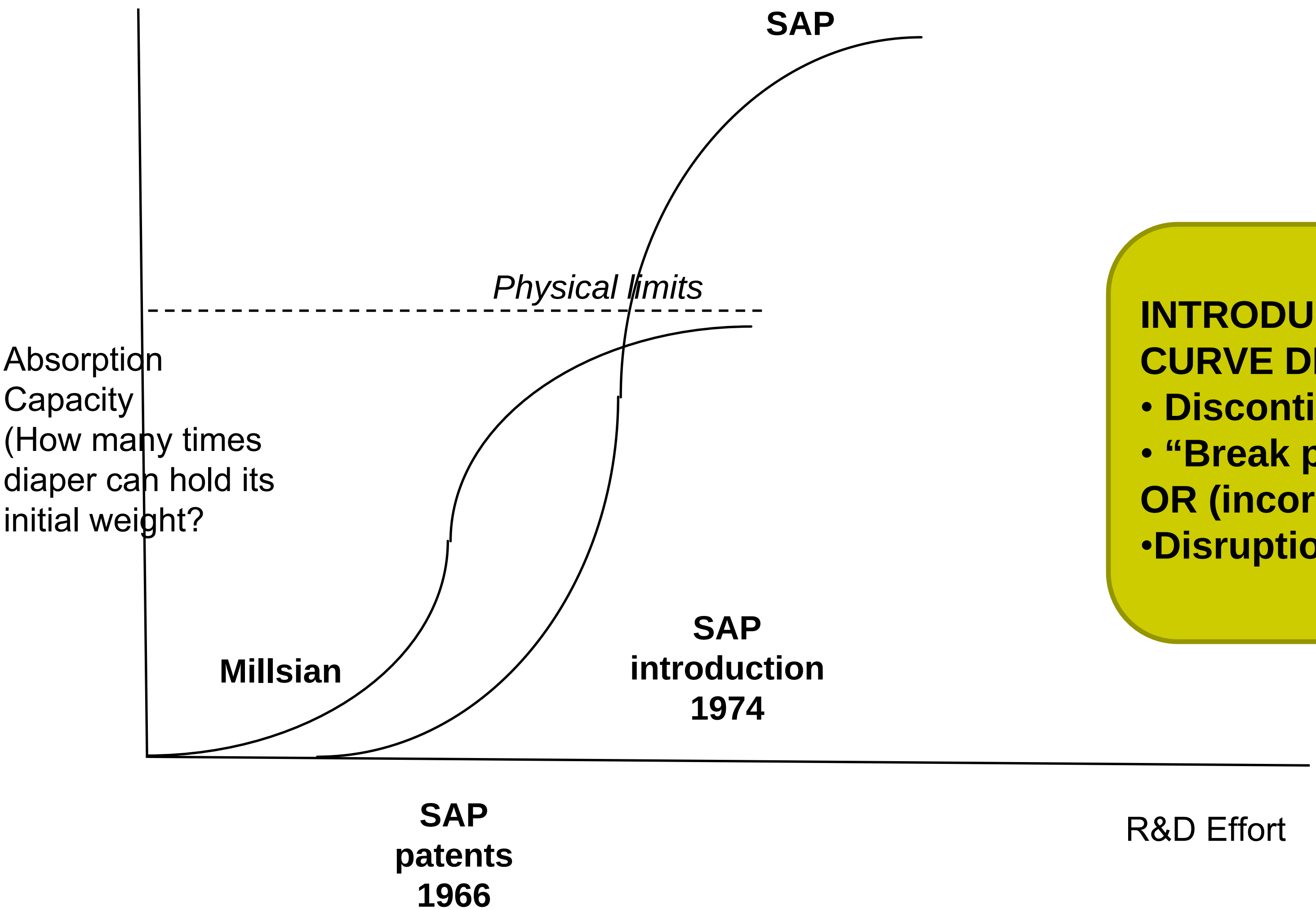
The Millsian (Absorbent core) diaper faced significant technological hurdles due to the tradeoff between size and absorbency...



Benefits of greater absorbency were at odds with massive increases in size – cost of size on the "shelf" and on the "body" were both important limitations to this approach

SAP technology facilitated a long period of sustaining innovations along the S curve – changed the absorbency versus size tradeoff...



INTRODUCTION OF A NEW CURVE DESCRIBED AS:

- **Discontinuity**
- **“Break point”**

OR (incorrectly)

- **Disruption**

Issues in using S Curves to analyze technological dynamics

- Progress as a result of the passage of time vs. progress as the result of returns to effort
- Do all good things come to an end?
- Which parameter(s) shall I predict?
- What level of aggregation – firm or industry
- What level of analysis – component vs. system v. process

The S curve is best viewed as a tool for triggering discussion, not as a "scientific reality"

Time or Effort?

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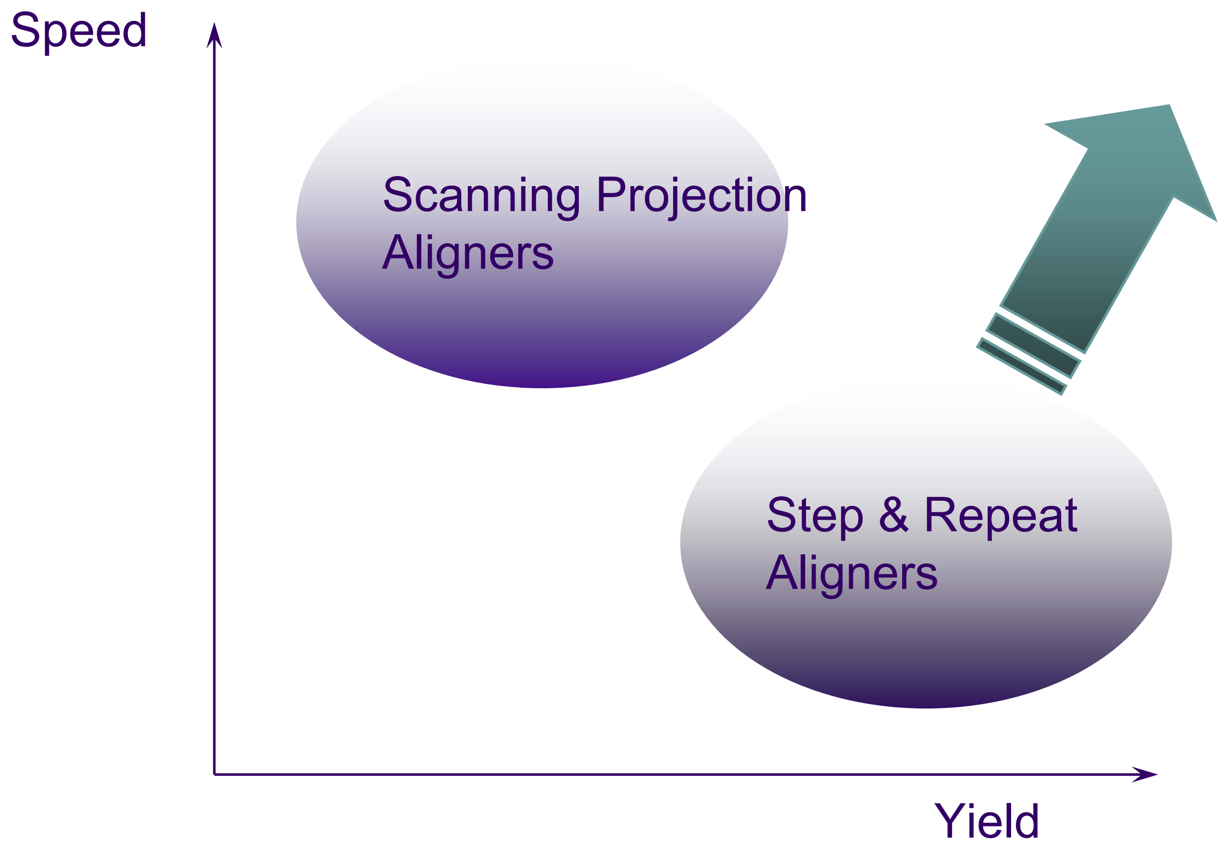
Figure 2 on p. 338 in Christensen, C. M. "Exploring the Limits of the Technology S-Curve. Part I: Component Technologies." *Production and Operations Management* 1, no. 4 (Fall 1992): 334-357.

Figure 2a charts the average area1 density of all disk drive models introduced for sale by all manufacturers in the world between 1970 and 1989. The pace of improvement has been remarkably steady over this period, averaging 34% per year; with time as the horizontal metric, no S-curve pattern of progress is yet apparent.

Figure 2b shows that what appeared in Figure 2a as a relatively constant rate of improvement over time in area density appears instead to be an increasing rate of improvement per unit of engineering e@rt applied.

Source: Christensen 1992

What parameter?
Metrics of interest may change over the technology S curve



S curves are probably complex landscapes of performance over a multi-dimensional surface – easier to plot several S curves with different parameters

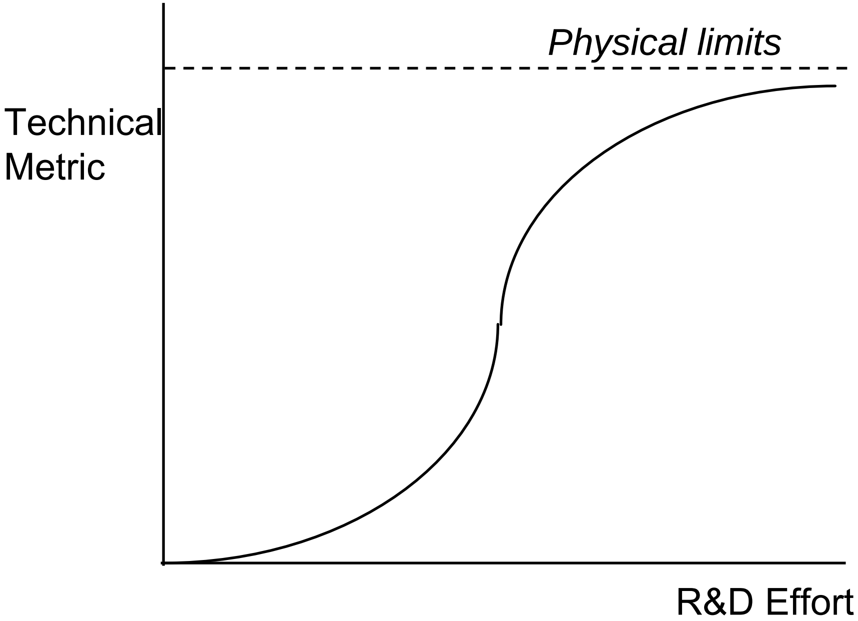
Firm vs. industry S-Curve revival

Image removed due to copyright restrictions.

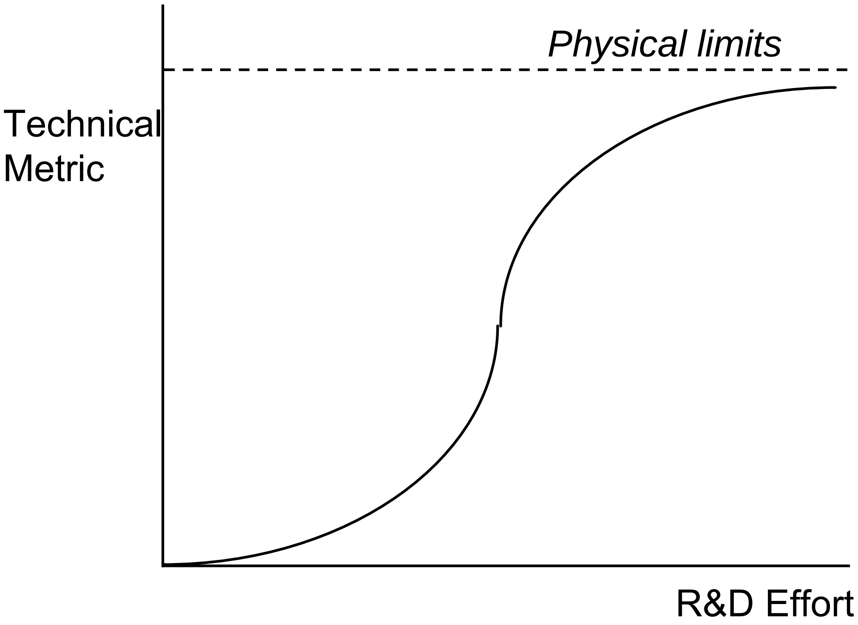
Figure 5 on p. 345 in Christensen, C. M. "Exploring the Limits of the Technology S-Curve. Part I: Component Technologies." *Production and Operations Management* 1, no. 4 (Fall 1992): 334-357.

Source: Christensen 1992

What level of analysis? Component vs. Architecture



Component-level:
No change in overall system architecture – in disk drives think of ferrite read/write heads shifting to thin-film heads



Architecture-level:
Change in the linkage of components – 14’ -> 8” -> 5.25’ disks. Or generations of optical photolithographic alignment equipment – contact-> proximity etc.

What level of analysis

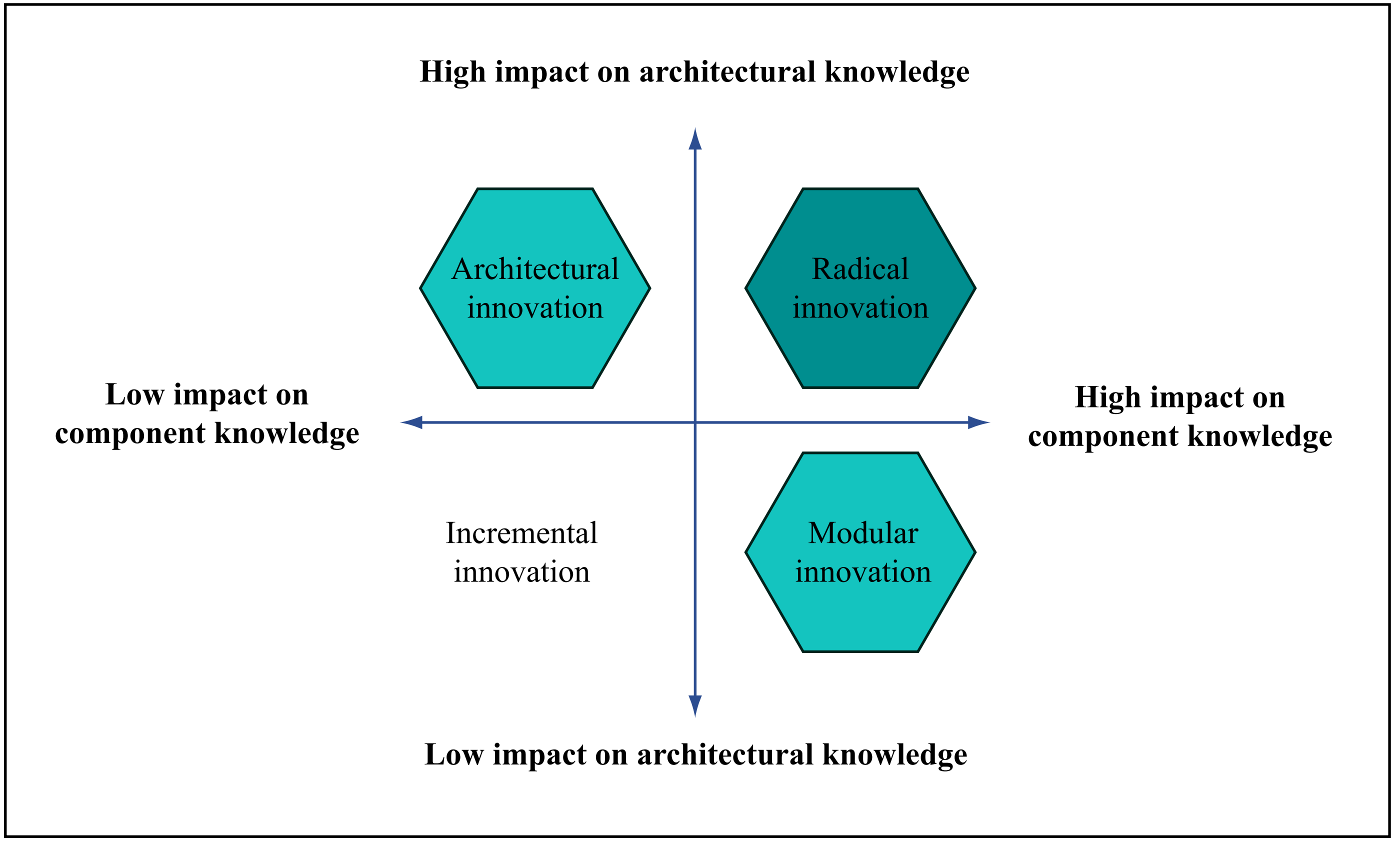


Image by MIT OpenCourseWare.

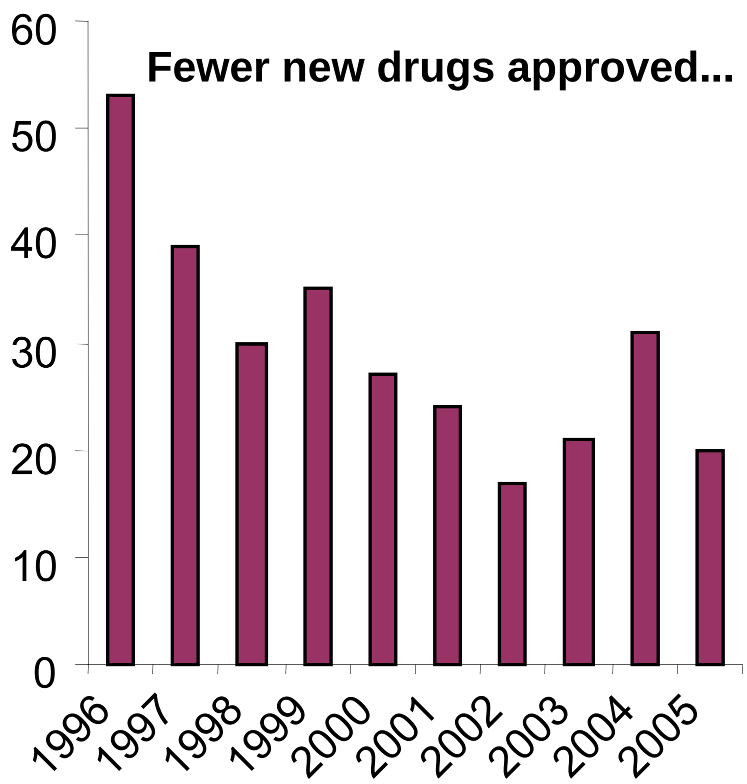
All three “purple boxes” would constitute a new S curve but only one is labeled “radical”

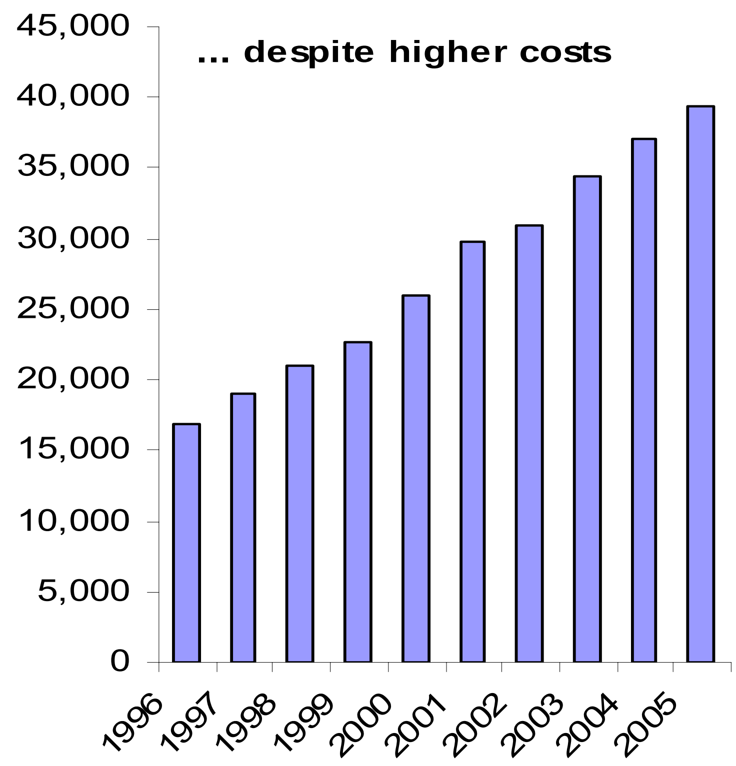
I WOULD CALL ALL THREE RADICAL & THEN SPECIFY

Adapted from: Henderson & Clark, 1990

Technology S-Curve in practice….the pharmaceutical industry

- Using the S-Curve perspective to analyze the so-called "productivity crisis" in the pharmaceutical industry





Origins of the Productivity Paradox

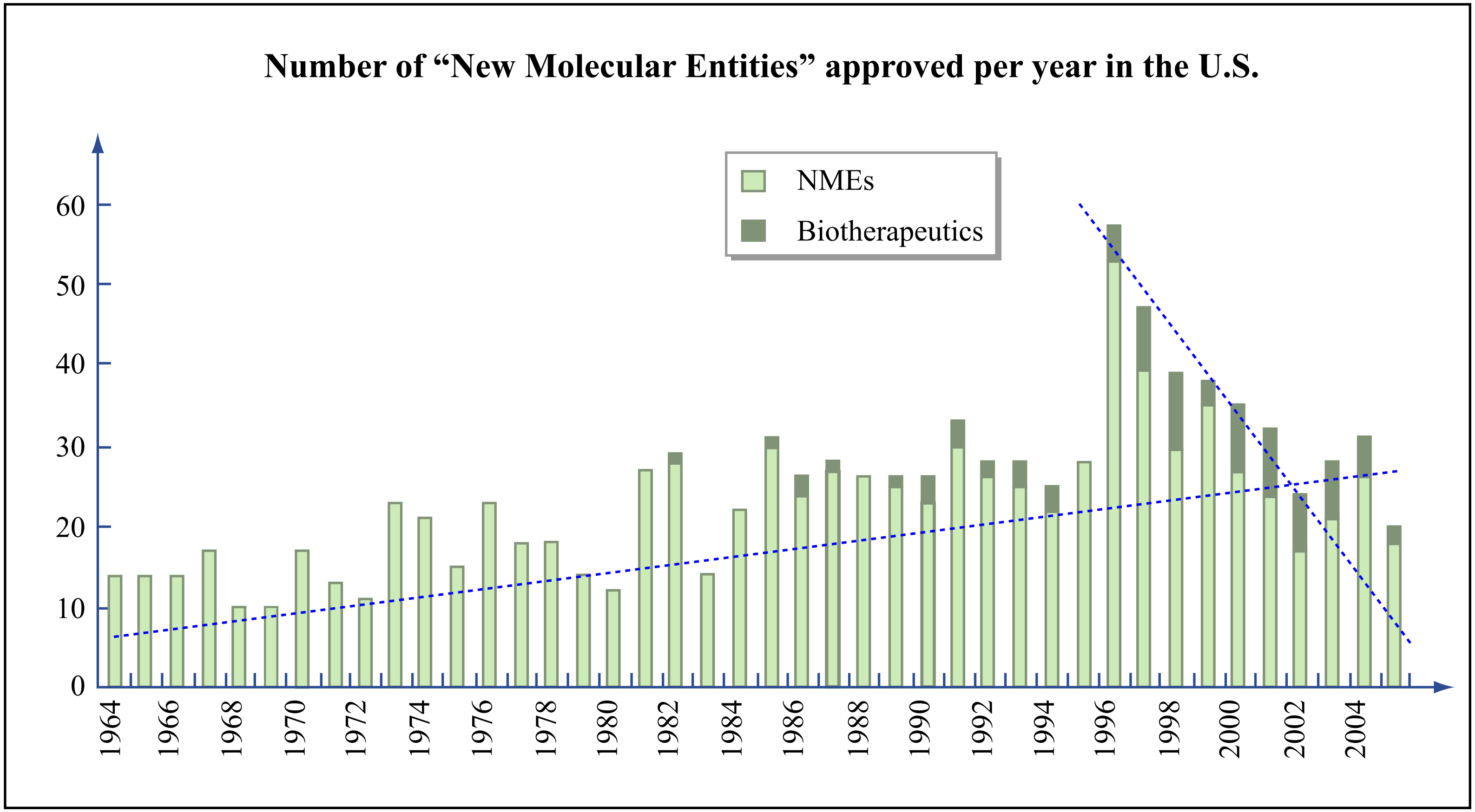
Widely debated by CEOs, analysts….surprising given

- Massive investments in innovation, yet the level of new FDA drug and biotherapeutic approvals is comparable with the 1980s
- Thirty years of dramatic scientific progress (from genetics to systems biology)
- Emergence of thousands of biotech companies (> 500 public)

What might an S-curve analysis tell us?

- Drawing the curve
- Patience is a virtue…

Getting the S-curve #s Right



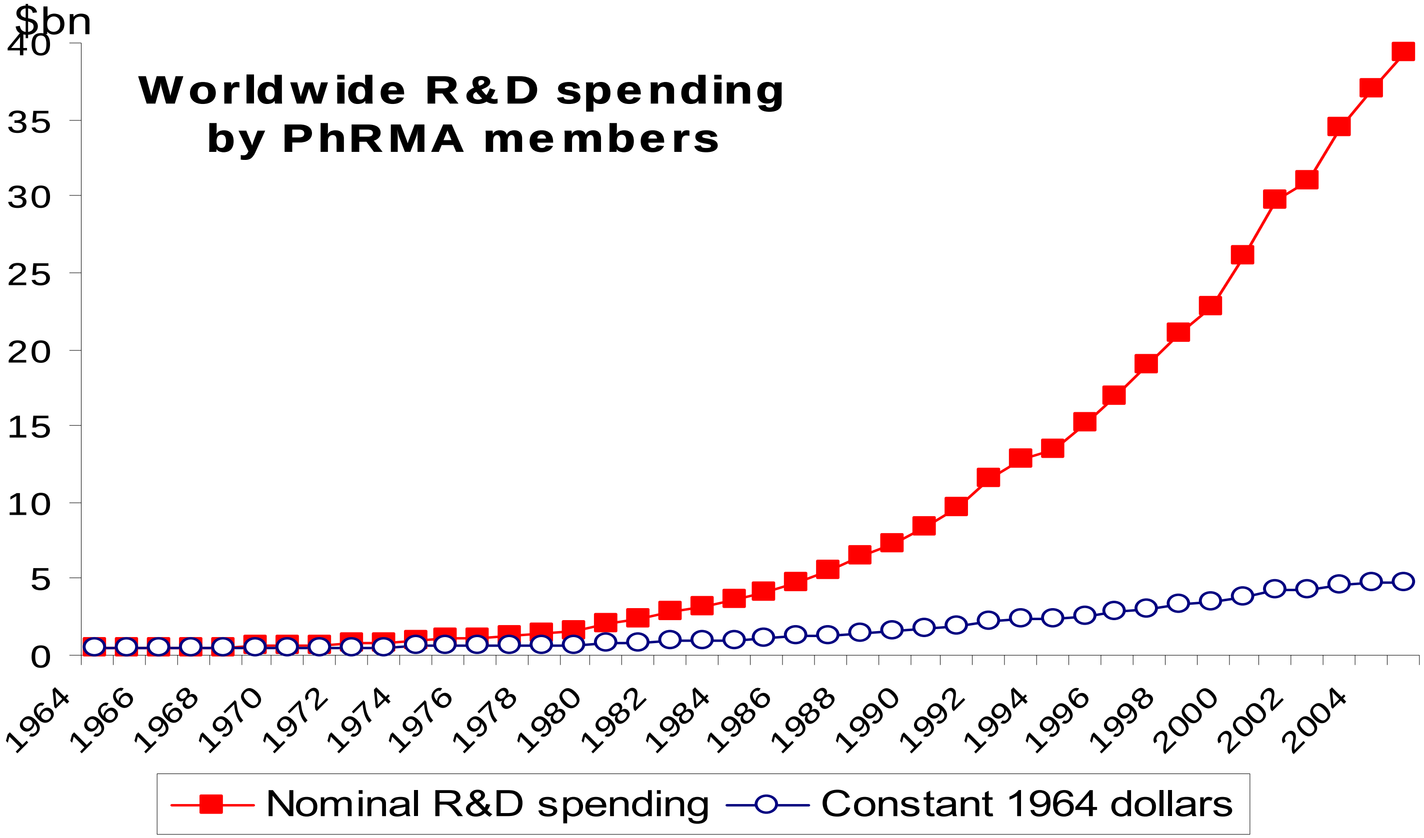
Source: FDA, Tufts CSDD

Image by MIT OpenCourseWare.

Anomalous period for the X axis…

In part due to an "overhang" cleared during the early years after PDUFA, the reduction in approvals since the late 1990s may simply be a "return to trend" (Berndt, et al, 2004)

Getting the S-curve #s Right

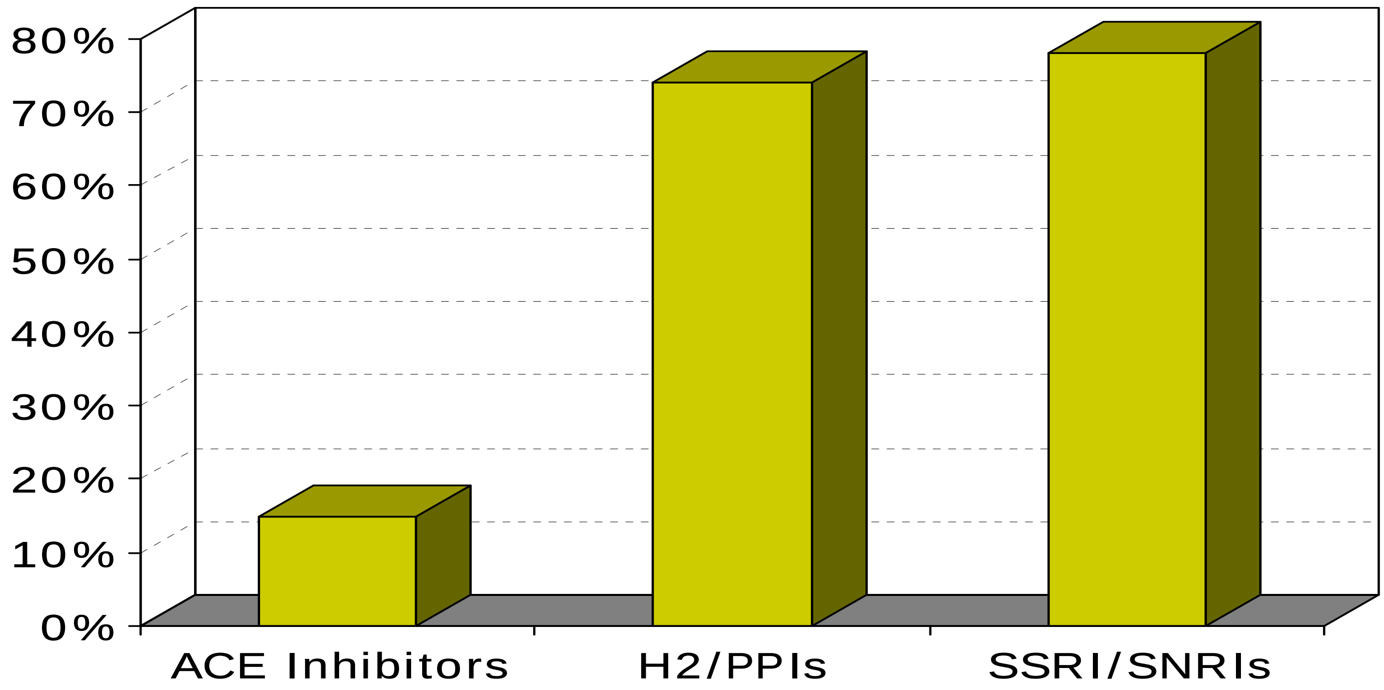


Data source: PhRMA, NIH Biomedical R&D Price Deflator

Inflating the Y axis…

While most discussions of increasing cost compare nominal expenditures, the cumulative impact of biomedical price inflation significantly reduces the measured growth rate in R&D expenditures (Cockburn, 2007)

Getting the S-curve #s Right

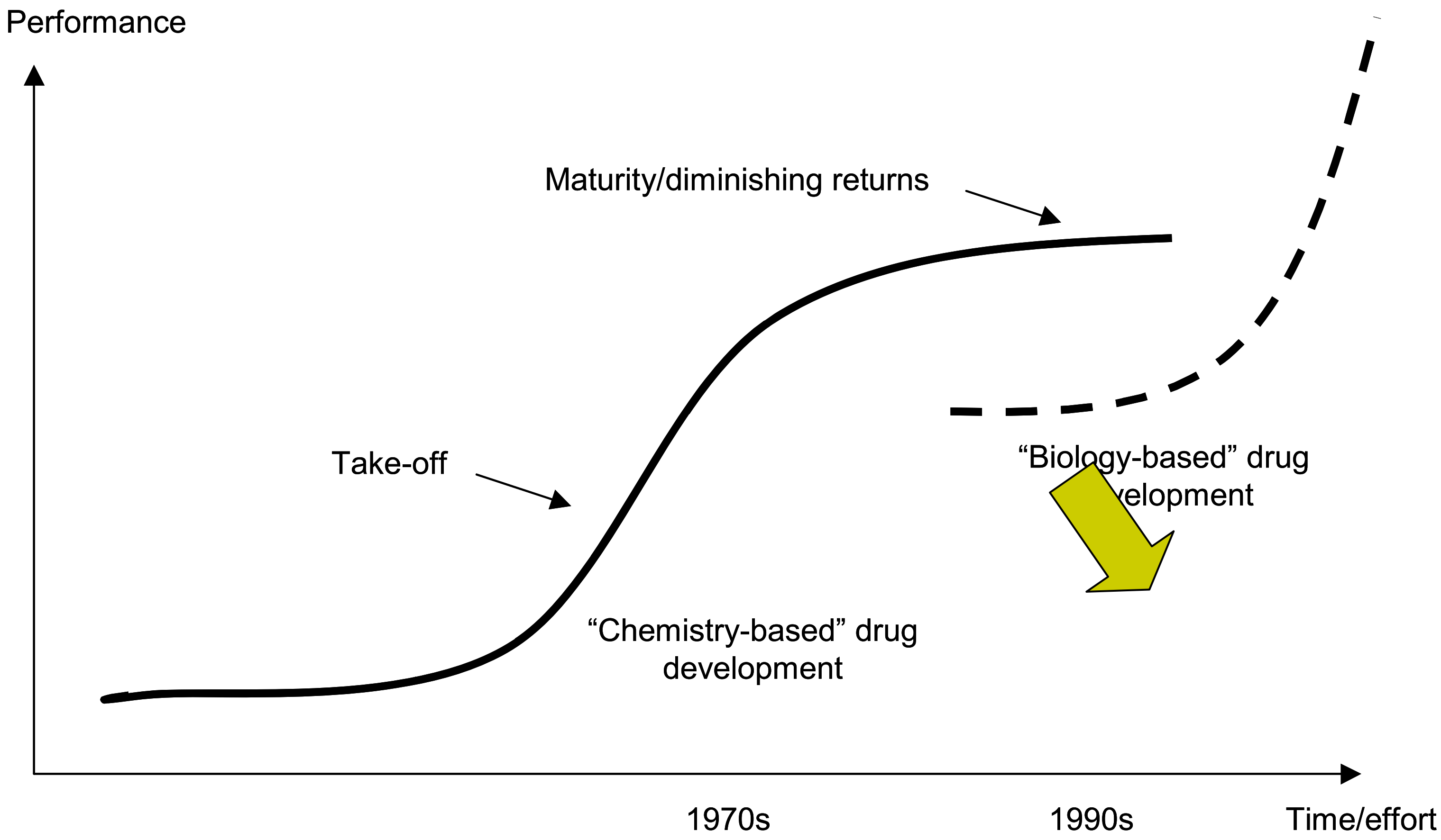


Data source: Berndt, Cockburn, Grépin (2005) “The Impact Of Incremental Innovation In Biopharmaceuticals: Drug Utilization In Original And Supplemental Indications.”

Not accounting for all progress on X axis….

High share of revenues for many drugs come from applications and indications that are only discovered after market introduction, and these uses are not always approved through formal FDA approval

Patience is a virtue…



Biopharmaceuticals is going through a familiar process of disruptive (i.e. costly) technological change from “chemistry” to “biology.” Do not be surprised if this takes quite a long time to materialize.

Patience is a virtue…

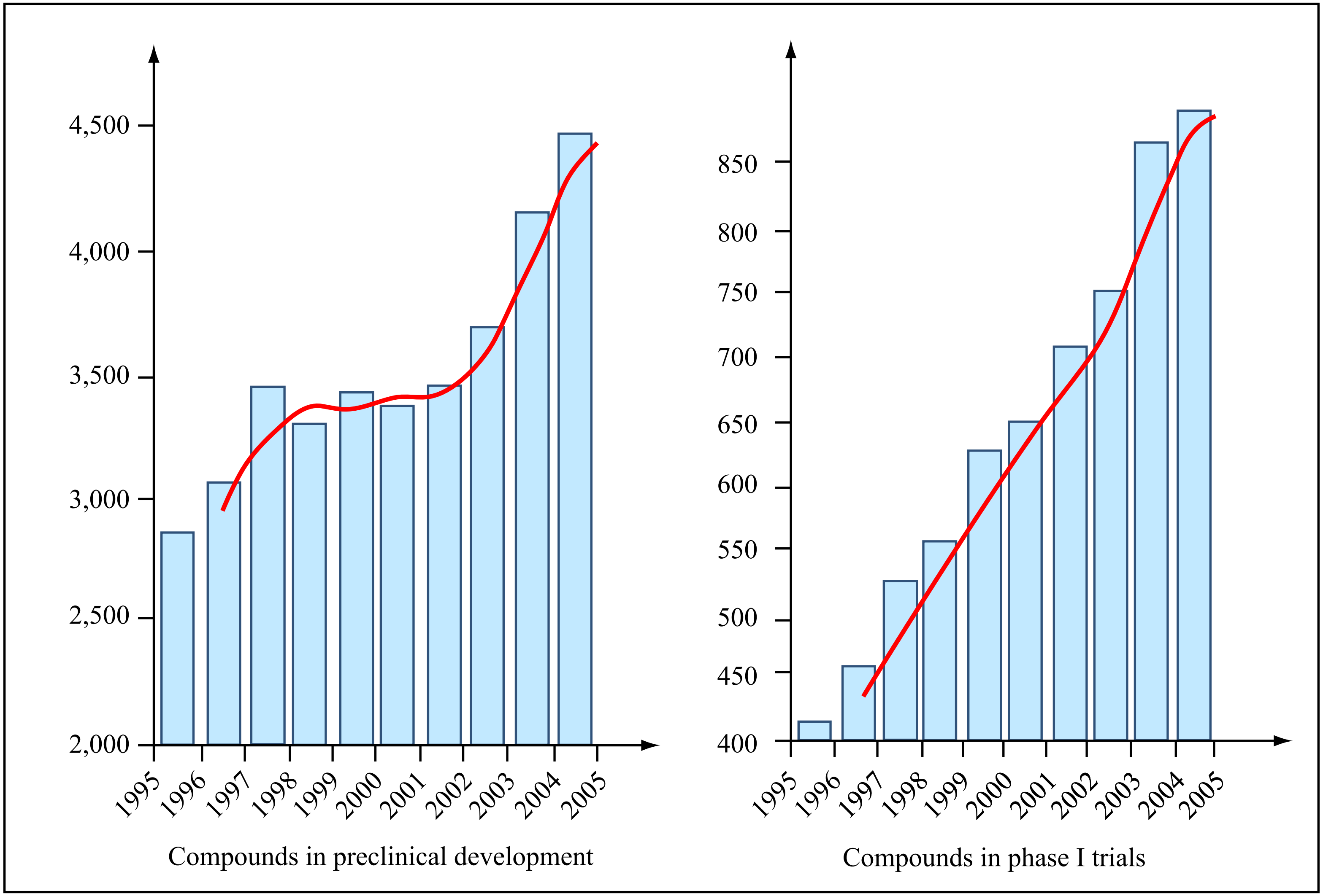


Image by MIT OpenCourseWare.

Data source: Pharmaprojects/Goldman Sachs, PAREXCEL Pharmaceutical R&D Sourcebook 2005/2006

While approvals slowed 2000-2005, there has been a dramatic increase in the number of promising compounds at earlier stages of the drug approval process

Managerial issues with using S Curves as part of opportunity analysis

Idealized approach is fine but in reality several issues…

- When to switch/join?
- Which S Curve to switch to/join?
- How to combine incremental vs. switching?
- How to organize to switch/ join?

When to switch curves

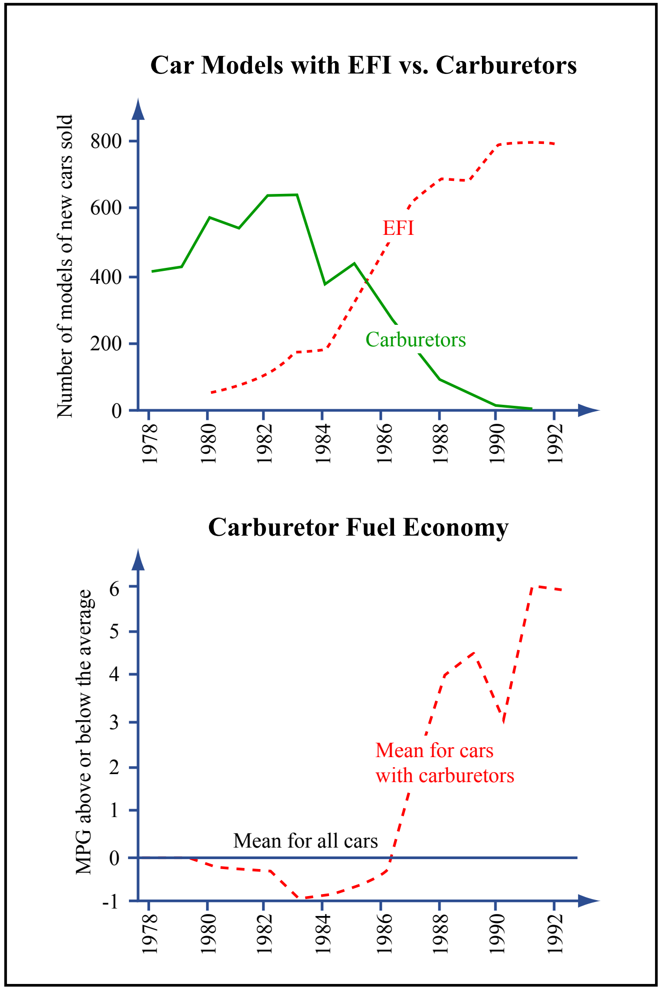
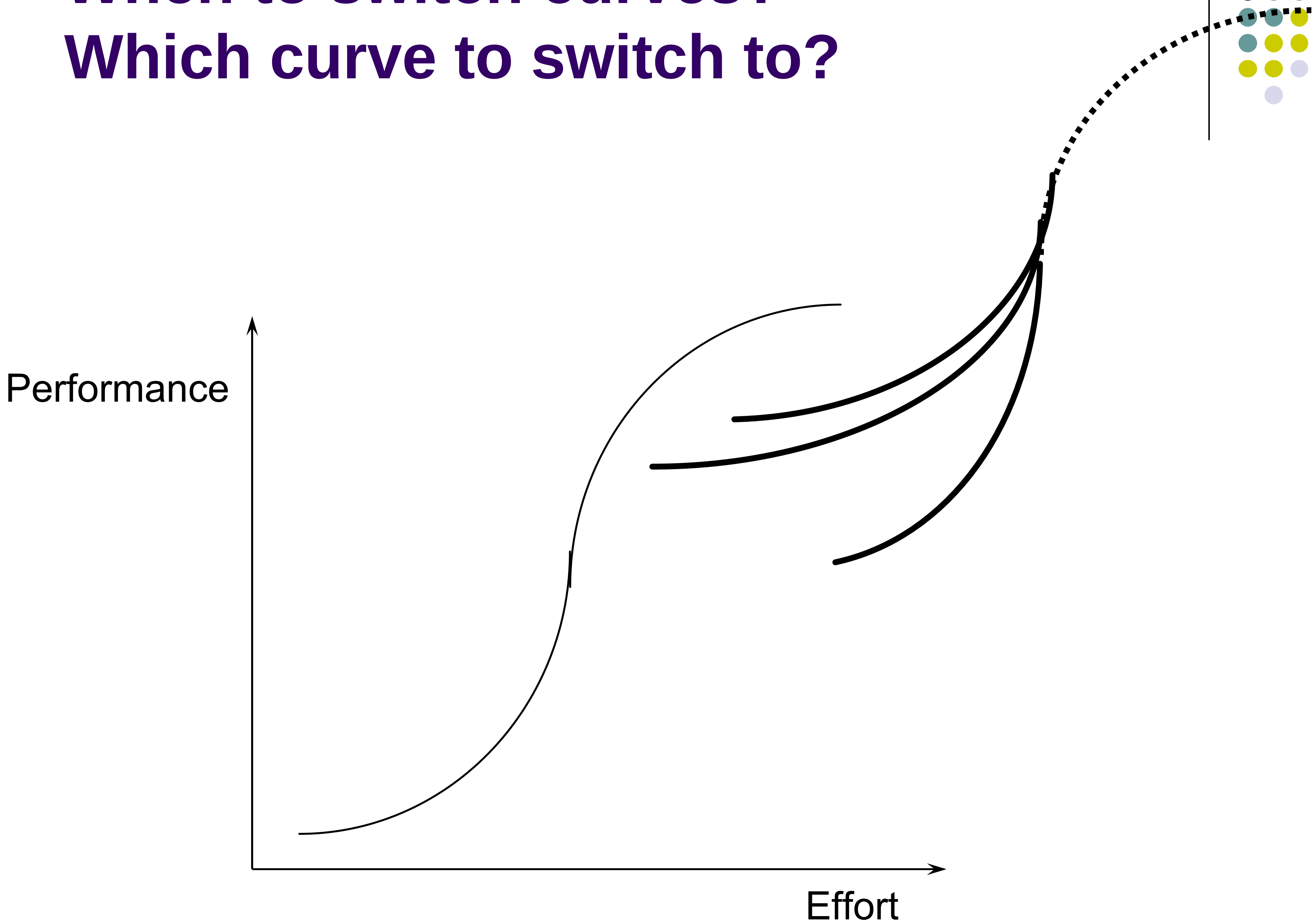


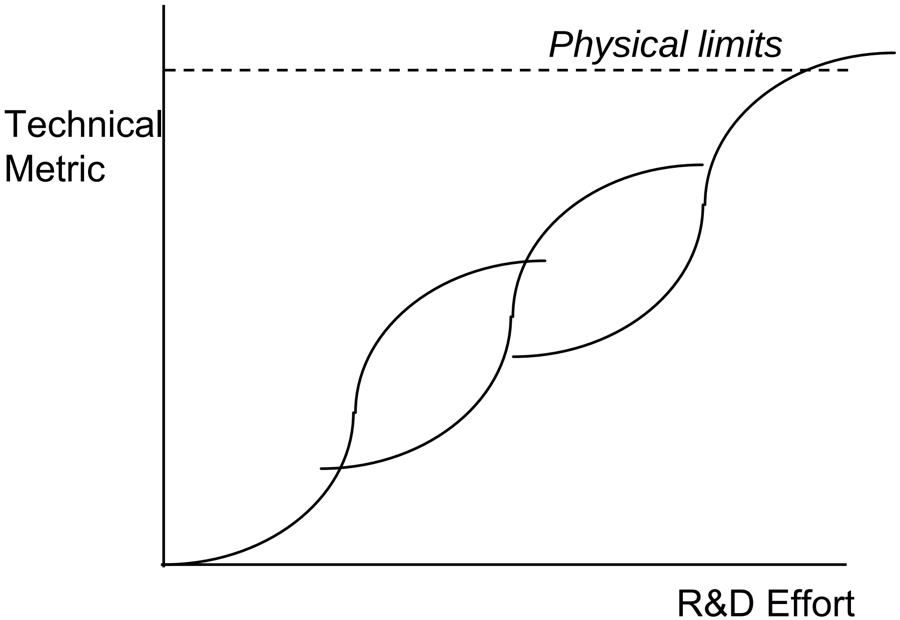
Image by MIT OpenCourseWare.

Adapted from: Snow 2008 “Beware of Old Technologies’ Last Gasps

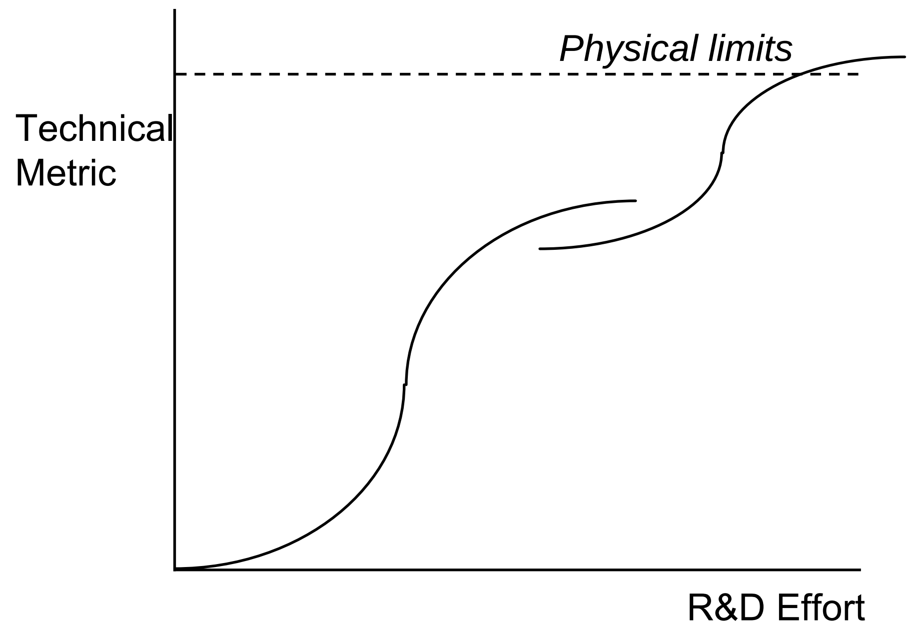
When to switch curves?
Which curve to switch to?



Balance of incremental vs. discontinuous



IBM – strategic leapers focused on new component technologies as a source of improvement with little movement up a give S curve or system optimization.
3:4 ratio of incremental vs. radical sources of improvement



HP - system masters focus on squeezing more incremental improvement out of given components
4:1 ratio of incremental vs. radical sources of improvement

Wrap-Up

- CORE DEFINITIONS
  - S-curve is a useful heuristic to describe robust pattern of technical change vs. effort
  - Innovations that move ALONG the curve are “incremental”
  - Innovations that shift to a NEW curve are discontinuities (NOT disruptions)
    - Discontinuities in “system” sometimes called “architectural”
    - Discontinuities in “components” sometimes called “modular”
    - I consider all discontinuities to be “radical”

Implications

Use technology S curve to answer the following questions:

- What are the dimensions of performance in our industry?
- Are there natural limits to performance improvement?
- Where are our competitors on the S-Curve? Which dimensions of performance are they working on?
- What does the available data tell you about what stage the industry is at and how much further it can go?

How reliable are your estimates & what are the key assumptions that justify your opportunity definition?

The S curve is best viewed as a tool for triggering discussion & revealing assumptions, not as a "scientific reality"

Next Class

- Implications of technology S curve dynamics for market S curve (diffusion) dynamics & for competitive dynamics

To put it another way…

- How should we map the ideas in the technology S-curve to the market S-curve & the definitions of discontinuity to Christensen: The Innovator's Dilemma:

  Sustaining vs. Disruptive Innovation

- May seem like semantics but top management teams in innovation-driven firms spend a lot of time on (often erroneous) definitions…