The Technology Imperative and
The Future of R&D Policy

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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”
The Technology Imperative

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

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

Source: Census Bureau, Foreign Trade Division
U.S. Trade Balances for High-Tech vs. All Manufactured Products, 1988-2008

Source: Census Bureau, Foreign Trade Division
## Trends in Value Added

<table>
<thead>
<tr>
<th>Industry (NAICS Code)</th>
<th>% Change in Value Added</th>
<th>R&amp;D Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP</td>
<td>132.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Manufacturing (31–33)</td>
<td>92.7</td>
<td>3.6</td>
</tr>
<tr>
<td>Motor vehicles and parts (3361-63)</td>
<td>84.0</td>
<td>-18.0</td>
</tr>
<tr>
<td>Textiles, apparel and leather (313-16)</td>
<td>8.2</td>
<td>-34.7</td>
</tr>
<tr>
<td>Computer &amp; Electronic Products (334)</td>
<td>144.5</td>
<td>9.0</td>
</tr>
<tr>
<td>Publishing, Including Software (511)</td>
<td>225.1</td>
<td>17.1</td>
</tr>
<tr>
<td>Information &amp; Data Processing (518)</td>
<td>305.4</td>
<td>8.7</td>
</tr>
<tr>
<td>Professional, Scientific &amp; Technical (54)</td>
<td>249.6</td>
<td>10.0</td>
</tr>
</tbody>
</table>

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**Underperformance**
Three Elements of R&D Policy:

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

Source: Bureau of Economic Analysis
Indicators of Underinvestment – Amount

R&D Intensity: Funding as a Share of GDP, 1953-2007

Source: National Science Foundation
Indicators of Underinvestment – Amount

National R&D Intensities, 2005
Gross R&D Expenditures as a Percentage of GDP

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

<table>
<thead>
<tr>
<th>State</th>
<th>% of Population</th>
<th>% of National R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>California</td>
<td>12.0</td>
<td>19.8%</td>
</tr>
<tr>
<td>Michigan</td>
<td>3.3</td>
<td>5.7%</td>
</tr>
<tr>
<td>New York</td>
<td>6.3</td>
<td>5.5%</td>
</tr>
<tr>
<td>Texas</td>
<td>7.8</td>
<td>4.4%</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>2.1</td>
<td>4.9%</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>4.1</td>
<td>4.6%</td>
</tr>
<tr>
<td>New Jersey</td>
<td>2.8</td>
<td>4.4%</td>
</tr>
<tr>
<td>Illinois</td>
<td>4.2</td>
<td>3.9%</td>
</tr>
<tr>
<td>Washington</td>
<td>2.1</td>
<td>3.7%</td>
</tr>
<tr>
<td>Maryland</td>
<td>1.8</td>
<td>3.7%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>46.5</strong></td>
<td><strong>60.5%</strong></td>
</tr>
</tbody>
</table>

Source: National Science Foundation
Indicators of Underinvestment – Composition

Trends in Federal R&D Funding, FY1976-2006
(constant FY2005 dollars)

Source: AAAS
Indicators of Underinvestment – Composition

Profit Differentials for Major and Minor Innovations

61% of Profits

Major Innovations
(14% of Launches)

39% of Profits

Incremental Innovations
(86% of Launches)

62% of Revenue

38% of Revenue

## Indicators of Underinvestment – Composition

<table>
<thead>
<tr>
<th>Forecast Year</th>
<th>“Directed Basic Research”</th>
<th>“New Business Projects”</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>-26</td>
<td>+18</td>
</tr>
<tr>
<td>1994</td>
<td>-26</td>
<td>+18</td>
</tr>
<tr>
<td>1995</td>
<td>-19</td>
<td>+31</td>
</tr>
<tr>
<td>1996</td>
<td>-6</td>
<td>+39</td>
</tr>
<tr>
<td>1997</td>
<td>-26</td>
<td>+28</td>
</tr>
<tr>
<td>1998</td>
<td>-14</td>
<td>+24</td>
</tr>
<tr>
<td>1999</td>
<td>-23</td>
<td>+31</td>
</tr>
<tr>
<td>2000</td>
<td>-9</td>
<td>+34</td>
</tr>
<tr>
<td>2001</td>
<td>-21</td>
<td>+44</td>
</tr>
<tr>
<td>2002</td>
<td>-11</td>
<td>+30</td>
</tr>
<tr>
<td>2003</td>
<td>-21</td>
<td>+7</td>
</tr>
<tr>
<td>2004</td>
<td>-17</td>
<td>+1</td>
</tr>
<tr>
<td>2005</td>
<td>-21</td>
<td>+8</td>
</tr>
<tr>
<td>2006</td>
<td>-8</td>
<td>+31</td>
</tr>
<tr>
<td>2007</td>
<td>-6</td>
<td>+31</td>
</tr>
<tr>
<td>2008</td>
<td>+4</td>
<td>+33</td>
</tr>
<tr>
<td>2009</td>
<td>-17</td>
<td>+22</td>
</tr>
</tbody>
</table>

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

Federal Research ("R") Funding: 1990-2009
Constant 2008 Dollars

$ billions


Total Federal “R”
Federal “R” w/o NIH

Note: FY2009 does not include stimulus funding.
Indicators of Underinvestment – Composition

DoD S&T Funding vs. Total DoD R&D, FY1976–2006
(constant FY2006 dollars)

$ billions

Total R&D: up 180%
S&T (6.1, 6.2, 6.3): up 100%

Source: AAAS; FY2006 estimate is President’s request
Industry Funds for R&D by Major Phase, 1991-2006
(in constant 2000 dollars)

- Development: up 94.3%
- Applied Research: up 45.7%
- Basic Research: up 7.4%

Source: National Science Foundation
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

Strategic Planning → Commercialization → Market Development → Value Added

Entrepreneurial Activity

Proprietary Technology

Science Base

Need for New Innovation Model

Economic Model of a Technology-Based Industry

Strategic Planning → Production → Market Development → Value Added

Entrepreneurial Activity

Risk Reduction

Proprietary Technologies

Generic Technologies

Infratechnologies

Science Base

Application of the Technology-Element Model: Biopharmaceuticals

<table>
<thead>
<tr>
<th><strong>Science Base</strong></th>
<th><strong>Infratechnologies</strong></th>
<th><strong>Generic Technologies</strong></th>
<th><strong>Commercial Products</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>genomics</td>
<td>bioinformatics</td>
<td>antiangiogenesis</td>
<td>cell encapsulation</td>
</tr>
<tr>
<td>immunology</td>
<td>biospectroscopy</td>
<td>antisense</td>
<td>cell culture</td>
</tr>
<tr>
<td>microbiology/</td>
<td>combinatorial chemistry</td>
<td>apoptosis</td>
<td>microarrays</td>
</tr>
<tr>
<td>virology</td>
<td>DNA sequencing and</td>
<td>bioelectronics</td>
<td>fermentation</td>
</tr>
<tr>
<td></td>
<td>profiling</td>
<td>biomaterials</td>
<td>gene transfer</td>
</tr>
<tr>
<td>molecular and</td>
<td>electrophoresis</td>
<td>biosensors</td>
<td>immunoassays</td>
</tr>
<tr>
<td>cellular biology</td>
<td>fluorescence</td>
<td>functional genomics</td>
<td>implantable delivery</td>
</tr>
<tr>
<td>nanoscience</td>
<td>gene expression analysis</td>
<td>gene delivery systems</td>
<td>systems</td>
</tr>
<tr>
<td>neuroscience</td>
<td>magnetic resonance</td>
<td>gene testing</td>
<td>nucleic acid</td>
</tr>
<tr>
<td>pharmacology</td>
<td>spectrometry</td>
<td>gene therapy</td>
<td>amplification</td>
</tr>
<tr>
<td>physiology</td>
<td>mass spectrometry data</td>
<td>gene expression systems</td>
<td>recombinant</td>
</tr>
<tr>
<td>proteomics</td>
<td>nucleic acid</td>
<td>monoclonal antibodies</td>
<td>DNA/genetic engineering</td>
</tr>
<tr>
<td></td>
<td>diagnostics</td>
<td>pharmacogenomics</td>
<td>separation</td>
</tr>
<tr>
<td></td>
<td>protein structure</td>
<td>stem-cell</td>
<td>technologies</td>
</tr>
<tr>
<td></td>
<td>modeling/analysis</td>
<td>tissue engineering</td>
<td>transgenic animals</td>
</tr>
<tr>
<td></td>
<td>techniques</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Public Technology Goods

Mixed Technology Goods

Private Technology Goods

Overcoming the Innovation Risk Spike (Valley of Death)

Policy Response

Economic Model of a Technology-Based Industry

Strategic Planning → Production → Market Development → Value Added

Entrepreneurial Activity → Risk Reduction

Proprietary Technologies → Infratechnologies

Generic Technologies

Science Base

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

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

Source: RTI International
## Potential Manufacturing Efficiency Gains from an Improved Technology Infrastructure

<table>
<thead>
<tr>
<th>Phase/Activity Cost</th>
<th>Baseline Production Costs</th>
<th>Potential Change in Cost by Phase/Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percentage of Total a</td>
<td>Baseline Total (millions)</td>
</tr>
<tr>
<td>Preproduction</td>
<td>30%</td>
<td>$1,900</td>
</tr>
<tr>
<td>Upstream processing</td>
<td>20%</td>
<td>$1,267</td>
</tr>
<tr>
<td>Downstream processing</td>
<td>40%</td>
<td>$2,533</td>
</tr>
<tr>
<td>Process monitoring and quality assurance testing</td>
<td>10%</td>
<td>$633</td>
</tr>
<tr>
<td><strong>Total commercial manufacturing costs</strong></td>
<td></td>
<td><strong>$6,333</strong></td>
</tr>
</tbody>
</table>

*a From Frost and Sullivan (2004). Source of estimates: RTI International*
Compression of Technology Life Cycles

New Global Life Cycles

Old Domestic Life Cycles

Potential or Actual Performance/Price

A B

C

Transition Between Two Technology Life Cycles

Potential or Actual Performance–Price Ratio

Current Technology

New Technology

A

B

Time

Life-Cycle Market Failure: Generic Technology

Current Technology

Potential or Actual Performance–Price Ratio

New Technology

Policy Response

Life Cycle Evolution: Infratechnology

Potential or Actual Performance–Price

Current Technology

New Technology

Time

Policy Response

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

Joint Industry-Government Planning

Strategic Planning

Production

Market Development

Value Added

Value Added

Market Planning Assistance

Technology Transfer (Universities, MEP)

Entrepreneurial Activity

Risk Reduction

Proprietary Technologies

Infratechnologies

Generic Technologies

Science Base

Measurement Standards

Interface Standards

Tax Incentives

Intellectual Property Rights

National Labs

Direct Funding of Firms, Universities, Consortia

National Labs (NIST)

Acceptance Test Standards; National Test Facilities

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 \( \sim 5 \text{ percent} \)

2) **R&E Tax Credit** should be restructured and enlarged to \( \sim 20 \text{ percent flat credit} \)

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