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Why Federal R&D Policy Needs to Prioritize Productivity to Drive Growth and Reduce the Debt-to-GDP Ratio

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The federal government should significantly increase spending on research and development that specifically targets technologies likely to boost productivity in order to spur growth and reduce the budget deficit.

KEY TAKEAWAYS

- Productivity growth is the key to increasing per-capita incomes and lowering the debt-to-GDP ratio.
- Technological innovation drives productivity growth, which is driven by spending on R&D. However, federal spending on R&D has fallen significantly as a share of GDP, and it is not explicitly focused on advancing technologies that drive productivity.
- Congress and the administration should significantly increase funding targeted to R&D that is focused on developing technologies that will boost productivity.
- Areas of research likely to drive future productivity include robotics, autonomous transportation systems, artificial intelligence, additive manufacturing, material sciences, microelectronics and advanced computing, and life sciences.

The greatest driver of economic progress since the dawn of the industrial revolution has been the development and adoption of technology, especially to either automate work or eliminate the need for it. This will remain just as true in the future. Today, the possibilities are near endless: robots, artificial intelligence (AI) systems, autonomous vehicles (AVs), and new materials are just a few technologies that promise to boost productivity. By expanding output, this process will lead to increased wages and better jobs. But developing and using technology to boost productivity growth rates will also play a key role in reducing the debt-to-GDP ratio, by increasing both gross domestic product (GDP) and tax revenues. But federal government spending on research and development (R&D) has fallen significantly as a share of GDP, and current R&D is not focused on advancing technologies that drive productivity. As such, Congress and the administration need to devote more direct and indirect funding to R&D that is focused on enabling technologies that will boost productivity. In short, it is time to add a new mission for federal R&D: boosting productivity.

Congress and the administration need to devote more funding to R&D focused on developing technologies that will boost productivity.

This report first describes the nature of the challenge of the national debt and the role of economic growth in reducing the debt-to-GDP ratio. It then describes productivity and how technological innovation drives productivity growth. It reviews the scholarly literature on the role of federal R&D in spurring productivity growth and why federal support for R&D corrects a number of serious market failures that otherwise would lead to economic underperformance. It then reviews a number of emerging technology areas, including robotics, AI, and new materials, which hold the promise of significantly boosting U.S. productivity growth.

Finally, it makes a number of policy recommendations related to federal support for productivity-enhancing research, including:

- Congress should expand the rate of the Alternative Simplified Credit for research from 14 percent to at least 25 percent.
- Congress should expand federal funding for R&D by $40 billion a year and target it to enhancing productivity.
- Congress should allocate a share of this additional funding to industry R&D consortia to support productivity-enhancing R&D, using the current Manufacturing USA Institutes as a model.
- Congress should direct the National Science Foundation (NSF) to establish a program whereby they award $1 million per year for five years to the top 200 or so academic researchers doing work in areas that would boost productivity, such as artificial intelligence and robotics.
- The White House Office of Science and Technology Policy (OSTP) should craft a national research roadmap for key productivity-enhancing technologies.
- OSTP should task all federal agencies that fund research with conducting an analysis of where their research investments can have the largest impact on productivity.

- Congress should require OSTP to establish multiagency, productivity-related R&D initiatives to identify not only key areas of R&D that have a significant potential impact on productivity, but also future areas of promise and areas where cross-agency coordination is needed.
- Congress should use this information to guide budget allocations, increasing funding for agencies that better demonstrate that their R&D efforts boost productivity.

If these increases in productivity-focused R&D boost productivity from the 1.4 percent growth projected by the Congressional Budget Office (CBO) to 3.4 percent a year (a rate similar to the one enjoyed in the 1960s when federal R&D was a much higher share of GDP than today), this rate would add $1.2 trillion per year in net federal revenues in 2039. It would reduce the projected annual deficit in 2039 from $2.6 trillion to $1.3 trillion. And it would reduce the projected debt-to-GDP ratio from 176 percent to 92 percent.

Finally, the report reviews and rejects seven possible issues and concerns with such a policy thrust, including (1) we cannot afford the investment; (2) it is government picking winners; (3) it will hurt the nation's basic science system; (4) eliminating tasks through productivity growth does not increase GDP; (5) there is nothing government can do to increase long-term growth rates; (6) growth is no longer possible; and (7) this will hurt workers and lead to higher levels of unemployment.

THE CHALLENGE OF THE NATIONAL DEBT

In 2018, CBO reported that the national budget deficit had reached $779 billion, with the national debt at $16 trillion. They now estimate the deficit will increase to $1.38 trillion by 2029, and the debt to $29.3 trillion. CBO estimates the debt-to-GDP ratio will increase from less than 40 percent in the first half of the 2000s to at least 95 percent by 2029, and potentially more if Congress changes some expiring policies.[1]

Eventually the debt-to-GDP ratio will have to stabilize. There are only a fixed number of options for how this plays out. The federal government could default on all or part of its debt, leading to significant economic problems. It could raise taxes or cut spending, but raising taxes can hurt growth and competitiveness, while cutting spending, especially entitlements, can impose real hardships on people. It could print more money to pay off debtors, but that would reduce real incomes, as would a tax increase. Moreover, absent a pending debt crisis, there is little evidence American voters, or hence elected officials, want to do any of this.

Boosting productivity growth leads to higher GDP and increases in per capita incomes, and thus living standards.

This leaves growth. GDP can grow in two ways: more hours worked or higher productivity (i.e., greater output per hour of work). We could increase hours worked by liberalizing immigration or raising the retirement age. Both would raise GDP, but would do less to raise per-capita GDP than working to directly boost productivity.[2] In contrast, boosting productivity growth leads to higher GDP and increases in per capita incomes, and thus living standards.

ECONOMIC GROWTH CAN REDUCE THE DEBT-TO-GDP RATIO

Gaining control over the nation's debt without an increase in economic growth and its resultant tax revenues would be extremely difficult, if not impossible, particularly given the political difficulties of limiting entitlement spending, especially for the elderly, or raising taxes in a significant enough way in order to make a real difference.

However, most economists point to the debt-to-GDP ratio, not the actual amount of debt, as the key challenge. Growth reduces the debt-to-GDP ratio by raising the denominator (growth) but also reduces the budget deficit because increased output results in increased tax revenues, all else equal.

If labor productivity growth continues at the rate of 1.4 percent (the CBO estimate for the next decade), GDP will grow to $30.8 trillion by 2049, assuming there is no corresponding growth in work hours (see figure 1). However, if the U.S. economy could achieve 3.4 percent productivity growth per year (a rate enjoyed for much of the 1960s), GDP would increase to $40.4 trillion by 2039 and $56.5 trillion by 2049. This added growth would generate an additional $2.4 trillion per year in federal revenues in 2039 from increased worker incomes, business profits, and other forms of national income.[3] It would reduce the projected deficit from $2.6 trillion to $235 billion, and the projected debt-to-GDP ratio from 170 percent to 65 percent.[4]

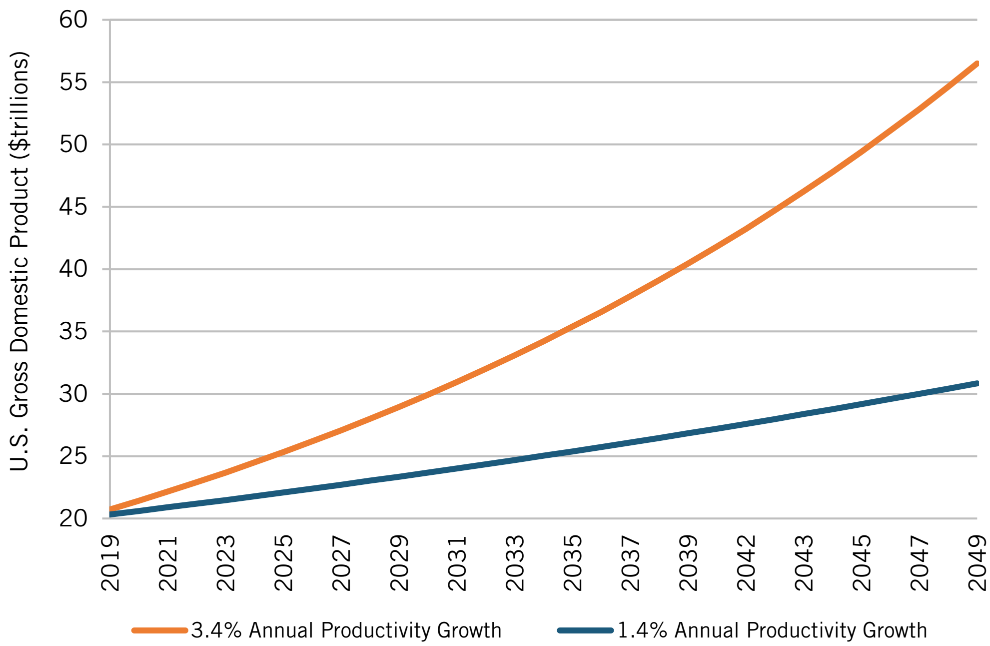
However, according to CBO models, increases in productivity lead to increased spending in mandatory outlays (largely because of the way Social Security increases are indexed to wages) and increased interest rates on federal debt. CBO assumes these two effects offset approximately 28 percent of the increase in federal revenues.[5] It should be noted that these offsetting effects are transfer payments—retirees earn more, as do holders of federal debt. In addition, if productivity growth were to increase, Congress could index Social Security and other wage-related entitlements in a way that reduces increases in outlays.

However, while the report offsets federal revenues by 28 percent, it is important to note that CBO's modeling assumption is debatable, in part because economic theory would suggest that interest rates would fall to their original levels after a certain period because higher productivity leads to increased savings that offset higher demand for capital. CBO assumes that higher productivity increases demand for capital investment but appears not to model the increase in savings that would result from higher productivity. In fact, while higher productivity increases the demand for money, it also increases the supply. A study by the Federal Reserve Bank of Cleveland found that between 1914 and 2016, low productivity was associated with higher interest rates, not lower.[6] More recently, the correlation between labor productivity growth and 10-year federal government bond yields from 1960 to 2018 were actually negative (-0.11 in the same year; -0.13 with bond rates lagged one year, and -0.18 with bond rates lagged two years), suggesting that, if anything, increased productivity reduces interest rates.[7]

Nevertheless, using the CBO adjustments, a 3.4 percent productivity growth rate would add additional net federal revenue of $1.7 trillion per year in 2039. It would reduce the projected deficit from $2.6 trillion to $898 billion, and the projected debt-to-GDP ratio from 157 percent to 79 percent. To be conservative, this paper uses a model wherein it takes five years before the effects of higher R&D are translated into higher productivity, in which case a 3.4 percent productivity growth rate would mean the GDP in 2039 would be $9.7 trillion higher than the base case. This would add an additional net federal revenue of $1.2 trillion per year in 2039 (using the CBO adjustment factor). It would reduce the projected deficit by half, from $2.6 trillion to $1.3 trillion, and the projected debt-to-GDP ratio from 176 percent to 92 percent.

Finding ways to raise the rate of productivity is all the more important because the U.S. economy is in a dangerous productivity slump. Labor productivity—a key measure of economic growth that tallies all the goods and services the country produces per hour of work—has been inching up at an anemic rate of just 1.2 percent per year since 2008. That's half the rate of the prior 13 years. This is the principal reason why wages and GDP growth have stagnated. While there is some debate about whether the productivity slowdown is real or reflects mismeasurement, there is considerable research to suggest the slowdown is not a measurement artifact.[8]

Figure 1: U.S. Economic Growth from Different Productivity Rates



WHAT IS PRODUCTIVITY?

To understand productivity, it is worth noting what it is not. Productivity is not a measure of how much an economy is producing. In other words, total output (GDP) is not a measure of productivity. Nor is productivity a measure of how many hours people work. Rather, in its simplest form, productivity is a measure of economic output per unit of input (i.e., it is an efficiency measure). The unit of input can be labor hours (labor productivity) or all production factors, including labor, machines, and energy (total-factor productivity). The former is the easiest to understand: If a barber previously cut 10 people's hair in 8 hours, but now cuts 12 people's hair in the same amount of time because of better technology (e.g., more efficient clippers), then the barber has increased their productivity by 20 percent.

Productivity can increase in a number of ways. One is for workers to work harder and faster. But this comes at the cost of worker satisfaction and, in some cases, safety, so gains are offset by "losses." But there are two better ways to raise productivity. The first is to help workers work more efficiently by reorganizing work processes and providing better tools or using better technology or business models to eliminate the need for some work. For example, automatic elevators obviated the need for elevator operators.[9] The second is to use technology to reduce the need for output. For example, take the roofing industry. Productivity could be increased by developing better technologies that help roofers install shingles more quickly. But it could also be increased by developing longer-lasting shingles. In this case, it might take the same amount of time to shingle a given roof, but the number of times that roof would need to be reshingled over the lifetime of the building would go down. Similarly, AVs will boost the productivity of taxi driving and truck driving. But the biggest productivity impact will be on reducing the need for work—in this case reducing the need for auto body repair workers or medical personal because of fewer accidents. This means the focus on any productivity agenda should not be on firms, but on output. How can society produce the same amount of value (i.e., quality-adjusted output) with fewer inputs? In other words, how can society increase total factor productivity?

Productivity is often confused with innovation and competitiveness.[10] As noted, productivity is the ratio of output to input, while innovation means developing an improved product (a good or service), production process, marketing method, or organizational method. The distinction between "product" and "process" innovation is important because product innovation usually affects the output side of productivity while process innovation affects the input side. Competitiveness relates to the economic health of a region's or nation's traded sectors, the output of which can be purchased by consumers outside the region or nation.[11]

To be sure, the three factors are related. For example, more innovation can support productivity and competitiveness. Faster computer chips boost the productivity of companies using machines with chips in them and also help semiconductor companies be more globally competitive. Likewise, productivity growth, especially in traded industries such as automobiles, can make economies more competitive be enabling companies to sell in global markets at lower prices. But each of the three is quite distinct in important ways. For example, rising productivity in a country's non-traded sectors would do little to improve the competitiveness of its traded sectors. In most nations, policymakers prioritize competitiveness first, innovation second, and productivity last, if at all. But for most economies, especially large and mid-sized ones, productivity is the most important driver of economic well-being. This is not only because the majority of jobs in most economies are in non-traded sectors wherein the benefits of productivity gains go directly to workers and domestic consumers, but most productivity gains come not from particular globally traded industries getting larger, but by all industries boosting productivity. This is true because in most economies the lowest-productivity industries are large, mostly non-traded sectors such as retail, health care, and personal services. And even within the manufacturing sector, historically a strong contributor to productivity growth, less-traded industries such as food manufacturing are productivity laggards.

Finally, there are two related measures of productivity: labor productivity and total factor productivity. Labor productivity is as it sounds: the output of workers divided by the number of hours of work. Total factor productivity is broader, and a measure of the productivity of all factors of production, including workers, energy, and machines. An economy might increase labor productivity by adding more machines, but total factor productivity could go up or down depending on whether the machines' output is worth their cost.

HOW TECHNOLOGICAL INNOVATION DRIVES PRODUCTIVITY GROWTH

Faster productivity growth is essential to not only boosting U.S. living standards, but also reducing the debt-to-GDP ratio. But how does productivity grow?

Productivity can grow in two ways: the growth effect (when most industries increase their productivity) and the share effect (when more-productive industries gain share at the expense of less-productive ones). The growth effect is by far the most important driver of productivity. For the United States, the Organization for Economic Cooperation and Development (OECD) found that the growth effect accounted for over 90 percent of U.S. productivity growth from 2000 to 2011.[12] Moreover, for a large economy such as that of the United States, with a relatively modest share of the economy traded globally (around 35 percent), large shifts in traded-sector output, as different traded sectors lose or gain share based on global competitiveness, is less likely. Over time, however, changes in consumer purchasing can affect productivity. For example, increased consumption of education and health care has lowered productivity growth as both sectors have experienced lower productivity than such sectors as manufacturing and agriculture.

Many studies that attempt to account for the various sources of growth in productivity and per capita income have found that technological change plays the key role.

How does productivity within industries grow? One way is through scale economies. For example, as retail firms have gotten bigger, sector productivity has increased because large retailers can take advantage of economies of scale to be more productive. Leaving aside the fact that many of these scale economies are enabled by technological innovation (e.g., e-commerce, software-enabled inventory systems, etc.), there are limits to increases in scale economies, particularly in the United States, which for many industries has already taken advantage of most of them.

Another way productivity grows is through the use of more "tools," or what economists call "capital intensity." It might be more productive for a farm to use two tractors rather than one, for example. But adding more of the same kind of capital leads to diminishing returns: The first tractor might have big impacts on productivity, but the third or fourth would have fewer. This is why, historically, most studies attempting to account for the sources of productivity growth have found that capital intensity plays only a modest role. According to University of California, Berkeley economist Brad Delong, "Growth accounting studies have found that capital deepening is responsible for only a small part of advances in labor productivity."[13] And in his landmark 1956 study, Robert Solow found that only 19 percent of long-run change in labor productivity was due to increased capital intensity; the remainder was due to what he called "technical change."[14] To use the tractor example, technical change would entail switching from a human-driven mechanical tractor to an autonomous one.

Many studies that attempt to account for the various sources of growth in productivity and per capita income have found that technological change (i.e., innovation) plays the key role. The 1996 Department of Commerce report, "Technology in the National Interest," estimated that about 80 percent of total factor productivity growth stemmed from technological innovation.[15] As Mohen and Hall wrote, "We can conclude from this brief survey of the empirical literature on innovation and productivity that innovation leads to a better productivity performance, or to be more precise to a better revenue per employee performance."[16] Klenow and Rodriguez-Clare decomposed the cross-country differences in income per worker into shares that could be attributed to physical capital, human capital, and total factor productivity.[17] They found that more than 90 percent of the variation in the growth of income per worker was the result of how effectively capital is used, with differences in the actual amount of human and financial capital accounting for just 9 percent.[18] Not all studies have found such a large share, but almost all have found that innovation and how capital is used is the main driver, with the expansion of existing capital accounting for a much smaller share.[19] In short, as economist Paul Romer wrote, "Our knowledge of economic history, of what production looked like 100 years ago, and of current events convinces us beyond any doubt that discovery, invention, and innovation are of overwhelming importance in economic growth… We could produce statistical evidence suggesting that all growth came from capital accumulation with no room for anything called technological change but we would not believe it."[20] In other words, as Aghion and Howitt wrote, "In the long run all of the growth in output per worker is caused by technological progress."[21]

The principal source of technological progress is R&D. Zvi Griliches's seminal empirical work on identifying the effect of R&D on productivity found a significant positive relationship between R&D and productivity.[22] A review of economic studies finds that when firms increase R&D investment by 1 percent, their productivity increases by 0.05 to 0.25 percent, or the equivalent to a 20 to 30 percent return on investment.[23] Kancs and Siliverstovs showed that R&D increases firm productivity with an average elasticity of 0.15.[24] An earlier review by CBO found smaller estimates with an elasticity of between 10 and 20 percent for firms and industries, with the rate of return for firms between 20 and 30 percent.[25]

However, firms and even industries are unable to capture all the benefits of their own R&D. As such, economy-wide impacts will be higher than firm and even industry impacts. Credible estimates indicate that a 1 percent increase in the R&D stock results in a 0.06 percent to 0.61 percent corresponding increase in economic productivity.[26] A credible middle-ground estimate from a study of G7 economies by David Coe and Elhanan Helpman found a productivity impact of 0.23 percent.[27] What this number indicates is that if the R&D capital stock increases by 1 percent, it causes GDP to increase by 0.23 percent.

There are several limitations to these and other related studies. First, they do not differentiate between types of R&D (e.g., basic, applied, development), areas of investment (e.g., process vs. product), or technical areas (e.g., electronics, chemicals, etc.) to determine whether particular types of R&D are likely to have larger effects on productivity. Also, many of the studies that look at the impacts of a firm's R&D on its productivity are looking too narrowly. For firms that are producing better "tools" and materials, most of the productivity effect of their R&D will be on other firms and organizations. For example, of the $12.7 billion Intel spent on R&D in 2016, the lion's share of the impact went to organizations around the world that were able to use electronic devices with superior performance.[28] Finally, scholars in the Schumpeterian tradition have argued that innovation and growth go through long cycles (of approximately 50 years) and that R&D in early phases of the technology cycle (when the technology is still not cheap enough or good enough to drive widespread, economy-wide innovation) has a larger impact on productivity than R&D performed in the later stages of the innovation cycle, when the technology is more mature and improvements are more incremental.[29]

THE ROLE OF FEDERAL R&D IN INNOVATION-BASED PRODUCTIVITY GROWTH

In the United States, businesses pay for about two-thirds of R&D. But the federal government supports R&D in two main ways: tax incentives and direct spending. The research and development tax credit (officially termed the "research and experimentation tax credit") provides companies with a tax credit (of 14 or 20 percent) on some of their investment in R&D. The scholarly literature is clear that the U.S. R&D credit spurs additional research, with most estimates in the range of an additional $1.30 to $2.00 for every $1 of credit.[30]

The federal government also invests money in R&D, some of which it performs itself and some of which is done by higher education or business. In 2015, the federal government invested approximately $121 billion in R&D. Historically, federal research funding has had differential impacts on productivity. Funding by the Department of Defense (DOD) to develop the Internet obviously had massive productivity impacts. Funding from NSF to understand black holes has had much less, if any, impact.

Publicly funded research has had an important effect on innovation and growth.

This is one reason skeptics of federal support for research have argued that it has minimal impact on productivity. For example, in an op-ed arguing basic science has little effect on innovation, Matt Ridley cited a U.S. Bureau of Labor Statistics (BLS) article as proof the return on investment from publicly financed R&D is near zero.[31] But what the BLS article was actually measuring was the impact of that R&D on the productivity of government agencies, which is in fact low.[32] After all, when the National Institutes of Health (NIH) funds research to treat diabetes or cancer, the results do very little to make NIH workers more productive. But the BLS article concluded that "many advances arising from university or government research eventually have an important indirect effect on growth," and that "programs, especially those in which university scientists compete for grants, such as the National Science Foundation, the National Institutes of Health, some Department of Agriculture programs, and DARPA [Defense Advanced Research Projects Agency] in the Department of Defense, appear to have a remarkable record."[33]

Other studies, including a review paper from OECD, have found that publicly funded research has had an important effect on innovation and growth.[34] For example, Griliches concluded that federal R&D in industry had a positive effect on productivity, though less of an impact than privately financed research.[35] Likewise, Guellec and van Pottelsberghe de la Potterie found that government research expenditures, in addition to private R&D, contribute to the rate of economic growth.[36] Another study of the U.K. economy found evidence of spillovers of private R&D and public R&D, with an estimated rate of return to public R&D of 20 percent.[37] To be clear, some federal R&D likely has little effect on productivity. But the real question is whether some areas of federal R&D expenditures have significant impacts on productivity, and the logic and evidence suggest the answer is yes.

WHY FEDERAL R&D INVESTMENT CORRECTS FOR MARKET FAILURES

Some argue that increases in federal spending on scientific and engineering research are not needed because the private sector can be relied on to adequately invest and drive innovation. There are two reasons why this is not correct. The first relates to spillovers from business-funded research wherein businesses invest less than what are societally optimal levels because they cannot capture all of the returns. This is a key rationale for policies such as the R&D tax credit. The second relates to the fact that government research often "crowds in" business research, leading firms to invest more than they would otherwise, thus increasing productivity and economic welfare.

Spillovers

When companies invest in R&D to develop a product or a production process, they can almost never retain all the benefits of that research, even if they patent the discovery. Competitors and others learn about and then capitalize on their research and discoveries. In other cases, the benefits to society are much greater than the revenues the firms are able to charge. These external benefits to producers and consumers are called spillovers.

To maximize societal welfare, firms should continue to expand investments in R&D until the marginal total benefits (the benefits to the firm, to other firms, and to society at large) falls to the cost of capital. But because firms rightly do not take into account external benefits, firms underinvest in R&D (from a societal perspective).

Economists have long attempted to measure the extent of spillovers from business R&D. As Griliches wrote: "There has been a significant number of reasonably well done studies all pointing in the same direction: R&D spillovers are present, their magnitude may be quite large, and social rates of return remain significantly above private rates. … The estimated social rates of return look, actually, surprisingly uniform in their indication of the importance of such spillovers."[38] A 1998 study by Jones and Williams computed the social rate of return from R&D and concluded that the optimal level was at least two to four times actual investment.[39] The fact that some economists estimate a 7 percent private return and 30 percent social rate of return on R&D suggests the optimal level of R&D investment in the U.S. economy is between three to four times larger than the total current level of private investment.[40] The overall social return from investment in information technology generally is over 80 percent.[41] When companies do basic research, the spillovers are even greater—as high as 150 percent.[42] Okubo and colleagues examined many different studies and concluded that the private return is 26 percent and the social return 66 percent.[43] Most recently Bloom and Van Reenen examined the change in the rate of R&D spillovers; in other words the differential rate between private and social returns from R&D. The authors found that spillovers actually increased over the last 40 years, with the ratio of social to private returns increasing from a factor of three to four. As they wrote, "There is certainly no evidence that the need to subsidize R&D has diminished."[44] This underinvestment means, absent policies to raise the after-tax rate of private return from R&D closer to the rate of the public return (either through R&D tax incentives, direct funding of business R&D, or even support for government and university research that businesses can use), economic growth will be reduced, and the new innovations that will improve our lives will come about more slowly.

Crowding In

Both private and public R&D can spur productivity growth. However, some free-market advocates argue that government R&D is not needed because the private sector is sufficient, and that in some cases public R&D substitutes for or "crowds out" private R&D. Regarding the first point—that there will be enough private sector investment without public R&D—the research previously described regarding spillovers clearly refutes this view.

With regard to crowding out, the scholarly evidence actually finds the opposite to be true: Public R&D "crowds in" private R&D, with increases in public R&D on average leading to greater, not less, business R&D. In other words, the more the government invests in R&D, the more businesses invest in R&D (all other factors constant). As an OECD study found, "Direct government funding of R&D performed by firms (either grants or procurement) has a positive effect on business financed R&D (one dollar given to firms results in 1.70 dollars of research on average)."[45] And an additional $1 of public contract research added to the stock of government R&D has the effect of inducing an additional $0.27 of private R&D investment.[46] Most other studies of the issue have found similar results, with the effect differing from around $0.10 to $0.30 of additional R&D for every $1 of government funding for university or government laboratory research.[47] What is more, research has shown there is a strong positive correlation between private R&D investment in a year, and public R&D spending in the year prior to that.[48] For the life-sciences industry, $1 of NIH support for research leads to an increase in private medical research of $0.32.[49] One survey of over 60 academic articles on whether public sector R&D crowds out private sector investments concluded, "There are a number of econometric studies that, while imperfect and undoubtedly subject to improvement and revision, between them make a quite convincing case for a high rate of return to public science in this [life science] industry. It is worth noting that there are, so far as we are aware, no systematic quantitative studies that have found a negative impact of public science."[50]

Public R&D "crowds in" private R&D, with increases in public R&D on average leading to greater, not less business R&D.

The reasoning behind the complementarity between private and public R&D is two-fold. First, public R&D investment corrects the market failure of private markets underinvesting in R&D (because businesses cannot capture the social benefits of R&D). Public R&D dollars expand the knowledge base, which businesses then invest further R&D into in order to turn research into innovative commercial products. Public support for a promising line of research helps convince firms to boost their own efforts in these areas. Advances in science and engineering make private development efforts more productive. Second, businesses that receive federal R&D funding are able to attract and expand private R&D investments. This stems from federal R&D grants having a strict evaluation process, which serves as a good indicator of the company's potential to private investors. For example, economist Sabrina Howell found that companies that receive a Small Business Innovation Research award doubled their chances of receiving venture capital in the future.[51]

How to Boost Productivity Through R&D

To make scientific and engineering research a stronger tool for driving productivity growth, the federal government needs to do two main things. The first is to spur an increase in government and business R&D. The second is to better allocate that R&D to areas most likely to spur productivity growth. This will require recognizing productivity-related innovation as a key national mission that deserves support from government the same way defense, health, and energy do. And it will require recognizing that the allocation of that funding cannot be determined solely on the basis of the interests of individual scientists, but rather should be based more on societal interests, as determined by government.

U.S. R&D funding is organized along two key areas. The first is mission-oriented. Congress provides R&D funding to agencies such as DOD, NASA, Department of Energy (DOE), and NIH to help accomplish national missions (defense, space exploration, energy, health, etc.). The second is related to advancing science, funded in part through DOE's Office of Science and NSF. (While NIH funds largely basic research, it is in the service of accomplishing the mission of improving health care outcomes.) There is, however, no dedicated allocation of funds for research to support innovations that would boost productivity, either by cutting costs or reducing the need for output. To the extent federal research funding generates innovation that boosts productivity, it is largely by happenstance. Research-funding agencies do not prioritize funding by productivity impact. In fact, they do not measure the impact on productivity, largely ignoring productivity altogether.

Moreover, the dialogue regarding federal science and technology policy has long been shaped by a belief in the linear model of innovation, which focuses on process with the view that if government gets the process right, good things will happen. In other words, by ensuring adequate peer review, effective technology transfer, and the right allocation between institutions, innovation and societal welfare will be maximized. Under this model, scientists largely determine funding choices, and any effort by society to choose priorities risks leading to bad science and suboptimal results. Yet, science-policy scholars have long found that the linear model does not accurately describe the innovation process.[52]

If we are to better boost productivity through research, the federal government needs to allocate the next marginal dollar on areas that have the biggest impact on economic growth.

The science community has long argued for more federal funding but has generally not supported prioritization, in part believing that if it sticks together and supports all fields that the overall pie will grow more and everyone will be better off. In other words, the science community provides little insight into how to allocate the federal research budget, especially the share going to non-mission-oriented research. As Michael Holland has written, "[The science community] make[s] no recommendation for setting long-term priorities, only that research should be a priority over other spending needs."[53] For them, the only prioritization should be between individual proposals from principal investigators based on merit, with the broad sense that all disciplines should see similar increases. However, as Holland rightly notes, there should be prioritization with relatively less funding going to areas with little direct societal impact: "The final claim on federal R&D funds should [be] discovery-oriented science. These are fields such as particle physics, cosmology, manned space flight or fusion, where the scientific or technical relevance of the program itself to current concerns are weak at best or non-existent."[54]

Of course, the response to the argument that society, through its elected representatives, should have an increased say in the allocation of research funding is that any area can lead to serendipitous discoveries. But as Holland pointed out, "Every federal research program has its favorite example of serendipitous outcome that privileges curiosity-driven discovery over strategic direction." [55] One would in fact be surprised if this spending did not have any practical outcomes.

If we are to better boost productivity through research, the federal government needs to allocate the next marginal dollar on areas that have the biggest impact on economic growth. The first step in that process would be to recognize that some federally supported research is much more likely than others to impact growth. As Fraumeni and Okuboo wrote, "The opinions of different authors regarding the share of fundamental research which could be considered to have commercial efficiency and as a consequence be included in the category of investments, ranges from a quarter to two-thirds."[56]

There are various frameworks by which such a prioritization could be targeted. One could be competitiveness. The notion would be that supporting advanced technology development would help U.S. firms gain global market share, and thereby help grow the U.S. economy. This is essentially what the Chinese government has done with its Made in China 2025 plan. While increased U.S. competitiveness is important, it is not the most important factor driving U.S. productivity growth (which is central to addressing the U.S. national debt challenge). Research shows that a nation's industrial mix (i.e., its competitiveness) is responsible for only a modest share (10 to 20 percent) of its productivity growth.[57] Rather, to maximize productivity, federal R&D should be focused on innovations that are likely to play an important role in boosting productivity. This can be achieved through innovations that make work more efficient (e.g., a more efficient roofer) or reduce the need for work (e.g., long-lasting roofing shingles). However, there is an overlap between many productivity technologies and competitiveness. For example, quantum computing and AVs will boost productivity while helping U.S. firms gain global market share.

KEY TECHNOLOGY AREAS TO DRIVE PRODUCTIVITY GROWTH

What are the types of research areas most likely to drive future productivity? Holders of the linear research model say there is no way to know. For them, research on black holes may hold the key for some breakthrough discovery that will power productivity. Who knows? It might. But to say society is not capable of identifying areas where the odds of greater productivity impact are higher than others is not true. The private sector does it every day. In general, there are several areas that hold promise, including materials for longer-lasting goods, health discoveries that reduce the cost of treatments, and technologies that either make workers more productive or eliminate the need for human labor completely.

It is striking just how little has been written about this question. There are few if any studies that attempt to identify the most important scientific, engineering, and technical areas in terms of their likely impact on productivity. Nonetheless, we can make some informed estimates as to which areas are likely to hold the most promise.

Robotics: Perhaps the most important technology is robotics. Improving productivity in many functions and industries that involve moving or transforming physical things (including humans) will depend on much better and cheaper robotic technology. To be sure, robots are already driving productivity. But we have barely scratched the surface of their potential because of limitations in functionality and costs. There is no reason why robots could not pick up litter or clean streets and parks. They could prepare and deliver food in restaurants, provide room service in hotels, or clean buildings. Robots could operate forklifts in warehouses, stock shelves in stores, lay bricks, dig trenches, and much more. They could pick vegetables, fruit, and other crops that now require manual labor. They could reduce the cost of caring for the elderly, both at home and in assisted-living facilities.[58] And, obviously, they can improve mining and manufacturing productivity, particularly of assembly functions. The myriad possibilities justify a very significant increase in funding for robotics research. Yet, NSF's National Robotics Initiative provides funding of between only $30 million to $50 million per year, much of which is quite basic in nature—as opposed to more applied and problem-solving research that would lead to innovations in robotics in the near future.[59]

Autonomous transportation systems: A related technology is autonomous systems, which are machines that can act without the guidance or control of human beings. Perhaps the most important autonomous system is AVs. ITIF estimates that if the United States' vehicle fleet were almost completely autonomous, there would be a savings of $1 trillion annually, in large part from the reduction in accidents resulting in the need for fewer workers repairing car bodies and attending to injured travelers, and to a lesser extent from the increase in automation in trucking and taxis.[60] The potential for autonomous systems extends to waterway shipping, bus travel, freight rail, forklifts, mining vehicles, and others.[61] Autonomous systems can deliver pizza, with drones delivering packages and even mail. While the private sector will do much of the development work, government can and should provide funding for earlier-stage research on autonomous technology, across a range of transportation modes.

Artificial intelligence: Improved AI will be critical to future productivity improvements, especially in knowledge-based work. AI could replace at least some of the work personal assistants now do (e.g., scheduling) and automate a range of other tasks (e.g., insurance underwriting). AI also holds promise for such tasks as language translation, financial advice, preventing machine breakdowns, improving industrial design, and maximizing oil-well performance.[62] AI will play a key enabling role in robotics, such as to pick crops. While private sector companies such as Google, Facebook, and Microsoft are funding AI research, there is a need for government funding of more longer-term, higher-risk research.[63] As a 2016 White House National Science and Technology Council report argued, "[S]ome important areas of [AI] research are unlikely to receive sufficient investment by industry, as they are subject to the typical underinvestment problem surrounding public goods."[64] In fact, NSF and DARPA funding for AI has declined from 2007 to 2017.[65]

Additive manufacturing: Additive manufacturing, or 3D printing, holds the potential to build an array of physical objects from the ground up by printing them. Clearly, additive manufacturing will play a more important role in making discrete objects.[66] But there will also be other applications that boost productivity. Stores might be able to eliminate certain inventory and shipping by printing objects on demand. Eventually, houses and other similar buildings will be 3D printed, at a significantly lower cost than hand-built buildings.[67] But research is still needed to improve process controls, tolerances, finishes, and the range of materials able to be used.[68]

There are few if any studies that attempt to identify the most important scientific, engineering, and technical areas in terms of their likely impact on productivity.

Material sciences: Improved design and manipulation of materials on all levels, including the molecular, is very promising for productivity improvements. While scientists are still discovering how to use the building blocks of atoms, they have already established that small changes in molecular structure can have big changes in performance. New materials hold great promise. If scientific research could develop paint that lasted not 10 or 20 years, but 50 or 100 years, painters' productivity would stay the same, but the labor society needs to allocate to painting buildings would fall dramatically. The same is true for materials such as road surfaces and roofing shingles that wear out. For example, rust has been estimated to cost the U.S. economy $400 billion per year.[69] Innovations that enabled significantly slower metal corrosion would boost productivity. Likewise, self-healing concrete could save billions of dollars in road-repair costs.[70] Much of this innovation will come from advances in nanotechnology, including nanomaterials such as graphene. In addition, innovations in meta-materials hold great promise.[71] These are custom-made materials that do not exist in nature and that have unique properties.[72] For example, these materials could be used to turn window glass into solar panels that generate electricity more cheaply than from conventional fossil fuel generation.

Microelectronics and advanced computing: Innovations in these areas will be critical in powering many of the related innovations discussed here. Faster computing and cheaper storage in particular will be important. High-performance computing (HPC) entails the use of "supercomputers" and massively parallel processing techniques to solve complex computational problems through computer modeling, simulation, and data analysis.[73] HPC systems can help rapidly solve difficult computational problems across a diverse range of scientific, engineering, and industrial fields. It will find extensive application in bolstering the innovation capacity of U.S. manufacturing industries, including aerospace, automotive, and consumer packaged goods, thereby helping them accelerate innovation cycles, reduce development costs, and speed time to market for innovative new products. Quantum computing represents a next-generation computing architecture that leverages principles from quantum physics, notably the unique behaviors of subatomic particles such as electrons and photons, to enable the development of computers with processing speeds potentially tens of thousands of time faster than today's fastest supercomputers. Moreover, because quantum computers will leverage quantum principles such as superposition and entanglement, they will not only be faster, but be able to tackle problems too complex for conventional supercomputers to solve at all—problems that require stretching beyond the realm of binary calculations into the realm of quantum physics, where the variable relationships between elements are immense. Quantum computing is already finding industrial applications and will have enormous implications in determining which countries' industries will lead tomorrow in sectors including manufacturing, life sciences, clean energy, finance, AI, and defense. Focusing R&D on more-advanced computing architectures such as HPC and quantum computing can deliver more-powerful computing systems that can better power machines to boost productivity.

Life sciences: Biological innovations hold great promise for reducing the need for services and preventing wasted goods, yet much of the focus of health R&D is largely on health outcomes, not on the additional productivity and cost-reduction benefits. Continued innovation in drug therapies will likely play a critical role in curing diseases and reducing health care costs.[74] This has been true in the past. For example, Murphy and Topel found that improvement in life expectancy from 1970 to 1990 added approximately $2.8 trillion to U.S. productivity, which equated to $12,000 per U.S. citizen, per added year of life expectancy.[75] The reduction in mortality rates from heart disease alone generated $1.5 trillion per year during this time period. The United BioSource Corporation examined the literature on the economic burden of lost productivity due to 11 chronic and 2 acute conditions. They concluded that the total drain on the nation's GDP in 2008 from lost productivity and labor force participation due to these conditions was as much as $1.4 trillion.[76]

The potential is likely to be even greater going forward as the U.S. population ages.[77] Murphy and Topel used their model to predict the future economic value of eliminating heart disease will be $48 trillion, and curing cancer will cost $47 trillion. Therefore, investments that produce even a modest 1 percent reduction in the cancer rate would be worth $500 billion annually.[78] The Milken Institute estimated that the most common chronic diseases are costing the U.S. economy more than $1 trillion annually, and potentially $6 trillion by 2050. A report by the World Economic Forum and the Harvard School of Public Health found that in 2030, cancer will cost the world $458 billion, cardiovascular disease $1.04 trillion, chronic obstructive pulmonary disease $4.8 trillion, and diabetes $745 billion.[79] One study found that seven chronic health conditions led to lost economic output of $1 trillion per year, including lost work days and lower output while working.[80] Health care innovations that reduce the need for medical care and treatment, including for mental illness and brain disease, will boost productivity, save on costs from disease, and improve labor force participation rates. The payoff from life-sciences innovation could be enormous. For example, ITIF estimated that spurring biopharmaceutical innovation to understand and cure brain disease and disorders could improve health outcomes for more than 50 million Americans, while increasing GDP by upwards of $1.5 trillion.[81] For instance, a 1 percent reduction in mortality from cancer would deliver roughly $500 billion in net present benefits, while a cure would deliver $50 trillion in present and future benefits.[82] Likewise, the financial impact of Alzheimer's disease is expected to soar to $1 trillion per year by 2050, with much of the cost borne by the federal government, according to the Alzheimer's Association report, *Changing the Trajectory of Alzheimer's Disease*.[83]

Continued innovation in drug therapies will likely play a critical role in curing diseases and reducing health care costs.

There are other related innovations that would reduce the need for services. Applications that would dramatically reduce tooth decay would significantly reduce the need for dentistry services. Slow-growing grass would reduce the need for lawn-mowing services. Gene-editing techniques such as the CRISPR method, which has been shown to prevent mushrooms from browning, will help increase food yield, reduce waste, and combat disease.[84]

POLICY RECOMMENDATIONS

As noted, faster productivity growth can significantly reduce the debt-to-GDP ratio. And while there are a host of policy changes that can help increase productivity, the most important is to spur more R&D, particularly R&D that is focused on areas that are likely to have a high impact on productivity. The scholarly literature on innovation policy is clear that while both tax incentives and research grants spur innovation, the former's impact is to spur more R&D generally, while grants can be targeted to particular R&D areas. As one report noted, "According to theory, direct R&D grants should be used for projects with low private returns, high social returns and high risk. R&D tax credits, on the other hand, allow firms to choose projects freely according to their private returns." Both instruments are needed to increase R&D and productivity.

Expand the R&D Credit

The United States was the first nation to establish an R&D tax incentive, when President Reagan supported legislation that went into effect in 1983. At least 24 other OECD nations now also provide a more generous tax incentive to companies for performing research.[85]

While the recent tax reform had several important achievements, including lowering the statutory rate and moving toward a territorial system, the combination of that lower statutory tax rate and the requirement that companies begin amortizing R&D expenses in five years reduces the tax incentives for conducting more research.[86] As such, **Congress should expand the rate of the Alternative Simplified Credit from 14 percent to at least 25 percent.** ITIF has calculated that expanding the R&D tax credit would pay for itself from the additional revenue growth in 15 years.[87] In other words, on a dynamic basis, the expanded credit would generate a net present value rate of return to government tax revenues in excess of the direct tax credit cost.

Expand Federal Funding for R&D by $40 Billion and Target it to Enhancing Productivity

Innovation policy scholars generally recognize that R&D tax incentives are important for influencing the overall level of business R&D, but not the type (basic or applied) or focus. Direct funding of R&D—to government labs; universities and other non-profits; state government agencies; and businesses—is a more targeted way of ensuring there is a greater focus on productivity-relevant research.

Federal R&D investment as a share of GDP averaged 1.52 percent per year from 1960 to 1980, as the United States led the world in the development of game-changing new innovations in aerospace, semiconductors, computing, information technology, and other 20th-century drivers of American economic prosperity. Yet total federal R&D investments fell to an average of less than 1 percent per year from 1981 to 2011, and then to 0.71 by 2018.[88] From 2010 to 2017, federal R&D spending fell from $170 billion to $143 billion in constant dollars.[89] If federal R&D investment had been sustained at the same levels as in the late 1970s as a share of GDP (1.2 percent), investment in 2018 would have been $100 billion greater ($243 billion). Clearly, if Congress had maintained federal R&D budgets (as a share of GDP) at the same levels as the 1970s, U.S. productivity and GDP would be larger today.[90]

To increase federal R&D funding, **Congress should appropriate an additional $4 billion per year for 10 years until total additional annual funding is $40 billion higher than the baseline.** Ramping up the funding levels gradually over 10 years would give STEM (science, technology, engineering, and mathematics) labor markets time to adjust to an expanded supply of scientists and engineers (including from STEM-based immigration). And these additional funds should be targeted to areas of research most likely to boost productivity.

Processes and Institutions for Investing More in Productivity-Enhancing R&D

Both Congress's and the administration's processes for allocating research funding largely ignore potential productivity impacts. In part, this is because the academic research community opposes such prioritization. The National Academies of Sciences reflects the standard view that the R&D budget should "serve national priorities and foster a world-class scientific and technical enterprise."[91]

To remedy this, the White House Office of Science and Technology Policy (OSTP) should craft a national research roadmap for key productivity-enhancing technologies. That process should seek input from industry on what areas of R&D are most likely to boost productivity. On the basis of this roadmap, research-funding or research-performing agencies would submit budget requests to The Office of Management and Budget (OMB) reflecting how their proposed investments would support this roadmap and how they will better prioritize funding to advance productivity. Agencies themselves should conduct their own analysis of where their research investments can have the largest impact on productivity. For example, NSF has launched its "NSF 2026 Idea Machine!" to help set the U.S. agenda for fundamental research in science and engineering. NSF should also launch a competition to solicit ideas for where NSF support could best boost productivity. Congress would use all of this information as guidance when it makes budget allocations, thereby increasing funding for agencies that better demonstrate their R&D efforts would do more to boost productivity.

Second, **Congress should draft legislation requiring the OSTP to establish multiagency, productivity-related R&D initiatives to not only identify key areas of R&D that potentially have a significant impact on productivity, but also future areas of promise and areas where cross-agency coordination is needed.** This approach would be modeled on existing cross-agency efforts such as the Networking and Information Technology Research and Development program and the National Nanotechnology Initiative.[92] As the Congressional Research Service has written, "These programs generally produce annual budget supplements identifying objectives, activities, funding levels, and other information, usually published shortly after the presidential budget release."[93]

Third, **Congress and the White House should make it clear to agencies that existing R&D should, wherever feasible, promote productivity improvement.** This has not always been the case. For example, the National Robotics Initiative, run by NSF, will only fund research on robotic technology that complements rather than replaces workers, even though the latter on average generate higher productivity gains.[94] Likewise, almost none of the Department of Agriculture (USDA) research budget is devoted to agricultural automation. OMB should examine most federal R&D funding areas across agencies and classify it by its expected impacts on productivity growth (high, medium, or low).

The processes for allocating research funding in both Congress and the administration largely ignore potential productivity impacts.

Fourth, **a significant share of the additional productivity R&D funding should be devoted to industry R&D consortia to support productivity-enhancing R&D.** In such a program, industry would come together to identify top areas of technical innovation that would do the most to boost productivity. Early-stage collaborative research can have important productivity benefits. Once industry identifies an area of research and commits at least half the funding, the government would commit matching funding for a period of at least five years. The National Institutes of Standards and Technology should be the natural home for this initiative.

The current Manufacturing USA institutes are the model for these.[95] However, there are only 14 of them, and most are focused on boosting the competitiveness of U.S. manufacturers through innovation. Moreover, their funding is relatively modest (approximately $330 million in FY2016.)[96] As such, funding should be increased to at least $4 billion per year, and the range of centers should be expanded to focus on areas ripe for productivity transformation. One area, for example, is construction technology. Measured construction-industry productivity has actually fallen over the last two decades. Yet technologies such as 3D printing and robotization hold great promise for transforming the industry. But the government does almost no R&D in this space, and the industry is too fragmented to support R&D within individual firms.

Fifth, **Congress should direct NSF to establish a new program whereby they award $1,000,000 per year for 5 years to the top 200 or so academic researchers doing work in areas that both industry values and would boost productivity.** One challenge today is—given the shortage of skilled workers, particularly in fields such as AI, in part exacerbated by limits on STEM immigration—companies increasingly recruiting faculty. Given cuts in higher-education funding from state governments and in federal research funding, leading academics spend much of their time grant writing and often face limits on their salaries, which together make them more likely to move to industry. The problem, of course, is that while individual firms may benefit, it weakens the overall innovation ecosystem because there are fewer top-quality university researchers to train the next generation.

Budget Offsets

These investments would boost GDP and federal revenues in the medium and longer term and for that reason deserve funding even in the absence of budget offsets. However, in a political environment that faces short-term pressures at the expense of longer-term considerations, it is worth briefly discussing offsets to these increased expenditures. Congress could consider a variety of measures on both the spending and tax sides.

Congress could cut or eliminate unproductive business subsidies. For example, between 1995 and 2012, the federal government paid over $292 billion to agricultural producers.[97] These programs are administered through direct payments, crop insurance programs, conservation subsidies, and disaster subsidies. Unlike, for example, support for USDA research, farm subsidies do not boost productivity or innovation. In fact, they lead to wasteful production. Eliminating all agricultural subsidies would save roughly $157 billion over 10 years.[98] In addition, the Congressional Research Service has predicted that during the period between 2013 and 2022, the federal government will spend $24.7 billion on subsidies specific to the oil and gas industry.[99] With the federal government effectively subsidizing every stage of the production process, oil and gas companies are able to expense costs incurred during exploration, preparation, drilling, and refining of fossil fuels. Firms in the industry also have the opportunity to take a tax deduction based on production levels, which can sometimes be greater than their total federal tax burden. Subsidies to the fossil fuel industry are unproductive, as commodity prices are enough to encourage future investment in the development of oil and gas.

Congress could also reduce the growth of Social Security payments. One way to achieve this would be to require a progressive index in computing benefits. Under progressive indexing, benefit increases would be tied to real wage increases for low-income workers and to inflation for high-income workers (which is higher than for low-income workers). Congress could also index cost-of-living adjustments to chain-weighted CPI because it does a better job of measuring real cost-of-living increases than the current CPI measure for Urban Wage Earners and Clerical Workers (CPI-W).

On the revenue side, Congress should also consider new sources of revenue to help pay for these investments such as raising the top marginal income tax rate on individuals.

Issues and Concerns

There are a number of arguments skeptics and opponents of such an R&D-focused productivity strategy will likely offer. This section addresses the most likely ones.

We Cannot Afford It

The two main proposals here (an expanded R&D credit and expanded federal R&D investment) will result in additional direct and indirect expenditures. Given the large federal budget deficit, the general consensus is the nation cannot afford to increase expenditures, and all areas of spending should be on the table to cut. But expansion of the R&D credit would pay for itself after 15 years through increased growth. And devoting an additional $40 billion per year (on an ongoing basis, after ten years) in order to boost productivity would more than pay for itself in federal revenues, even if productivity growth could be increased from 1.4 percent to just 1.5 percent per year. Moreover, because they increase GDP growth, both the R&D credit and R&D spending lead to a reduction in the debt-to-GDP ratio.

It is Picking Winners

Some, particularly certain free-market economists, will argue that a productivity agenda—by which they mean a welfare-reducing allocation of investment by government—picks winners. To be sure, there can be cases wherein government investments lead to reduced growth. But there are two reasons why this agenda does not involve picking winners in the traditional sense. First, the R&D tax credit does not pick particular firms or types of R&D. It simply tries to account for a market failure of firms investing less than is societally optimal in R&D because of spillovers. Firms get to decide whether, and in what kind of R&D, they want to invest. Second, much of the proposed R&D spending would go to the kind of precompetitive research companies are unlikely to do on their own. In addition, because of the significant spillovers from corporate R&D, companies will underinvest in research compared with societally optimal levels. And to the extent some of the direct funding goes to support industry R&D efforts, the funds would be allocated only to areas where industry coinvests in research consortia. So, in this sense, these two initiatives both correct for market failures.

Because they increase GDP growth, both the R&D credit and R&D spending lead to a reduction in the debt-to-GDP ratio.

There is another market failure few economists discuss, and that is the market failure from growth itself. As Harvard's Benjamin Friedman wrote in *The Moral Consequences of Economic Growth,* "Economic growth; meaning a rising standard of living for the majority of citizens—more often than not fosters greater opportunity, tolerance of diversity, social mobility, commitment to fairness, and dedication to democracy."[100] In contrast, when an economy stagnates, "the resulting frustration generates intolerance, ungenerosity, and resistance to greater openness of individual opportunity. It erodes people's willingness to trust one another, which in turn is a key prerequisite for a successful democracy."[101] Firms acting on their own do not take into account these social costs when considering investments that could lead to growth.

This Will Hurt the Nation's Basic Science System

One likely argument against such an agenda is it will be inimical to the nation's basic research science system. Supporters of the current federal research funding system will argue that only by funding basic science, directed by individual researchers chosen by merit, will innovation truly advance. There are two main responses. This proposal calls for up to $40 billion a year in new funding for research to be devoted to areas most likely to enable innovations that drive productivity. Existing funding of curiosity-directed research would not be cut. In fact, given that some researchers currently receiving funds in this area might voluntarily choose to apply for funds related to productivity-enhancing research, there could well be less competition for curiosity-directed researchers.

Second, it is not the case that all of this new funding would turn universities away from their "true" mission of knowledge discovery for knowledge's sake.[102] As North Carolina State University professor Denis Gray has documented, industry-university partnerships have no negative effects on academic freedom.[103] But it is simply not the case that industry funding comes at the price of high-quality, independent research. If it did, then institutions such as Stanford and MIT would be only slightly better than second-tier state universities in their research quality, given how much money they receive from industry. In their and many other cases, high-quality, independent research attracts industry support. The key is not the independence or even the phase of the research, but rather the orientation. Universities focused more on what Donald Stokes termed "Pasteur's' quadrant"—basic research directed at a specific challenge or problem—are the ones likely to receive more productivity-focused funding.[104]

Eliminating Tasks Does Not Increase GDP

Some might argue innovations that reduce the need for tasks to be performed (e.g., longer-lasting concrete) or automate work directly (e.g., using a robot to replace a worker) will lower GDP by eliminating work overall, leading to slack resources. If this were true, U.S. unemployment would be very high, as technology has done this for centuries. As long as monetary policy is responsibly loose during periods of high productivity, and workers are able to gain skills and capabilities to move to new work, the resources that are freed up will produce new, additional output society needs, thereby adding to the new output technology creates (e.g., roads that last longer), and leading to higher GDP.[105]

Government Cannot Increase Long-term Productivity Growth Rates

A related argument is that government can do nothing to boost growth in the long run; that it is fixed. Princeton economist Alan Blinder spoke for many conventional neo-classical economists when he wrote, "Although economics can tell the government much about how to influence aggregate demand, they can tell it precious little about how to influence aggregate supply."[106] Economist Frank Levy agrees, stating, "We cannot legislate the rate of productivity growth."[107]

These views are grounded in the conventional economic growth model that sees rates of growth as fixed over the long run; and to the extent technological innovation plays a role, it is exogenous to the model.[108] But alternative "endogenous growth" models that incorporate innovation into the economic growth model show that growth rates are not fixed because knowledge can create innovation, which in turn makes capital more efficient. As Brown University economist Peter Howitt wrote, "Endogenous growth theory challenges this neoclassical view by proposing channels through which the rate of technological progress, and hence the long-run rate of economic growth, can be influenced by economic factors."[109] A simple thought experiment should suffice. If government funds research that leads to the development of artificial general intelligence, clearly long-run growth rates would be significantly higher than if this technology were not developed or were developed later.

Growth Is Over

In contrast to those who see advanced economies as being on the cusp of unprecedented innovation and growth, others argue that growth is largely over and that there are no more innovations to power it, even if government were to fund R&D. If this is the case, why invest considerable sums in an attempt to facilitate the arrival of new growth-enabling technologies? Economist Robert Gordon, author of *The Rise and Fall of American Growth,* is the economist most widely credited with this view, and has warned of the "the death of innovation and the end of growth."[110]

Devoting an additional $40 billion per year in order to boost productivity would more than pay for itself in federal revenues, even if productivity growth could be increased from 1.4 percent to just 1.5 percent per year.

But Gordon does not appear to understand the potential of emerging technologies to improve productivity. For example, he is dismissive of the promise of autonomous vehicle technology, writing about AVs that this "category of future progress is demoted to last place because it offers benefits that are minor."[111] He goes on to say the "consumer surplus of being able to commute without driving are relatively minor."[112] Yet, a number of studies have found that the benefits of AVs will be quite large, on the order of over $1 trillion a year in savings, with most of the benefits coming from a reduction in accidents.[113] Because AVs will dramatically cut the costs of accidents, the auto body repair business will radically shrink, along with the associated benefits to productivity. Moreover, the savings in medical costs from reduced accidents will be quite large.

AVs and intelligent transportation systems that will help us make more efficient use of our roadways could deliver tremendous productivity and thus economic benefits. A Reason Foundation study found that reducing congestion and increasing travel speeds enough to improve access by 10 percent to key employment, retail, education, and population centers within a region increases regional production of goods and services by 1 percent. The study reported that achieving "free-flow traffic conditions" (that is, reducing congestion) around key urban and suburban destinations in eight U.S. cities—Atlanta, Charlotte, Dallas, Denver, Detroit, Salt Lake City, the San Francisco Bay Area, and Seattle—could boost their economies alone by $135.7 billion and generate close to $9 billion in new tax revenues.[114]

Moreover, "stagnationists" such as Gordon have a long history of proclaiming the end of innovation during economic downturns. In 1899, at the end of an awful economic decade, Charles H. Duell, commissioner of the U.S. Office of Patents, stated, "Everything that can be invented has been invented." Forty years later toward the end of the Great Depression, Alvin Hansen argued in his presidential address before the American Economic Association that, unlike in the past when railroads, electricity, and the automobile had propelled growth, "we cannot take for granted the rapid emergence of new industries as rich in investment opportunities."[115] But such pessimists were wrong in the past and are wrong now. As Joseph Schumpeter stated, "There is no reason to expect slackening of the rate of output through exhaustion of technological possibilities."[116]

Too Much Job Loss

Perhaps the most powerful argument some might make against an R&D-based productivity agenda is it will lead to job loss. Today policy makers are already assailed by Casandra-like warnings that innovation is accelerating—so fast, in fact, that most of us will become out-of-work detritus in the wake of the new machines of the "Second Machine Age" or "Fourth Industrial Revolution"—take your pick. Why would we want government to try to accelerate that process? If anything, some pundits are calling for government to slow the process of automation, for example, by instituting a new tax on robots and other related machines.[117] As such, many policymakers believe they cannot afford to support policies that boost productivity because productivity gains come at the expense of needed job growth. If productivity advances come with employment retreat, then policymakers would be well within their rights to be concerned about supporting policies to advance productivity. But fortunately, they need not worry, for there is no tradeoff.

Today's pessimistic view that productivity kills jobs suffers not only from a lack of historical perspective, but also from a fundamental flaw in logic.

Today's pessimistic view that productivity kills jobs suffers not only from a lack of historical perspective, but also from a fundamental flaw in logic. That flaw is not that all people who lose their jobs will get jobs making the new machines, as no rational organization spends money to increase productivity unless the savings are greater than the costs. If there are the same number of jobs in a company making the machines as there are lost in the companies using the machines, then costs could not have fallen.

So, it is not that jobs will be created in the new "robot" firms, it is that they will be created across the economy from the new demand higher productivity enables. To see how, we need to look at second-order effects—something techno-pessimists do not do. If jobs in one firm or industry are reduced or eliminated through higher productivity, then, by definition, production costs go down. These savings are not put under the proverbial mattress, but rather they are recycled into the economy, in most cases though lower prices or higher wages. This money is then spent, which creates jobs in whatever industries supply the goods and services that people spend their increased savings or earnings on. As a side note, the same logic is true for profits as well. Even if all the savings went to profits, those profits are distributed to shareholders who in turn spend at least some of it, creating demand that is met by new jobs. Even if the shareholders do not spend all of it, the savings reduce interest rates, which leads to new capitalized spending (e.g., car loans and mortgages) and investment, which in turn creates jobs in the firms producing this additional output. Moreover, because of competitive pressures in industries, firms do not have unlimited pricing power. If they did, then firms could just raise prices now. Competitive markets force firms to pass savings along in the form of lower prices (or higher wages). As long as monetary policy recognizes the positive forces from productivity and, where appropriate, responds to short-term layoffs from "productivity shocks" with monetary easing full employment should be the norm.

As a recent study by Deloitte notes, technological innovation creates jobs in four different ways.[118] First, in some sectors where demand is responsive to price changes, automation reduces prices but also spurs more demand, which leads to, at least, compensating job creation. For example, as prices for televisions have fallen while overall quality has increased, people have bought many more TVs. Second, jobs related to the manufacture of the automation equipment are created. Workers are employed in factories making robots. Third, in some industries, technology serves as a complement to workers, making output more valuable and thereby leading to increased demand. For example, as doctors have gained better technology, the demand for health care has increased. Finally, reduced prices from automation increase consumers' purchasing power, which creates jobs in the industries in which they spend their new additional income.

The "productivity kills jobs" argument is refuted not only by logic, but by data and econometric studies. Historically, there has actually been a negative relationship between productivity growth and unemployment rates. In other words, higher productivity meant lower unemployment. This correlation is shown in the 2011 McKinsey Global Institute report, "Growth and Renewal in the United States: Retooling America's Economic Engine."[119] McKinsey looked at annual employment and productivity change from 1929 to 2009 and found that increases in productivity were correlated with increases in subsequent employment growth, and the majority of years since 1929 feature concurrent employment and productivity gains. In looking at 71 10-year slices, only 1 percent of them evinced declining employment and increasing productivity. The rest showed increasing productivity and employment. In looking at 76 5-year periods, just 8 percent had declining employment and increasing productivity.

Finally, notwithstanding the techno-utopian claims that we are right around the corner from an era of unprecedented innovation and growth, the reality is that the next wave of innovations will likely be no different in scale and scope from prior ones, and if anything, could be less, absent robust policies—including R&D support—to advance the innovation wave. This is not to say we should not do more to help workers who do lose their jobs from automation transition to new jobs or occupations. As ITIF has articulated, there is a much governments can and should do to reform existing workforce education, training and adjustment systems.[120] But if governments are concerned about slow economic and wage growth and want to reduce growing budget deficits, then the last thing they should do is oppose technological innovation that would boost productivity.[121]

CONCLUSION

For decades, those focused on the troubling growth of the federal budget deficit have counseled policymakers to cut spending and increase taxes. But policymakers have ignored this counsel, instead increasing spending and cutting taxes. While such traditional advice is still sound, it is time for a supplementary approach that seeks to grow the U.S. economy by spurring productivity-enhancing technologies. To be sure, other factors such as workforce development, entrepreneurship, regulatory reform, the right competition and trade policy, and sector strategies are also important to drive productivity. But the articulation of such a national productivity strategy is beyond the scope of this report.[122]

The advantage of the approach here—boosting R&D focused on productivity—is that, if successful, it will not only reduce the debt-to-GDP ratio, it will boost per-capita income.[123] To be sure, such a strategy could increase the debt in the short run, but would hold great promise for significantly reducing the debt-to-GDP ratio in the long run. In this sense, congressional appropriators, CBO, and federal agencies need to focus on both the long run and innovation-driven productivity growth.

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About ITIF

The Information Technology and Innovation Foundation (ITIF) is a nonprofit, nonpartisan research and educational institute focusing on the intersection of technological innovation and public policy. Recognized as the world's leading science and technology think tanks, ITIF's mission is to formulate and promote policy solutions that accelerate innovation and boost productivity to spur growth, opportunity, and progress.

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