Manufacturing R&D Strategies for a Global Economy

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The Bottom Line:

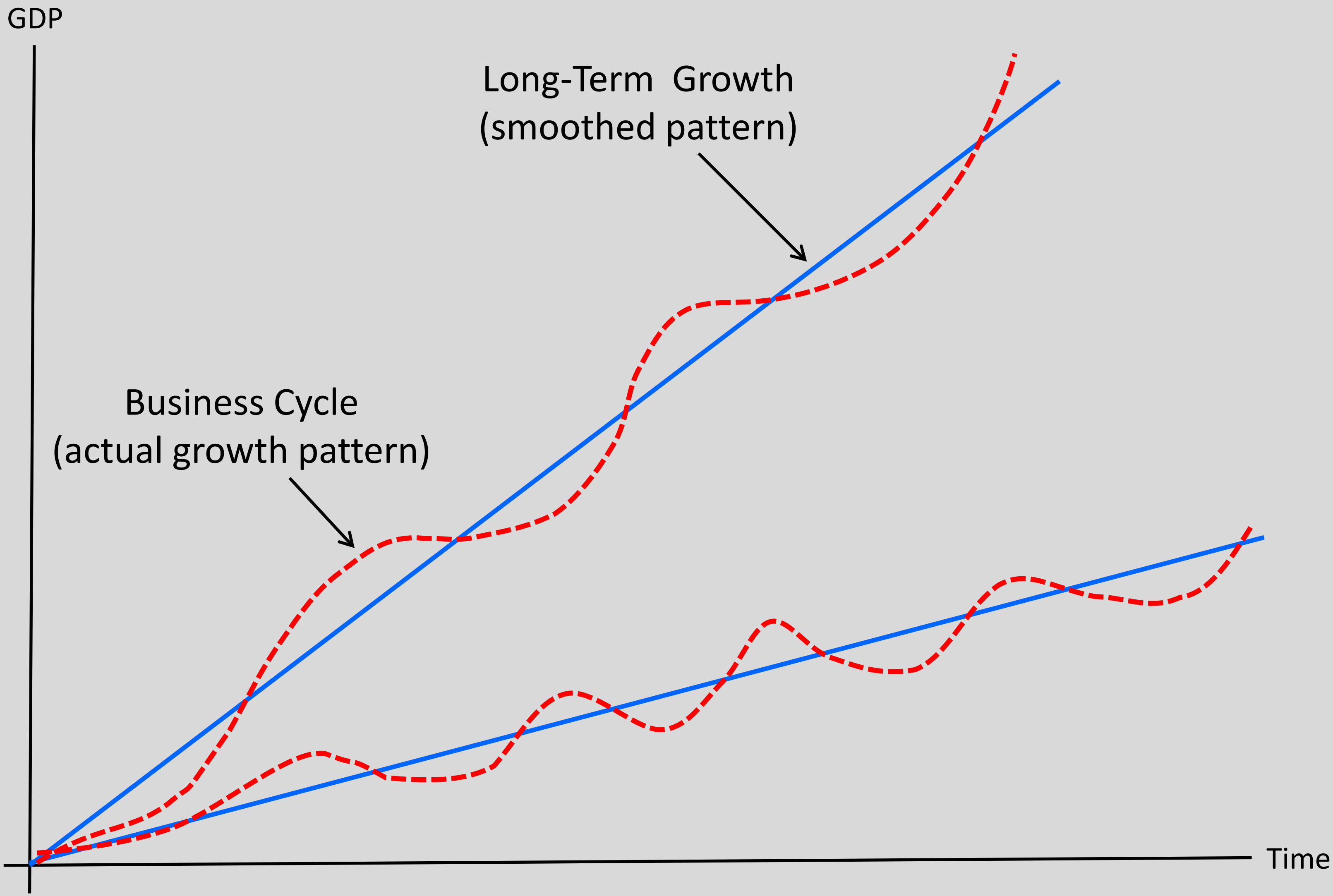
1) The U.S. economy is in long-term decline relative to the global economy
2) Technology is the long-term driver of productivity growth and hence growth in real wages
3) The U.S. has been underinvesting in R&D for decades
4) This underinvestment is now being manifested in a range negative economic growth indicators
5) The federal government is the major culprit
6) The existing underinvestment phenomena must be addressed by the appropriate policy instruments
7) Matching different types of underinvestment with policy response mechanisms requires an updated economic growth model
8) Applying such a framework demands an innovation policy analysis infrastructure—hardly exists in the United States

The Bottom Line – National Economy

- For the last decade (2000-2009)
  - Average annual real GDP growth was 1.9 percent
  - U.S. Private Nonfarm employment declined 2.4 percent
  - Household real income declined 4.8 percent
- However, the current economic growth policy debate is focused on macroeconomic issues: government spending vs. deficit reduction, monetary base expansion vs. potential inflation effects
- Inadequate attention is being given to structural problems, which must be dealt with or macroeconomic problems will not be solved
- Bottom Line: The structure of an economy determines long-run rates of growth

Source: Gregory Tassey, "Beyond the Business Cycle: The Need for a Technology-Based Growth Strategy," forthcoming.

Long-Term vs. Short-Term Growth Trends



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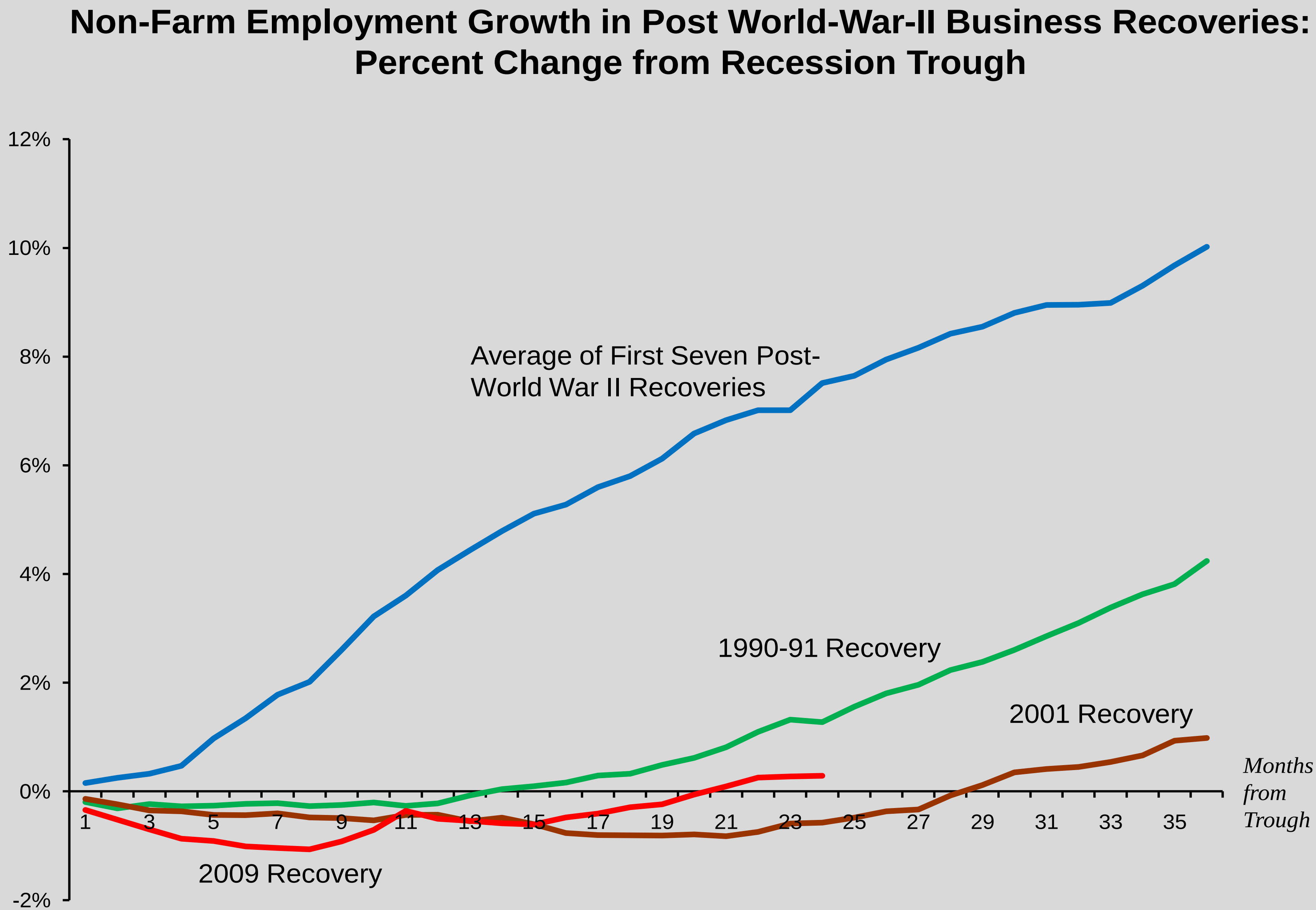
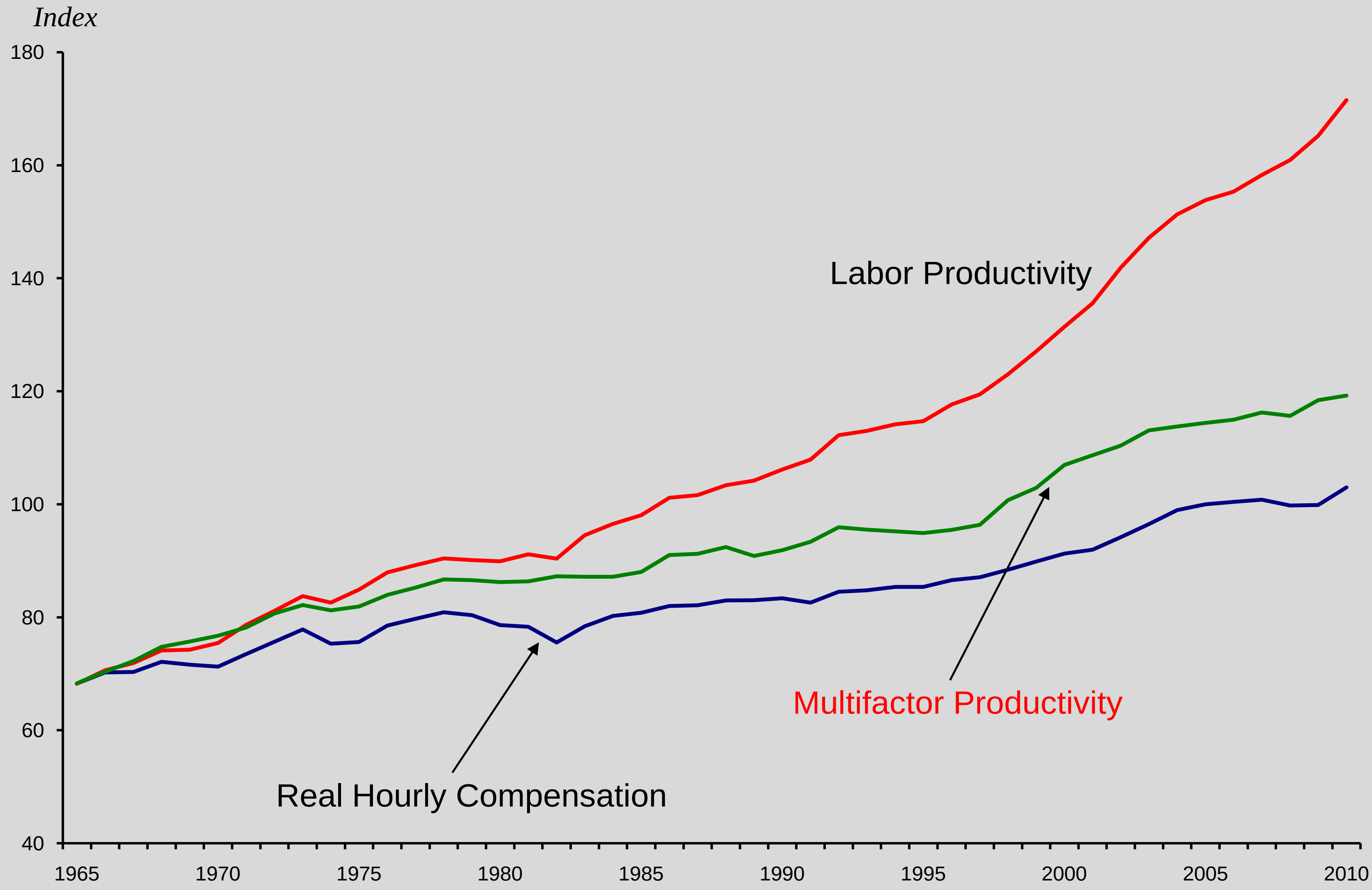


Source: G. Tassey, *The Technology Imperative* (updated); BLS for employment data; NBER for recession trough dates

Policy Focus: Multifactor Productivity

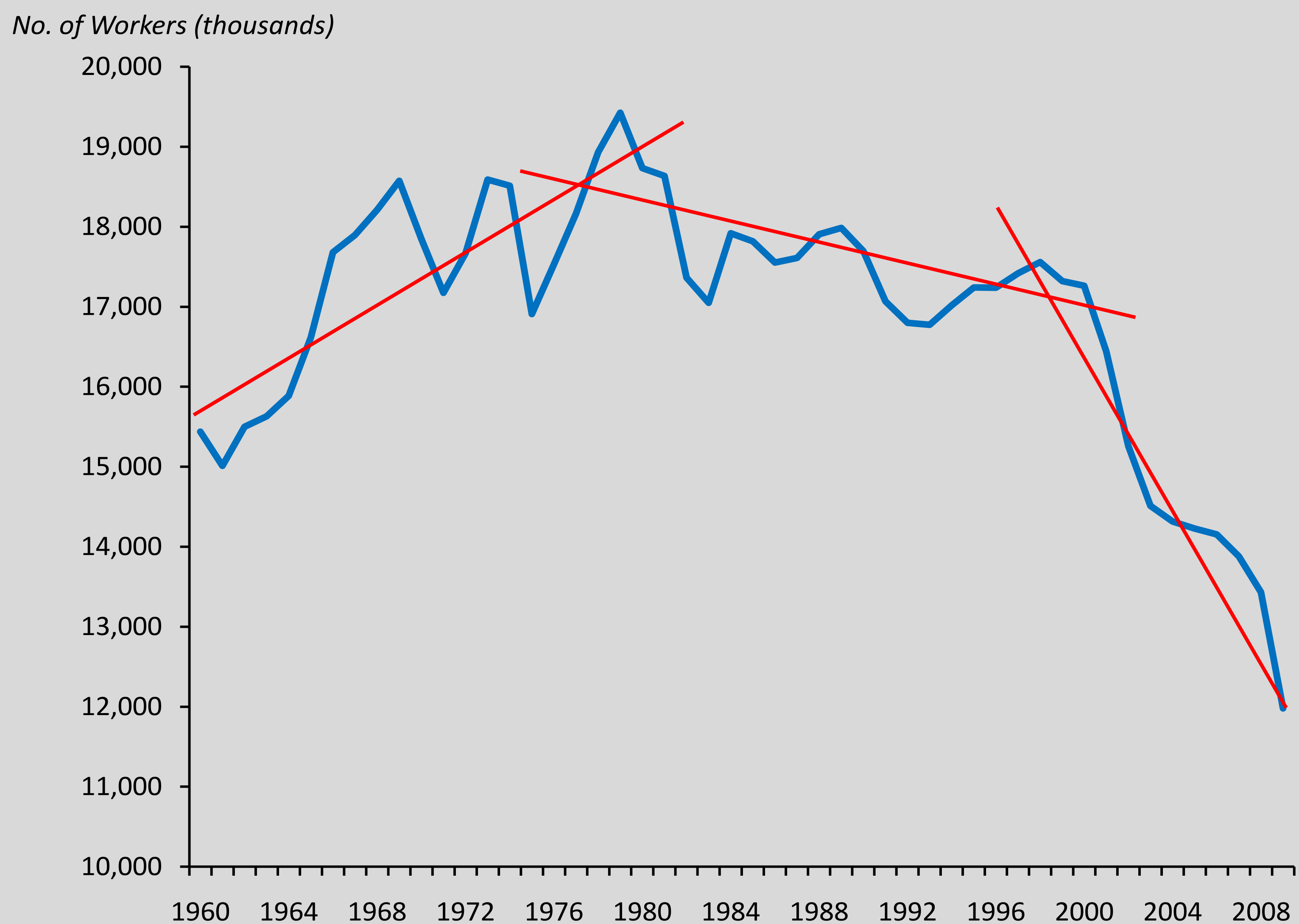
Trends in Productivity and Income Private Non-Farm Sector, 1965-2010



Source: Bureau of Labor Statistics

Underperformance – Manufacturing

US Manufacturing Employment: 1960–2009



Source: Bureau of Labor Statistics

Importance

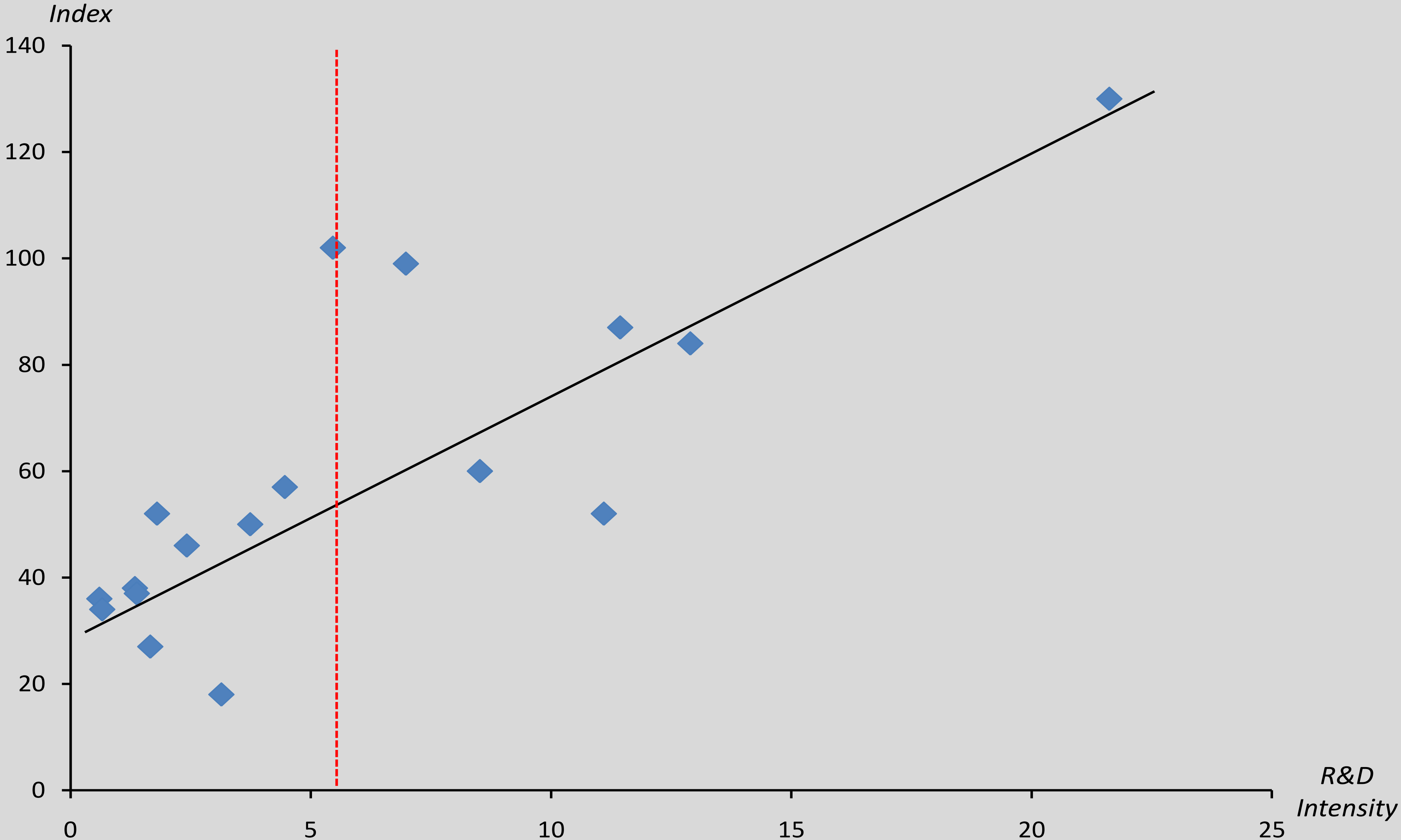
Economic importance of Domestic Manufacturing:

1) Diversification:
   a) Manufacturing contributes $1.6 trillion to GDP and employs 11 million workers
   b) High-tech service jobs are increasingly ''tradeable'' and 30 economies have policies in place to promote service exports
2) Manufacturing accounts for 67% of US industry-performed R&D and an equal share of U.S. industry's scientists/engineers
3) Therefore, the fast-growing high-tech services sector must have close ties to manufacturing
4) Majority of trade is in manufactured products

Importance

Rate of Innovation vs. R&D Intensity:

Percent of Companies in an Industry or Subsector Reporting Product or Process Innovation, 2003-2007



Source: Gregory Tassey, "Beyond the Business Cycle: The Need for a Technology-Based Growth Strategy," forthcoming. Index = sum of percent of companies in an industry reporting product innovations and percent reporting process innovations. R&D intensity data from *Science and Engineering Indicators 2010* , Appendix Table 4-14; innovation data from Mark Boroush, "NSF Releases New Statistics on Business Innovation," NSF *InfoBrief*, October 2010

Importance

Relationship Between R&D Intensity and Real Output Growth

Industry (NAICS Code)	Average R&D Intensity, 1999-2007	Percent Change in Real Output, 2000-2007
R&D Intensive:		
Pharmaceuticals (3254)	10.5	19.1
Semiconductors (3344)	10.1	15.4
Medical Equipment (3391)	7.5	28.4
Computers (3341)	6.1	106.2
Communications Equip (3342)	13.0	-42.3
	Group Ave: 9.5	**Group Ave: 25.4**
Non-R&D Intensive:		
Basic Chemicals (3215)	2.2	25.5
Machinery (333)	3.8	2.4
Electrical Equipment (335)	2.5	-13.6
Plastics & Rubber (326)	2.3	-4.5
Fabricated Metals (332)	1.4	4.9
	Group Ave: 2.5	**Group Ave: 2.9**

Sources: NSF for R&D intensity and BLS for real output.

Underperformance – Manufacturing

Poor Technology Life-Cycle Management:

The United States has been the "first mover" and then lost virtually all market share in a wide range of materials and product technologies, including

- oxide ceramics
- semiconductor memory devices
- semiconductor production equipment such as steppers
- lithium-ion batteries
- flat panel displays
- robotics
- solar cells
- advanced lighting

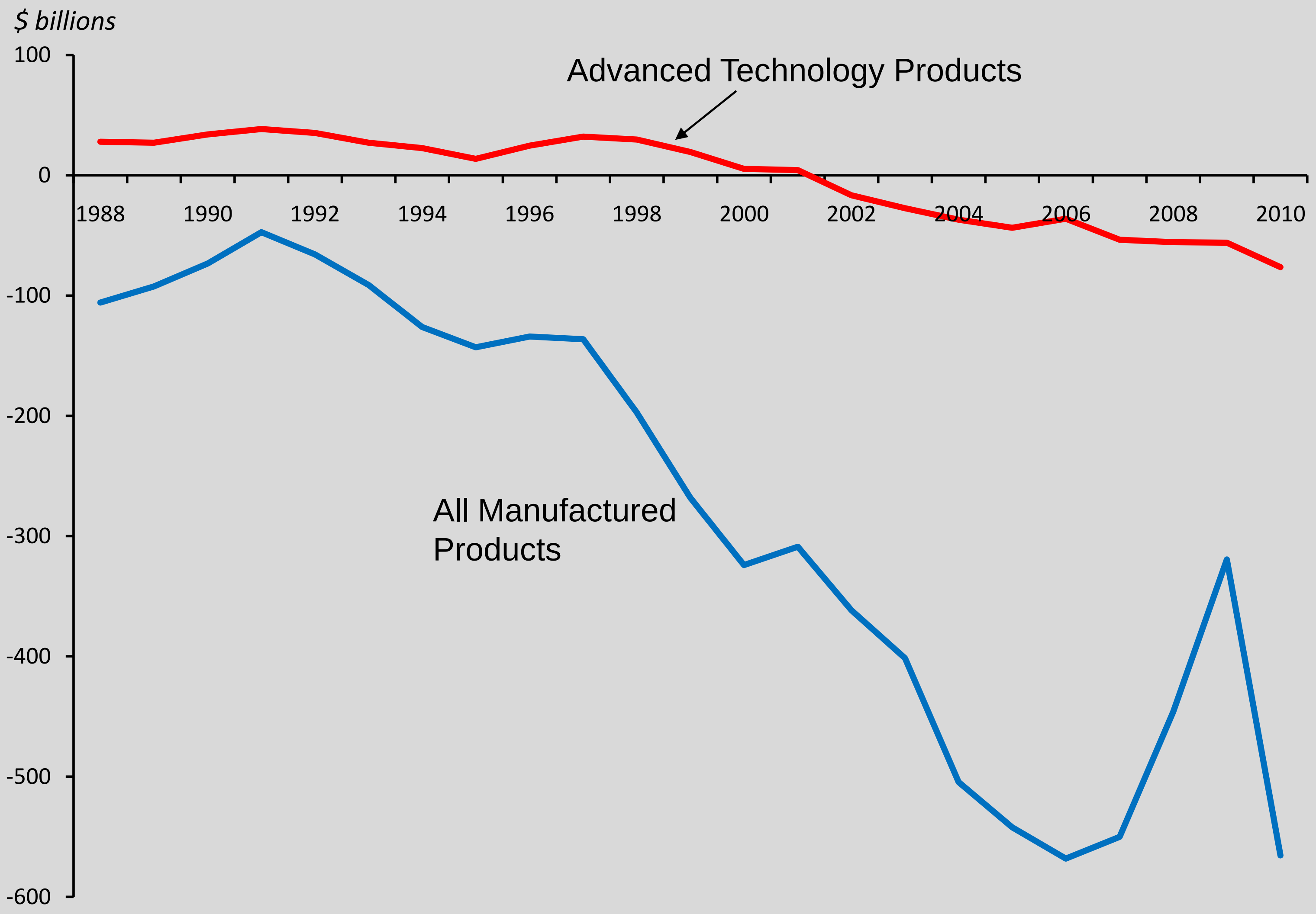
Underperformance – Manufacturing

High-tech offshoring is multi-step process, driven by (1) increasingly attractive skilled labor and (2) capital and R&D subsidies:

1) Manufacturing is offshored to take advantage of local-market opportunities and increasingly skilled labor (assembly in China, components in Taiwan, Korea)
   - Initially require small amount of supporting R&D
   - Host country frequently subsidizes plant and equipment
2) Host country gains some R&D experience and expands R&D infrastructure to capture synergies at "entry" tier in high-tech supply chain
3) Host country begins to integrate forward into design and/or backward into components to capture higher value added
   - China—backward to components (from assembly)
   - Taiwan—forward to electronic circuits (from components)
   - Korea—forward to electronic products (from components)
4) These economies are now beginning to integrate forward into services
5) Economic policy point: Co-location synergies are captured

Underperformance – Manufacturing

U.S. Trade Balances for High-Tech vs. All Manufactured Products, 1988-2010

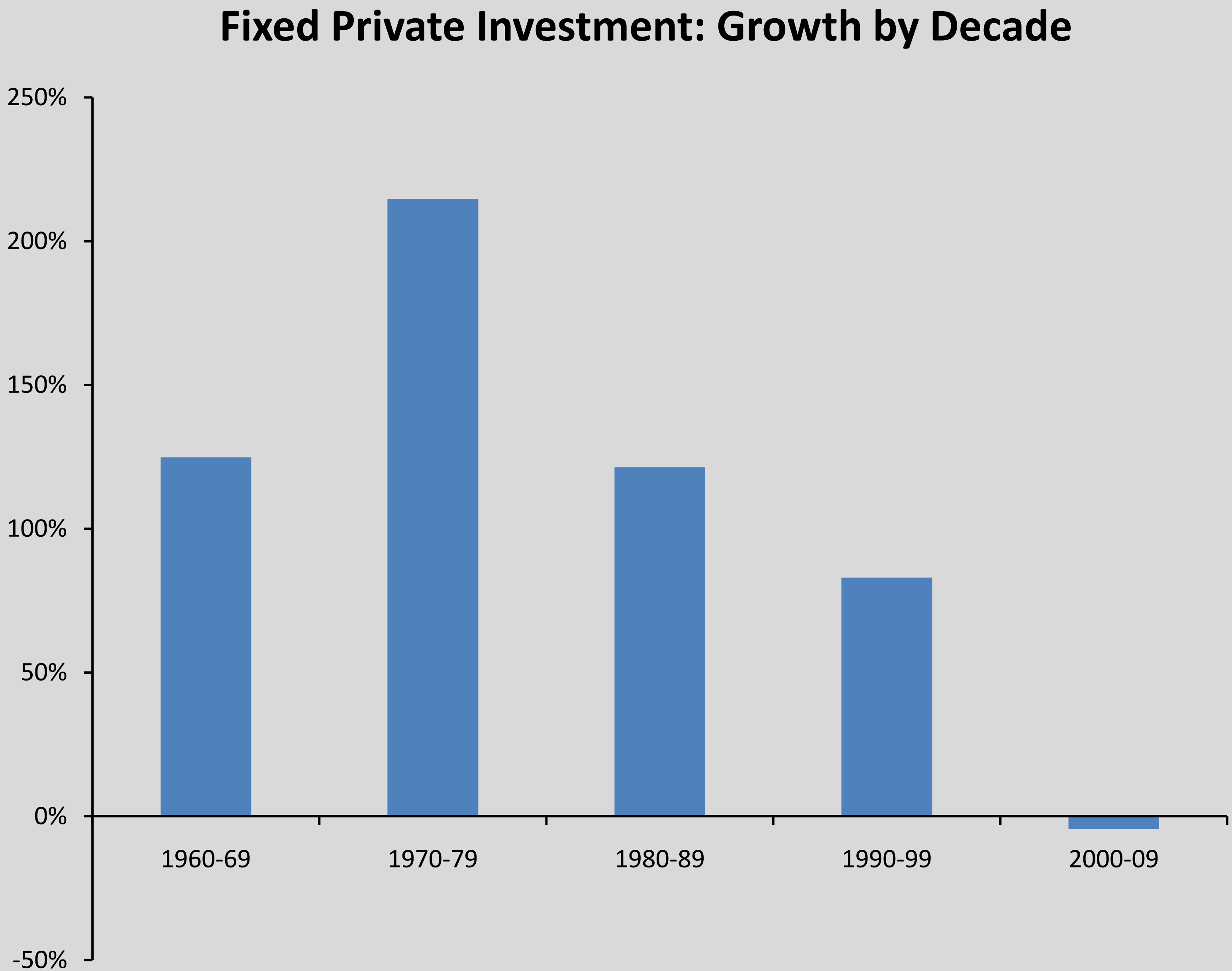


Source: Census Bureau, Foreign Trade Division for ATP data; International Trade Administration for all manufactured products

Trends in Manufacturing R&D Needing Policy Attention

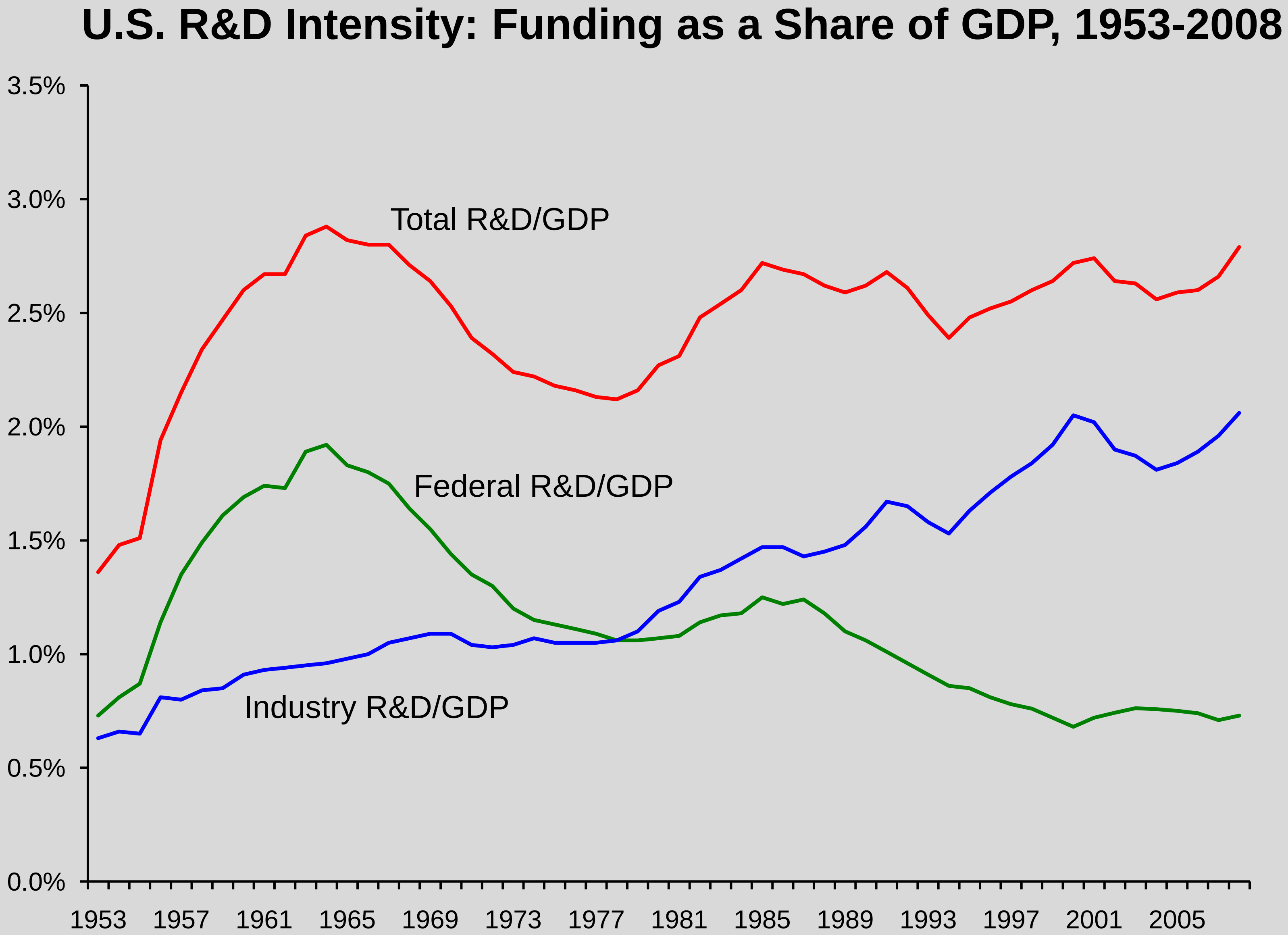
- Manufacturing's average R&D intensity at 3.7 percent has remained flat since the mid-1980s
- Manufacturing R&D intensity
  - has not been helped by offshoring of low R&D-intensive industries
  - pales compared to truly "R&D-intensive" industries, whose ratios range from 6 to 22 percent
- Need is great as
  - most of the global economy's $1.3 trillion annual R&D spending targets manufacturing technologies
  - U.S. manufacturing firms are increasing offshore R&D at *three* times the rate of domestic R&D spending
- Government funding of manufacturing R&D increases the sector's R&D performance intensity from 3.7 to 4.1 percent

Underinvestment – Aggregate



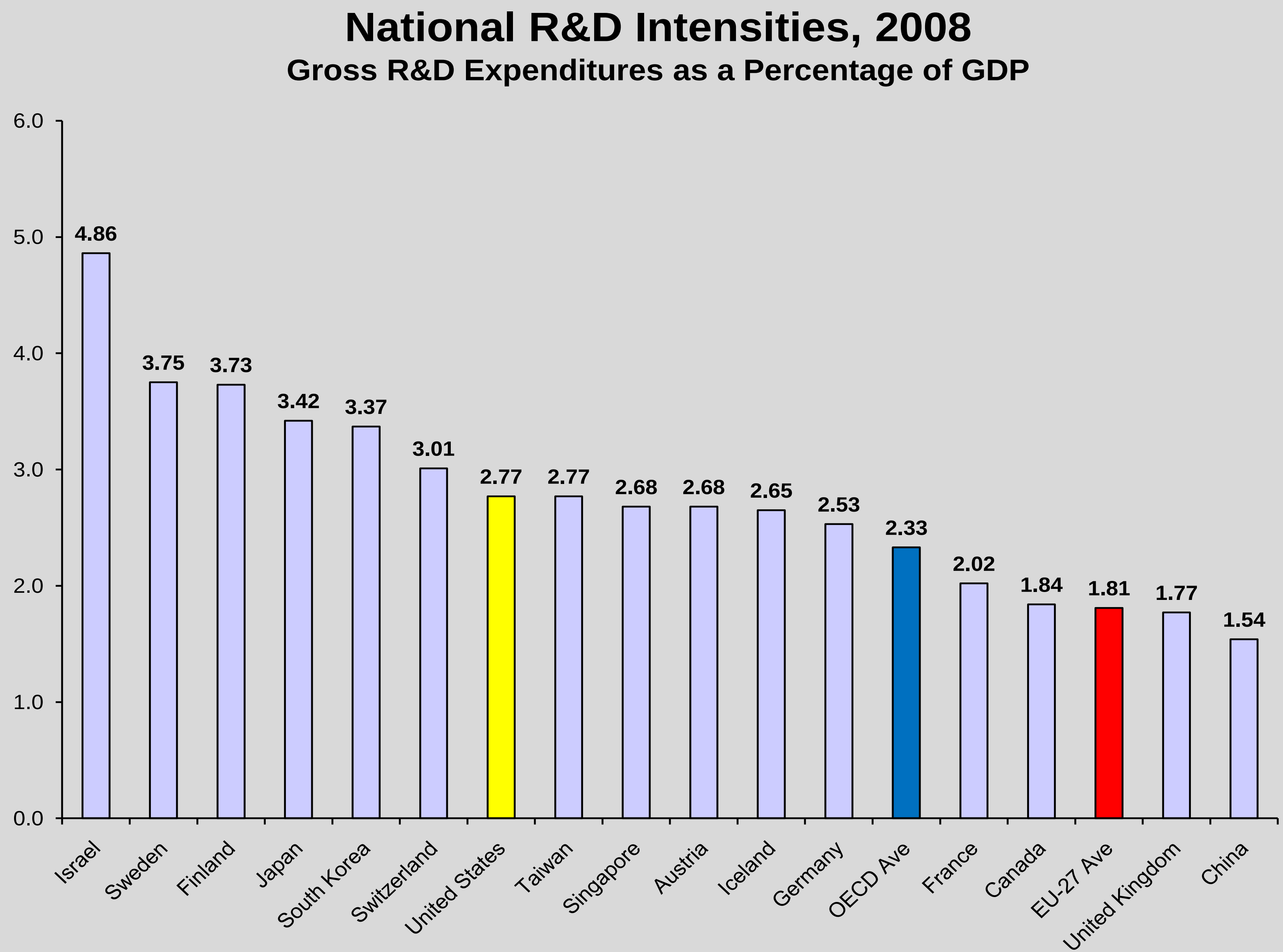
Source: Gregory Tassey, "Beyond the Business Cycle: The Need for a Technology-Based Growth Strategy," forthcoming. Data from Bureau of Economic Analysis, NIPA Table 5.3.5 (includes both equipment and software)

Underinvestment – Amount of R&D



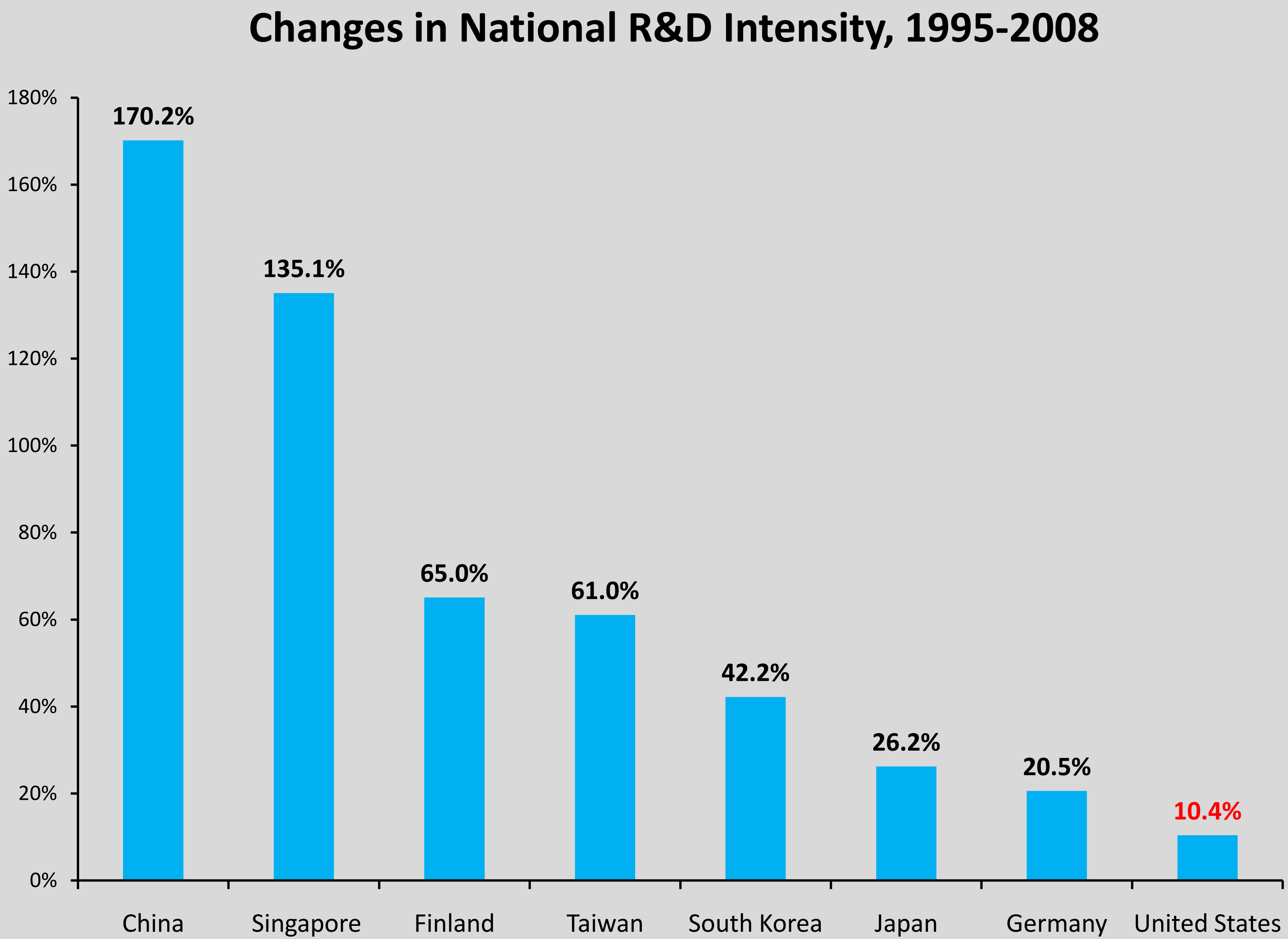
Gregory Tassey, "Rationales and Mechanisms for Revitalizing U.S. Manufacturing R&D Strategies," *Journal of Technology Transfer 35* (2010): 283-333. Data from the National Science Foundation.

Underinvestment – Amount of R&D



Source: OECD, *Main Science and Technology Indicators*, 2010.

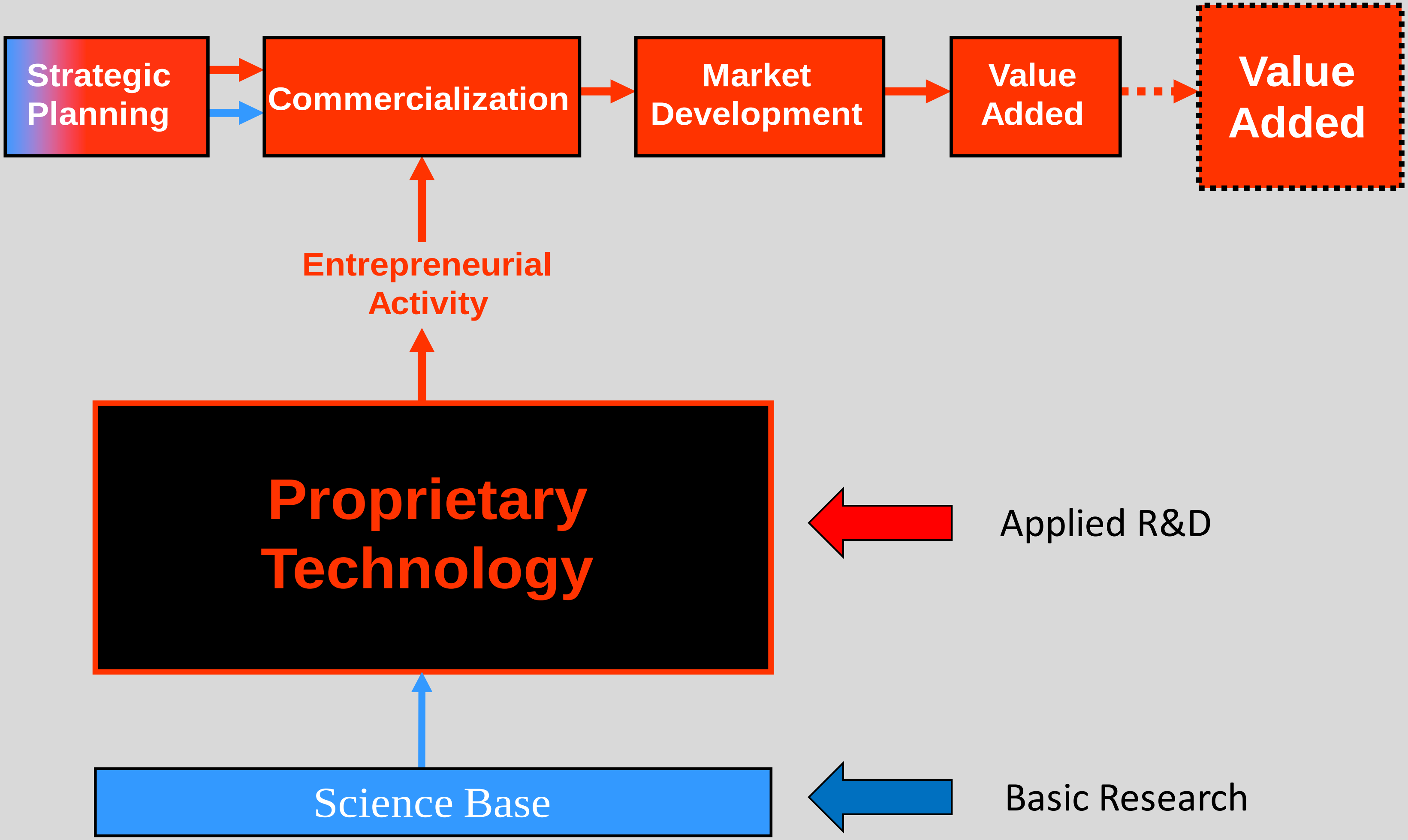
Underinvestment – Amount of R&D



Source: Gregory Tassey, "Beyond the Business Cycle: The Need for a Technology-Based Growth Strategy," forthcoming. Data from OECD, *Main Science and Technology Indicators*, 2010/1.

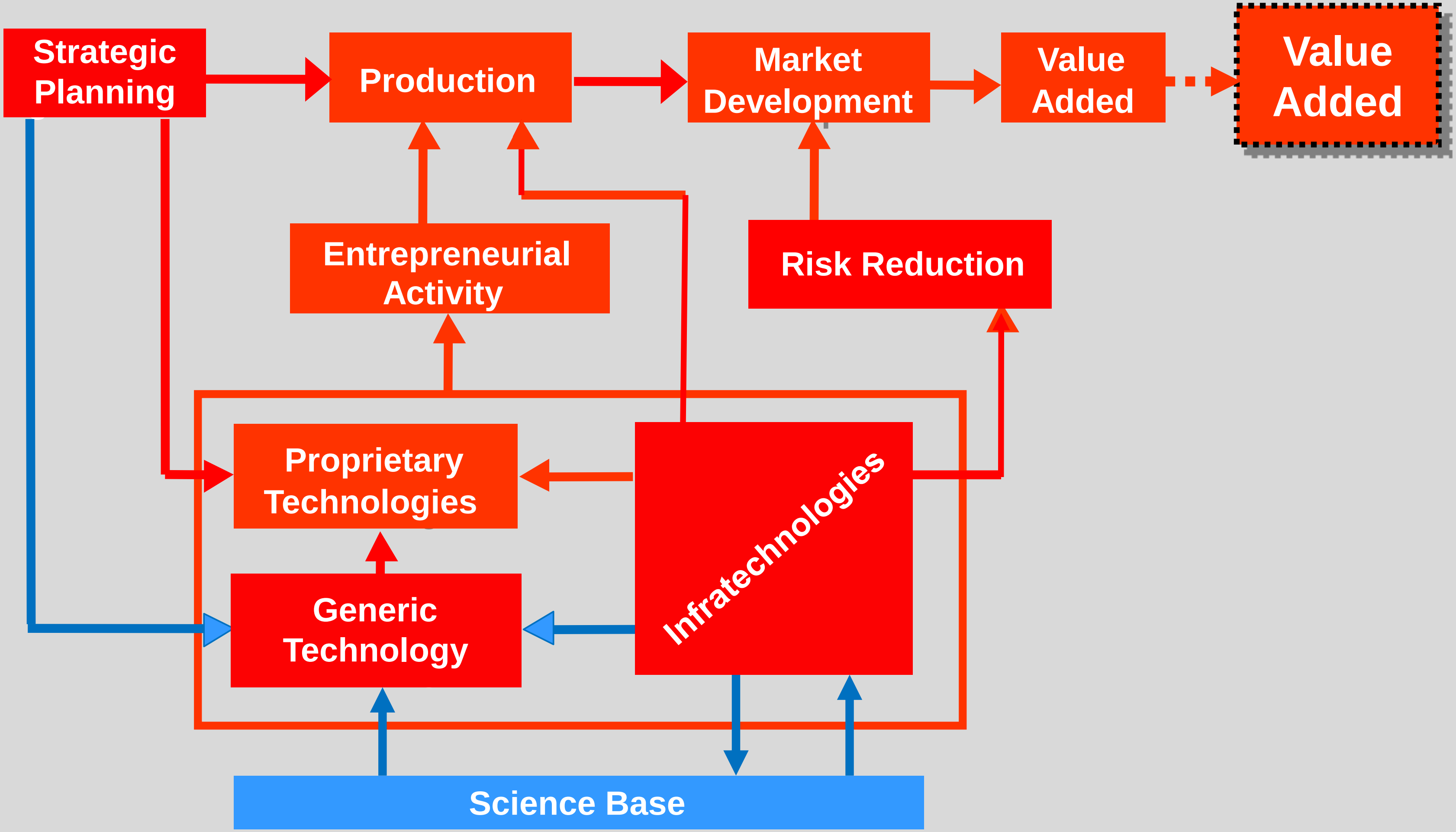
Identifying Underinvestment – Technology-Element Growth Model

"Black Box" 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.

Economic Model of a Technology-Based Industry



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Identifying Underinvestment – Technology-Element Growth Model

Application of the Technology-Element Model: Biotechnology

Science Base

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

Infratechnologies

- bioinformatics
- bioimaging
- biomarkers
- combinatorial chemistry
- DNA sequencing and profiling
- electrophoresis
- fluorescence
- gene expression analysis
- magnetic resonance spectrometry
- mass spectrometry
- 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

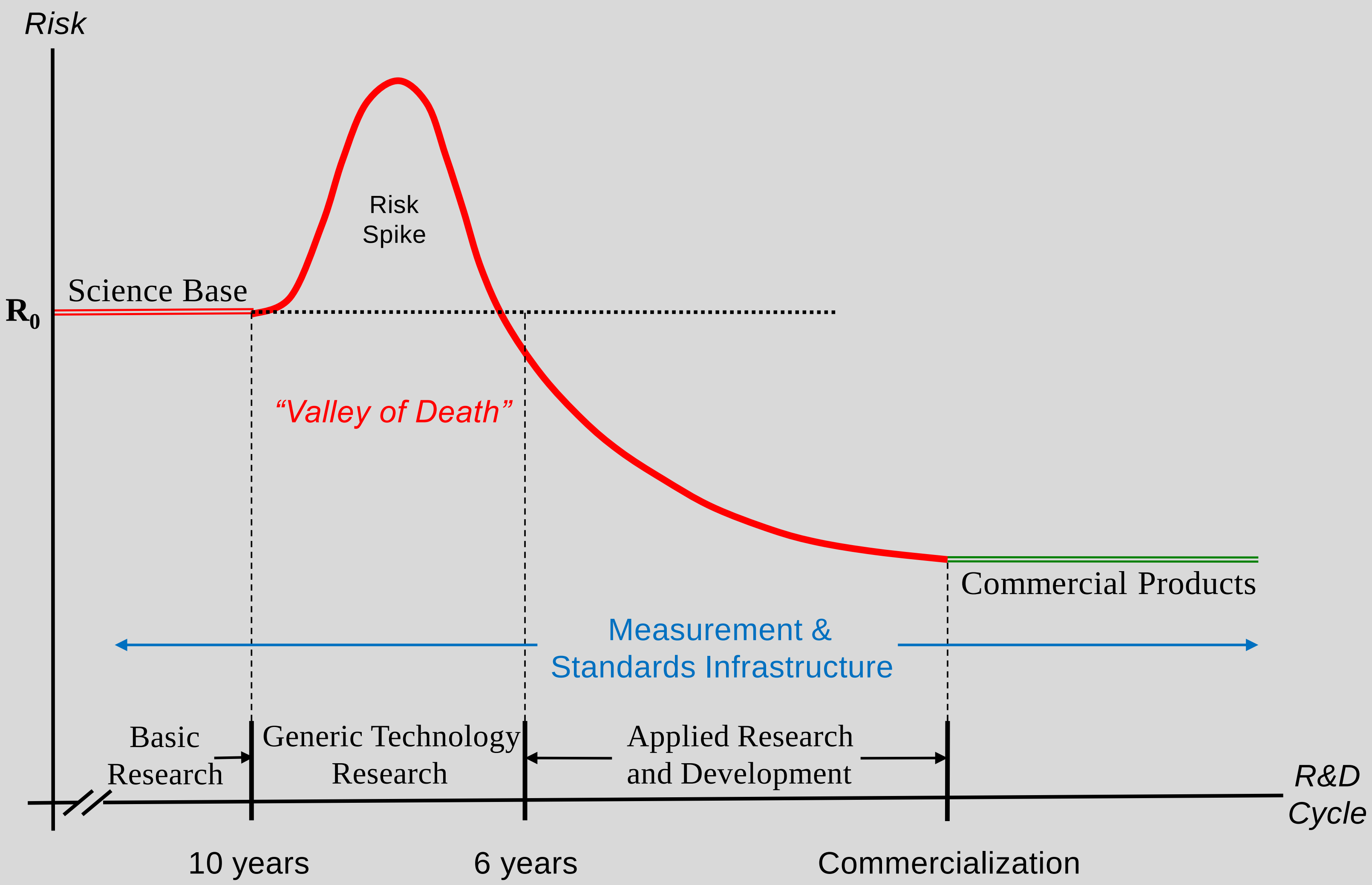
- coagulation inhibitors
- DNA probes
- inflammation inhibitors
- hormone restorations
- nanodevices
- neuroactive steroids
- neuro-transmitter inhibitors
- protease inhibitors
- vaccines

Public Technology Goods ← Mixed Technology Goods → Private Technology Goods

Gregory Tassey, *The Technology Imperative*, Edward Elgar, 2008

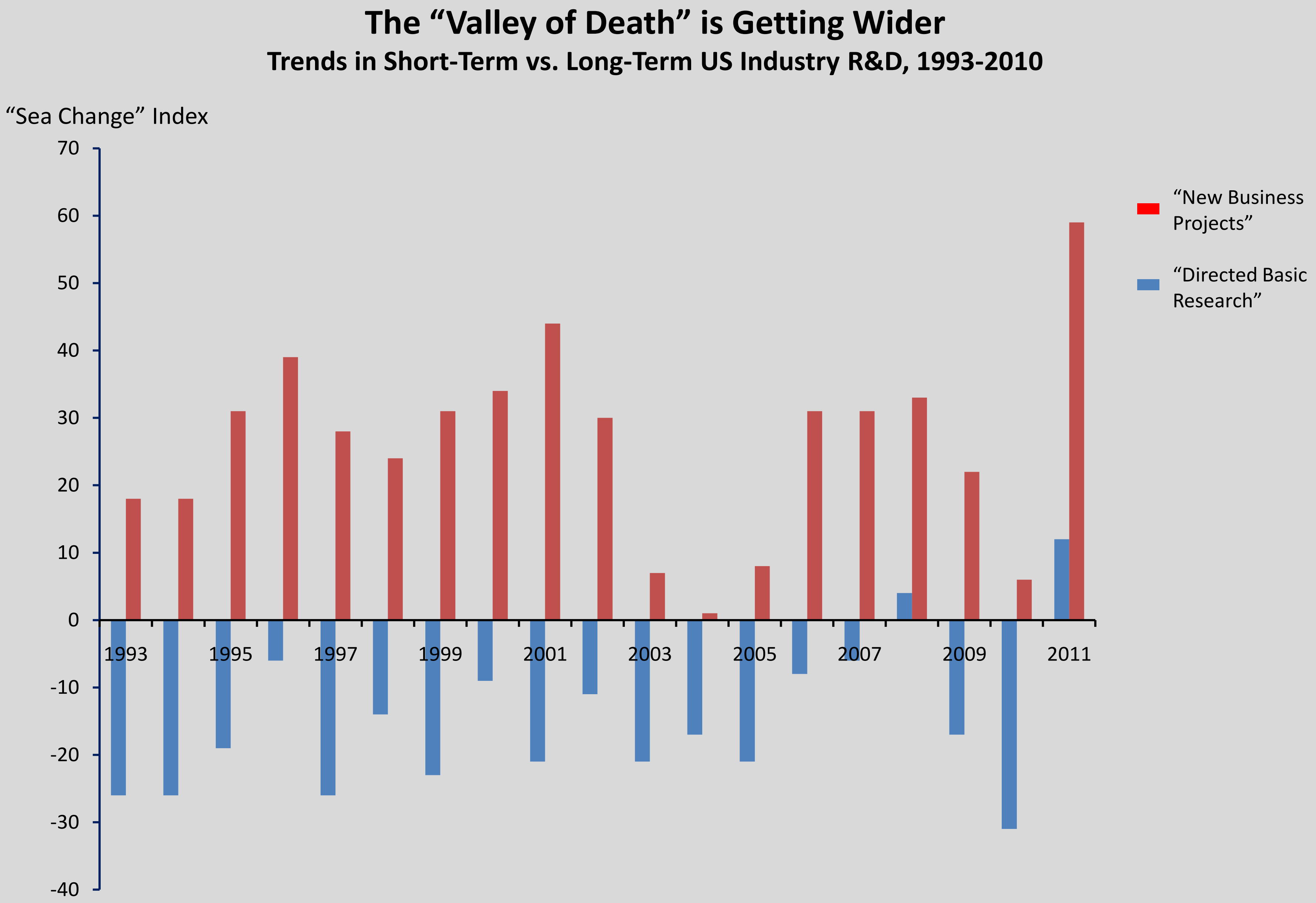
Causes of Underinvestment – Composition of R&D

Overcoming the Innovation Risk Spike (Valley of Death)



Source: Gregory 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)

Causes of Underinvestment – Composition of R&D



Source: Gregory Tassey, "Beyond the Business Cycle: The Need for a Technology-Based Growth Strategy" (forthcoming); Compiled from the Industrial Research Institute's annual surveys of member companies.

Causes of Underinvestment – Composition of R&D

Federal R&D Portfolio is not Optimized for Economic Growth

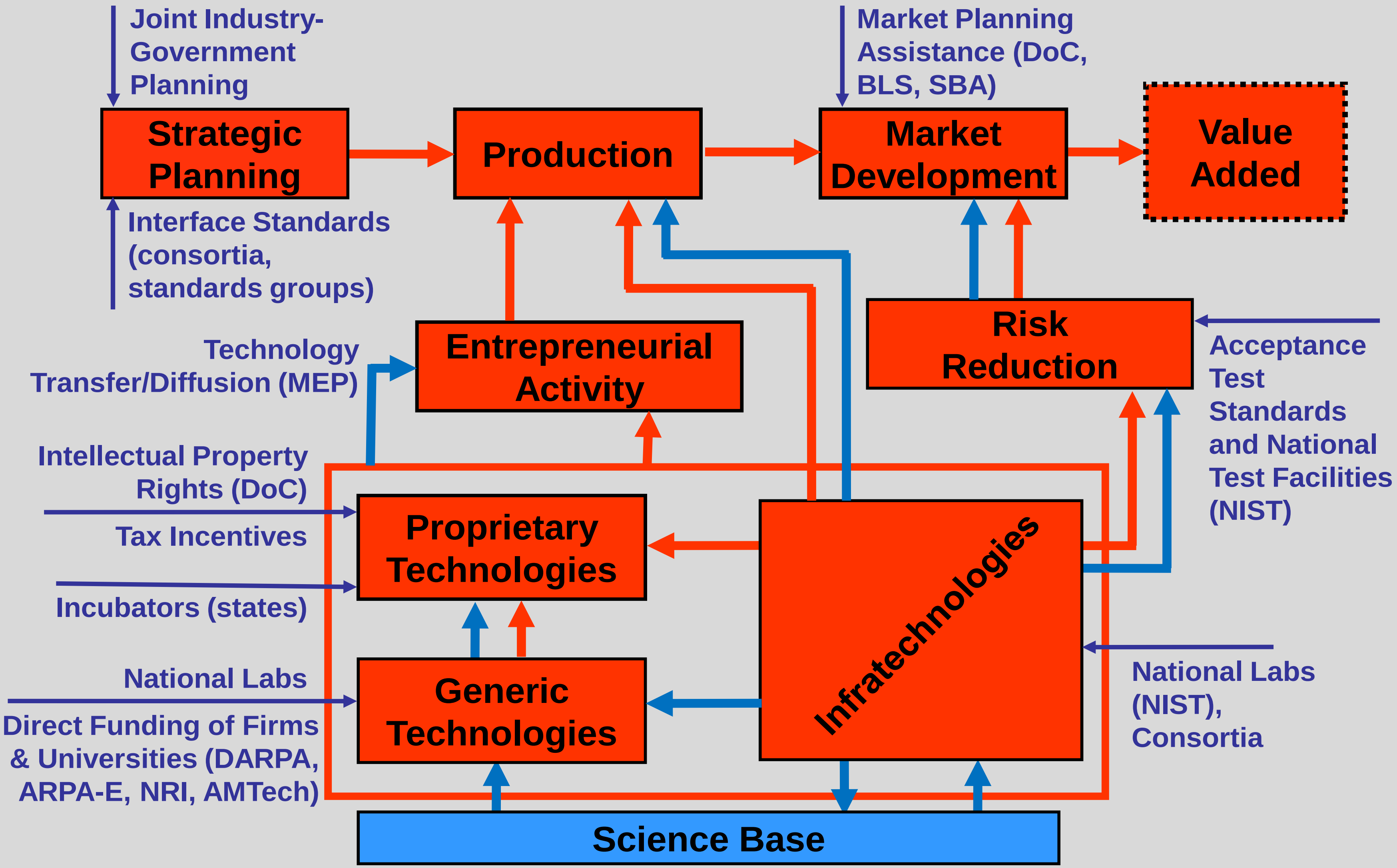
- Historical focus has and continues to be on "mission" R&D programs (social objectives such as defense, health, energy, space, environmental)—90 percent of federal R&D
  - National defense and health account for 81 percent of the federal R&D budget
  - Using NAICS codes to track federally funded R&D performed by industry,
    - 75 percent of federal R&D allocated to the manufacturing sector goes to two NAICS 4-digit industries: aerospace and instruments
    - These two industries account for 15 percent of company-funded manufacturing R&D and about 10 percent of high-tech manufacturing value added

Policy Implication: While economic activity is stimulated by this skewed funding strategy, the federal portfolio is not close to being optimized for economic growth

- Example: federally funded "generic" (proof-of-concept) technology research
  - Defense (DARPA): $3.1 billion
  - Energy (ARPA-e): $400 million
  - General economic growth (NIST's ATP/TIP): $60 million

Sources: National Science Foundation: *Federal R&D Funding by Budget Function, FY 2008-10*, Table 2; *Science and Engineering Indicators 2010*, Appendix Table 4-13; Bureau of Economic Analysis R&D Satellite Account

Science, Technology, Innovation, Diffusion (STID) Policy Roles



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Needed Conceptual Revisions in the Management of R&D Policy

- Policies must be developed by working backward from market needs assessments (demand-pull, as opposed to technology-push): Mass customization, flexible production structures, smart manufacturing, IT-driven supply-chain integration)
- Modern technologies are complex systems: More attention to system-level R&D and associated productivity drivers
- Complexity is pushing industrial R&D backward in high-tech supply chains: R&D strategies must be integrated across entire supply chain
- Reject the Black-Box model: Emphasize funding proof-of-concept ("generic") technology research and infratechnology research
- Need systematic funding of technology elements with public-good content
  - Replace point-source funding (single university researchers, individual firms), with portfolio approach (DARPA; AMTech)
  - Supply-chain-wide scope

Three Targets of R&D Policy:

- Amount of R&D
  - Lower the user cost of R&D capital to increase industry's risk-adjusted expected rate of return
- Composition of R&D
  - Better manage the technology life cycle through adjustments to support for the several phases in the R&D cycle and the technology element targeted
- Efficiency of R&D
  - Increase the output and shorten the duration of the R&D cycle, and accelerate diffusion of developed technologies through regional innovation clusters and adoption of portfolio management methods

Efficiency Example: Co-location synergies through Innovation Clusters

- More effective R&D portfolio management
- More complete availability of complementary R&D assets/capabilities
- More effective strategic planning among tiers (industries) in the relevant high-tech supply chains
- Faster diffusion of technical knowledge

Major Policy Targets for Advanced Manufacturing:

1) Increase industry's aggregate investment in R&D by leveraging the nation's R&D intensity
2) Increase early-phase R&D, which exhibits substantial market failure (systematic underinvestment), but is critical to the development of new manufacturing technology platforms
3) Deliver this support through more efficient mechanisms, in particular, various forms of partnering and shared infrastructure among industry and universities to achieve better strategic planning, R&D performance, and technology diffusion
4) Foster technology infrastructures that enable market entry by firms of all sizes, thereby enabling maximum product diversity and facilitating manufacturing technology system integration
5) Update and expand the educational infrastructure through targeted curricula in community colleges, broader support for STEM in universities, and policy reform to encourage immigration of highly skilled workers
6) Increase the speed and breadth of the diffusion of new manufacturing technologies through expanded and more efficient technology transfer mechanisms
7) Enable rapid scale-up to commercially efficient volumes of production through the assurance of access by entire advanced manufacturing supply chains to supporting technology infrastructure and to adequate financing by domestic capital markets

The Bottom Line:

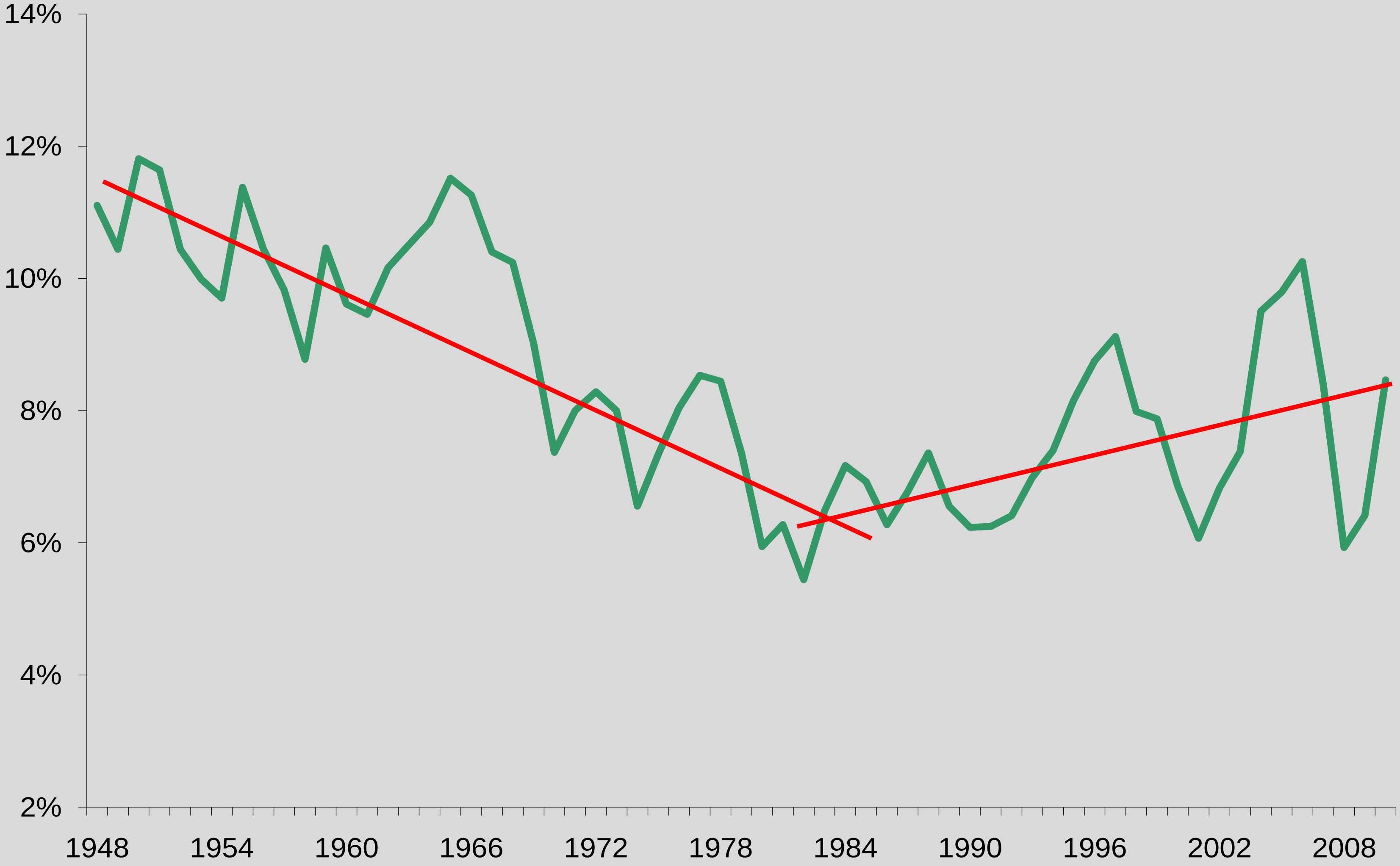
1) Amount of R&D: The manufacturing sector's R&D intensity should be doubled to 6-7 percent
2) Amount of R&D: Restructure the R&E Tax Credit and enlarge it to approximately a 20 percent flat credit
3) Composition of R&D: A single advanced manufacturing policy entity should be created to manage a portfolio optimized for economic growth
4) Composition of R&D: Federal R&D funding strategies must be element-based, distinguishing among science, generic technology (proofs of concept), and infratechnologies
5) R&D efficiency and Diffusion of R&D: Increase focus on regional technology clusters
6) Dynamic Management: Improve timing and adjustment of policies over technology life cycle through a STID policy analysis function

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

– Robert Louis Stevenson

BACKUP

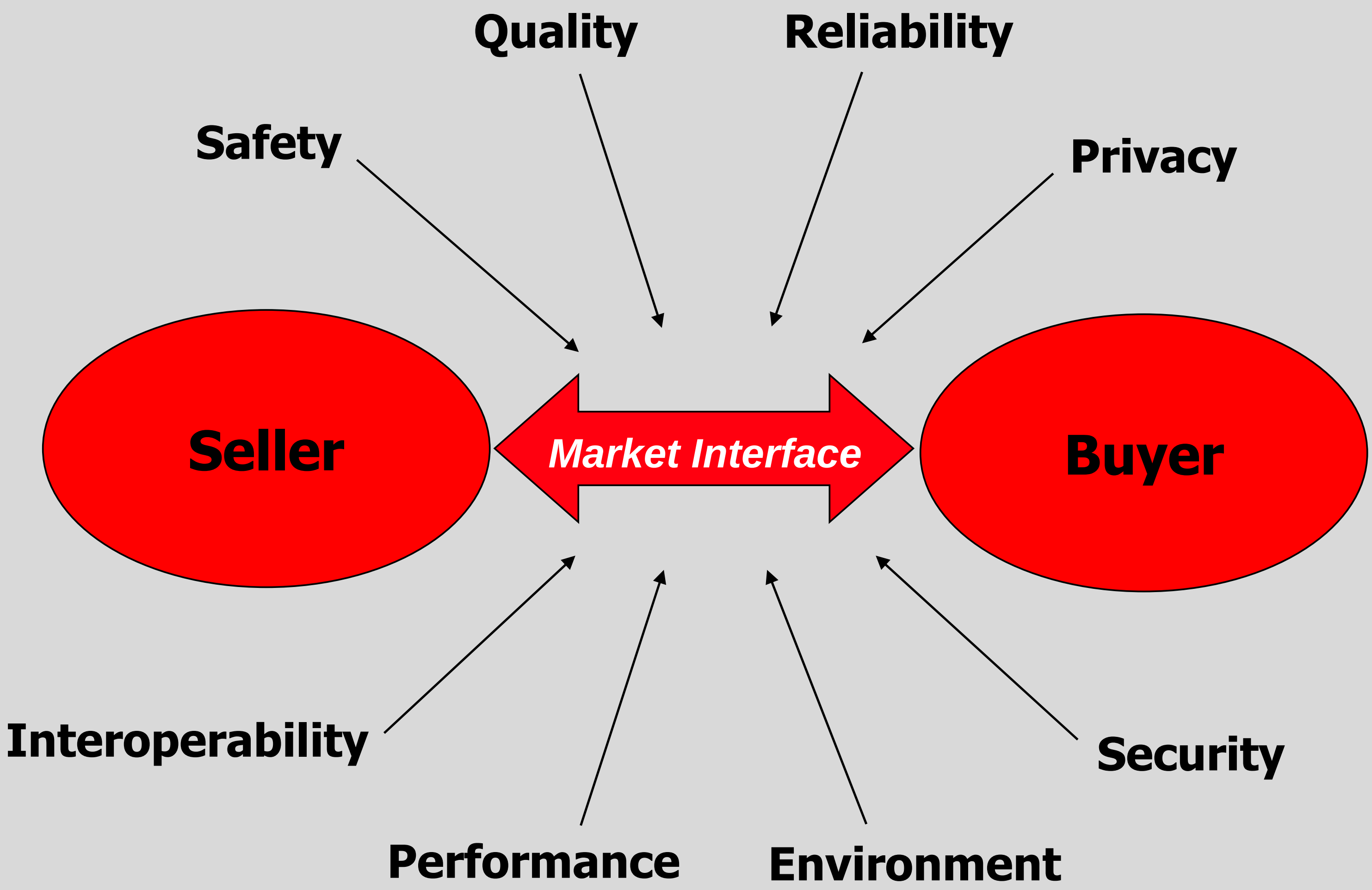
Ratio of U.S. Domestic Corporate Profits Before Taxes to GDP, 1948-2010



Gregory Tassey, "Beyond the Business Cycle: The Need for a Technology-Based Growth Strategy," forthcoming. Data from Bureau of Economic Analysis, NIPA Table 1.14 (line 11) for corporate profits before taxes (Gross Value Added).

Causes of Underinvestment – Composition of R&D

Complex Infrastructure for Efficient Transactions in High-Tech Markets



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

Potential R&D Cost Reductions in Biopharmaceutical Development with Improved Infratechnologies

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**

Underperformance

- Constantly hear small firms create most jobs
  - A few new firms create most of the jobs among small firms
- But, although multinationals account for less than 1% of total US companies, they are responsible for
  - 25% of US private-sector gross profits in 2007
  - 31% of growth in real private-sector GDP since 1990
  - 48% of total US goods exports in 2007
  - 74% of domestic private-sector R&D spending*
- Therefore multinationals are a major driver of domestic economic growth
- Lack of job growth in domestic operations of multinationals is the result of globalization

*Source: McKinsey Global Institute, *Growth and Competitiveness in the United States: The Role of its Multinational Companies*, June 2010

Underperformance

**Domestic and Offshore Growth in
Multinational Corporations' R&D and Value Added, 2004-2007**

	Domestic Operations	Majority-Owned Foreign Affiliates
Value Added	17.7%	36.6%
R&D Spending	22.0%	35.7%

Source: Bureau of Economic Analysis

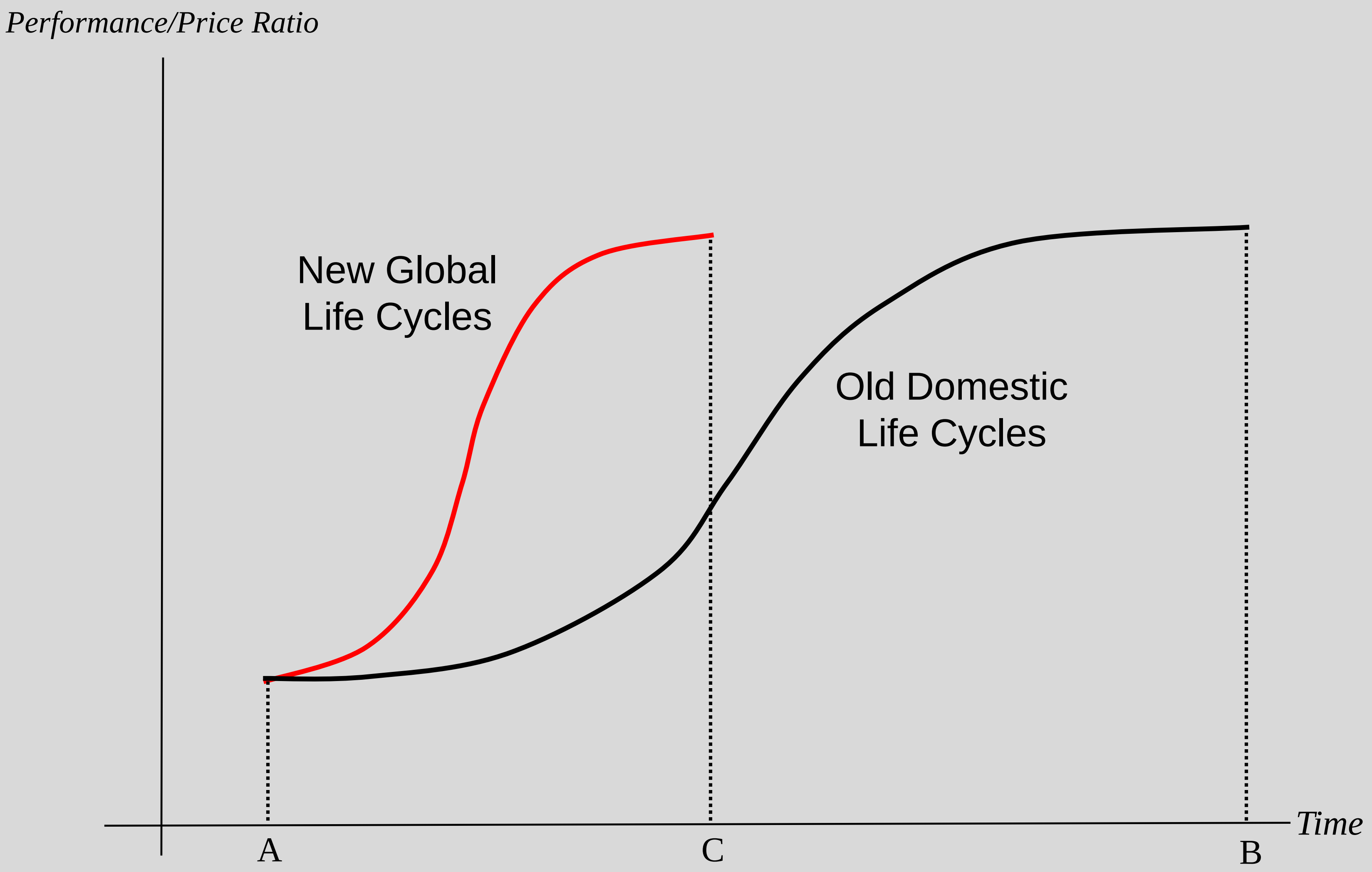
Long-Term Deterioration of U.S. Educational System is Constraining Future Economic Growth Potential

- Ranking of America's 15-year-old students by PISA among 65 countries*
  - Reading skills: 14th
  - Science: 17th
  - Math: 25th
- Top-scoring geographic region within a country: Shanghai, China*
- The U.S. school year
  - Average school year in the world is 200 days (many industrialized nations have school years that are much longer)
  - By the time U.S. students complete K-12, they have gone to school more than a full school year less than the average for other nations**

* Program for International Student Assessment (PISA);
** Fast Facts. (2006). *Journal of Property Management, 71(5): 9*

Causes of Underinvestment – Life Cycle Management

Compression of Technology Life Cycles



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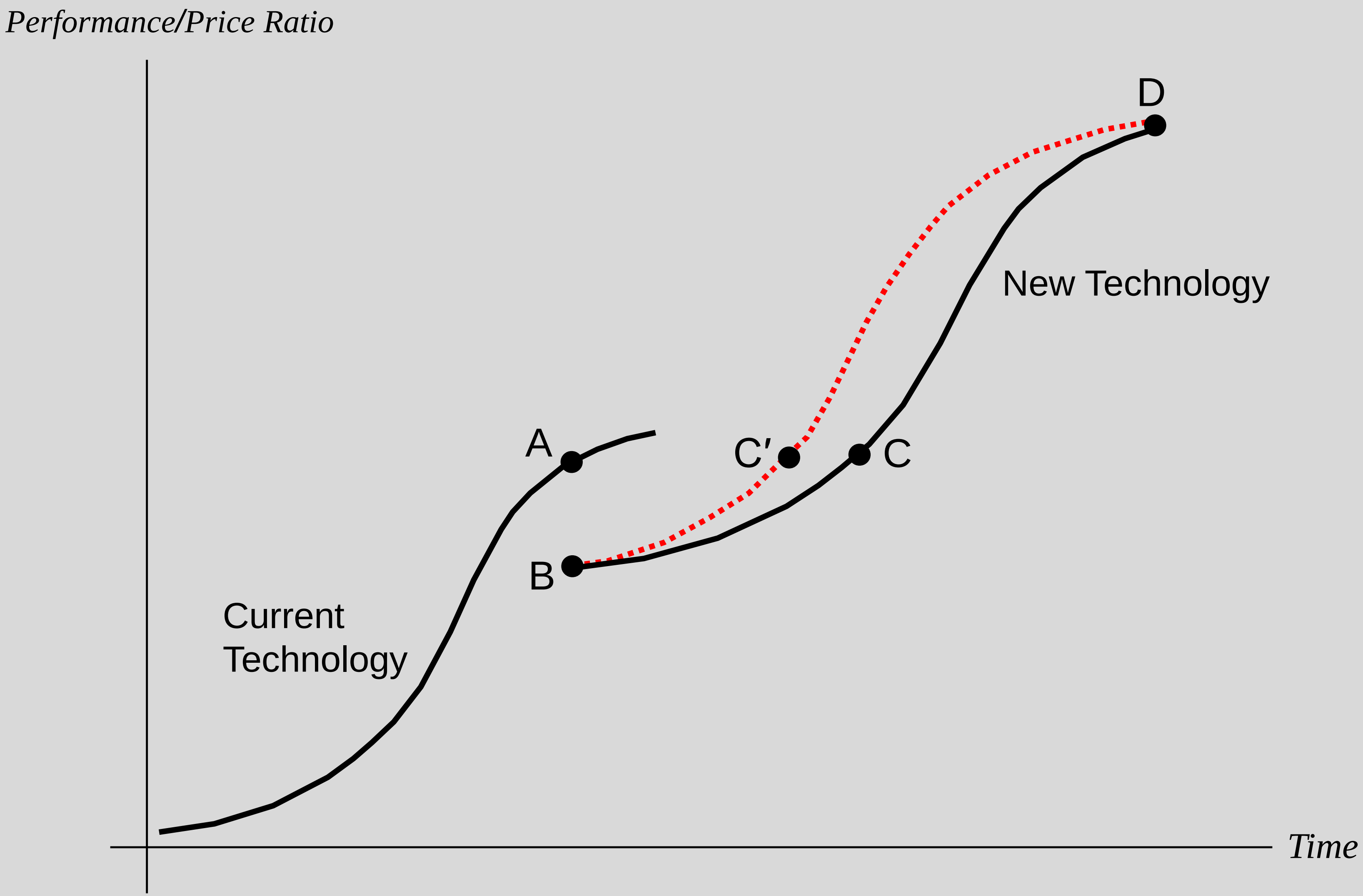
Life-Cycle Market Failure: Generic Technology



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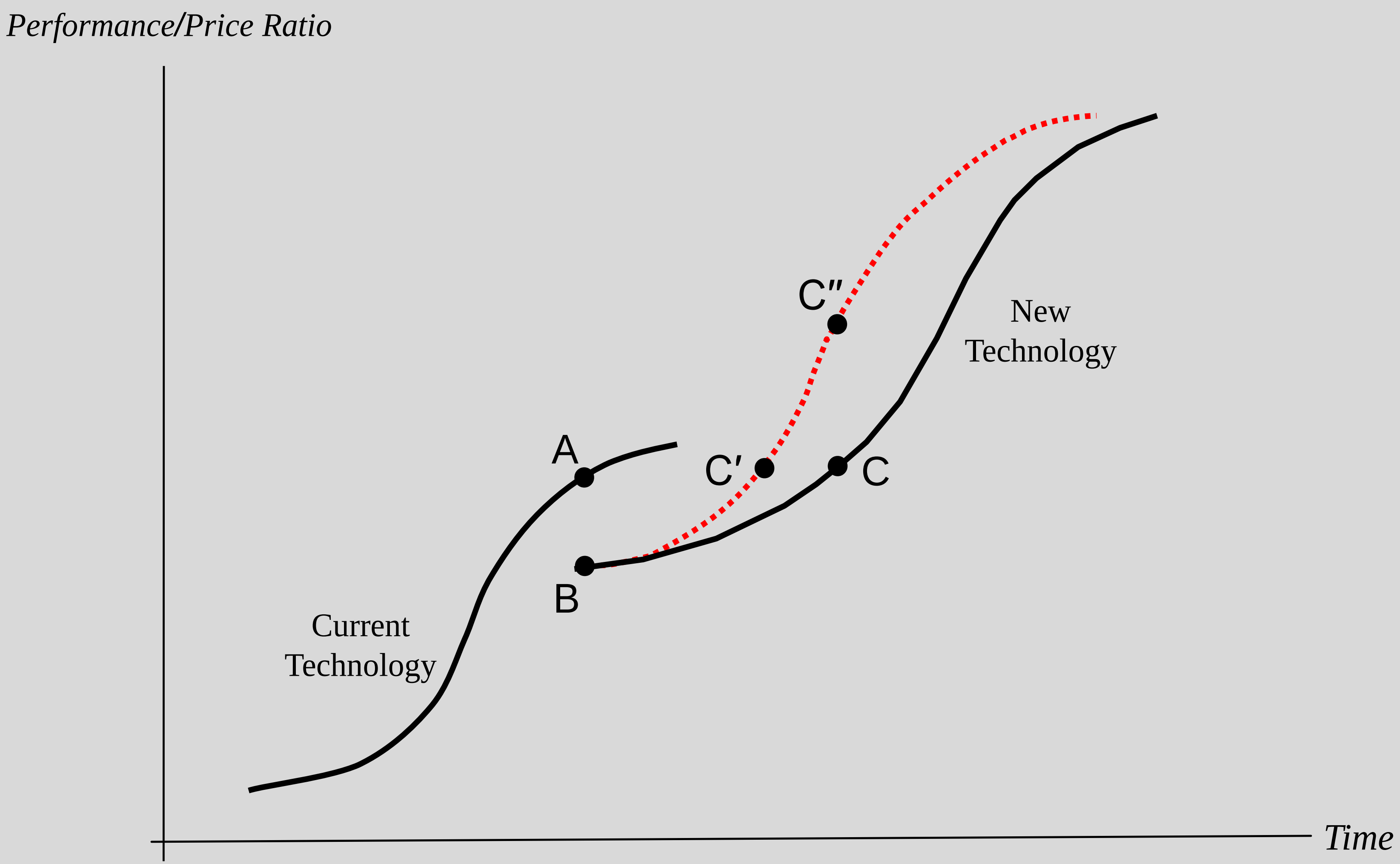
Causes of Underinvestment – Life Cycle Management

Life Cycle Evolution: Infratechnology



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