The Technology Imperative and The Future of R&D Policy

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The Technology Imperative

Declining *relative* US performance is the result of expanding globalization:

- "The world is flat"
  - Global diffusion of competitive assets
  - Technology has become a major competitive asset
- Technology enables nations to "tip the flat world"

Who is doing the "tipping?

- Global R&D trends portend increasing difficulties for U.S. economic outperformance
- 2008 shares of $1 trillion of global R&D:
  - Americas: 38.8%
  - Asia: 32.7%
  - Europe: 25.2%
- Three technology-based regional economies
- Policy implication: no single economy dominates

Data: "Change Becomes Watchword for 2009's World of R&D", *R&D Magazine*, December 2008.

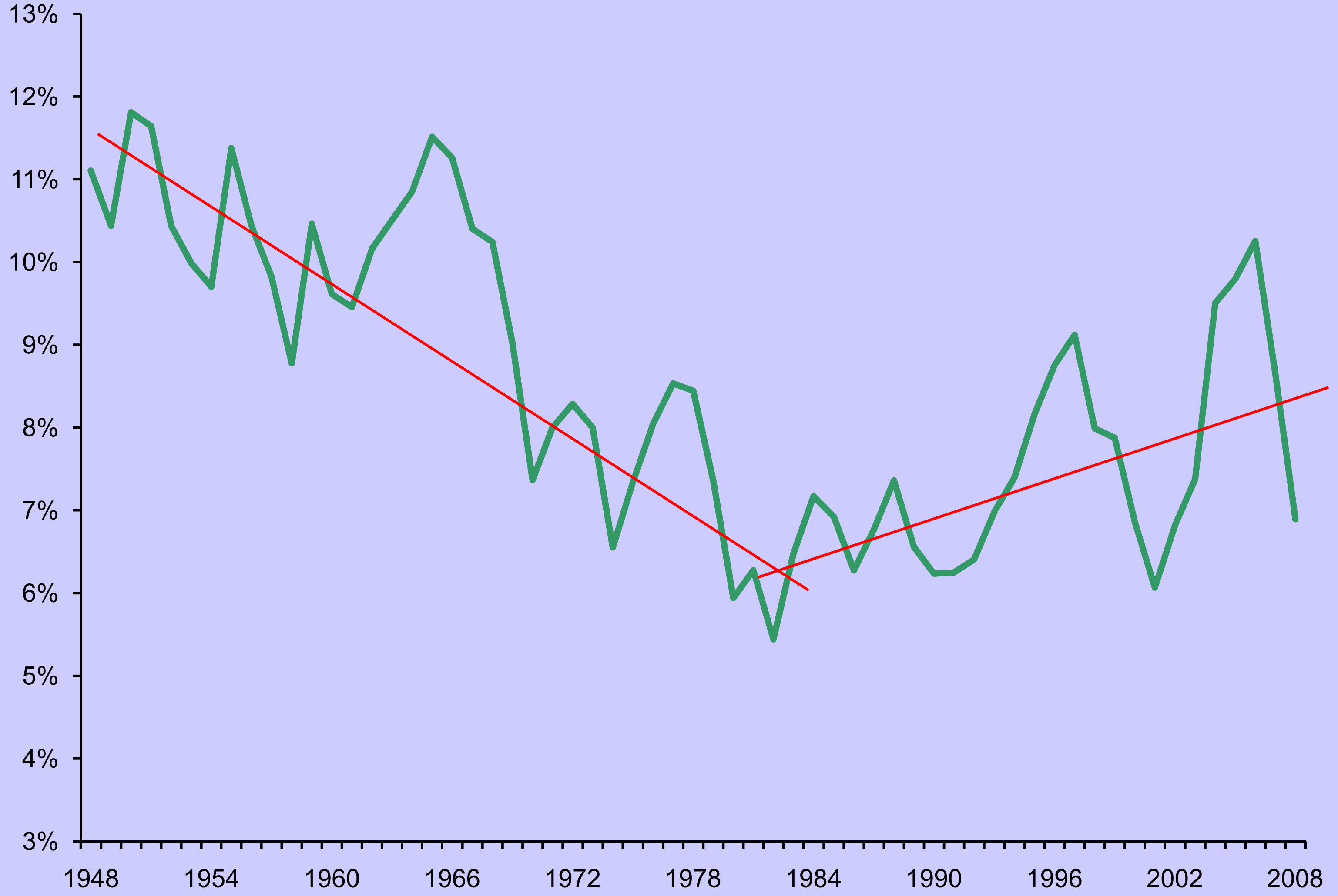
The Technology Imperative

All economies pursuing new growth paradigm based on

- Evolutionary shift in corporate strategy
  - National ➞ Multinational ➞ Global
  - Reduced stake in the "home" economy
  - Larger share of domestic GDP
- Emergence of governments as competitors
  - Increasingly complex relationships with global corporations

Underperformance

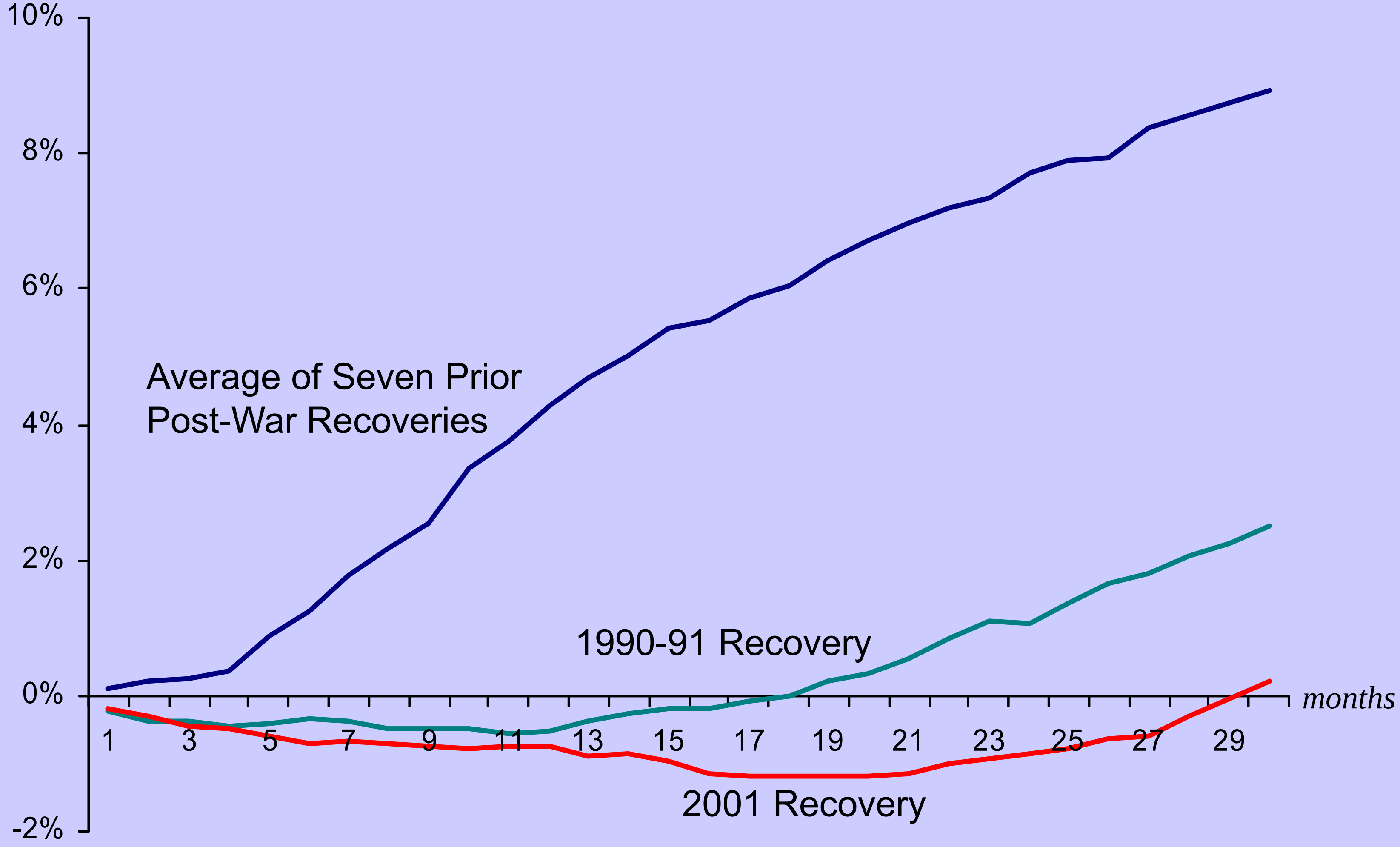
U.S. Domestic Corporate Profits Before Taxes to GDP, 1948-2008



Source: Bureau of Economic Analysis, NIPA Table 1.14 for corporate profits before taxes (Gross Value Added). Domestic profits exclude receipts by all U.S. corporations and persons of dividends from foreign corporations, U.S. corporations' share of reinvested earnings of their incorporated foreign affiliates, and earnings of unincorporated foreign affiliates net of corresponding payments.

Underperformance

Non-Farm Private Sector Employment Growth in Post World-War-II Business Recoveries: Percent Change from Recession Trough



Sources: G. Tassey, *The Technology Imperative*; BLS for employment data; NBER for recession trough dates

Paradigm shifts are slow and difficult:

- Structural problems are complex and take a long time to manifest themselves
  - Once embedded, they take a long time to fix
  - The crisis results from resistance to adaptation
    - *Installed-base effect* (sunk costs in intellectual, physical, organizational and marketing assets)
  - *Installed-wisdom effect* (current approach is the best one)
  - "The long run is not viewed as a problem until you get there, then it's a crisis"

Need new economic drivers:

- The new growth paradigm requires revisions to two long-standing economic concepts:
  - Static version of the "law of comparative advantage"

    Imperative: Switch to a dynamic version

  - Schumpeter's "one-sector" creative destruction model

    Imperative: Modify to a two-sector, full life-cycle model

Response: Improved R&D Policy Analysis

(1) Demonstrate importance of technology for economic growth

(2) Identify indicators of underperformance at the macroeconomic level
- Productivity growth
- Trade balances
- Corporate profits
- Employment and earnings

(3) Estimate magnitude and composition of underinvestment
- Specific R&D investment trends
- Investment by phase of the R&D cycle
- Technology diffusion rates

(4) Identify causes of underinvestment
- Excessive technical and/or market risk
- Appropriability problems
- Inadequate risk taking

(5) Develop policy responses and management mechanisms
- Policy instruments matched with underinvestment phenomena
- Economic impact assessments

Importance of the Technology-Based Economy

1) **Technology** accounts for **one-half of output** (GDP) growth

2) **High-tech portion** of industrialized nations' **manufacturing** output has increased by a factor of between 2 and 3 over past 25 years

3) **High-tech portion** of global **trade in goods** has tripled in the past 25 years

4) **Median wages** in all 29 BLS "high-tech" industries **exceed median for all industries;** 26 of these industries exceed national median by **>50%**

5) **Technologically stagnant sectors** show **slow productivity growth** resulting **above-average price increases**

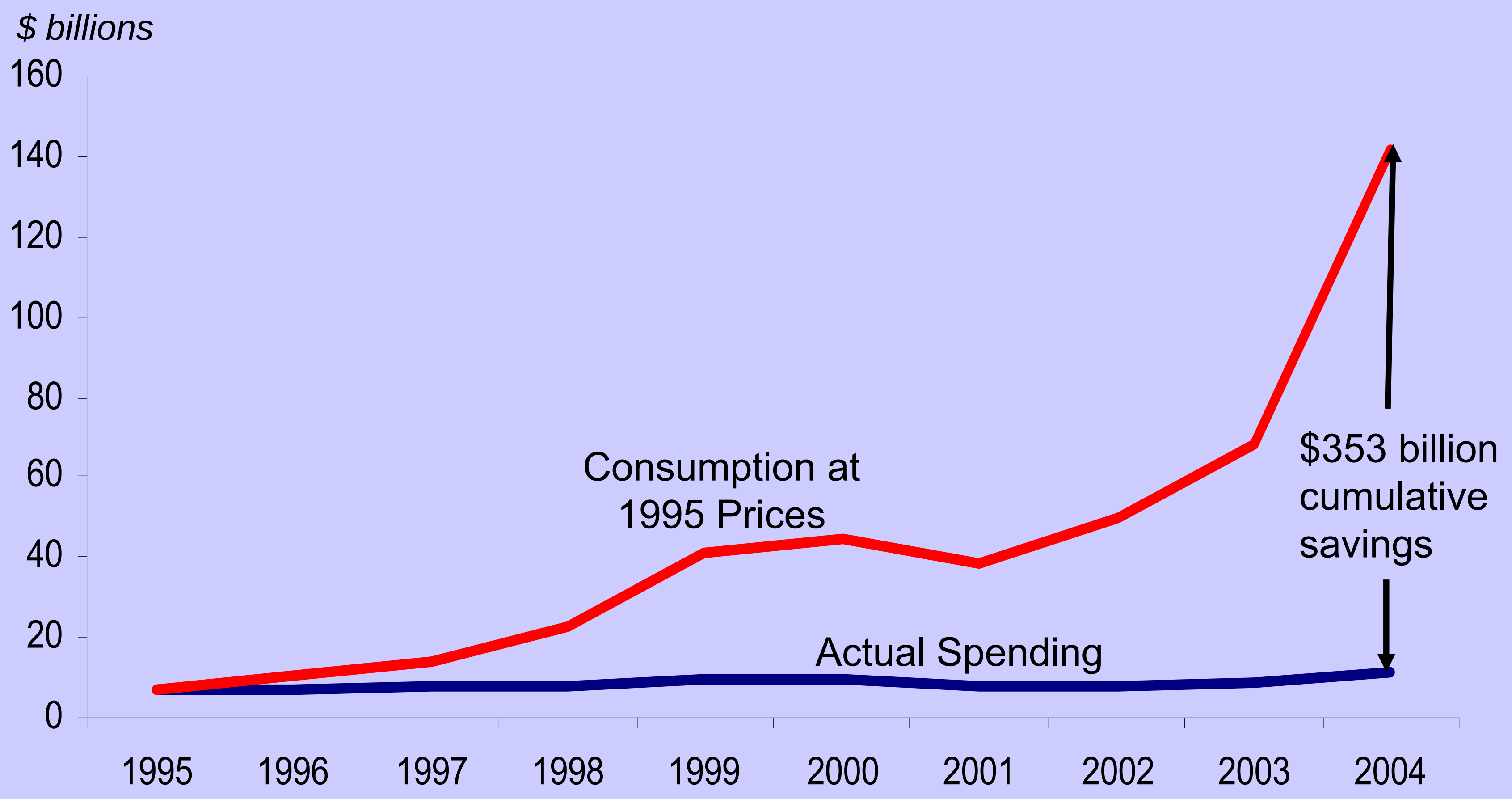
6) **Acceleration** of U.S. productivity growth in 1990s is entirely **due to technology investments**

7) **Productivity advantage** of the U.S. economy over other OECD countries **accounts for 3/4 of the per capita income gap**

8) **Rate of return** from R&D is **four times** that from physical capital

Importance of the Technology-Based Economy

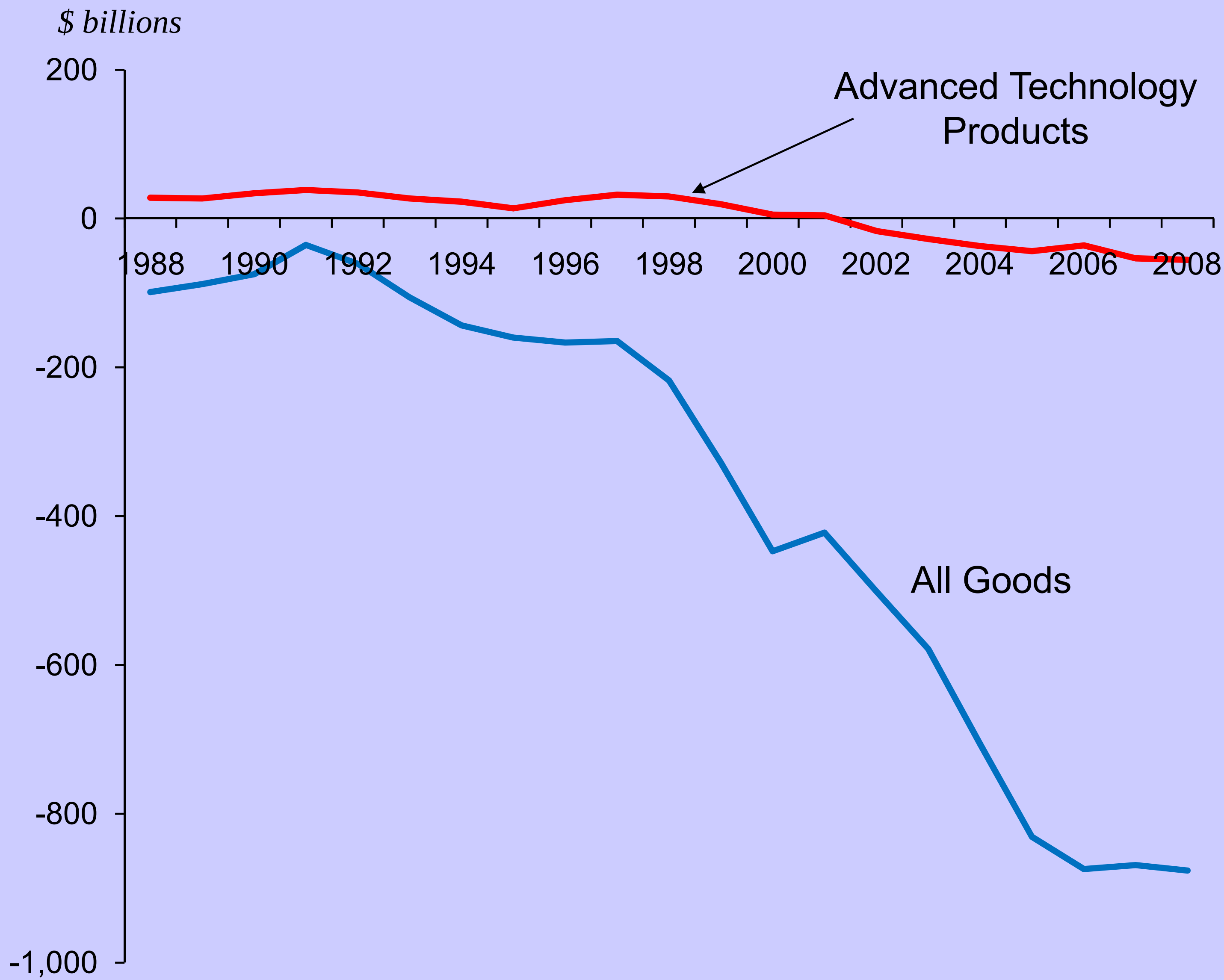
Impact of Technological Change: Government Computer Purchases in Actual and 1995 Prices



Source: Bureau of Economic Analysis and Semiconductor Industry Association
Note: Consumption data include federal, state, and local governments

Underperformance

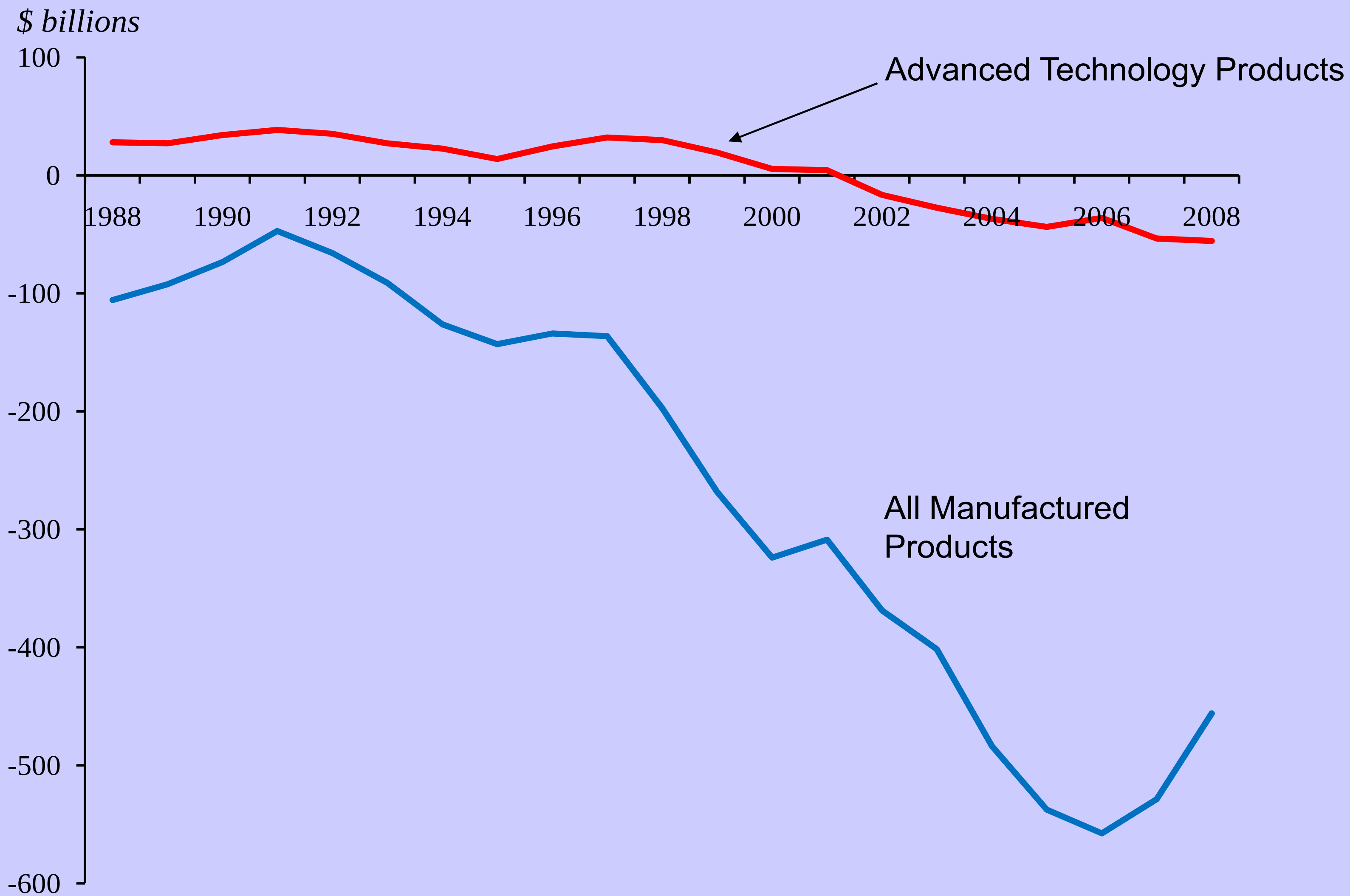
U.S. Trade Balances for High-Tech vs. All Goods, 1988-2008



Source: Census Bureau, Foreign Trade Division

Underperformance

U.S. Trade Balances for High-Tech vs. All Manufactured Products, 1988-2008



Source: Census Bureau, Foreign Trade Division

Underperformance

Trends in Value Added

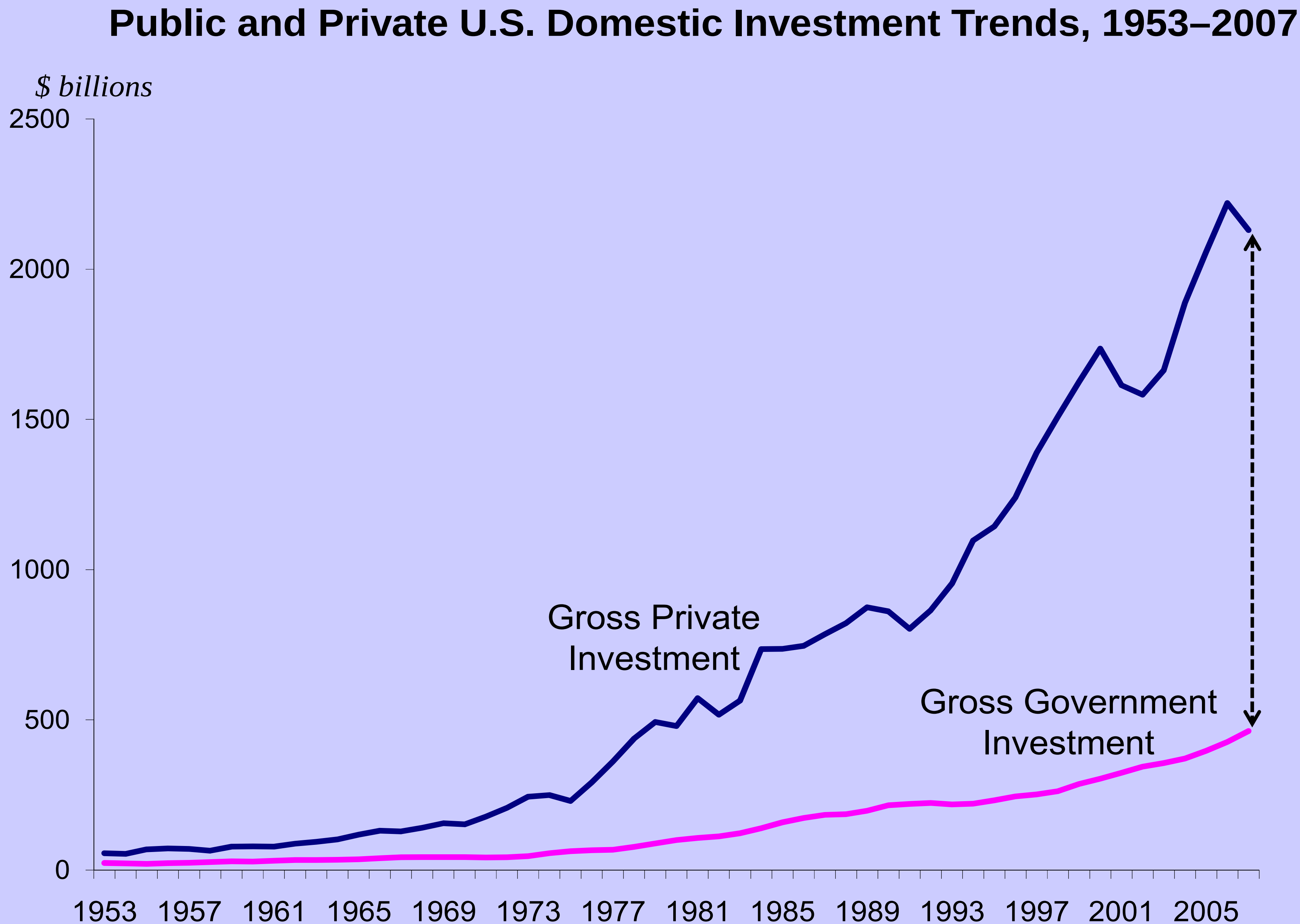
Industry (NAICS Code)	% Change in Value Added		R&D
	1985–2000	2000–2006	Intensity
GDP	132.6	34.4	2.6
Manufacturing (31–33)	92.7	8.7	3.6
Motor vehicles and parts (3361-63)	84.0	-18.0	2.5
Textiles, apparel and leather (313-16)	8.2	-34.7	1.6
Computer & Electronic Products (334)	144.5	-24.7	9.0
Publishing, Including Software (511)	225.1	28.8	17.1
Information & Data Processing (518)	305.4	81.7	8.7
Professional, Scientific & Technical (54)	249.6	37.1	10.0

Underperformance

Three Elements of R&D Policy:

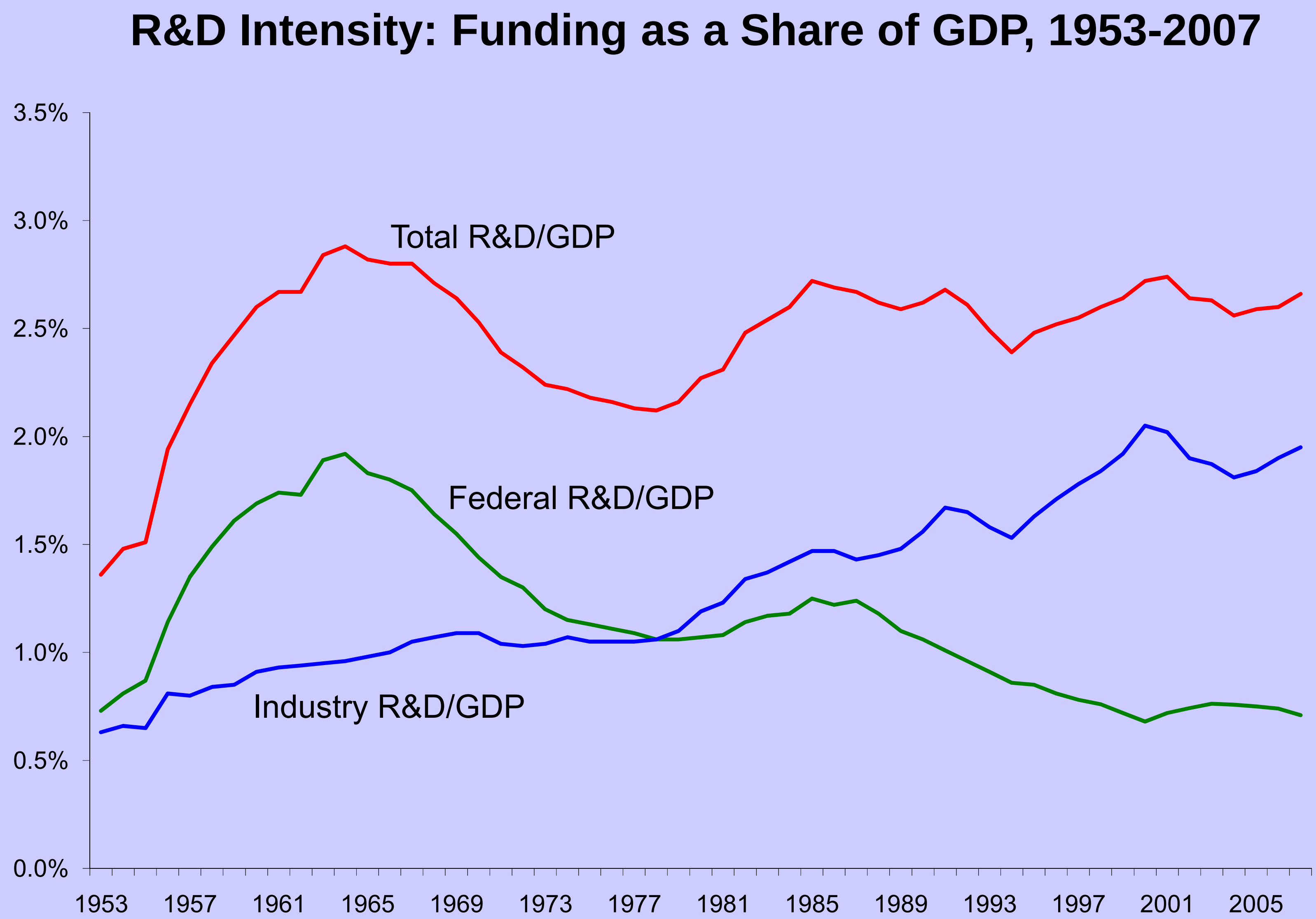
- Amount of R&D
- Composition of R&D
- Efficiency of R&D

Indicators of Underinvestment – Aggregate



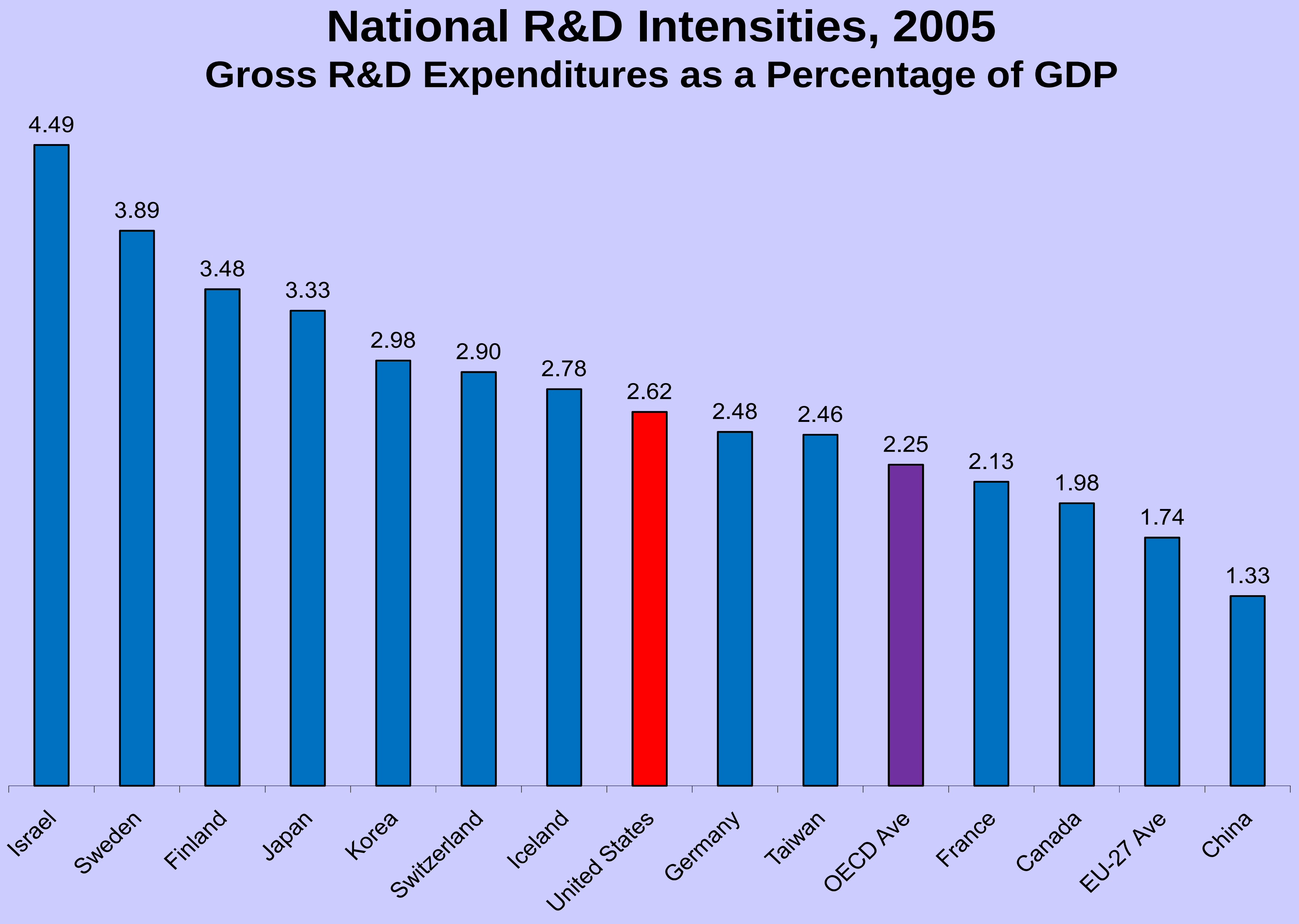
Source: Bureau of Economic Analysis

Indicators of Underinvestment – Amount



Source: National Science Foundation

Indicators of Underinvestment – Amount



Source: OECD, *Main Science and Technology Indicators*, May 2007

Indicators of Underinvestment – Amount

- **High-Tech Sector:**
  - Electronics
  - Pharmaceuticals
  - Communication Services
  - Software and Computer-Related Services
- **Accounts for 7 – 10 percent of GDP**
- **Bottom Line:** The other 90+ percent of the economy is susceptible to market share erosion and decline

Indicators of Underinvestment – Amount

Geographic Concentration:

- Six states account for almost one-half of all R&D
- Ten states account for 60 percent of all R&D
- **Bottom Line:** The remaining 40 states are not a high-tech economy

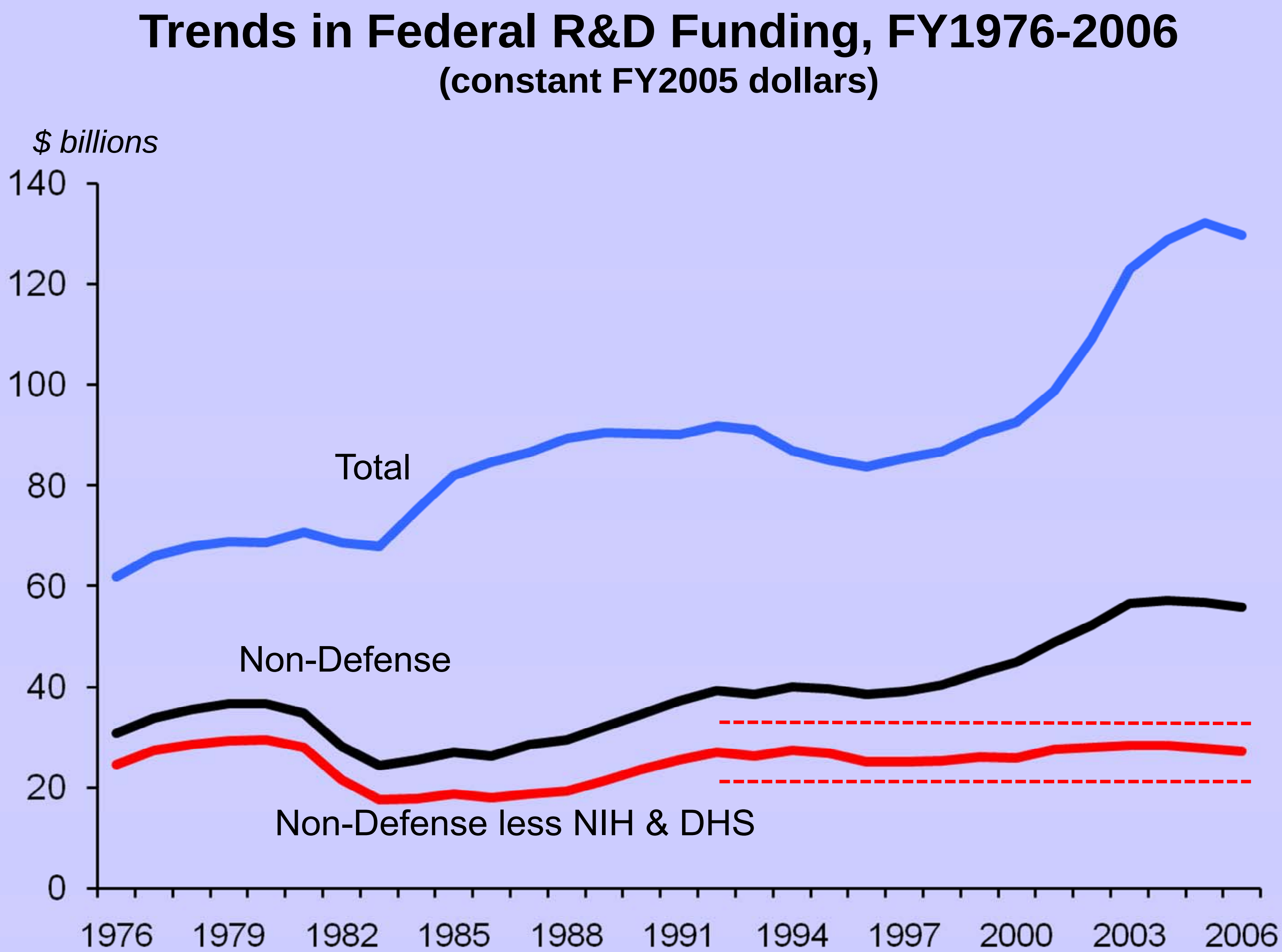
Indicators of Underinvestment – Amount

Geographic Distribution of U.S. R&D: Top Ten States by Share of R&D Performance, 2006

State	% of Population	% of National R&D
California	12.0	19.8%
Michigan	3.3	5.7%
New York	6.3	5.5%
Texas	7.8	4.4%
Massachusetts	2.1	4.9%
Pennsylvania	4.1	4.6%
New Jersey	2.8	4.4%
Illinois	4.2	3.9%
Washington	2.1	3.7%
Maryland	1.8	3.7%
Total	46.5	60.5%

Source: National Science Foundation

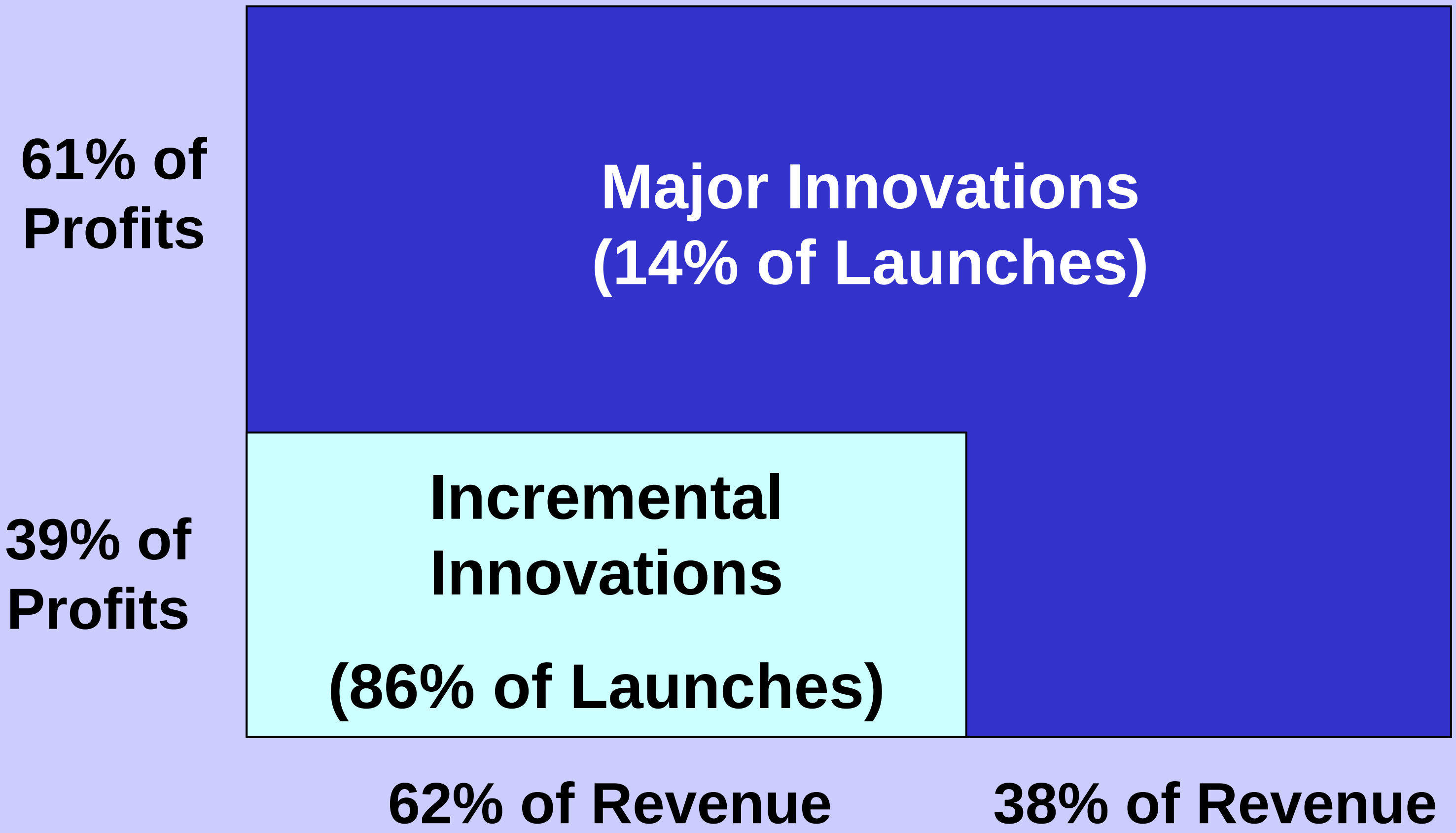
Indicators of Underinvestment – Composition



Source: AAAS

Indicators of Underinvestment – Composition

Profit Differentials for Major and Minor Innovations



Source: W. Chan Kim and Renee Mauborgne, "Value Innovation: The Strategic Logic of High Growth", *Harvard Business Review*, 1997

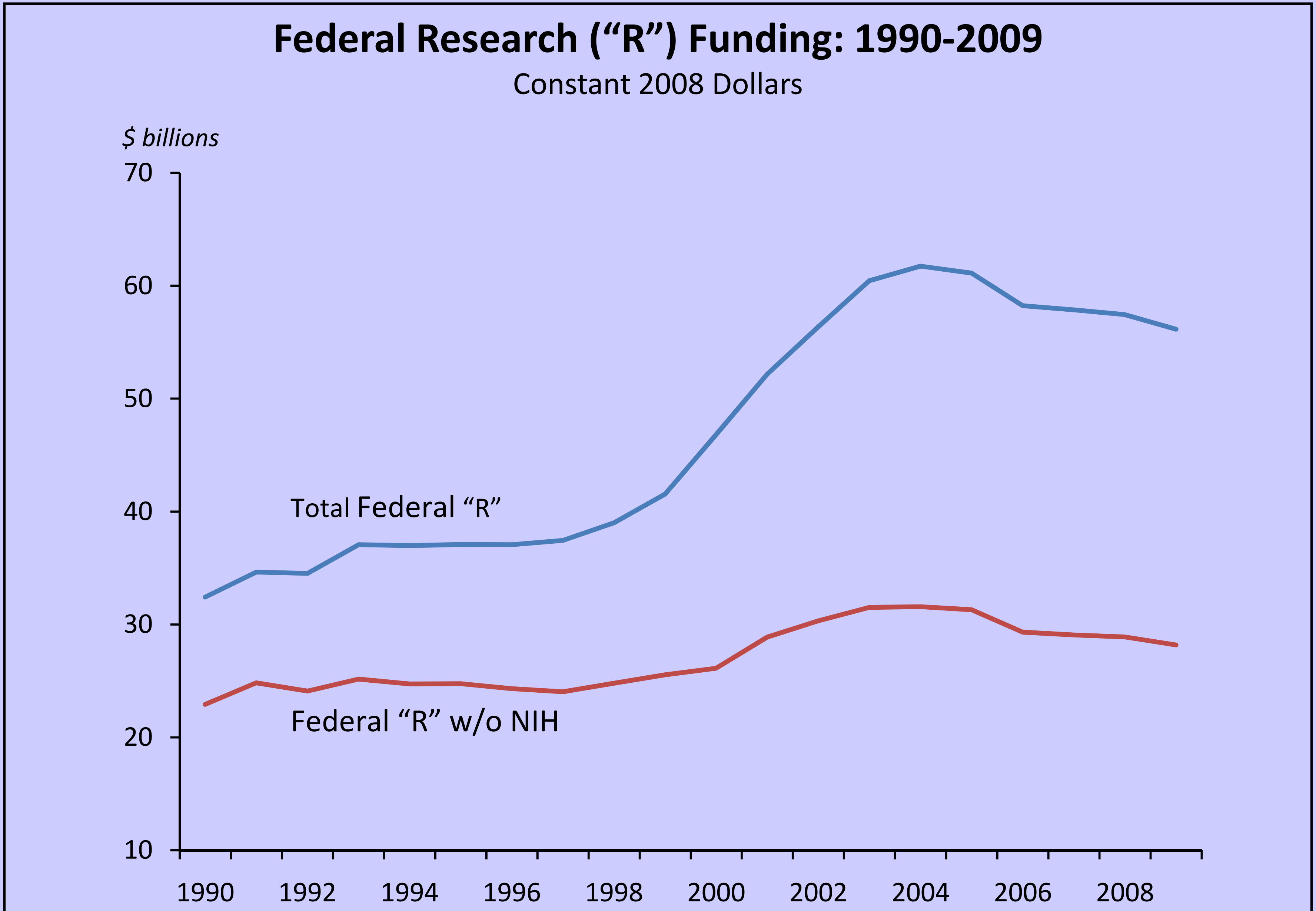
Indicators of Underinvestment – Composition

IRI "Sea Change" Index:

Forecast Year	"Directed Basic Research"	"New Business Projects"
1993	**-26**	**+18**
1994	**-26**	**+18**
1995	**-19**	**+31**
1996	**-6**	**+39**
1997	**-26**	**+28**
1998	**-14**	**+24**
1999	**-23**	**+31**
2000	**-9**	**+34**
2001	**-21**	**+44**
2002	**-11**	**+30**
2003	**-21**	**+7**
2004	**-17**	**+1**
2005	**-21**	**+8**
2006	**-8**	**+31**
2007	**-6**	**+31**
2008	**+4**	**+33**
2009	**-17**	**+22**

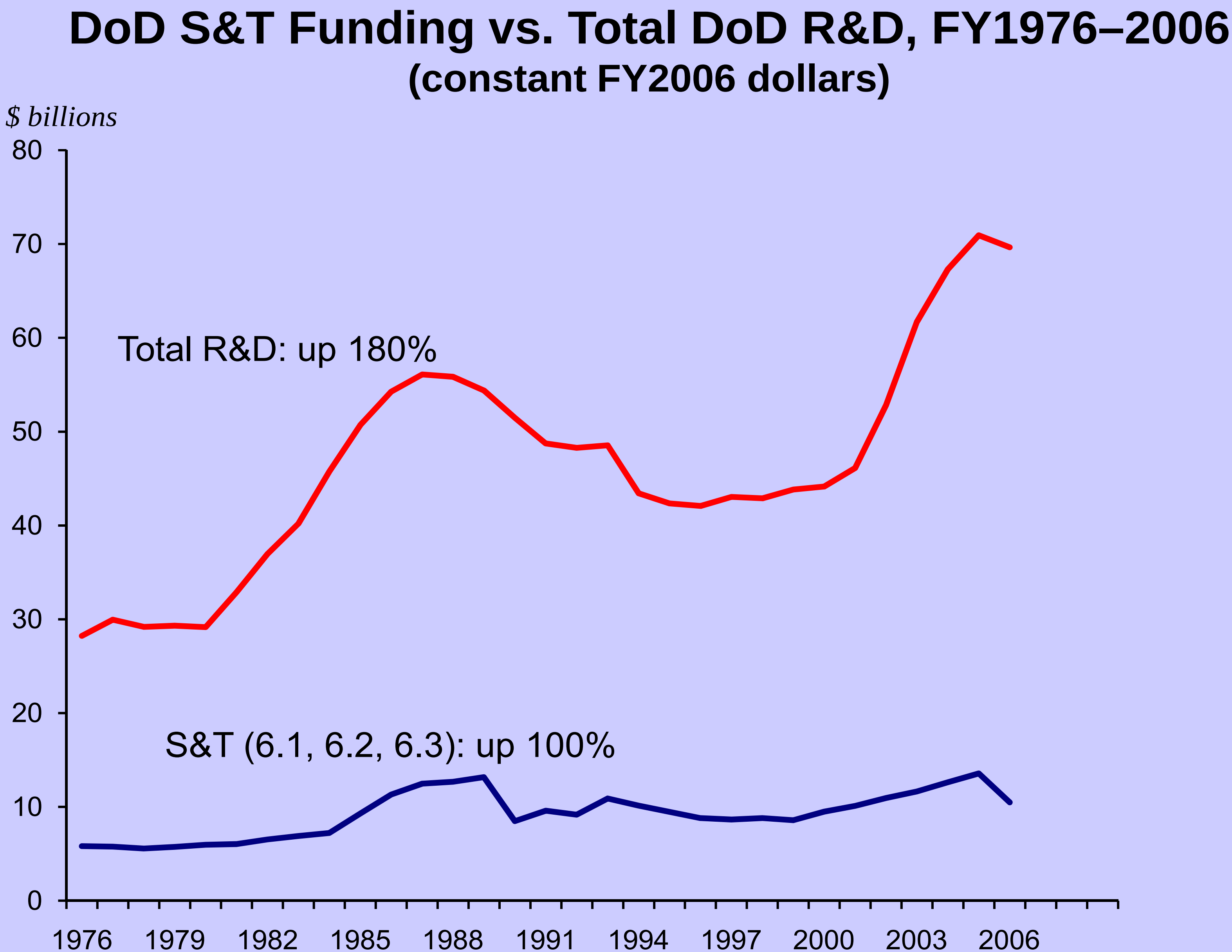
Source: Industrial Research Institute's annual surveys. The Sea Change Index is calculated by subtracting the percent of respondents reporting a planned decrease in the particular category of R&D spending from the percent planning an increase of greater than 5 percent. Sample size varies from year to year, but is approximately 100 firms.

Indicators of Underinvestment – Composition



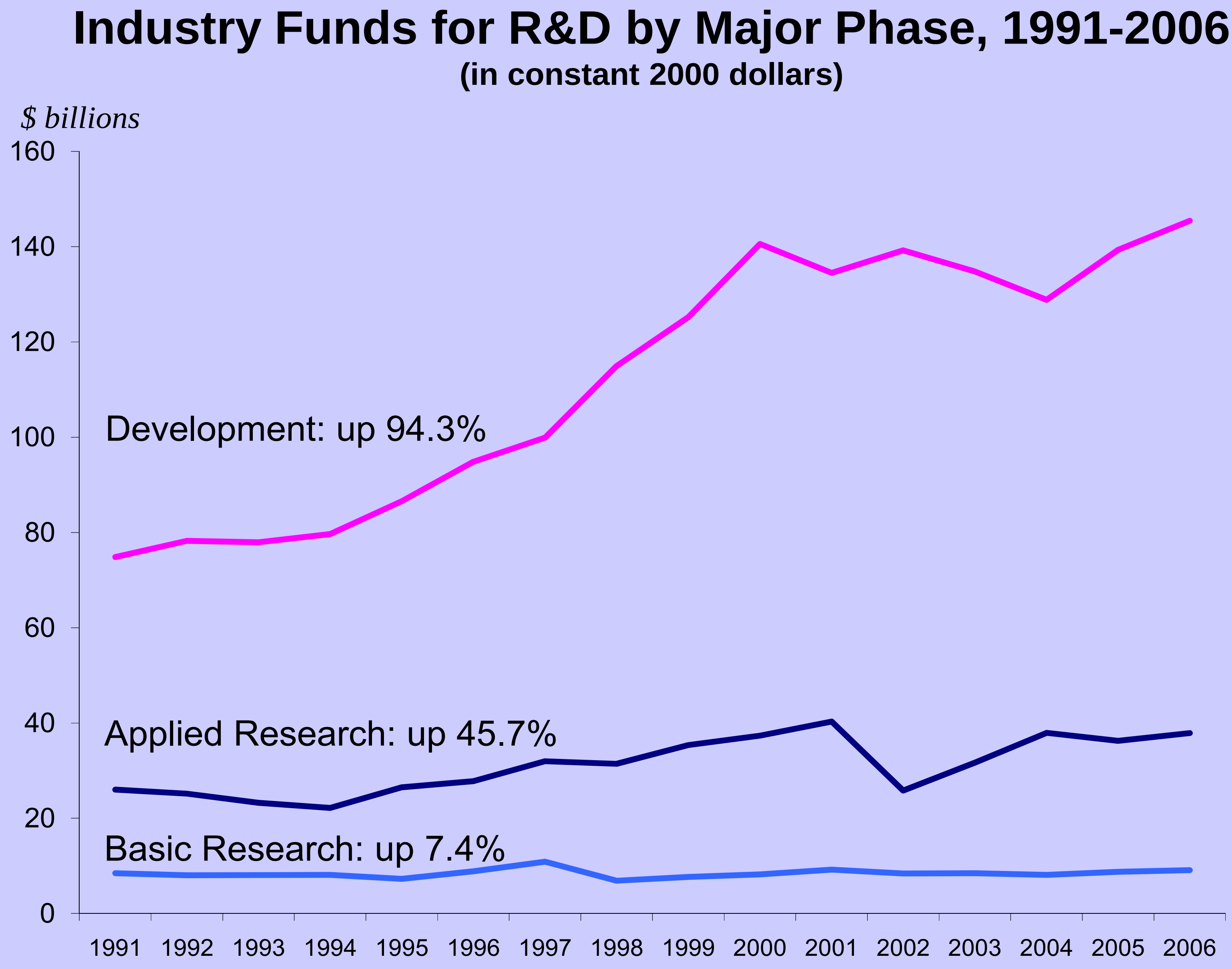
Note: FY2009 does not include stimulus funding.

Indicators of Underinvestment – Composition



Source: AAAS; FY2006 estimate is President's request

Indicators of Underinvestment – Composition



Source: National Science Foundation

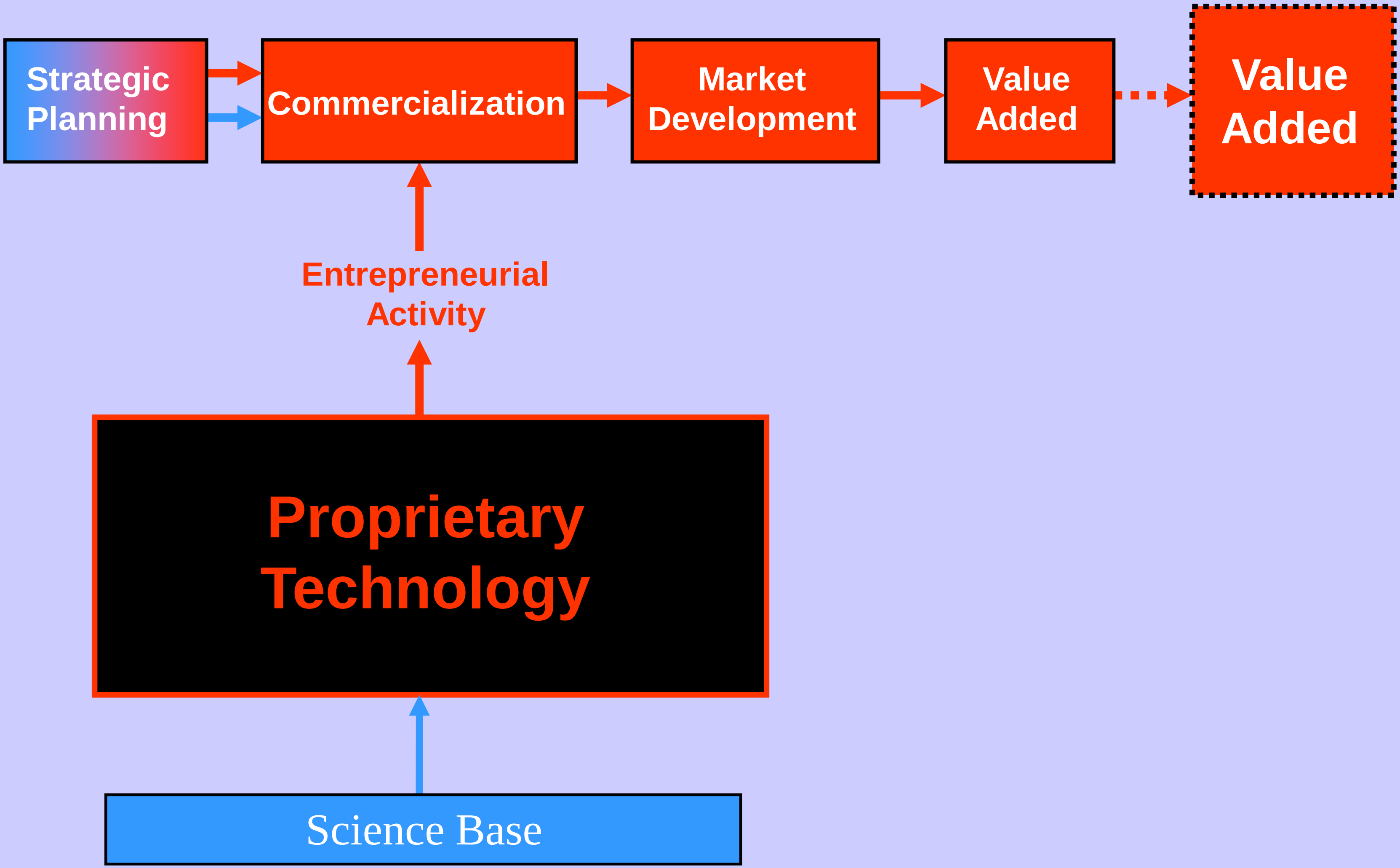
Need for New Innovation Model

Address the three targets of R&D policy:

- Amount of R&D
- Composition of R&D
- Efficiency of R&D

Need for New Innovation Model

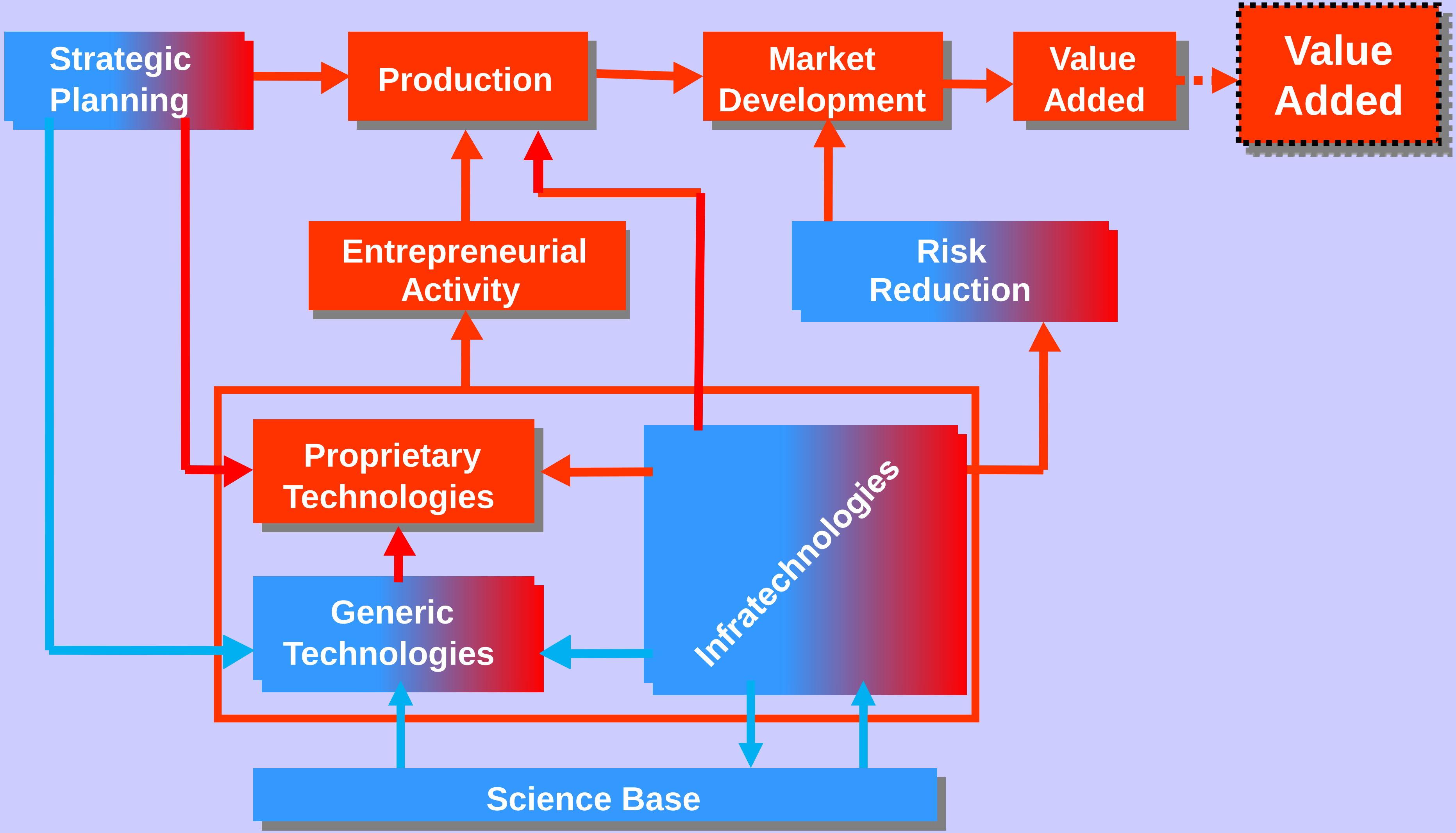
"Black Box" Model of a Technology-Based Industry



G. Tassey, *The Technology Imperative*, Edward Elgar, 2007

Need for New Innovation Model

Economic Model of a Technology-Based Industry



Gregory Tassey, *The Technology Imperative*, 2007; and, "The Disaggregated Technology Production Function: A New Model of Corporate and University Research", *Research Policy*, 2005.

Policy Response

Application of the Technology-Element Model: Biopharmaceuticals

Science Base

- genomics
- immunology
- microbiology/ virology
- molecular and cellular biology
- nanoscience
- neuroscience
- pharmacology
- physiology
- proteomics

Infratechnologies

- bioinformatics
- biospectroscopy
- combinatorial chemistry
- DNA sequencing and profiling
- electrophoresis
- fluorescence
- gene expression analysis
- magnetic resonance spectrometry
- mass spectrometry data
- nucleic acid diagnostics
- protein structure modeling/analysis techniques

Generic Technologies

Product

- antiangiogenesis
- antisense
- apoptosis
- bioelectronics
- biomaterials
- biosensors
- functional genomics
- gene delivery systems
- gene testing
- gene therapy
- gene expression systems
- monoclonal antibodies
- pharmacogenomics
- stem-cell
- tissue engineering

Process

- cell encapsulation
- cell culture
- microarrays
- fermentation
- gene transfer
- immunoassays
- implantable delivery systems
- nucleic acid amplification
- recombinant DNA/genetic engineering
- separation technologies
- transgenic animals

Commercial Products

- coagulation inhibitors
- DNA probes
- inflammation inhibitors
- hormone restorations
- nanodevices
- neuroactive steroids
- neuro-transmitter inhibitors
- protease inhibitors
- vaccines

Public Technology Goods

Mixed Technology Goods

Private Technology Goods

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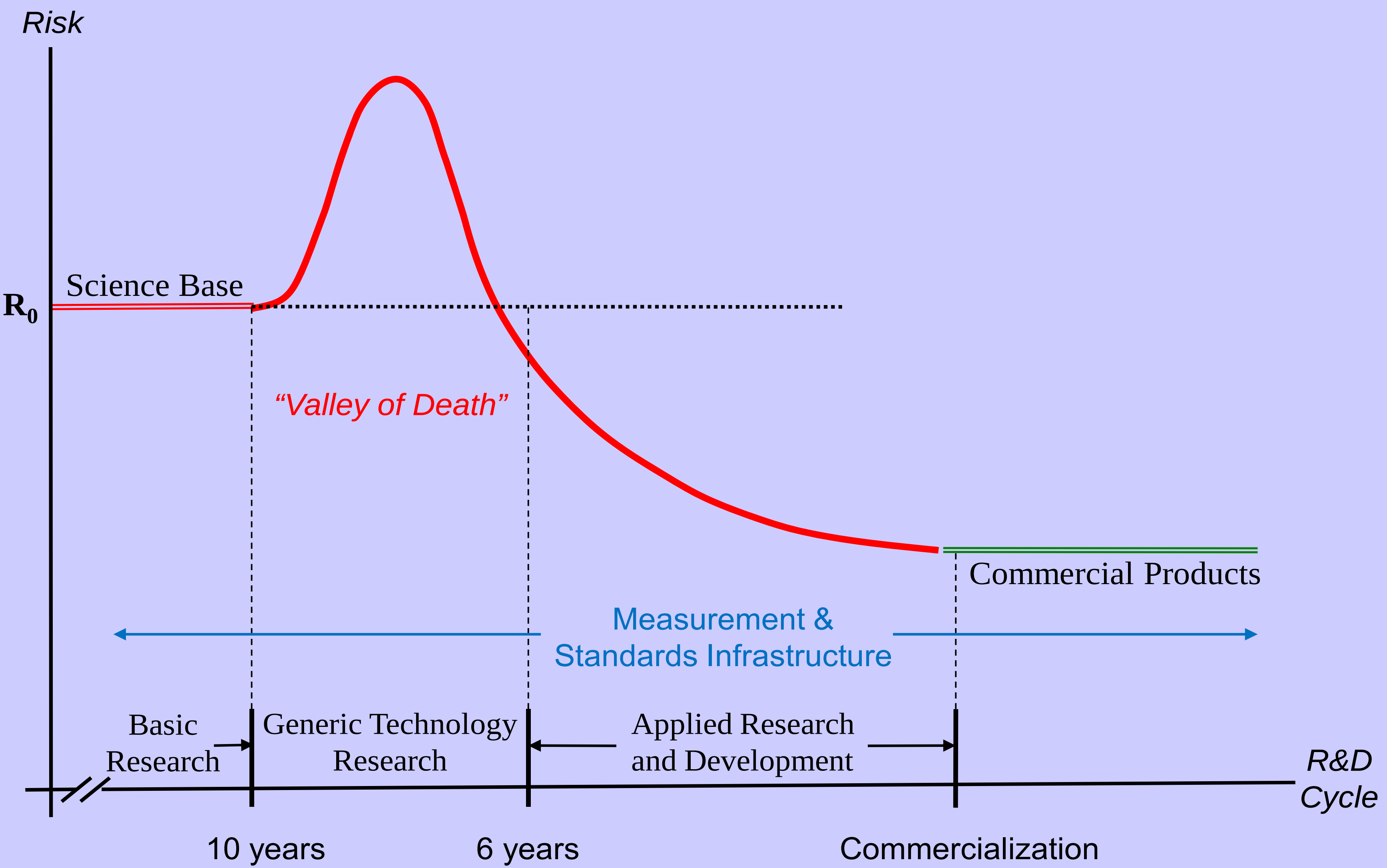
Policy Response

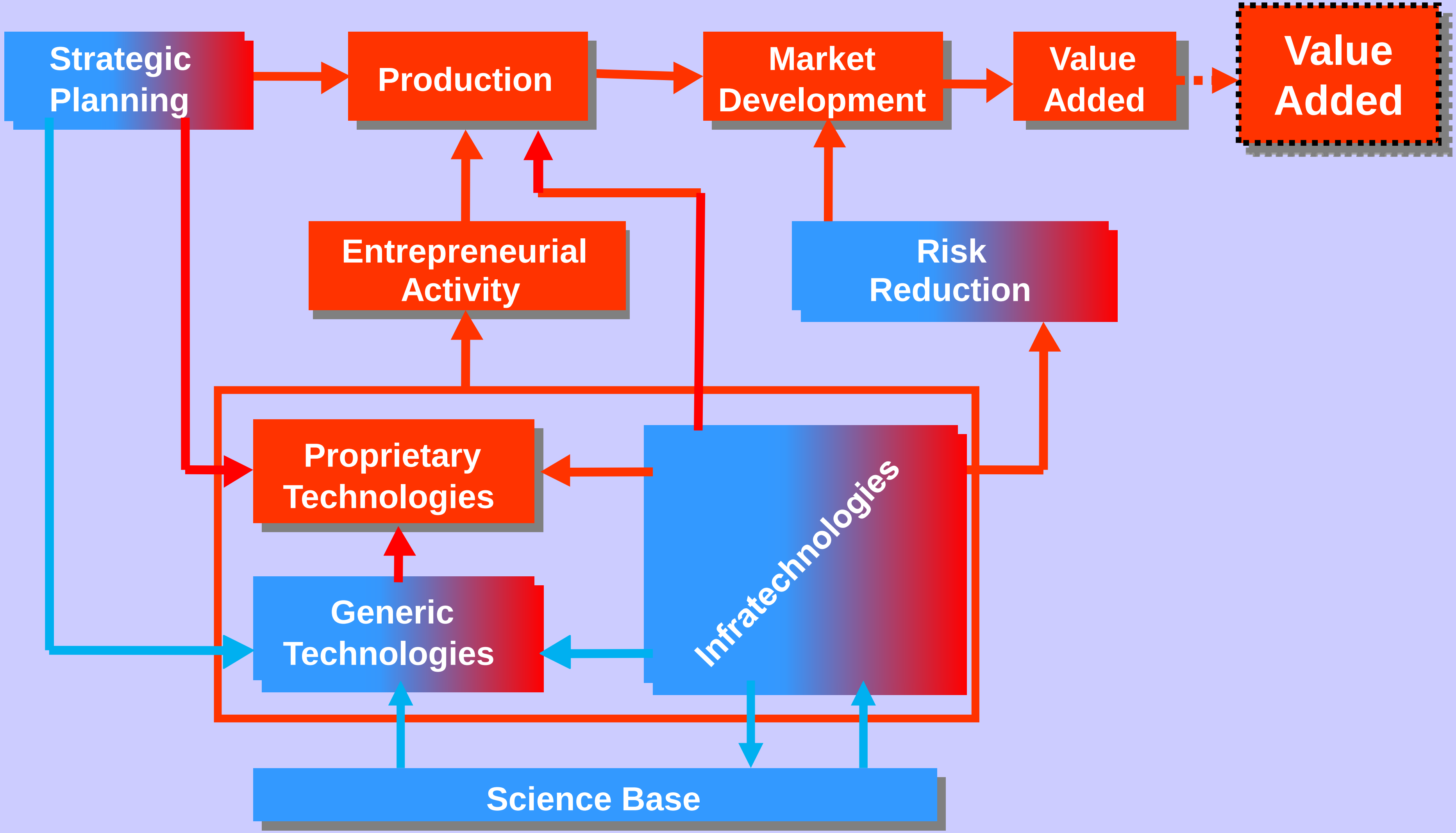
Overcoming the Innovation Risk Spike (Valley of Death)



Source: G. Tassey, "Underinvestment in Public Good Technologies", *Journal of Technology Transfer 30: 1/2* (January, 2005); and, "Modeling and Measuring the Economic Roles of Technology Infrastructure", *Economics of Innovation and New Technology 17* (October, 2008)

Policy Response

Economic Model of a Technology-Based Industry



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Policy Response

Potential R&D Cost Reductions in Biopharmaceutical Development with an Improved Technology Infrastructure

Technology Focus Area	Expected *Actual* Cost per Approved Drug (millions)	Percentage Change from Baseline	Expected *Present-Value* Cost per Approved Drug (millions)	Percentage Change from Baseline	Development Time (months)
Baseline	*$559.6*	—	*$1,240.9*	—	*133.7*
Individual Scenarios					
Bioimaging	—	—	—	—	—
Biomarkers	$347.9	–38%	$676.9	–45%	108.2
Bioinformatics	$375.0	–33%	$746.3	–40%	116.6
Gene expression	$345.8	–38%	$676.0	–45%	111.9
Combined Scenarios					
Conservative	$421.2	–25	$869.6	**–30**	**122.4**
Optimistic	$289.2	–48	$533.1	**–57**	**98.1**

Source: RTI International

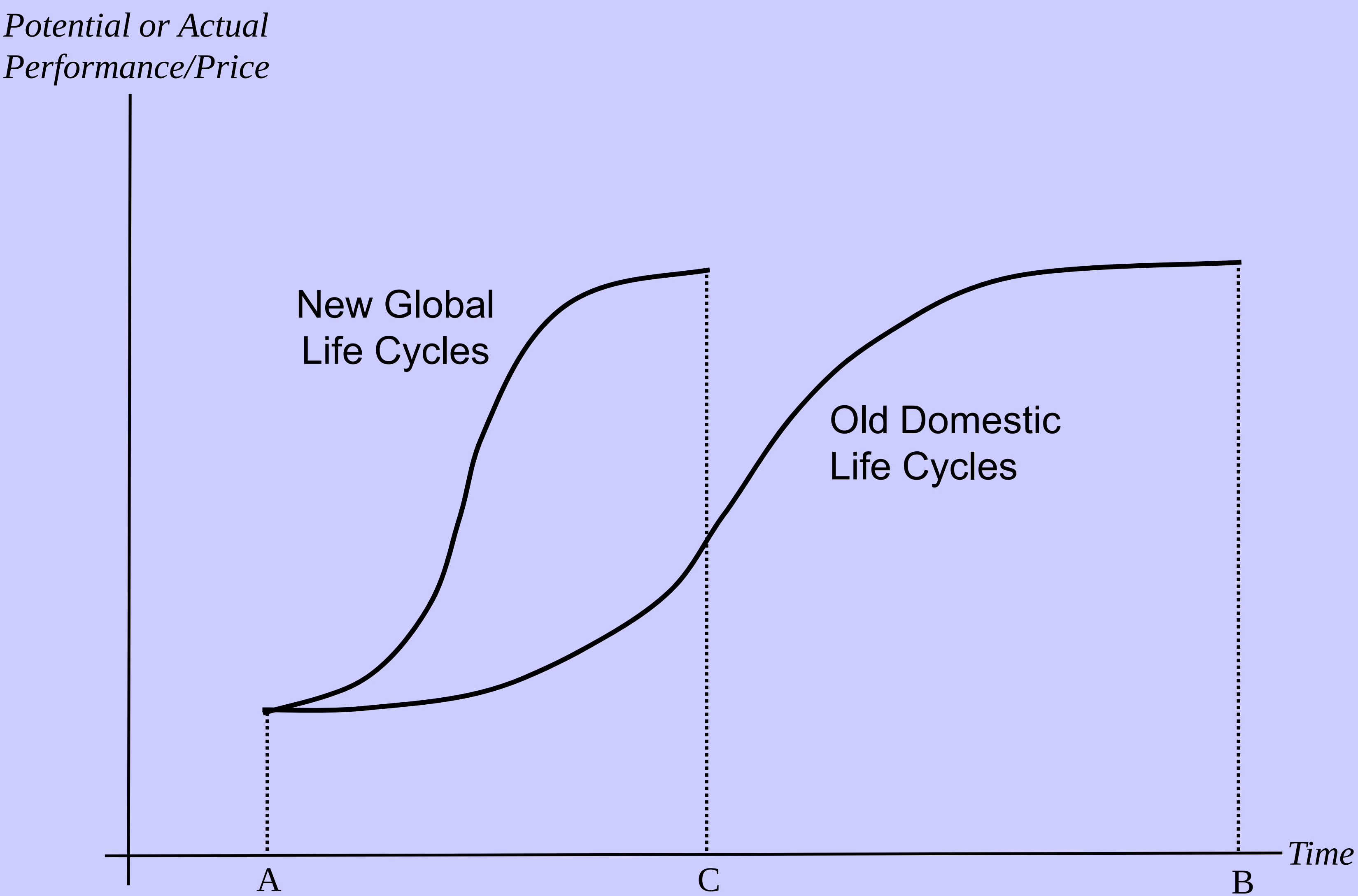
Policy Response

Potential Manufacturing Efficiency Gains from an Improved Technology Infrastructure

Phase/Activity Cost	Baseline Production Costs		Potential Change in Cost by Phase/Activity		
	Percentage of Total [a]	Baseline Total (millions)	Percentage Change	Change in Cost (millions)	Costs under an Improved Infrastructure (millions)
Preproduction	30%	$1,900	–29%	–$551	$1,349
Upstream processing	20%	$1,267	–18%	–$228	$1,035
Downstream processing	40%	$2,533	–22%	–$557	$1,976
Process monitoring and quality assurance testing	10%	$633	–23%	–$146	$491
Total commercial manufacturing costs		**$6,333**		**–$1,482**	**$4,851**

[a] From Frost and Sullivan (2004). Source of estimates: RTI International

Compression of Technology Life Cycles



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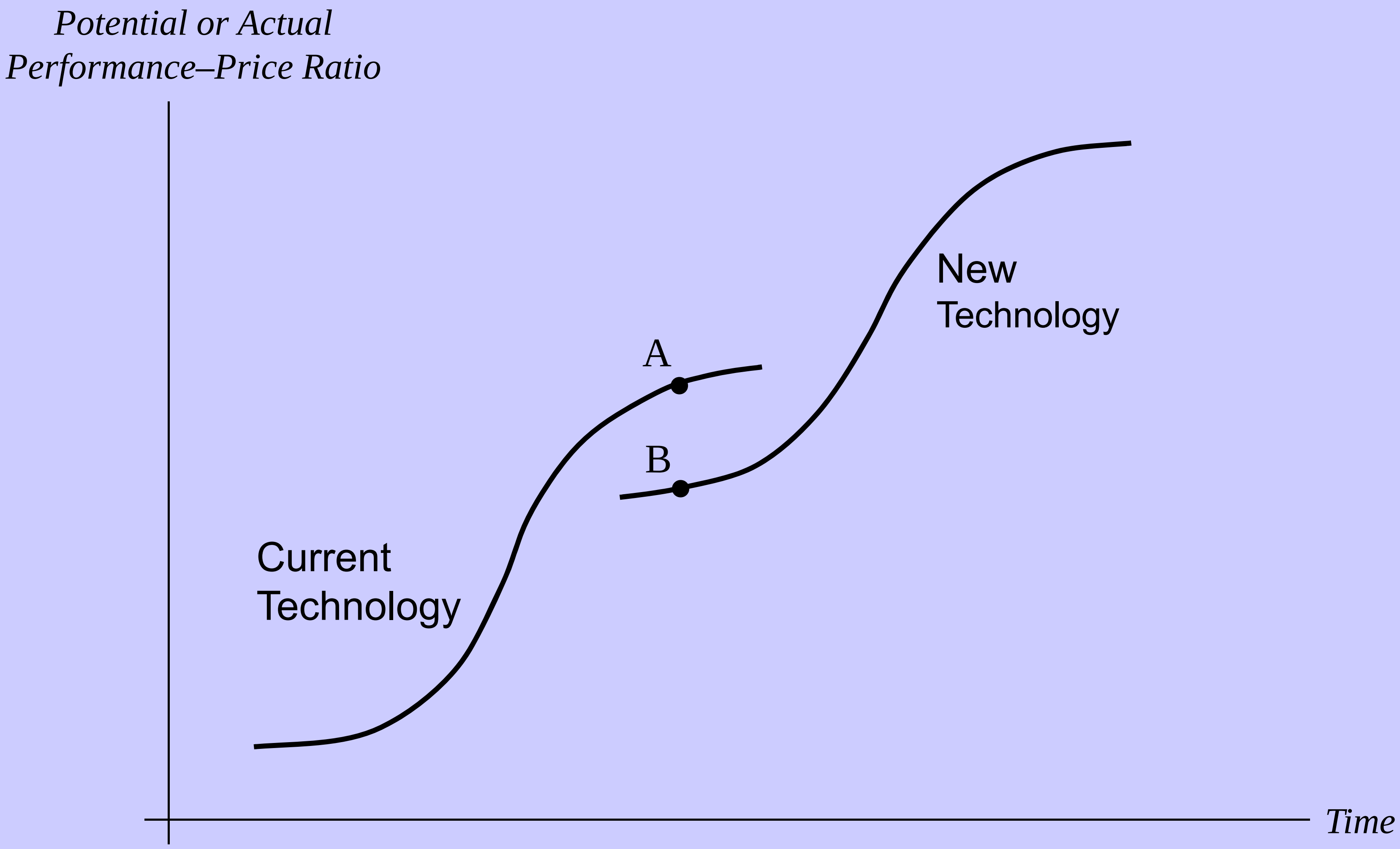
Policy Response

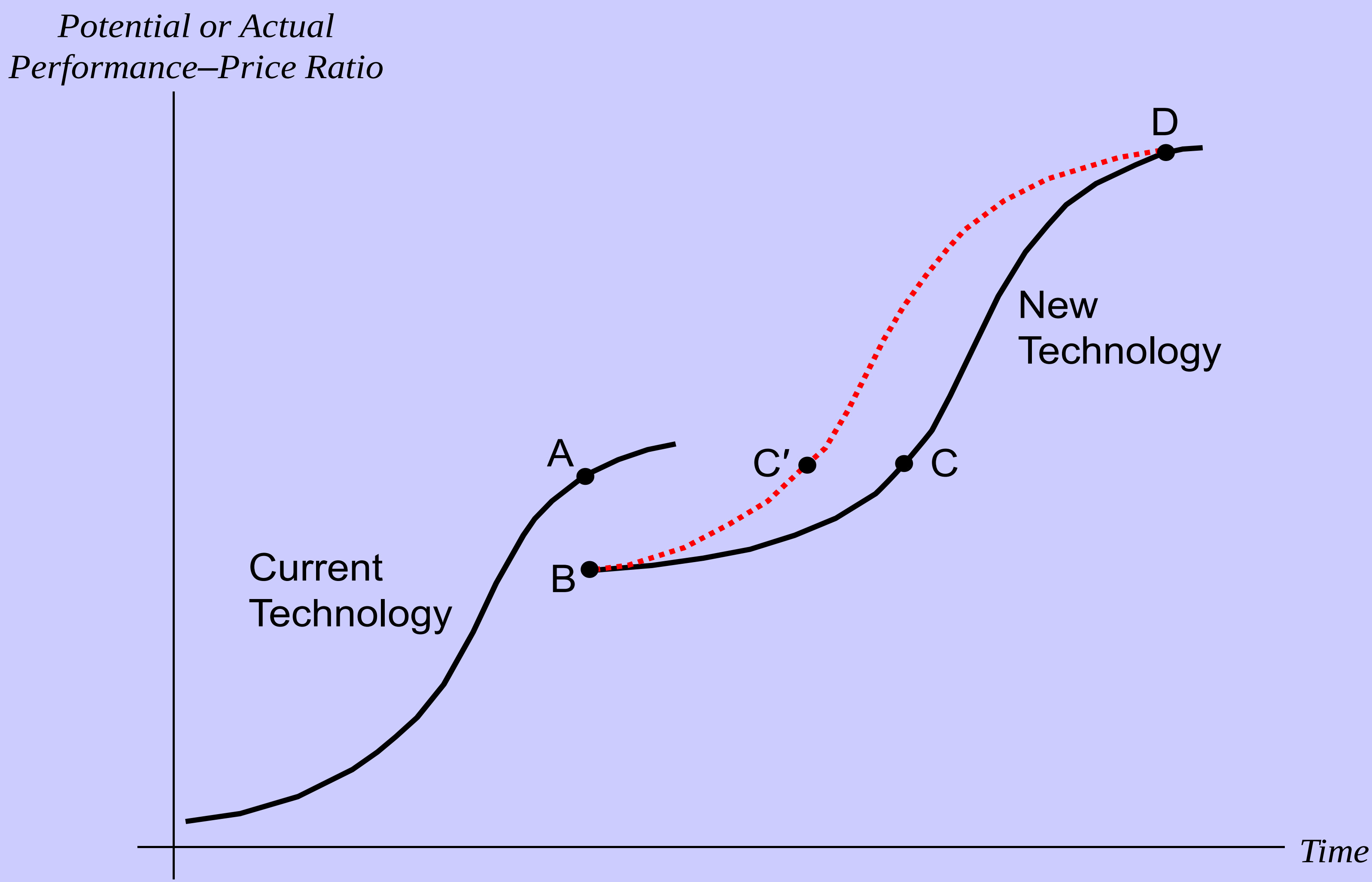
Transition Between Two Technology Life Cycles



Source: Gregory Tassey, *The Technology Imperative, 2007.*

Policy Response

Life-Cycle Market Failure: Generic Technology



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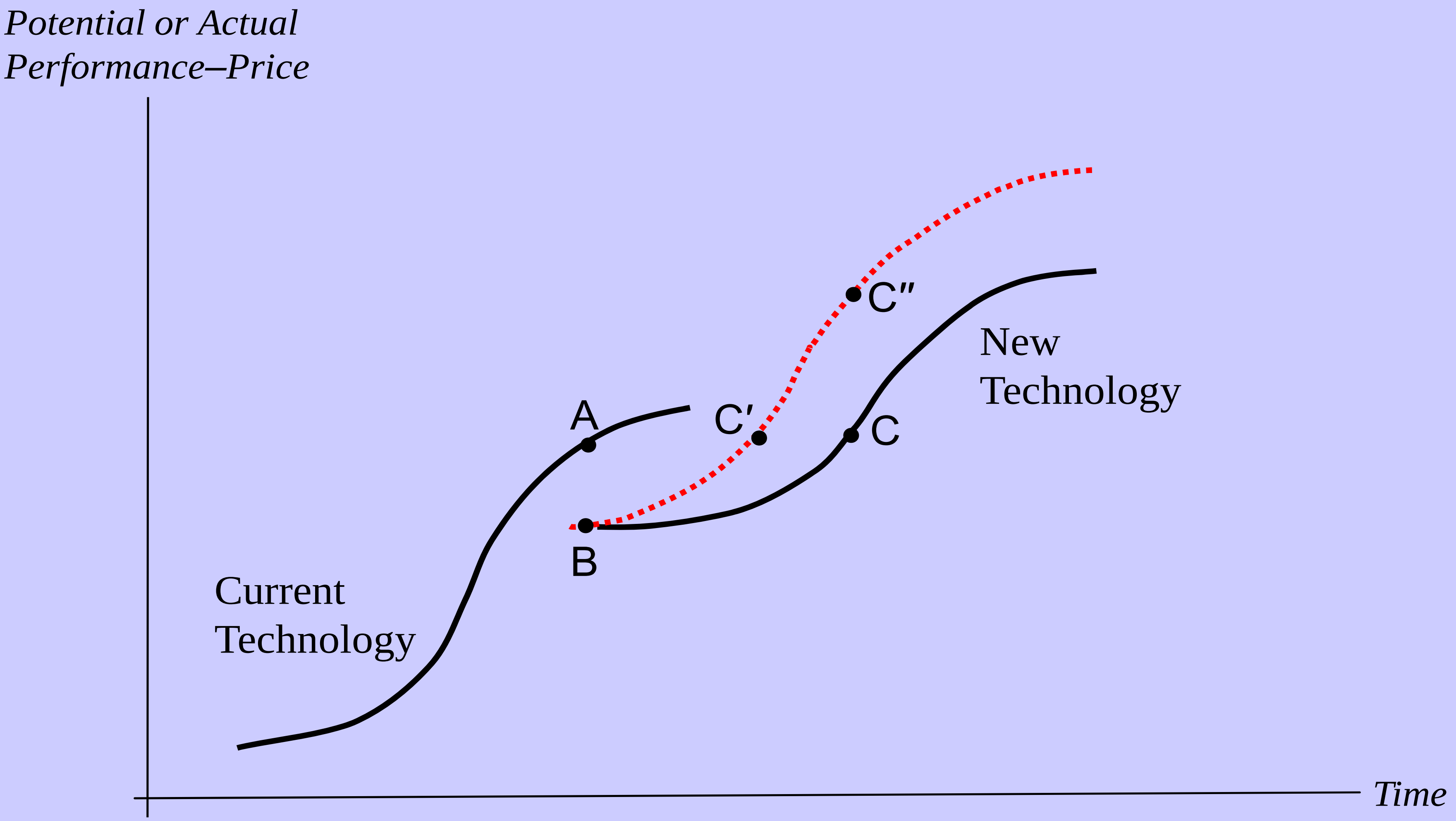
Life Cycle Evolution: Infratechnology



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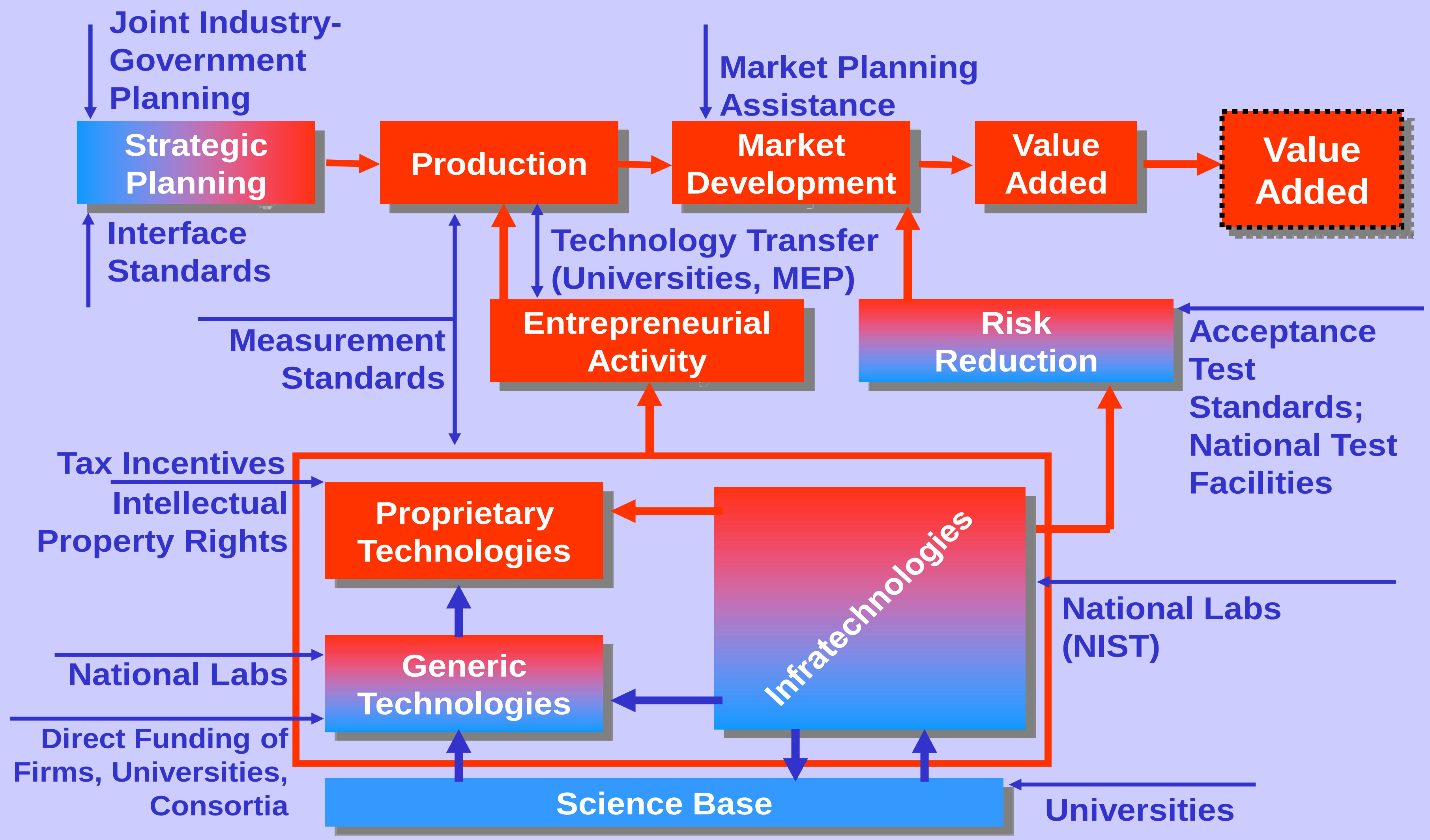
Policy Response

Targets for Science, Technology, Innovation and Diffusion (STID) Policy



G. Tassey, *The Technology Imperative*, Edward Elgar, 2007

Response: Improved R&D Policy Analysis

- **Tax Incentives: R&E Tax Credit**
  - Temporary for 28 years; renewed 13 times
  - No consensus on market failure targeted (size of credit)
  - Limited analysis of the credit's impacts (efficiency)
  - No analysis of alternative tax structures (efficiency)
- **Government Funding of R&D**
  - Okay to fund breakthrough *technology* research & applied R&D to support social objectives (90% of fed R&D budget)
  - Not okay to fund *any* technology research to support economic growth (ATP ⟶ TIP)
  - No explicit agreement on underinvestment (market failure)

Policy Principles

1) The high-income economy must be the high-tech economy – *higher R&D intensity*
2) Technology life cycle must drive policy – *dynamic policy management, research efficiency*
3) Technology-based competition is a public-private problem – *public-private asset (multi-element) growth model*
4) Policy emphasis must be on relatively immobile assets – *skilled labor and innovation infrastructure*
5) U.S. technology-based growth policy process must be improved – *more resources and better scope and integration*

R&D Policy Imperatives

1) R&D intensity should be doubled to ~ 5 percent
2) R&E Tax Credit should be restructured and enlarged to ~ a 20 percent flat credit
3) Federal R&D must be increased and better balanced using a portfolio approach optimized for economic growth
4) Government R&D funding must be element based
   a) science
   b) generic technology (proofs of concept)
   c) infratechnologies
5) R&D efficiency must increased
   a) more technology clusters
   b) better timing of policies over technology life cycle

“Sooner or later, we sit down to a banquet of consequences”

– Robert Louis Stevenson