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Advanced Manufacturing: A New Policy Challenge

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ABSTRACT

In 2016 the political system experienced significant disruption in part due to a working class voting block suffering from a long decline in American manufacturing, which became particularly acute in the decade of the 2000s. Manufacturing employment fell by one-third in this period, 64,000 factories closed, manufacturing capital investment and output suffered, and the productivity rate dropped. The U.S. had been systematically shifting production abroad, and experts began to realize as the next decade began that the decline in its production capability was starting to affect its innovation capacity — which had long been viewed as its core economic strength.

This article reviews the origins of the policy response to this dilemma, which came to be called "advanced manufacturing." Implementation has just begun and the next several years should reveal whether these policies could begin to have

*William B. Bonvillian is a lecturer at MIT and until 2017 was director of MIT's Washington Office. He teaches courses on innovation policy at MIT, Georgetown and Johns Hopkins SAIS, and is coauthor of two books on innovation. He was an advisor to MIT's "Production in the Innovation Economy" study of 2013-14, and worked on the President's Advanced Manufacturing Partnership reports. Material in this article will be elaborated on in an upcoming book on this subject with Peter Singer, from MIT Press. Views expressed here are the author's.

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an effect on American manufacturing decline. The article traces the way the foundational concepts were developed in a series of reports from in and out of government. It explores how, for the first time, an innovation system response was considered and developed to strengthen the U.S. production system. It examines the key new policy mechanism created by the administration and supported by Congress, the manufacturing innovation institutes, a complex public–private collaborative model to develop new production technologies and processes, with supporting workforce education. It reviews how the new institutes are working, lessons learned as they have started up and possible enhancements that could expand their policy reach.

While this model may create efficiencies and productivity gains to help put existing U.S. manufacturers back in competition with lower cost and lower wage competitors abroad, the article finds there is a second problem. The U.S. developed in the 1980s and 1990s a new innovation system based on venture capital for entrepreneurial startup firms for implementing the IT and biotech innovation waves. That venture system has now largely shifted to support software firms, and has abandoned startups planning to manufacture "hard" technologies. In effect, the U.S. is fencing off firms that manufacture from its venture-based innovation system. This is now driving the next generation of manufacturers to production abroad, which will have significant societal consequences longer term. This article reviews new models to tackle this problem, essentially substituting technology and know-how rich spaces for capital.

These new approaches — an advanced manufacturing program — if implemented, could play a role in reconstituting the manufacturing sector, broaden the startup model, and start to reverse the serious social disruption the manufacturing decline has led to.

1

Introduction — The Decline of American Manufacturing and its Social Cost

The 2016 American Presidential Election told a story of social disruption: the political system had to confront a large group of dissenting voters who had left the existing political establishment.[1] Observers called them angry, but anger has root causes and grievances. A December 2015 Post-ABC poll told what most sensed — these voters tilted toward male, white, and poor.[2] Other polls told us the most important single predictor for these Donald Trump voters was they didn't go to college.[3] A study from the Hamilton Project informs this picture: full year employment of men with a high school but without a college degree dropped from 76%

[1]This section draws from, William B. Bonvillian (2016) "Donald Trump's Voters and the Decline of American Manufacturing", *Issues in Science and Technology*, Summer, 27–39. The editor's approval to use this material is sincerely appreciated.

[2]Janell Ross, (2015) Who Really Supports Donald Trump, *Washington Post*, Dec. 15, 2015 (summary of Washington Post-ABC News poll), July 27, 2015, Available at: https://www.washingtonpost.com/news/the-fix/wp/2015/12/15/who-really-supports-donald-trump-ted-cruz-ben-carson-marco-rubio-and-jeb-bush-in-5-charts/; Janell Ross, Donald Trump's Surge is All About Less-educated Americans, Washington Post, July 27, 2015. (summary of Wash. Post-ABC News poll), https://www.washingtonpost.com/news/the-fix/wp/2015/07/27/donald-trumps-surge-is-heavily-reliant-on-less-educated-americans-heres-why/?tid$=$a_inl.

[3]See generally, Derek Thompson, Who are Donald Trump's Supporters, Really, *The Atlantic*, March 1, 2016, relied on in this section.

in 1990 to 68% in 2013; the share of these men who did not work at all rose from 11% to 18%. While real wages have grown for men and women with college degrees, they have fallen for men without college degrees: the median income of men without high school diplomas fell by 20%, and fell 13% for men with high school diplomas or some college, between 1990 and 2013.[4] A Rand survey tells us another key feature: voters who agreed with the statement "voters like me don't have any say about what the government does" were 86% more likely to vote for Trump.[5] They felt they have no voice and no power. These voters also resented trade agreements, resented immigrants competing for jobs and more come from areas where racism historically has been more prevalent.

So there are a number of strands to this voter dissent but the economic elements tell us an evolving story that we are only starting to face. Americans in the postwar era developed a myth of classlessness — we were all middle class. Development in the postwar period of an innovation-based growth model and expansion of mass higher education made the nation rich, enabling rising expectations and a dream of egalitarian democracy. Then Donald Trump woke the country up to see a working class out there, cut adrift from the middle class and in tough economic straits. It began to blow up the myth of the American middle class.

Part of the story is education. Higher education since the industrial revolution has become increasingly tied to economic wellbeing. Economists Claudia Goldin, Lawrence Katz, and David Autor argue that the continuing advances in industry since the industrial revolution require an ever-increasing level of technological skill in the workforce.[6]

[4] Melissa S. Kearney, Brad Hershbein and Elisa Jacome, Profiles of Change: Employment, Earnings and Occupations from 1990–2013 (Hamilton Project paper, Brookings April 20, 2015).

[5] Michael Pollard and Joshua Mendelsohn (2016). Rand Commentary, Rand Kicks Off 2016 Presidential Election Panel Survey, March 28, 2016. Available at: http://www.rand.org/blog/2016/01/rand-kicks-off-2016-presidential-election-panel-survey.html.

[6] Claudia Goldin and Lawrence F. Katz, (2008). *The Race Between Education and Technology*. Cambridge, MA: Harvard University Press; David Autor, (2014). "Skills, Education and Rise of Earnings Inequality Among the 99 Percent," *Science*, 344, (6186), 843–850.

They portray two curves: (1) an ever-growing curve of the technological advance implemented by industry, and (2) a corresponding rising curve in the technological skill base in the workforce needed to support this technological advance. In a successful, technologically advanced economy, the societal skill base curve must stay parallel to and ahead of the technology implementation curve. The U.S. created a system for public mass higher education through the Land Grant College Act in 1862 which gradually scaled then dramatically enlarged access through GI Bill — these were perhaps its most important social legislation ever. For a hundred years, the education curve stayed ahead of the technology implementation curve, but starting in the 1970s, the U.S. allowed the higher education graduation rate to stagnate while the required skills expanded. These economists argue that this development is a major cause of the growing income disparity in the U.S.. While the U.S. upper middle class kept ahead of the technological skill curve, increasing its graduation rate, the lower middle and lower classes did not. This created a gap in the skill base, allowing the upper middle class to ride the technological advance earning a wage premium and leaving the other classes behind, with a significant income gap growing in recent decades between the two. Education is an important story helping to explain growing economic inequality and Trump voters.

But lurking among the other strands is a deep manufacturing story that arguably has made this problem more acute. The public didn't take manufacturing seriously in recent decades because a series of well-established economic views reassured them. Economists offered a number of perspectives: manufacturing was agriculture — we were losing manufacturing jobs because of major productivity gains; the production economy would naturally be replaced by a services economy; low wage, low cost producers must inevitably displace higher cost ones; don't worry about loss of commodity production, the U.S. will retain a lead in producing the high value advanced technologies; the benefits of free trade always outweigh any adverse effects; and innovation is distinct from production — innovation capacity remains even if the production is distributed worldwide. None are correct.

1.1 Manufacturing in decline — the decade of the 2000s

The U.S. manufacturing sector had a devastating decade between 2000–2010 and has only partially recovered.[7] The decline is illustrated by four measures: employment, investment, output, and productivity assumptions.[8]

Employment: Over the past 50 years manufacturing's share of GDP shrank from 27% to 12%. For most of this period (1965–2000), manufacturing employment generally remained constant at 17 million; in the decade from 2000 to 2010 it fell precipitously by almost one-third, to under 12 million, recovering by 2015 to only 12.3 million.[9] All manufacturing sectors saw job losses between 2000 and 2010,[10] with sectors most prone to globalization, led by textiles and furniture, suffering massive job losses.

Investment: Manufacturing fixed capital investment (plant, equipment, and IT), if cost adjusted, actually declined in the 2000s (down 1.8%) — the first decade this has occurred since data collection began.[11] It declined in 15 of 19 industrial sectors.[12] Some 64,000 manufacturing

[7] ITIF (Adams Nager and Robert Atkinson), The Myth of America's Manufacturing Renaissance: the Real State of U.S. Manufacturing (Washington, DC: ITIF report, Jan. 20, 2015).

[8] See generally, ITIF (Robert Atkinson, Luke Steward, Scott Andes, and Stephen Ezell), Worse Than the Great Depression: What the Experts are Missing About U.S. Manufacturing Decline (Washington, DC: ITIF report, March 19, 2012).

[9] Bureau of Labor Statistics (BLS), Current Labor Statistics (CES) (manufacturing employment-Analytical Tables, Table 7 Jan. 2017), https://www.bls.gov/web/empsit/tab7.txt See detailed review of manufacturing job loss in ITIF, Worse Than the Great Depression, 4–19; Robert E. Scott, (2015) Economic Policy Institute, Manufacturing Job Loss: Trade not Productivity is the Culprit, EPI report, August 11, 2015. Available at: http://www.epi.org/publication/manufacturing-job-loss-trade-not-productivity-is-the-culprit/ (citing BLS data).

[10] BLS, CES (employment in manufacturing industries).

[11] Bureau of Economic Analysis (BEA), Fixed Assets Accounts (investments in private fixed assets by industry, http://bea.gov; see analysis in ITIF, Worse Than the Great Depression, 47–58.

[12] ITIF (Luke A. Stewart and Robert D. Atkinson), Restoring America's Lagging Investment in Capital Goods. Washington, DC: ITIF Oct. 2013, p. 1, http://www2.itif.org/2013-restoring-americas-lagging-investment.pdf.

plants closed between 2000 and 2013, with only a slight recovery since then.[13]

Output: Data shows U.S. manufacturing output growth of only 0.5%/year between 2000–2007 (before the Great Recession hit), and zero output growth/year between 2007–2014, despite the gradual overall economic recovery following 2008.[14] This was behind both GDP growth and population growth. In the Great Recession itself, manufacturing output fell dramatically, 10.3%, between 2007 and 2009, followed by the slowest economic recovery in total GDP in 60 years.[15]

Productivity: Recent analysis shows that while the productivity growth rate in manufacturing averaged 4.1%/year between 1989–2000, while the sector was absorbing the gains of the IT revolution, between 2007–2014, it fell to only 1.7% a year.[16] Because productivity and output are tied, the decline and stagnation in output cited above is a major cause of the lower level of productivity in that period. Adjusted against 19 other leading manufacturing nations, the U.S. was 10th in productivity growth and 17th in net output growth.[17] So productivity increases were not the significant cause of the one-third decline in manufacturing employment many thought.[18] Political economist Suzanne Berger has noted that economists thought manufacturing was agriculture — a story of relentless productivity gains allowing an ever smaller workforce ever greater output. She found the ag analogy was simply incorrect in recent years.[19] This means we have to look at an overall decline in the sector itself for reasons why manufacturing lost nearly one-third of its workforce in a decade.

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[13]BLS, Databases, Tables & Calculators, Quarterly Census, Manufacturing Establishments 2001–2015, http://data.bls.gov/pdq/SurveyOutputServlet.

[14]Scott, EPI Manufacturing Job Loss.

[15]ITIF, Worse than the Great Depression, 30–42.

[16]BLS, Labor Productivity and Costs, Productivity Change in the Manufacturing sector, http://www.bls.gov/lpc/prodybar.htm.

[17]ITIF, Worse than the Great Depression, 42 (adjusted from BLS data).

[18]Scott, EPI Manufacturing Job Loss; ITIF, "Worse than the Great Depression," 39.

[19]Suzanne Berger and the MIT Task Force on Production in the Innovation Economy (2014) *Making in America*. Cambridge, MA: MIT Press, pp. 28–33.

To summarize, U.S. manufacturing employment was down, manufacturing capital investment was down, manufacturing output was down, and manufacturing productivity was lower than previously assumed. Overall, the U.S. manufacturing sector has been hollowing out. The post 2009 manufacturing recovery from a recession has been the slowest in history; while there has been some manufacturing job and output recovery they remain below pre- recession levels. The underlying structural problems in the sector still need addressing.

1.2 Manufacturing and trade

Success in a highly competitive world rewards nations and regions that produce complex, value-added goods and sell them in international trade. While world trade in services is growing, world trade in goods is four times trade in services.[20] Complex, high value goods (including capital goods, industrial supplies, energy technologies, communication and computing, transport, and medicines) make up over 80% of U.S. exports and a significant majority of imports. The currency of world trade is in such high value goods, and will remain so indefinitely. Yet, the U.S. in 2015 ran a trade deficit (balance of payments in imports over exports) of $832 billion in manufactured goods in 2015.[21] As of 2015, that total included a $92 billion deficit in advanced technology products which keeps growing.[22] The theory that the U.S. could keep moving up a production food chain — it could lose commodity production and keep leading production of advanced technology goods[23] — is undermined by this data. Gradual growth in the services trade surplus ($227 billion

[20]DG Trade Statistics (Jan. 2016). *World Trade in Goods, Services*. FDI, Available at: http://trade.ec.europa.eu/doclib/docs/2013/may/tradoc_151348.pdf.

[21]BEA, (2015). Foreign Trade, Exports, Imports and Balance of Goods by Selected NAICS-Based Product Code, Exhibit 1 in FT-900 Supplement for 12/15, Feb. 5, 2016. Available at: https://www.census.gov/foreign-trade/Press-Release/2015pr/12/ft900.pdf.

[22]BEA, (2015). Trade in Goods with Advanced Technology Products, Exhibit 16, Available at: https://www.census.gov/foreign-trade/balance/c0007.html.

[23]See, for example, Catherine L. Mann, Institute for International Economics, International Economics Policy Briefs, Globalization of IT Services and White Collar Jobs, N. PB03-11 (Dec. 2003), http://www.iie.com/publications/pb/pb03-11.pdf.

in 2015)[24] is dwarfed by the size and continuing growth of the U.S. deficit in goods; the former will not offset the latter anytime in the foreseeable future. So a services economy does not allow us to dispense with a production economy.

1.3 Macro-economic factors

US policy makers, under the influence of standard macro-economic theory, were largely content to allow US manufacturing capacity to erode and shift offshore because they were confident that the knowledge and service economy would readily replace lost jobs and salaries from lost manufacturing; it hasn't worked.

Recent decades have seen extended periods (1982–1987; 1998–2004; 2014–2016) where the dollar had high value against leading foreign currencies, with Treasury secretaries and Federal Reserve chairs generally supportive of a strong dollar.[25] This tended to put manufacturing exporters at a disadvantage by raising their prices in foreign markets. In parallel, from 1981 on, U.S. consumption as a share of GDP began rising, reaching 69% in 2011, higher than the level in other developed economies.[26] The strong dollar also helped push the country toward what many consider over-consumption compared to savings and investment; there was a growing production/consumption imbalance. The combination of an open trading regime, generally strong dollar, high consumption rates and open financial markets created advantages for competitor nations' exports.

The situation between China and the U.S. substantiates the point: the U.S. runs a deficit-ridden, effectively import-oriented economic policy while China has been able to force savings rates and investment to

[24]BEA, U.S. International Trade in Goods and Services, Exhibit 1, Feb. 5, 2016. Available at: https://www.census.gov/foreign-trade/Press-Release/2015pr/12/ft900.pdf.

[25]Federal Reserve Bank of St. Louis, Economic Research, Trade Weighted U.S. Dollar Index: Major Currencies. Available at: https://research.stlouisfed.org/fred2/series/DTWEXM (Updated September 5, 2016).

[26]World Bank Data, Household Final Consumption Expenditure (% of GDP), Table, Available at: http://data.worldbank.org/indicator/NE.CON.PETC.ZS (accessed May 14, 2015).

record levels and subsidize and grow exports. This contrast suggests policy differences not an inherent and inevitable manufacturing employment or sectoral decline in advanced economies. Germany's continuing strong manufacturing sector is the obvious counter example. Its manufacturing workers are much more highly paid than their U.S. equivalents, it employs 20% of its workforce in manufacturing[27] and runs a major manufacturing trade surplus, including with China.[28] It tells us a high-cost, high-wage production sector doesn't inevitably lose out to a low-cost one.

1.4 China's manufacturing rise

China, after a three decade effort, is now the largest manufacturing economy in the world; a MAPI study found its share grew by 2012 to 22.4% of world manufacturing activity, with the U.S. in second place with 17.4%.[29] China has four times the population of the U.S. although its manufacturing intensity of $1,856 per capita value-added in 2012 is high for a developing economy, it is well behind advanced countries such as the U.S. (at $6,280) — so its growth trend will likely continue over time. Chinese global exports in manufactured goods in the first half of 2016 of $935 billion were 68% larger than the $555 billion of U.S. exports; this is striking because in 2000, U.S. manufactured exports were three times larger than Chinese exports.[30]

[27] Federal Reserve Bank of St. Louis. Economic Research (FRED) (2010). Percent of Employment in Manufacturing in Germany, Available at: https://fred.stlouisfed.org/series/DEUPEFANA.

[28] Michael Hennigan (2015) *finfacts*, Germany's Record Trade Surplus in 2015, Feb. 10, 2016 (citing Statistisches Bundesamt, Wiesbaden 2015), Available at: http://www.finfacts.ie/Irish_finance_news/articleDetail.php?Germany-s-record-trade-surplus-in-2015-US-UK-France-in-deficit-520. Germany benefits from participating in the European-wide currency (Euro), which, in effect, subsidizes its exports.

[29] Manufacturers Association for Productivity and Investment (MAPI) (Dan Meckstroth, Chief Economist), China has a Dominant Share of World Manufacturing, MAPI paper, Jan. 2014, https://www.mapi.net/blog/2014/01/china-has-dominant-share-world-manufacturing.

[30] Ernie Preeg, (2016) Senior Advisory for Trade and Finance, MAPI, Farewell Report on U.S. Trade in Manufactures, August 15, 2016. Available at: https://www.mapi.net/forecasts-data/my-farewell-report-us-trade-manufactures.

What led to this rapid shift in a field the U.S. dominated for a century? Part of the story is deliberately neo-mercantilist policies to mandate technology shifts and to dominate markets by flooding them with below cost goods. There is an IP theft story, too.[31] But there is another less recognized factor we can no longer ignore. Most have assumed China's rise is predominately due to low production costs from cheap labor and cheap parts. There is also an assumption in the U.S. that manufacturing must naturally migrate to low cost producers and that the knowledge required for production processes is relatively trivial and readily replicable; neither is true. As Jonas Nahm and Edward Steinfeld argue, neither explains China's rise.[32] Instead, they find that China has undertaken a new link between process innovation and manufacturing.

They find that China's form of innovative manufacturing specializes in rapid scale-up and cost reduction. It has joined together previously unparalleled skills in simultaneous management of tempo, production volume, and cost, which enables production to scale up quickly and with major reductions in unit cost. This capability has allowed China to expand even in industries that are highly automated or not on governmental priority and support lists, despite limited labor cost advantage or government subsidies, respectively. So low labor costs and government subsidies and support are not sufficient to explain China's success in manufacturing.

China has developed production processes that were previously considered in developed nations fully mature and impervious to further cost reductions or technological improvements. The key to this ability to innovate new production processes has been the ability of Chinese firms to accumulate of firm-specific expertise in manufacturing

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[31] See generally, Carl J. Dahlman (2013). *The World Under Pressure; How China and India are Influencing the Global Economy and Environment.* (Stanford, CA.: Stanford University Press.)

[32] Jonas Nahm and Edward S. Steinfeld (2011) Scale-Up Nation: China's Specialization in Innovative Manufacturing, *World Development* 54, 288. See also, Daniel Breznitz and Michael Murphree, (2011) *Run of the Red Queen: Government, Innovation, Globalization and Economic Growth in China*. New Haven, CT: Yale University Press.

through extensive, multidirectional inter-firm learning, taking advantage of international knowhow from multinationals and building on it.[33]

1.5 Trade effects

How has this rise played out in the U.S. Economists long held that free trade gains always offset losses as trading partners played to their comparative advantage. Paul Samuelson moved toward a more realistic perspective in a noted 2004 article: while unemployment due to trade may eventually be made up, "the new labor-market clearing real wage has been lowered by this vision of dynamic fair trade" creating "new net harmful U.S. terms of trade."[34]

Economists David Autor, David Dorn and Gordon Hanson have been substantiating this picture.[35] They find that the trade relationship between the U.S. and China, formed in the 1990s and formally recognized in the 2001 WTO agreement, affected a large number of labor-intensive industries in the U.S., where significant numbers of those jobs shifted to China. Their study finds this shift came with a heavy cost to U.S. workers, where many blue-collar jobs particularly disappeared, with the communities where they worked also punished economically on a continuing basis. Their findings that adverse consequences of trade are so enduring — the U.S. hasn't yet been able to get past the shock of the loss of millions of jobs in numerous communities — is counter to traditional economic assumptions about the ultimate gains of trade. The net impact on workers in U.S. regions heavily affected by competition from China was particu-

[33] Nahm and Steinfeld, Scale-Up Nation.

[34] Paul A. Samuelson, "Where Ricardo and Mill Rebut and Confirm Arguments of Mainstream Economists Supporting Globalization," *Journal of Economic Perspectives*, 18(3) (Summer 2004), 135–137, 144–145. This work builds on his earlier Stolper–Samuelson theorem (where there are two goods and two factors of production (capital and labor), and specialization remains incomplete, one of the two factors — the one that is scarce — must end up worse off as a result of opening up to international trade, in in absolute terms; anticipates effect of globalization on developed nation income distribution). Wolfgang Stolper and Paul A. Samuelson, "Protection and Real Wages," *Review of Economic Studies*, 9(1941), 58–73.

[35] David Autor, David Dorn, and Gordon Hanson (January 2016). The China Shock: Learning from Labor Market Adjustment to Large Changes in Trade, NBER Working Paper No. 21906.

larly serious. The study examined the direct impact of Chinese industry on incomes in some 700 urban areas ("commuting zones") reviewed, comparing workers in heavily impacted areas (at the 75th percentile of exposure to Chinese competition) with workers in less affected areas (at the 25th percentile). They found a reduction in annual income of $549 per adult between the two, while per-capita income from offsetting federal assistance only rose by $58. The growth of trade with China, they find, has tended to make lower skilled workers worse off on a sustained, ongoing basis. There was no relatively "frictionless" economic adjustment to other industries; there was so much "friction" that middle class workers out of jobs still haven't recovered. Little offsetting growth was found in industries not affected by this "China shock." Instead, workers did not make up lost wages and their communities entered a slow, continuing decline.

As economics Nobelist A. Michael Spence has noted, "Globalization hurts some subgroups within some countries, including the advanced economies . . . The result is growing disparities in income and employment across the U.S. economy, with highly educated workers enjoying more opportunities and workers with less education facing declining employment prospects and stagnant incomes."[36] Just as manufacturing employment was a key to enabling less educated workers to enter the middle class after World War II, the loss of manufacturing jobs is correspondingly a key element in the decline in real income for a significant part of the American middle class in the past few decades. Obviously the 2008–2009 Great Recession, where manufacturing was a leading victim, played a role, but there appears no getting around the trade effects, which have been longer term.

But are these macro and trade factors don't appear to be a complete explanation for U.S. manufacturing decline — we must also look at what was happening at ground level — at the innovation level.

[36] A. Michael Spence (2011). "The Impact of Globalization on Income and Employment: The Downside of Integrating Markets," *Foreign Affairs* 90(4), July–August 28–41, Available at: https://www.foreignaffairs.com/articles/united-states/2011-06-02/globalization-and-unemployment.

1.6 The "innovate here/produce there" assumption

Since World War II, the U.S. economy has been organized around leading the world in technology advance. It developed a comparative advantage over other nations in innovation, and as a result, it led all but one of the significant innovation waves of the twentieth century, in aviation, electronics, space, computing, the internet, and biotech, although it had to play catch-up to Japan on quality manufacturing. Its operating assumption was that it would innovate and translate those innovations into products. By *innovating here/ producing here*, it would realize the "full spectrum" of economic gains from innovation at all the stages, from research and development, to demonstration and testbeds, to initial market creation, to production at scale, and to the follow-on life cycle of the product.[37] This "full spectrum" worked — the U.S. became the richest economy the world had ever seen. The U.S. for the past two-thirds of a century has been playing out economic growth theory — that the predominant factor in economic growth is technological and related innovation — and demonstrating that it works.

But in recent years, with the advent of a global economy, the "innovate here/produce here" model no longer holds. In some industrial sectors, firms can now sever R&D and design from production. Codeable IT-based specifications for goods that tie to software controlled production equipment have enabled this "distributed" manufacturing.[38] While manufacturing once had to be integrated and vertical, firms using the distributed model can *innovate here/produce there*. It appears this distributed model works well for many IT products, as well as for commodity products.[39] Apple is the standard-bearer for this model,

[37] This discussion draws on William B. Bonvillian (2012). Reinventing American Manufacturing — The Role of Innovation, *Innovations*, 7(3), 99–100. See also, William B. Bonvillian and Charles Weiss (2016), *Technological Innovation in Legacy Sectors*. New York: Oxford University Press, pp. 37–54, 87–95.

[38] Suzanne Berger (2005). *How We Compete: What Companies Around the World Are Doing to Make it in Today's Global Economy*. New York: Doubleday Currency, pp. 251–277.

[39] Gary Pisano and Willy Shih (2009). Restoring American Competitiveness, *Harvard Business Review*, July–August, 114–125, Available at: http://hbr.org/2009/07/restoring-american-competitiveness.

continuing to lead in dramatic IT innovations, but distributing virtually all its production to Asia.

However, there appear to be many sectors where the distributed model doesn't work well, that still require a close connection between research, design, and production. Capital goods, aerospace products, energy equipment, and complex pharmaceuticals appear to be examples of this phenomenon. In these sectors, production and R&D/design are the yin and yang of innovation. Here, the production infrastructure provides constant feedback to the R&D/design infrastructure. Product design and innovation is most efficient when tied to a close understanding and linkage to manufacturing processes. However, if R&D/design and production must be tightly linked, the innovation stages — R&D and design — may have to follow production offshore. "*Produce there/innovate there*" may be even more disruptive than "*Innovate here/produce there*." These twin developments bring the economic foundations of U.S. innovation-based economic success into question. It means that innovation investments won't lead to "full spectrum" economic gains. What good, taxpayers might ponder, is a world-leading innovation system if much of the gains flow elsewhere?

1.7 The innovation perspective

If the picture on the U.S. production side is problematic, what of the innovation side of the equation? The U.S. retains the world's strongest early stage innovation system in the face of growing competition. Any manufacturing strategy must seek leverage from this comparative innovation advantage. However, U.S. R&D in the past has had only a very limited focus on the advanced technologies and processes needed for production leadership. This is in sharp contrast to the approach to manufacturing R&D taken by Germany, Japan, Korea, Taiwan and now China, which have "manufacturing led" innovation.[40] The U.S. has simply not applied its innovation system to what turns out to be a crucial innovation stage, production, particularly initial production of complex, high value technologies. This stage involves highly creative en-

[40] Bonvillian and Weiss, *Legacy Sectors*, 25, 184–185.

gineering and design, and often entails rethinking the underlying science and invention — it is part of the innovation process not severed from it. So innovation is not just R&D distinct from production, innovation capacity includes the production stage. Missing this created a major gap in its innovation system.

While the major U.S.-based multinational manufacturing firms fund most of the nation's technology development stage and so have the capacity to keep up on the innovation front, the majority of the U.S. manufacturing sector belongs to the 250,000 small and mid-sized firms lacking this capacity. The base of small and mid-sized manufacturers represents 86% of U.S. manufacturing establishments, and employs more than half of its manufacturing workforce. It is largely outside the innovation system.

1.8 The reach of manufacturing into the American economy

Manufacturing remains a major sector of the U.S. economy: official statistics tell us manufacturing is approximately 12.1% of U.S. GDP contributing $2.09 trillion to our $17.3 trillion economy and employs 12.3 million in a total employed workforce of some 150 million.[41] Manufacturing workers are paid substantially more than service sector workers, 20% higher than nonmanufacturing.[42] Growth economists tell us that 60% or more of historic U.S. economic growth comes from technological and related innovation; as the dominant implementation stage for innovation, manufacturing is a critical element in the innovation system, although the U.S. hasn't understood it this way. Industrial firms employ 64% of our scientists and engineers, and this sector performs 70% of industrial R&D.[43] Thus our manufacturing strength and the strength

[41]BLS, Industries at a Glance, Manufacturing: NAICS 31–33, Workforce Statistics (July 2016), Available at: http://www.bls.gov/iag/tgs/iag31-33.htm.

[42]Susan Helper, Timothy Kruger and Howard Wial (2012). *Why Does Manufacturing Matter? Which Manufacturing Matters?*, Washington, DC: Brookings, pp. 4–5, https://www.brookings.edu/wp-content/uploads/2016/06/0222_manufacturing_helper_krueger_wial.pdf.

[43]Gregory Tassey (2010). Rationales and Mechanisms for Revitalizing U.S. Manufacturing and R&D Strategies, *Journal of Technology Transfer*, 35(3), 301, citing BEA and NSF data.

of our innovation system are directly linked.

Despite the decline in the manufacturing employment base, manufacturing remains a major workforce employment source for the economy, measured largely by workers at the production stage. But the official data is collected at the establishment level not firm levels. Should we limit the view of manufacturing to the production moment? Why is manufacturing measured at the factory? This arguably only provides a partial perspective on the role of this sector.

The manufacturing sector, instead, can be better viewed as an hourglass.[44] At the center, the narrow point of the hourglass, is the production moment. But manufacturing employment can't be looked as simply the production moment. Pouring into the production moment is a much larger employment base, which includes those working in resources, those employed by a wide range of suppliers and component makers, and the innovation work force, the very large percentage of scientists and engineers employed by industrial firms. Flowing out of the production moment is another host of jobs, those working in the distribution system, retail and sales, and on the life cycle of the product. The employment base at the top and bottom of the hourglass is far bigger than the production moment itself.

Arranged throughout the hourglass are lengthy and complex value chains of firms involved in the production of the goods — from resources to suppliers of components to innovation, through production, to distribution, retail and life cycle — a great array of skills and firms, and largely what we would count as services. But they are tied to manufacturing. If we removed the production element, the value chains of connected companies are snapped and face significant disruption. While the lower base of the hourglass, the output end, may be partially restored if a foreign good is substituted for a domestic good, the particular firms involved will be disrupted. The upper part of the hourglass, the input end, with its firms and their employees, doesn't get restored.

When these complex value chains are disrupted, it is very difficult to put them back together. That's why, historically, once the U.S. loses an economic sector, it is so hard to resurrect — it doesn't come back.

[44] Bonvillian, Reinventing American Manufacturing, 118–119.

We don't collect data in this "value chain" way on our industrial sector; the closest data we have is job multiplier data, which doesn't tell the full story. Understanding manufacturing in terms of the hourglass and the value chains within it may provide part of the explanation for the economy's current predicament over job loss, job creation, and declining median income.

A recent Manufacturers Alliance for Productivity and Innovation (MAPI) study developed new data perspectives to tell more of this value chain story[45]:

- The manufactured goods value chain plus manufacturing for other industries' supply chains accounts for about one-third of GDP and employment in the U.S.
- The domestic manufacturing value-added multiplier is 3.6, which is much higher than conventional calculations. For every dollar of domestic manufacturing value-added destined for manufactured goods for final demand, another $3.60 of value-added is generated elsewhere in the economy.
- For each full-time equivalent job in manufacturing dedicated to producing value for final demand, there are 3.4 full-time equivalent jobs created in nonmanufacturing industries; this job multiplier is far higher than in any other sector. Higher value-added production industries appear to have even higher multipliers.

The report's central finding is that the current estimates of manufacturing's share of the GDP are partial and seriously understated; when the full scope of the manufacturing footprint is examined, it could amount to around one-third of the U.S. economy, not one-tenth. The studies by Autor and colleagues noted above tend to bear out the widespread economic effects of its decline.

There is not only a macro-economic story in U.S. manufacturing but also an innovation system story. The failure of the U.S. innovation

[45] Manufacturers Alliance for Productivity and Innovation (MAPI) Foundation (Dan Meckstroth, Chief Economist), The Manufacturing Value Chain is Bigger than You Think (Washington, DC: MAPI Foundation report Feb. 16, 2016).

system to consider the production stage as an important element of that system is problematic enough when the scope and role of manufacturing is judged according to current estimates; if manufacturing is viewed through this larger value chain lens, the consequences really must be reckoned with.

1.9 Manufacturing and democracy

New work by Autor and coauthors tends to bear out the relationship of disruption in the manufacturing sector to disruption in the political system.[46] Analyzing Congressional elections between 2002 and 2010, they found that increased exposure of local labor markets to foreign competition, particularly from China, tended to push both political parties toward candidates at their ideological extremes, polarizing the political process. The Trump candidacy is an extension of this development.

The frustrated voters identified at the outset have now completely disrupted one of the nation's two major political parties. There may be potential long term consequences for the political system, which is indeed being pushed to its ideological edges. These voters appear stuck in their declining industrial communities strewn across the midwest, the northeast, and parts of the industrial south — where could they move, to do software in Silicon Valley, biotech in Boston? As a number of economists are grasping, their cities and towns have gone into failure mode. But they latched onto a new voice, a profoundly disturbing voice to many. The voice of confrontational messages dominated night after night of evening news. This working class was the historic base of Roosevelt's Democratic Party, they backed JFK, began to shift parties in the Reagan era, and they have now blown up the Republican party — the party of Main Street and Wall Street, of Lincoln and Taft, of country club and corner store, even of Rand Paul and the Kochs. It is now clear they are so sizable neither party can afford to ignore them — the parties must find a way to work through their issues that have been long ignored as if this community was invisible. It's not only elective politics;

[46] David Autor, David Dorn, Gordon Hanson, and Kaveh Majlesi, Importing Political Polarization? The Electoral Consequences of Rising Trade Exposure, paper, MIT economics website, April 25, 2016.

the ideological disruption of longstanding party doctrine is potentially powerful as well, because the parties had embraced or tolerated a series of economic views that cast these people out. Will the political system be flexible enough to accommodate these recent outcasts? What would such a policy accommodation look like? In particular, could the political parties rethink their stance on policies on manufacturing?

This is not the first time the parties have had to confront a manufacturing challenge. In the 1980s, as the realization dawned on industrialists and policymakers that Japan had launched a new kind of manufacturing system, heavily innovation-oriented around quality in production, the political system was forced to react. Japan's quality revolution was built on new precision in production technologies, tied to new production processes and new enabling business models. U.S. industry took a long time to understand and to try to catch up, and meanwhile the U.S. lost innovation leadership of two major sectors, auto and consumer electronics. As Kent Hughes has described, the political system was affected by anxiety and frustration, particularly in the region most disrupted by Japan's new quality manufacturing system, the industrial Midwest — the origin of the term "rustbelt." [47] There was a political outcry, comparable but not as pervasive as the current one.

The Republican Party response was around its traditional mantra of capital supply: Congressman Jack Kemp from Buffalo and Senator Bill Roth from Delaware proposed significant changes in marginal tax rates.[48] Traditional Democrats called for what was known at the time as "industrial policy."[49] Noting the industry interventionist policies of Japan's Ministry of International Trade and Industry (MITI),[50] they called for sustaining failing firms and sectors, and their employees, to enable a turnaround. Labor retraining, education, and assistance were part of the proposals, essentially a labor supply approach, a longstand-

[47]The story of the U.S. response to Japan's quality manufacturing paradigm is detailed in, Kent Hughes (2005). *Building the Next American Century — The Past and Future of American Economic Competitiveness*. Washington, DC: Wilson Center Press, drawn on here.

[48]Hughes, *Building the Next American Century*, pp. 60–61.

[49]Hughes, *Building the Next American Century,* pp. 45–49.

[50]Hughes, *Building the Next American Century*, pp. 50–51, pp. 74–77, 85.

ing Democratic mantra. It was classical economics all over again — each party locked in on one of the two major elements of classical economics' growth theory, capital supply and labor supply, solutions long imbedded in their political philosophies. But classical economics, as Robert Solow demonstrated, lacked a sound theory of economic growth.[51] Both parties, then, lacked workable growth policies. They had missed the advent of growth economics (often termed innovation economics), initially articulated by Solow, which found that technological and related innovation was the dominant causative factor in growth. Capital supply and labor supply remained significant factors, but were not close to the importance of technological innovation.

There were glimmers of this recognition within in the parties. President Ronald Regan named John Young, CEO of Hewlett Packard to lead a Commission on Industrial Competitiveness (the "Young Commission"), given the Japan challenge. Young's Commission argued for R&D growth and new public-private partnerships to accelerate technology advances.[52] Its 1984 recommendations were largely ignored by the Republican administration, but a number of the ideas were picked up in Congress' Omnibus Foreign Trade and Competitiveness Act of 1988.[53] A few "Atari Democrats," including Senators Gary Hart[54] and Al Gore,[55] began to focus on the importance to growth of "sunrise" industries, and this "future" perspective was adopted by the House Democratic caucus, which led to the 1988 Act and other legislation.[56] This included efforts to bring basic research closer to the market, and Sematech, the early

[51] Robert M. Solow (1987). *Growth Theory, An Exposition.* 2nd edn. New York, Oxford: Oxford University Press, pp. ix–xxvi (Nobel Prize Lecture, Dec. 8, 1987), Available at: http://nobelprize.org/nobel_prizes/economics/laureates/1987/solow-lecture.html/

[52] Hughes, *Building the Next American Century*, 153–168.

[53] Omnibus Foreign Trade and Competitiveness Act of 1988, P.L. 100–418, 19 U.S.C., sec. 2901, et seq.

[54] Hughes, *Building the Next American Century,* 137–141.

[55] Hughes, Building the Next American Century, 290. Gore led passage of the High Performance Computing Act, passed in 1991, P.L. 102–194, 105 Stat. 1594, 15 USC 5501, to support the emerging "information superhighway."

[56] See, Hughes, *Building the Next American Century*, 170–198. Technology legislation of the period is summarized in, William B. Bonvillian (2014). "The New Model Innovation Agencies: An Overview," *Science and Public Policy*, 42(4), 28–29.

model of a successful public–private collaboration on manufacturing innovation that brought significant advances to semiconductor equipment production to retain U.S. semiconductor technology leadership.[57]

However, the political need to respond with new manufacturing policies was swept away by the success of the innovation-induced information technology innovation wave.[58] The IT wave transformed the decade of the 1990s into one of the strongest growth spurts in recent U.S. history, with strong GDP and productivity gains. The lessons of the manufacturing challenge of the 1980's went largely unlearned.

As the IT boom moderated, as China offered a new manufacturing challenge, and as the Great Recession threw the economy and the manufacturing sector in particular into a nosedive, a new kind of social disruption accelerated, and the political system had to pay attention again. This time the administration in power pursued a manufacturing innovation agenda.

1.10 The response — advanced manufacturing

The Obama Administration promised in 2012 to deliver one million new manufacturing jobs by 2016; only half materialized by then. But they did make manufacturing innovation the centerpiece of their technology agenda, hoping to have 15 advanced manufacturing institutes in place or selected by the beginning of 2017. These are organized around advanced production technologies, promising dramatic production efficiencies to offset U.S. higher wage levels to restore manufacturing competitiveness. They aim to reconnect the innovation system to the production system, trying to rebuild a manufacturing ecosystem to better link small and large production firms and university engineering and science. It was a promising start, but more is mandated. The R&D system could do much more to focus on new manufacturing technologies and processes. Innovative startups that could manufacture high value goods either lack scaleup financing or are shifting production to contract manufacturers in places like Shenzhen. Could there be new technology and know-how

[57] Larry D. Browning and Judy C. Shetler, *Sematech: Saving the U.S. Semiconductor Industry.* College Station, Texas: Texas A&M Press 2000.

[58] Dale Jorgenson, (2001). U.S. Economic Growth in the Information Age, *Issues in Science and Technology.* Available at: http://www.issues.org/18.1/jorgenson.html.

rich spaces in the U.S. where they could test and launch pilot production here not there? These three developments — the new focus on manufacturing innovation, the development of manufacturing innovation institutes, and a new support system for manufacturing startups — amount to a major shift in U.S. technology policy. This new innovation focus can be termed Advanced Manufacturing. These developments are the subject of this work.

An innovation response is not the only step required; manufacturing is a complex system, there is no single silver bullet. The Obama Administration tried hard to increase college graduation rates, grow community college attendance and improve workforce training — more is needed, including new online and blended learning systems for training. New thinking on macro, fiscal, tax and trade policies and adjustments, and on longstanding economic assumptions, is still required. Trade-affected community assistance and job retraining must be rethought. The current political denouement tells us more will be needed from future Administrations. But there will be no going back to the GM plants of the 1950s; the next generation of manufacturing will look very different, organized around advanced technologies, and the jobs in the hourglass of manufacturing value chains, not simply at the factory, will be the real way of evaluating the sector's strength. None of these steps requires counter-productive industrial policy.[59] But innovation policy with public–private collaborations will need to be a centerpiece.

There are major policy implications here. The U.S. can continue to ignore the manufacturing sector and let it slide, but the consequences — to its innovation system, and therefore to economic growth, and therefore to social wellbeing — now appear significant. But there also appear to be consequences for its democracy and its inclusive ideals; it can continue to write off a working class community but this will pay dividends in social and political disruption and affect governance. The study below explores the innovation policy alternatives around the new effort toward Advanced Manufacturing.

[59]See, for example, Charles L. Schultze (Fall 1983). Industrial Policy: A Dissent, The Brookings Review, 2(1), 3–12, Available at: https://www.jstor.org/stable/20068627?seq=1#page_scan_tab_contents.