What is Wrong With U.S. Manufacturing?

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October 2012
Need Institutionalized Process for Managing Science, Technology, Innovation, and Diffusion (STID) Policy:

(1) Demonstrate importance of the policy issue for economic growth

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

(3) Estimate underinvestment in technology as determinant of growth
   - Specific R&D investment trends
   - Investment by phase of the R&D cycle
   - Technology diffusion rates
   - Scale-up

(4) Identify causes of underinvestment using technology-based models
   - Excessive technical and/or market risk
   - Appropriability, information, expertise, capital market problems

(5) Develop/select policy responses and management mechanisms
   - Policy instruments matched with underinvestment phenomena
   - Metrics for policy management and impact assessment
Projected slow rate of economic growth is manifestation of inadequate long-term investments in productivity growth

- For the last decade (2000-2010)
  - Average annual real GDP growth was 1.7 percent
  - U.S. private nonfarm employment declined 3.3 percent
  - Real disposable personal income grew 11.9 percent
  - Median household real income declined 7.0 percent
- 23.5 million people were unable to find full-time jobs, double the 12 million working in U.S. manufacturing (July 2012)
- 47 million Americans on food stamps (June 2012)
- However, the current economic growth policy debate is focused on macrostabilization issues:
  - Government spending vs. deficit reduction
  - Monetary base expansion vs. potential inflation effects
(1) Importance of the Policy Problem – Wrong Growth Policy Model

Macrostabilization vs. Long-Term Growth Strategies

Economic importance of A National Strategy for Advanced Manufacturing:

- As an independent economy, the value added produced by the U.S. manufacturing sector would rank 9th in the world.

- Important for diversification in a highly competitive global economy:
  - Contributes $1.7 trillion to GDP and employs 11 million workers.
  - High-tech service jobs are increasingly “tradeable” and 30 economies have policies in place to promote service exports.

- Manufacturing accounts for:
  - 70% of US domestic industry-performed R&D.
  - 60% of U.S. domestic industry’s scientists/engineers.
  - 70% of patents issued to U.S. companies/residents.


- High-tech services must have close ties to its manufacturing base:
  - Large high-tech manufacturing firms are integrating forward into services.

- The majority of trade is in manufactured products—deficits for last 37 years.

- Yet, neoclassical economists are okay with offshoring all manufacturing.
(2) Underperformance – The High-Tech Economy

The Bottom Line: The high-income economy must be the high-tech economy

1) Technology is the long-term driver of productivity growth and hence growth in real wages

2) Median wages in BLS “high-tech” occupations exceed median for all industries by 50-100 percent

3) But, the U.S. economy is in long-term decline relative to the global economy due to underinvestment in R&D, capital formation, and workforce training

4) This underinvestment is now being manifested in a range negative economic growth indicators (productivity, real income, trade, GDP)

5) High-tech sector is small part of the U.S. economy, giving it low political influence

6) Existing underinvestment phenomena must be addressed by appropriate policy instruments—requires a STID economic growth model

7) Applying such a framework demands a STID policy analysis infrastructure—hardly exists in the United States
(2) Underperformance – Manufacturing


Source: Bureau of Labor Statistics
Policy Focus: Multifactor Productivity
Trends in Productivity and Income: U.S. Manufacturing Sector, 1987-2010

Source: Bureau of Labor Statistics

(2) Underperformance – U.S. Economy
Non-Farm Employment Growth in Post World-War-II Business Recoveries: Percent Change from Recession Trough

Source: G. Tassey, *The Technology Imperative* (updated); BLS for employment data; NBER for recession trough dates
U.S. Trade Balances for High-Tech vs. All Manufactured Products, 1988-2011

Cumulative drain on GDP over this period is $8.25 trillion (2011 dollars)

Source: Census Bureau, Foreign Trade Division (“Trade in Goods with Advanced Technology Products” and “U.S. Trade in Goods and Services (FT900), Exhibit 15” for the manufacturing trade balance)
(2) Underperformance – R&D Intensity and Innovative Output

Rate of Innovation vs. R&D Intensity:
Percent of Companies in an Industry Reporting Product and/or Process Innovations, 2003-2007

### Relationship Between R&D Intensity & Real Output Growth in Manufacturing Industry

<table>
<thead>
<tr>
<th>Industry (NAICS Code)</th>
<th>Ave. R&amp;D Intensity, 1999-2007</th>
<th>Percent Change in Real Output, 2000-07</th>
<th>Percent Change in Real Output, 2000-09</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R&amp;D Intensive:</strong></td>
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<tr>
<td>Pharmaceuticals (3254)</td>
<td>10.5</td>
<td>17.9</td>
<td>4.9</td>
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<tr>
<td>Semiconductors (3344)</td>
<td>10.1</td>
<td>17.0</td>
<td>1.1</td>
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<tr>
<td>Medical Equipment (3391)</td>
<td>7.5</td>
<td>34.6</td>
<td>39.5</td>
</tr>
<tr>
<td>Computers (3341)</td>
<td>6.1</td>
<td>109.9</td>
<td>147.0</td>
</tr>
<tr>
<td>Communications Equip (3342)</td>
<td>13.0</td>
<td>-40.0</td>
<td>-59.7</td>
</tr>
<tr>
<td><strong>Group Ave:</strong></td>
<td><strong>9.5</strong></td>
<td><strong>27.9</strong></td>
<td><strong>26.6</strong></td>
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<tr>
<td><strong>Non-R&amp;D Intensive:</strong></td>
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<td></td>
<td></td>
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<tr>
<td>Basic Chemicals (3251)</td>
<td>2.2</td>
<td>25.6</td>
<td>-7.8</td>
</tr>
<tr>
<td>Machinery (333)</td>
<td>3.8</td>
<td>2.3</td>
<td>-22.4</td>
</tr>
<tr>
<td>Electrical Equipment (335)</td>
<td>2.5</td>
<td>-13.4</td>
<td>-33.4</td>
</tr>
<tr>
<td>Plastics &amp; Rubber (326)</td>
<td>2.3</td>
<td>-5.2</td>
<td>-28.0</td>
</tr>
<tr>
<td>Fabricated Metals (332)</td>
<td>1.4</td>
<td>2.6</td>
<td>-23.6</td>
</tr>
<tr>
<td><strong>Group Ave:</strong></td>
<td><strong>2.5</strong></td>
<td><strong>2.4</strong></td>
<td><strong>-23.1</strong></td>
</tr>
</tbody>
</table>

Sources: NSF for R&D intensity and BLS for real output.
(2) Underperformance – Maintaining Domestic Supply Chains

High-tech offshoring is a multi-step process, driven by (1) increasingly attractive skilled labor, (2) R&D and capital subsidies, and (3) supply-chain synergies

1) Originally, offshoring of manufacturing was for local-market opportunities

2) Increasingly, motivation is to access cheaper but also skilled labor
   ▪ Required small amount of supporting R&D
   ▪ Host country frequently subsidizes plant and equipment

3) Host country gains R&D experience at “entry” tier in high-tech supply chain

4) Host country begins to integrate forward into design or backward into components
   ▪ China—backward to components (from assembly)
   ▪ Taiwan—forward to electronic circuits (from components)
   ▪ Korea—forward to electronic products (from components)

4) **Economic policy point**: Co-location synergies are being lost in U.S. and captured in Asia
   ▪ Between 2011 and 2013, **81 new semiconductor fabs** will begin operations globally—six of them in the United States (SEMI)
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 (e.g. OLED)
Trends in Manufacturing R&D Needing Policy Attention

- 37 consecutive years of trade deficits
- Manufacturing sector’s average R&D intensity (3.7 percent) has remained flat since the mid-1980s
  - has not been helped by offshoring of low R&D-intensive industries
  - pales compared to truly “R&D-intensive” industries, whose ratios range from 5 to 22 percent
- Need for effective policy response is great
  - most of the global economy’s $1.4 trillion annual R&D spending targets manufacturing technologies
  - Technology life cycles are being compressed
  - 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
U.S. R&D Intensity: Constant for 45 Years

Funding as a Share of GDP, 1953-2008

Total R&D/GDP

Federal R&D/GDP

Industry R&D/GDP

National R&D Intensities, 2009
Gross R&D Expenditures as a Percentage of GDP

Changes in National R&D Intensity, 1995-2009

Shares of Domestic Manufacturing Value Added from Moderate and High R&D-Intensive Industries

The “Valley of Death” (New Technology Platforms) is Getting Wider

Trends in Short-Term vs. Long-Term US Industry R&D, 1993-2011

Fixed Private Investment in Hardware & Software
(growth by decade in 2005 dollars)

Source: Gregory Tassey, “Beyond the Business Cycle: The Need for a Technology-Based Growth Strategy,” (Science and Public Policy, forthcoming). Data from Bureau of Economic Analysis, NIPA Table 5.3.5 (includes both equipment and software) and Table 5.3.4 (price indexes for fixed private investment)
“Black Box” Model of a Technology-Based Industry

(4) Causes of Underinvestment – Conventional Wisdom

Neoclassical economics ignores market failure rationales for government support of STID policies:

- Excessive risk (increase costs)
- Knowledge spillovers (reduce benefits)
- Long development time (reduce benefits)
- Economies of scope (reduce benefits)
- Prices spillovers (reduce benefits)
- Information asymmetries (increase costs)
- Coordination inefficiencies (increase costs)
Technology Platforms: Overcoming the Early-Phase R&D Risk Spike

Infratechnologies for Efficient Transactions in High-Tech Markets

Federal R&D Portfolio is not Optimized for Economic Growth

- Historical focus has and continues to be on “mission” R&D programs (national 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 R&D and about 10 percent of high-tech 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: “technology platform” (proof-of-concept) 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
Application of the Technology-Element Model: Nanotechnology Platforms

<table>
<thead>
<tr>
<th>Science Base</th>
<th>Infratechnologies</th>
<th>Technology Platforms</th>
<th>Commercial Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbon-based nanomaterials</td>
<td>biological detection and analysis tools</td>
<td>carbon nanotubes</td>
<td>hardened nanomaterials for machining/drilling</td>
</tr>
<tr>
<td>cellulosic nanomaterials</td>
<td>in silico modeling &amp; simulation tools</td>
<td>dendrimers</td>
<td>flame-retardant nanocoatings</td>
</tr>
<tr>
<td>magnetic nanostructures</td>
<td>in-line measurement techniques to enable closed-loop process control</td>
<td>hybrid nanoelectronic devices</td>
<td>sporting goods</td>
</tr>
<tr>
<td>molecular nanoelectronic materials</td>
<td>sub-nanometer microscopy</td>
<td>ultra-low-power devices</td>
<td>solar cells</td>
</tr>
<tr>
<td>quantum dots</td>
<td>high-resolution nanoparticle detection</td>
<td>self-powered nanowire devices</td>
<td>sunscreen/cosmetics</td>
</tr>
<tr>
<td>optical metamaterials</td>
<td>thermally stable nanocatalysts for high-temperature reactions</td>
<td>nanoparticle fluorescent labels for cell cultures and diagnostics</td>
<td>targeted delivery of anticancer therapies</td>
</tr>
<tr>
<td>solid-state quantum-effect nanostructures</td>
<td></td>
<td>metal nanoparticles &amp; conductive polymers for soldering/bonding</td>
<td>biodegradable and lipid-based drug delivery systems</td>
</tr>
<tr>
<td>functionalized fluorescent nanocrystals</td>
<td></td>
<td>nanoparticle sensors</td>
<td>self-repairing &amp; long-life wood composites</td>
</tr>
<tr>
<td>quantum-confined structures</td>
<td></td>
<td>epitaxy</td>
<td>anti-microbial coatings for medical devices</td>
</tr>
</tbody>
</table>

Mixed Technology Goods

- inkjet processes for printable electronics
- purification of fluids with nanomaterials
- roll-to-roll processing

Public Technology Goods

- hardened nanomaterials for machining/drilling
- flame-retardant nanocoatings
- sporting goods
- solar cells
- sunscreen/cosmetics
- targeted delivery of anticancer therapies
- biodegradable and lipid-based drug delivery systems
- self-repairing & long-life wood composites
- anti-microbial coatings for medical devices
- nanoscale motion microscopes

Policy Imperative: Increase Investment in Science, Technology, Innovation, and Diffusion (STID)

- New roles for governments
  - Compete as much as private companies
  - Future roles will be more complex rather than larger
  - Must manage the entire technology life cycle

- Major real asset categories determining competitiveness:
  - Technology (intellectual capital)
  - Skilled labor (human capital)
  - Hardware and software (non-human capital)
  - Technical infrastructure (public capital)
  - Industry structure & behavior (organizational capital)
Needed: **Total-Technology-Life-Cycle Growth Strategy**

- Germany has a **trade surplus** in manufacturing, even though compared to the United States, it has a
  - Approximately same R&D intensity (2.82 percent vs. 2.90 percent for U.S.)
  - 26 percent higher average hourly manufacturing labor compensation

**Reason**: Germany has **more comprehensive/intensively managed STID policy**
- Coordinated government R&D programs
- Strongly integrated R&D and manufacturing
- Highly skilled labor force across all technology occupations
- Optimized industry structure (support for both large firms and SMEs)
- Highest % of manufacturing value added from R&D-intensive industries

- Other nations using similar growth strategies
  - U.S. projected to fall behind EU27/AP regions in nanotech products (Lux Research)
Compression of Technology Life Cycles
Raises Technical and Market Risk

Compression of Technology Life Cycles

New Global Life Cycles

Old Domestic Life Cycles

Performance/Price Ratio

Time

A

C

B

(4) Causes of Underinvestment – Life-Cycle Mismanagement


31
Life-Cycle Acceleration: Technology Platform Development

Current Technology

New Technology

A
B
C
C'
D

Life Cycle Market Failure: **Infratechnology**

**Performance/Price Ratio**

- **A**
- **B**
- **New Technology**
- **C**
- **C'**
- **C''**

**Current Technology**

**New Technology**

- **e.g., semiconductor industry has ~1600 standards**

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Joint Industry-Government Planning

Strategic Planning

Production

System Integration

Market Development

Value Added

Scale-Up Incentives

Market Targeting Assistance and Procurement Incentives

Entrepreneurial Activity

Risk Reduction

Proprietary Technologies

Infratechnologies

Technology Platforms

Science Base

Technological Transfer/Diffusion (MEP)

Interface Standards (consortia, standards groups)

Technology Transfer/Diffusion (MEP)

Intellectual Property Rights (DoC)

Tax Incentives

Incubators (states)

National Labs

Direct Funding of Firms & Universities (DARPA, ARPA-E, NRI, AMTech)

Acceptance Test Standards and National Test Facilities (NIST)

National Labs (NIST), Consortia

Summary: Complexity of Modern Manufacturing Technologies Leads to Three Targets of R&D Policy

- **Amount of R&D**
  - Create financial incentives for private companies to increase investments in R&D and increase the R&D intensity of the manufacturing sector
  - Increase Federal investment in research aimed at broad sector growth objectives in addition to those related to agency missions

- **Composition of R&D**
  - Create incentives for private-sector investment in early phases of R&D cycle
  - Create public-private partnerships to meet industry’s long-term research needs and IP management requirements through support for technology clusters
  - Fund research aimed at manufacturability to overcome scaling issues
  - Target the “other” 90% of manufacturing value added (outside NAICS 3345 and 3364)
  - Eliminate barriers to private investment in new firms (high technical risk, appropriability, skilled labor acquisition, and process-capability barriers)

- **Efficiency of R&D**
  - Improve timing and content of R&D through road mapping and portfolio management techniques
  - Increase rates of return and shorten the R&D cycle through technology clusters
  - Build in technology transfer through cluster design and co-located supply chain
Summary: Major Targets of Technology-Based Growth Policy

1) Increase *industry’s aggregate investment in R&D* and thereby leverage the Nation’s R&D intensity

2) Increase *technology platform and infratechnology R&D support in early phases of R&D cycle*

3) Deliver this support through *more efficient policy mechanisms*

4) Foster *technology infrastructures* that enable market entry by SMEs and adjust over technology life cycle

5) Update and expand the *educational infrastructure*

6) Increase the *speed and breadth of the diffusion* of new technologies

7) Enable *rapid scale-up* to commercially efficient volumes of production

8) Improve *policy management techniques* through planning & evaluation
## Advanced Manufacturing Policy Targets and Implementation Mechanisms

<table>
<thead>
<tr>
<th>Policy Target</th>
<th>Policy Action Required</th>
<th>Specific Targets</th>
<th>Economic Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase aggregate investment in R&amp;D</td>
<td>• Switch to a single flat 10 percent credit</td>
<td>• 5 percent average R&amp;D intensity for manufacturing sector</td>
<td>• Recognizes complementary roles for industry and government</td>
</tr>
<tr>
<td></td>
<td>• Increase government funding</td>
<td>• Reverse 50-year decline in Federal R&amp;D intensity</td>
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<tr>
<td>Increase amount and efficiency of proof-of-concept research that results in new technology platforms</td>
<td>• Promote joint industry-government funding of proof-of-concept research targeted at broad sector growth</td>
<td>• Expand funding through government-wide portfolio management mechanism</td>
<td>• Removes suboptimal portfolio structure resulting from existing set of individual agency portfolios</td>
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<tr>
<td></td>
<td>• Promote partnering for proof-of-concept technology research</td>
<td>• Establish regional technology-based clusters involving universities, government, and industry</td>
<td>• Facilitates strategic planning, complementary asset sourcing, risk pooling, and rapid diffusion of technical knowledge</td>
</tr>
<tr>
<td></td>
<td>• Fund infratechnology research</td>
<td>• Government laboratories</td>
<td></td>
</tr>
<tr>
<td>Foster effective industry structures and supporting technical infrastructures</td>
<td>• Ensure research consortia within clusters include SMEs</td>
<td>• Provide interface standards early in R&amp;D cycle</td>
<td>• Promotes market entry by firms of all sizes, thereby enabling maximum product diversity and efficient system integration</td>
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<tr>
<td></td>
<td>• Improve infrastructure that supports start-ups</td>
<td>• Focus financial and technical infrastructure support on young high-tech startups</td>
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<tr>
<td></td>
<td></td>
<td>• Provide university entrepreneur training and incubators/accelerizers</td>
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<td></td>
<td></td>
<td>• Provide infrastructure support for distribution</td>
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<tr>
<td>Modernize and expand educational infrastructure</td>
<td>• Adjust college curricula</td>
<td>• Increased STEM support through scholarships and career promotion</td>
<td>• Broadens and deepens skilled labor pool</td>
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<tr>
<td></td>
<td>• Change roles of high schools and community colleges</td>
<td>• Vocational training, apprenticeships through clusters</td>
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<tr>
<td>Enable rapid scale-up to commercially efficient production volumes and diversity</td>
<td>• Expand manufacturing process technology infrastructure</td>
<td>• Support process demonstration and actual shared production facilities</td>
<td>• Accelerates commercialization and market share growth, counteracting incentives from Asian nations</td>
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<tr>
<td></td>
<td>• Accelerate capital formation &amp; market penetration</td>
<td>• Provide procurement specifications through clearing house</td>
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<tr>
<td></td>
<td></td>
<td>• Investment tax credit</td>
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“Sooner or later, we sit down to a banquet of consequences”

– Robert Louis Stevenson