# Estimating the economic and budgetary effects of research investments

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Abstract: Many US federal agencies model the economic and budgetary effects of research and development (R&D) investments -- both public R&D and private R&D -- as if R&D were the same as any other form of investment, such as physical capital investment. However, in recent decades a broad base of evidence has developed suggesting that such modeling may result in projections that are not well-aligned with the actual economic and budgetary effects of R&D investments. In this paper, we attempt to synthesize the economic evidence relevant to estimating the economic and budgetary effects of R&D, and examine how and where this research literature could potentially be incorporated into the standard projections produced by various federal agencies.

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Both researchers and policymakers have long recognized innovation as a key driver of long-term economic growth. From a policy perspective, one of the most common ways in which governments attempt to promote innovation is through subsidizing research and development (R&D) investments, either through providing direct government funding for R&D or via tax provisions that change the after-tax price of private R&D with the goal of changing the rate and/or composition of privately funded research.

The research literature – both theoretical and empirical – has provided a variety of support for the idea that R&D tax and subsidy policies can generate statistically and economically significant effects on innovation- and growth-related outcomes. While the research literature historically evolved in somewhat separate strands of macroeconomic theory and microeconomic evidence, in recent years progress has been made on stitching together micro evidence with macro aggregates in a way that allows this literature to speak more clearly and credibly to an evidence-based view of how changes to R&D tax and subsidy policies would be expected to affect productivity and economic growth.

This progress in the research literature is fortuitously coincident with active Congressional interest in various R&D-related legislative provisions, including changes to federally funded research investments, such as the CHIPS and Science Act (117th Congress, H.R. 4346), and changes to R&D-related tax incentives, such as the 2017 tax act (115th Congress, H.R. 1). But unfortunately, the research evidence on the economic effects of R&D investments has largely been absent from these policy debates.

If this research literature had been incorporated into recent policy discussions around the CHIPS and Science Act, it is possible that Congress's decisions over whether to fully fund the investments authorized in the CHIPS Act would have been different. Given the information that was provided, Congressional appropriations for the federal research agencies in 2023 and 2024 fell below the levels authorized by CHIPS. For example, in fiscal year 2024, the gap between appropriations and authorizations was over $7 billion (Hourihan 2023). Congressional decisions of whether to fulfill authorizations with appropriations are a policy choice. As far as we are aware, federal agencies such as the Congressional Budget Office (CBO) have never been asked to provide Congress with publicly disclosed quantitative estimates–based on the research literature–of the expected effects of such policy choices on the US economy and the federal budget. In addition, CBO's projections of the economic and follow-on budgetary effects of federally funded R&D are not included in the standard cost estimates that CBO provides to Congress when they are considering legislative provisions related to federally funded R&D.

The paper is organized as follows. Section I provides a brief background on federally funded R&D as well as some key aspects of private R&D relevant to tax provisions. Section II exposits a concrete example of how federal agencies currently model R&D – namely, the framework used by CBO to evaluate the economic effects of federal investments, including R&D – and, within the context of that framework, takes stock of the evidence from the research literature on the economic effects of R&D investments. Section III then discusses how and where this evidence from the research literature could potentially inform three additional applications: CBO's cost estimates of legislative provisions related to federally funded R&D, JCT's revenue estimates of R&D-related tax provisions, and modeling of R&D in baseline budgetary and economic projections such as the total factor productivity projections generated by the Federal Reserve and by CBO. Throughout the paper, we highlight connections to the research literature and illustrative examples of how this research might be communicated to Congress and the public in discussions about R&D-related policies.

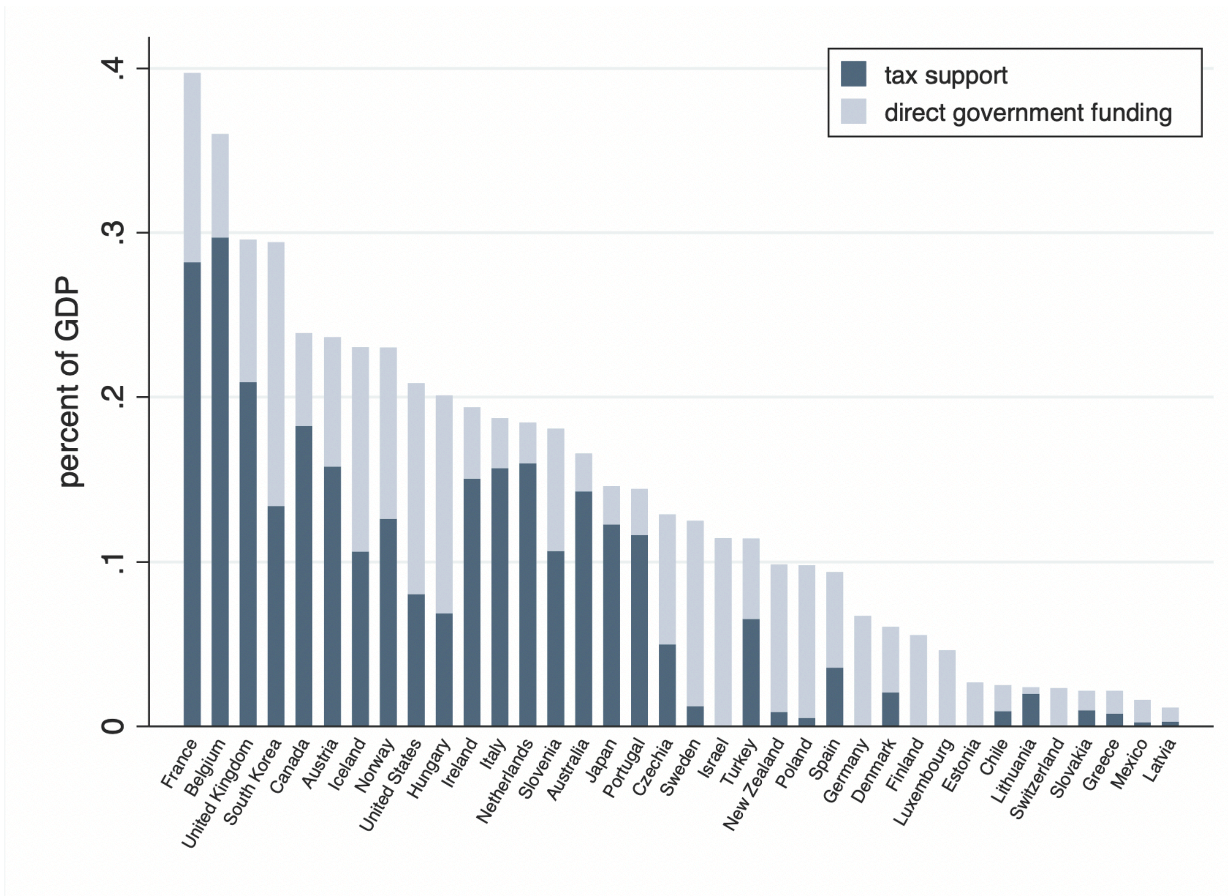
**I. Preliminaries: Federally funded and private R&D**

Governments frequently subsidize research and development (R&D) investments both directly, through the direct provision of government funding for R&D, and indirectly via tax provisions that change the after-tax price of private R&D.

When discussing private R&D investments it is important to keep in mind that, by default, R&D is treated in business and tax accounting – and was treated in the US National Economic Accounts until 2013 – as a current expense item for businesses, with expenses like scientists' wages and lab materials being deducted as a current cost of production rather than over time in the form of depreciation as with investment in physical capital (Moylan and Okubo 2020). As described by Bloom et al. (2019), this implies that the tax code automatically treats private R&D more generously than physical capital investment, because most R&D expenses are current costs that can be written off in the year in which they occur, whereas investments in physical capital must be written off over several years. But in addition to this structural advantage in the tax code, many countries provide additional direct fiscal incentives for private R&D investments, such as allowing additional deductions to be made against tax liabilities.

Figure 1 provides a very rough characterization – using data from OECD countries in 2017 – of the cross-country variation in direct government funding for R&D and tax support for private R&D, as defined in OECD (2015). Tax support is a small share of total government support for R&D in some countries like New Zealand and Finland, whereas direct government funding is a small share of total government support in some countries like Australia and the Netherlands.

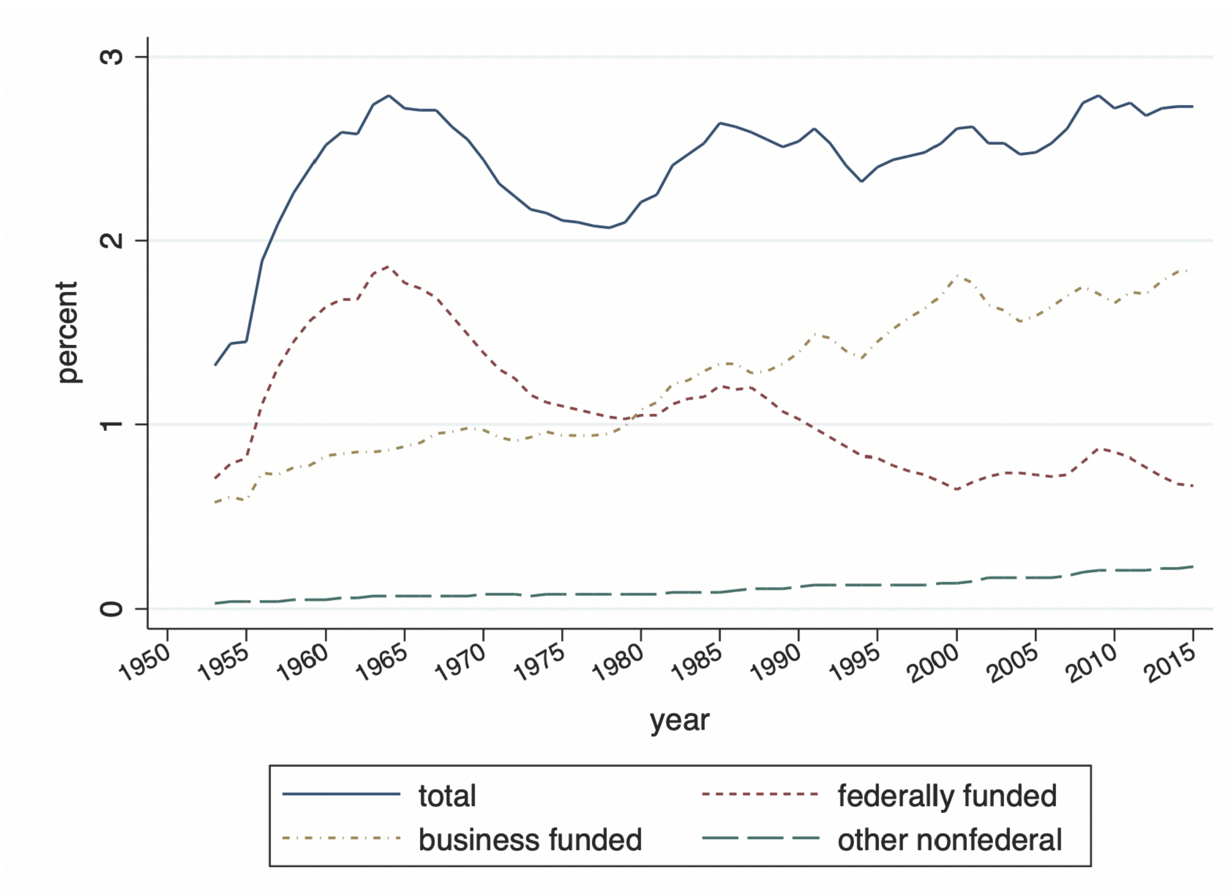
**Figure 1.** Direct government spending and government tax support for business R&D in 2017




<u>Notes</u>: Reprinted from Figure 4 in Bryan and Williams (2021). Government tax support combines national and sub-national tax support for business R&D expenditure. Data on national tax support is not available in Israel. Data on sub-national tax support is not available in the US and Spain. Source: Organization for Economic Co-operation and Development (2020).

Focusing on the US, estimates by the staff of the Joint Committee on Taxation (JCT) and the US Treasury suggest the tax credit for increasing research activities (26 U.S. Code § 4) has been, in recent years, one of the largest US tax expenditures in terms of total projected revenue effects – roughly $20 billion (according to JCT) to $25 billion (according to Treasury) in 2023.[2] In terms of direct spending, in 2015 the US federal government was responsible for around $128 billion of R&D (NSF 2018, Table 4-17). Historically, federally funded R&D – as defined in OMB Circular A-11 (2024) – used to be the largest component of US R&D spending. However, as shown in Figure 2, continuously since 1980 business-funded R&D has outpaced federally funded R&D as a share of GDP.

**Figure 2.** US R&D as a share of GDP, by source of funds: 1953-2015




Notes: Reprinted from Figure 2 in Bryan and Williams (2021). This figure shows US R&D spending – total and by source – as a share of GDP from 1953 to 2015. Source: Appendix Table 4-1 of National Science Foundation (2018).

[2] For example, see https://www.jct.gov/publications/2023/jcx-59-23/ for JCT's estimates from December 2023. The first US federal R&D tax credit was introduced in 1981, although as noted by Bryan and Williams (2021) R&D tax policy was in fact the first recommendation in Vannevar Bush's *Science: The Endless Frontier* (1945).

Looking at US federally funded R&D in more detail, Table 1 lists federal obligations for R&D by agency for the six agencies with the largest R&D obligations in fiscal year 2015. While federal research support involves many different federal government departments and agencies, the largest in dollar terms were the Department of Defense (DOD) and the Department of Health and Human Services (HHS, which includes the National Institutes of Health, or NIH).

**Table 1.** Federal obligations for R&D, by agency and type of work: 2015

| | | | | | **Percentage of total R&D** | | |
|---|---|---|---|---|---|---|---|
| **Agency** | **Total R&D** | **Basic research** | **Applied research** | **Development** | *Basic research* | *Applied research* | *Development* |
| All agencies | 128,573.2 | 31,527.1 | 32,118.2 | 64,927.8 | 24.5 | 25.0 | 50.5 |
| Department of Defense | 61,513.5 | 2,133.4 | 4,558.1 | 54,822.1 | 3.5 | 7.4 | 89.1 |
| Department of Health and Human Services | 30,272.1 | 15,076.9 | 15,119.9 | 75.4 | 49.8 | 49.9 | 0.2 |
| Department of Energy | 11,391.0 | 4,460.4 | 4,181.1 | 2,749.5 | 39.2 | 36.7 | 24.1 |
| National Aeronautics and Space Administration | 11,360.7 | 3,209.7 | 2,329.7 | 5,821.3 | 28.3 | 20.5 | 51.2 |
| National Science Foundation | 5,669.7 | 4,973.9 | 695.8 | 0.0 | 87.7 | 12.3 | 0.0 |
| Department of Agriculture | 2,341.0 | 924.5 | 1,203.9 | 212.7 | 39.5 | 51.4 | 9.1 |

Notes: Source: Table 4-17 of National Science Foundation (2018). Millions of current dollars. This table lists the six agencies with the largest R&D obligations in fiscal year 2015.

Table 1 also reports, for each of these agencies, federal obligations for R&D across three categories referred to as type of work: basic research, applied research, and development. On average, federal R&D is around 25% basic research, around 25% applied research, and around 50% development research. However, these averages mask sharp differences across these agencies in the type of work they support. Around 89% of DOD's R&D is development, whereas 88% of NSF's R&D is basic research. HHS's R&D (which, again, includes NIH) is nearly evenly split between basic research and applied research, and the Department of Energy's portfolio is roughly evenly split across all three categories. NASA's portfolio mirrors the overall federal averages quite closely, while the Department of Agriculture primarily supports applied research (51%) and basic research (40%).

## II. Connecting evidence on the economic effects of R&D with policy analysis

In order to ground our discussion of the research literature on the economic effects of R&D investments in the context of a specific example, in this section we start by expositing (briefly) the framework used by the Congressional Budget Office (CBO) to evaluate the economic effects of federal investments, including R&D.

CBO's work is a useful example in part because CBO's published reports provide a particularly clear and transparent description of their framework around which we can structure our discussion. While this framework is of course specific to CBO, our understanding is that, like CBO, many if not most federal agencies model R&D – by default – as if it were the same as any other form of investment. Note that this modeling of R&D as investment is natural in part because it dovetails with the fact that, starting in 2013, R&D was incorporated into the US National Economic Accounts as investment, after the National Income and Product Accounts (NIPAs) were revised to count expenditures on intellectual property – including R&D – as investment.[3]

### *II(a). CBO's 2021 framework for modeling federal investments*

CBO models the macroeconomic and budgetary effects of federal investment in physical capital, education, and R&D in a unified framework (see, for example, CBO 2013, 2014b, 2016, 2019, 2021a). This unified framework offers consistency across the wide variety of goods and services

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[3] Patrick Driessen thoughtfully pointed us to BEA (2013), which notes that this change to recognize R&D as investment increased GDP by the amount of business R&D investment and by the consumption of fixed capital (CFC) associated with R&D investment by non-profit institutions serving households (NPISH) and by general governments; BEA's preliminary estimates suggested this change increased GDP by about 2 percent, or 300 billion. Eaton and Kortum (2021) argue that this current practice of treating R&D as investment and incorporating the stock of R&D into the stock of physical capital inappropriately treats R&D as a rival factor of production, even though R&D is typically modeled as non-rival. They develop a theoretical framework based on that insight and draw out implications for measuring intangibles and productivity growth.

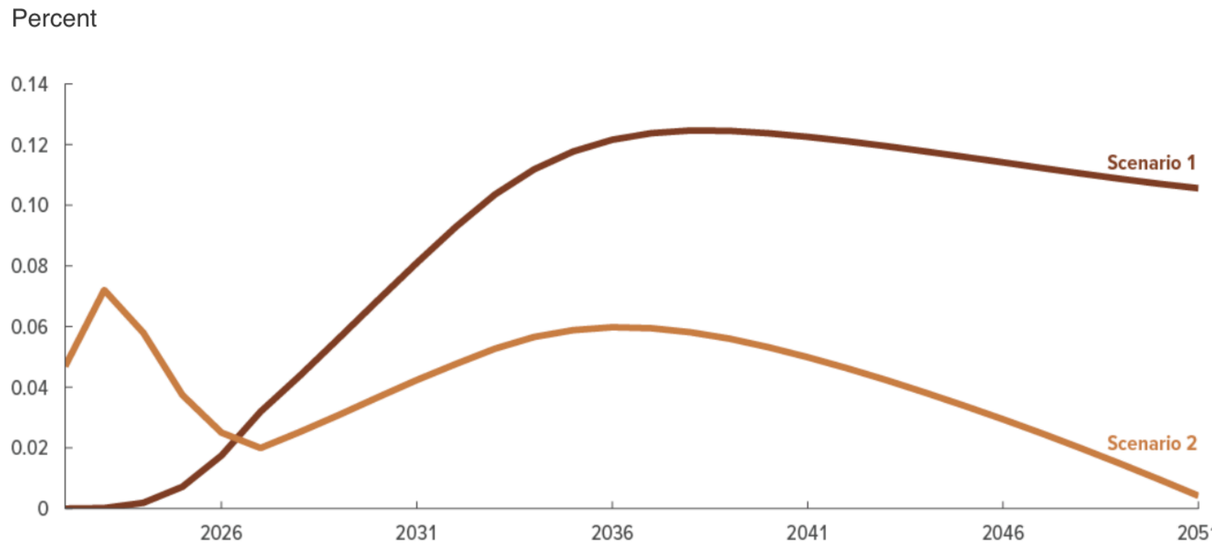
funded by the federal government with the intention of increasing private sector productivity and economic growth in the future.

In 2021, CBO published (2021b) a report titled *Effects of Physical Infrastructure Spending on the Economy and the Budget Under Two Illustrative Scenarios*.[4] At a conceptual level, the framework presented in this 2021 report is essentially unchanged from CBO's previous descriptions of their framework for analyzing the macroeconomic and budgetary effects of federal investments. What was new in the 2021 report is that it laid out in much more concrete terms how the agency would tailor that framework to specific applications, which the 2021 report illustrated with the example of physical infrastructure investments. This step forward was valuable in part because it clarifies what assumptions need to be made in order to apply this framework to a given example, such as R&D.

The 2021 report focuses on two illustrative scenarios that would increase federal investment in physical infrastructure by $500 billion over 10 years: scenario 1 is deficit-neutral, financing the infrastructure investment by reducing the government's noninvestment purchases; scenario 2 finances the infrastructure investment by increasing federal borrowing. For both scenarios, CBO models the increase in economic output stemming from changes in productivity; in the second scenario, CBO also models how the increased spending affects overall demand and output in the short-term, and the effect of increased federal borrowing on private investment (so-called "crowding out," which dampens output). Figure 3 summarizes CBO's estimates of the effects of these illustrative scenarios on GDP.

[4] As discussed by Elmendorf et al. (2024), this report was prepared in response to a request from then-Senator Robert Portman, who wanted to bring a more comprehensive – that is, dynamic – analysis to bear in discussions of the bipartisan Infrastructure Investment and Jobs Act (Bolton 2021). Section III(a) discusses dynamic scoring in more detail.

**Figure 3.** CBO (2021) estimates of changes in real GDP from two illustrative scenarios




Notes: Reprinted from Figure 1 in CBO (2021b). See [www.cbo.gov/publication/57327#data](www.cbo.gov/publication/57327#data). Under both scenarios, funding for physical infrastructure would increase by $50 billion annually for 10 years. Under Scenario 1, the resulting increase in outlays would be fully offset by a reduction in the government's noninvestment purchases; under Scenario 2, it would be financed by increased borrowing. Effects are estimated relative to CBO's July 2021 economic projections. Real GDP is gross domestic product adjusted to remove the effects of inflation. Years are calendar years.

In expositing how to apply this framework to a different policy change, the report lists five factors that need to be modeled:

1. How quickly funding leads to outlays
2. How outlays are financed
3. How much outlays increase productivity
4. How quickly outlays increase productivity
5. How state and local governments respond to additional federal funding

As we will describe in Section III, modeling of the first factor need not draw on the research literature but rather would be drawn directly from the legislative text or analogous sources for whatever specific policy is being modeled. Likewise, the second factor can be analyzed in CBO's standard frameworks. For example, for legislative spending provisions without explicit funding provisions, CBO typically applies estimates such as those from Huntley (2014) to quantify the extent to which larger deficits would crowd out private capital. Models such as CBO's budgetary feedback model (Frentz et al. 2020) can be applied to estimate how changes in the macroeconomy are expected to affect the federal budget. Hence, the remainder of this section focuses on summarizing the evidence relevant to the remaining three factors for the case of federally funded R&D.[5]

*II(b). How do R&D outlays affect productivity?*

The research literature on this question historically evolved in somewhat separate strands of macroeconomic theory and microeconomic evidence. On the macroeconomic theory side, the Solow-Swan model (Solow 1956, Swan 1956) exposited a framework within which there would be no sustained economic growth in the absence of improvements in the state of technology. However, the Solow-Swan model generates growth only by introducing an exogenous rate of technological progress.[6] Subsequent work focused on innovation-based endogenous growth models (e.g., Romer 1990, Aghion and Howitt 1992, Grossman and Helpman 1991) which instead modeled technological progress as a function of incentives, so that new ideas did not just fall from the sky but instead were the product of very intentional, endogenous decisions about research investments made by firms and researchers. This type of setup naturally allows for government policies that affect research investments – such as federally funded subsidies to R&D as well as R&D-related tax provisions – to affect productivity and growth.

The traditional justification that economists have exposited for why such government policies could be welfare improving rests on an assumed market failure: because ideas are public goods, we expect them to be under-provided by the private market (see, e.g., Nelson 1959 and Arrow 1962). Consistent with this idea, Jones and Summers (2022) argue that a calibration of modern growth theory models implies a social rate of return to R&D that is likely to be quite high. Bloom, Schankerman, and Van Reenen (2013) present evidence from a more structural, production-function based approach that leverages cross-state variation in R&D tax credits, and estimate that the social returns to R&D are 2-4 times as large as the private returns.

Taken together, these macroeconomic theory approaches and these two more quantitative papers (Jones and Summers 2022; Bloom, Schankerman, and Van Reenen 2013) suggest that

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[5] See also CBO (2018a), which is essentially a call for research on some R&D-specific parameters needed to apply such a framework to the case of R&D. For an earlier treatment of federally funded R&D by CBO, see also CBO (2007).

[6] Contemporaneously, the empirical literature on so-called "growth accounting" by Solow (1957) and others suggested that the share of long-run economic growth that could not be explained by changes in capital and labor inputs was quite high; subsequent work argued that the bulk of this "Solow residual" could be explained by technological progress.

knowledge spillovers exist, are quantitatively important in magnitude, and are a key driver of productivity and growth. However, this type of indirect evidence does not itself provide guidance on what types of policy changes might change knowledge spillovers and productivity growth in practice. This is where the microeconomic literature has made progress over – say – the last decade.

A series of papers by Pierre Azoulay, Joshua Graff Zivin, Danielle Li, and Bhaven Sampat – perhaps most notably Azoulay et al. (2019) – carefully stitched together data on federal R&D funding from the US National Institutes of Health (NIH) to citations of those NIH grants in patents linked to new drug approvals, combined with quasi-experimental variation in NIH funding, in order to quantify the contribution of NIH funding to the development of new drugs. In a similar spirit, Myers and Lanahan (2022) combined variation in state-specific matching policies for US Department of Energy grants with carefully constructed data on geographic and technological linkages across firms to quantify R&D spillovers. Both papers conclude that spillovers from federally funded R&D are substantial – with firms capturing at most half of the returns. However, neither paper was able to trace the quasi-experimental variation in federal R&D through to quantify effects on productivity and growth.

Most relevant to our work here are two recent papers – Fieldhouse and Mertens (2023) and Dyevre (2023) – which build on this literature and directly tackle the challenge of estimating the relationship between federally funded R&D and productivity. Notably, while the two papers rely on quite different empirical approaches, they end up reaching quantitatively similar conclusions which, together with the evolution of the literature described above, increases our confidence in their estimates.

Fieldhouse and Mertens (2023) build on the work of Romer and Romer (1989) and others in constructing a narrative classification of the universe of significant postwar changes in R&D appropriations for five major federal agencies from 1947-2019: the Department of Defense (DOD), Department of Energy (DOE), National Aeronautics and Space Administration (NASA), National Institutes of Health (NIH) within the Department of Health and Human Services, National Science Foundation (NSF), and their historical precursors. As we will discuss, the nature of this data – being built directly from information on appropriations – is in many ways ideal for mapping the structurally estimated returns from this approach to various policy applications. Taken at face value, Fieldhouse and Mertens' estimates imply net returns of

180-204 percent, and suggest that federally funded R&D is responsible for around 25 percent of post-war productivity growth in the US.

Dyevre (2023) constructs a more micro-based approach, linking data on US firms over a similar time period (1950-2020) to two sources of quasi-experimental variation. First, building on the work of Jaffe (1986), he constructs measures of the exposure of firms to different US federal agencies' R&D investments based on the distribution of firms' patents across technological areas. Second, building on Kling's (2006) foundational work on judge leniency, Dyevre extends the work of Sampat and Williams (2019), which leveraged quasi-random variation in the assignment of patent applications to patent examiners at the US Patent and Trademark Office. Combining both estimates in a general equilibrium model in the spirit of Luttmer (2007) and Jones and Kim (2018), Dyevre estimates that the decline in federally funded R&D can explain around a third of the decline in US TFP growth from 1950-2018.

Connecting back to the 2021 CBO infrastructure report, let us emphasize a few key implications of this literature for that framework.

First, <u>the returns to federally funded R&D appear to be substantially higher than the returns to other forms of federal investment such as physical infrastructure</u>. In the absence of evidence to the contrary, CBO and other agencies appear to – by default – often model R&D as if it has the same returns as any other form of investment, such as physical capital investment. For example, CBO (2016) acknowledges that rates of return can be different for different types of federal investment, but notes that because the empirical literature at that time did not – in CBO's assessment – offer a satisfactory way to estimate different rates of return for different types of federal investment, CBO applied a single rate of return that was meant to capture the average return on different types of federal investments. CBO (2021b) states that on the basis of published studies of the US economy, CBO projects that an additional dollar of federally funded infrastructure capital increases real potential GDP by 12.4 cents on average. The agency estimates that the stock of public capital depreciates over time at an annual rate of 3.2 percent, so the net effect is an increase of 9.2 cents.

The available literature suggests that the returns to federally funded R&D are notably higher than this estimate.[7] Consider as an example the Fieldhouse and Mertens estimate; we will return below to discuss this estimate in the context of other estimates in the literature. Fieldhouse and Mertens (2023) apply a depreciation rate of 16 percent, and estimate that even after applying that higher depreciation rate that their estimated returns to R&D (Table 2) substantially exceed those for public infrastructure assumed by CBO. Their preferred estimate is a net rate of return of 197%, or nearly two dollars on average for each additional dollar of federally funded R&D (as opposed to the 9.2 cents net effect used by CBO by default for federal investments).[8]

In part because Fieldhouse and Mertens (2023) document (Appendix D.5) that their estimates are quite sensitive to the assumed depreciation rate, the appropriate depreciation rate is itself worth discussing. What the appropriate depreciation rate is for R&D – sometimes referred to as the “Griliches problem” (Griliches 1979) – is a classic question in the economics of productivity. Fieldhouse and Mertens cite the 16% depreciation rate as the average depreciation rate for government R&D calculated by the Bureau of Economic Analysis (BEA). However, that 16% figure is generally attributed to Li (2012), where Table 4 suggests a 16% depreciation rate of business R&D assets for “scientific research and development.” At a conceptual level, this figure is perhaps most accurately described as a private returns depreciation rate for applied R&D (or for development investments). One can imagine heterogeneity along two relevant dimensions that would be relevant for contrasting that 16% figure with the rate that is conceptually appropriate for federally funded R&D. First is the basic research versus applied (or development) distinction, if there is reason to think (as BEA has itself noted) that basic R&D depreciates more slowly. Second is the distinction between private and social returns, which may differ in both timing and levels.[9]

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[7] Note that the 12.4 cents estimate was framed by CBO (2021b) as being specific to physical infrastructure, rather than as an average rate of return across different types of federal investments (which could have included R&D).
[8] Note that Fieldhouse and Mertens’ estimate is not a direct mapping to returns to potential GDP as in CBO’s estimate, but the impulse response functions reported for TFP and potential GDP in Figures 6 and 7 are qualitatively similar.
[9] As an extreme example, the private returns to R&D on a pharmaceutical drug largely end when the drug comes off patent, and in levels would include product market spillovers to other firms (which would not be included in a social returns estimate); in contrast, social returns to the same R&D investment may be higher post-patent expiration (if generic entry expands access), and may in many cases continue for years beyond patent expiration.

Our read is that BEA has not consistently defined nor applied different depreciation rates for government R&D and private R&D, and when different depreciation rates have been proposed by BEA they have often been motivated by differing investment portfolios rather than differences in depreciation rates of a given portfolio of investments funded by a different source.[10] For example, Moylan and Okubo (2020) initially apply a depreciation rate of 11% for R&D investment, and later exposit a scenario which assumes a 20 percent depreciation rate for business R&D and an 8.3 percent depreciation rate for R&D by non-profits and general government; they note that public R&D is "closer to basic research and would be likely to obsolesce more slowly." The cross-agency variation in basic, applied, and development research reported in Table 1 could form the basis for assigning agency-specific depreciation rates that vary as a function of these differences.[11]

Our discussion in this section thus far has focused attention on evidence from one paper, Fieldhouse and Mertens. But of course, federal agencies generally prefer not to base their projections on estimates from a single paper. In this case, the implied returns estimates in Dyevre (2023) are a similar order of magnitude. But rather than simply choosing between these two estimates, or taking a simple average, agencies may prefer to collate information from a broader set of studies.

One methodology for doing this would be to construct a broader distribution of estimates based on what could be called "surrogate endpoints" for productivity, drawing on an analogy with clinical trials.[12] Traditionally, clinical trials are required to show that a drug induces statistically significant improvements in survival. However, in some cases, regulators such as the US Food and Drug Administration instead accept evidence that a drug improves an intermediate or surrogate endpoint – such as the level of cancer in a patient's blood or bone marrow – because changes in that outcome are a reliable indicator that changes in mortality will be observed later.

[10] Note that BEA is in the process of developing a new satellite account that measures research and development activity in a framework consistent with the measurement of GDP and other BEA statistics; the first milestone of this project – some experimental statistics – was issued in May 2024: https://www.bea.gov/data/special-topics/research-and-development-satellite-account.

[11] CBO (2021a) cites a 2013 BEA publication BEA Depreciation Estimates which reports separate depreciation rates for different categories of federal defense and non-defense R&D – ranging from 7% for NASA R&D to 19% for extramural defense R&D – but that publication does not clarify whether that heterogeneity was modeled as a function of the mix of basic, applied, and development research across agencies.

[12] On the clinical trials example, see Budish et al. (2015); see also Athey et al. (2024).

In the case of policy changes affecting the level of federally funded R&D, some studies – such as Fieldhouse and Mertens (2023) and Dyvere (2023) – quantify the effects of policy changes on productivity directly. However, a broader set of studies quantify effects on outcomes that, according to both theory and empirical evidence, co-move with productivity but are observed on a shorter time-horizon; patents are one example.[13] One could incorporate the literature quantifying the effects of changes in federally funded R&D on patenting into estimates of the effects of federally funded R&D on productivity in two ways:

1. First, one can infer an estimate of the relationship between R&D and patents, and – separately – of the relationship between patents and productivity from the two studies that analyze all three variables (Fieldhouse and Mertens 2023; Dyvere 2023)
2. Second, one can instead infer the relationship between patents and productivity from studies such as Kogan et al. (2017), which estimate how patents affect productivity in a non-R&D context, and apply that scaler to studies estimating the relationship between federally funded R&D and patents (such as Azoulay et al. 2019 and Myers and Lanahan 2022)

While we are not aware of this approach having been applied in the past, it seems useful not just for our example of federally funded R&D and productivity, but that it could be analogously applied to other policy changes affecting any given factor (such as high skilled immigration) thought to affect productivity as well. An analogy is CBO's work on climate and temperature (e.g. Herrnstadt and Dinan 2020), which applies a two-stage model to estimate the impact of climate change on temperature, and the effect of changes in temperature on GDP.

Second, <u>for the case of R&D, the literature does not support the standard assumption that public investments are less productive than private investments</u>.[14]

CBO (2016) notes that in CBO's assessment the average productivity of public investment is three-fourths as high as the average productivity of private investment, in general (that is, from all types of investment, including R&D). CBO (2018a) indicates that productivity estimate is based primarily on researchers' estimates of the productivity of investment in public physical capital because there are (or were, at the time) few estimates of the direct effect on output of

[13] For example, CBO (2016) notes – correctly, in our view – that as of that time researchers had estimated the effect of federal investment in R&D on various outcomes such as the number of patents granted, but that there was little evidence of how those outcomes affect output.

[14] We are particularly grateful to Kevin Bryan, Matt Clancy, Lisa Larrimore Ouellette and Bhaven Sampat for discussions that shaped this section.

federal investment in R&D. However, there are both theoretical reasons and indirect empirical observations, discussed below, suggesting that for the case of R&D the average productivity of public investment is greater than private investment. A null hypothesis of equal returns on the margin to public or private R&D is very difficult to reject given the state of the evidence.

Public R&D and private R&D, on average, differ on a number of dimensions. For the case of drug development, a common characterization is that federal R&D – largely through the NIH – supports basic research at universities, which then generates a risk set of clinical compounds from which private firms can choose to invest additional applied and experimental development R&D in, such as through clinical trials, to bring a subset of those compounds through the process of testing safety and efficacy on the path towards a subset of drugs actually reaching patients. Of course, interactions across public and private R&D differ tremendously across sectors, and it is important not to over-generalize from one example such as the drug development case. However, a roughly similar characterization emerges from aggregate data on private and public R&D by performing sector (NSF 2018, Table 4-3): around 7% of private R&D and 30% of federal R&D go towards basic research, whereas around 78% of private R&D and 41% of federal R&D go towards experimental development research, with the remainder (15% and 28%, respectively) going towards applied R&D.[15]

That difference across public and private R&D in what share is basic versus applied/development research matters in part because work dating back to Nelson (1959) has argued that basic R&D is less patentable, less easy to appropriate, and generates larger spillovers – and hence, in expectation, generates larger returns in terms of productivity growth. Aghion, Dewatripont, and Stein (2008) present a theoretical model clarifying the respective advantages of academic (implicitly, publicly-financed) and private-sector research, from which they argue it is socially optimal to have earlier stage, more "basic" research takes place in academia even without relying on differences in spillovers or differences in patentability in terms of having a larger number of candidate projects explored.

In terms of empirical data points, Dyevre (2023) documents a number of relevant facts from which he argues – somewhat indirectly – that public R&D is likely to generate larger spillovers than private R&D. First, he documents that public R&D tends to produce patents that rely more

[15] NSF (2018, Table 4-3) also reports analogous statistics for non-federal public R&D, which are even more heavily skewed towards basic research (55%) than federal public R&D (30%).

heavily on basic science than does private R&D. Second, he documents that public R&D tends to produce higher impact patents, as measured by contributing to the opening of a new technological field in the patent data. Third, and most directly relevant for productivity spillovers, he estimates that public R&D tends to generate spillovers across a wider range of patent classes than private R&D.

These findings resonate with a broader literature that has – for example – generally estimated lower returns to defense R&D relative to non-defense R&D, given that as noted in Table 1 defense R&D tends to be applied/development (96.5%) rather than basic (3.5%). CBO (2018a) notes that the agency typically distinguishes between defense and nondefense R&D, noting that while defense research sometimes provides civilian benefits, the majority of defense R&D does not provide spillover benefits to the private sector, and – as a result – does not substantially influence CBO's analysis of macroeconomic outcomes. The literature generally provides support for such a distinction. For example, Fieldhouse and Mertens note that they find little evidence that a positive shock to defense R&D leads to any persistent productivity effect, at least on a 15-year time horizon, and Moretti, Steinwender, and Van Reenen (2023) – who focus exclusively on defense R&D – estimate smaller productivity effects than Fieldhouse and Mertens estimate for non-defense R&D.

*II(c). How quickly do R&D outlays affect productivity?*

CBO (2021b) notes that the agency expects that additional federal spending on physical infrastructure would increase productivity with the following lag structure: 40 percent of the effect occurring in the first year after the spending, 80 percent occurring by the second year after the spending, and 100 percent occurring by the seventh year after the spending.

Both common sense and empirical evidence suggest that federal investments in R&D translate into changes in private sector productivity on a slower time scale. Consistent with that idea, CBO (2018b) notes that in the absence of other evidence, the agency estimates that the macroeconomic effects of spending on basic R&D begin only after 20 years, and that it will take another 20 years to realize the full effect. For applied R&D, CBO models the effects as beginning sooner – starting after 10 years – but still taking another 20 years to realize their full macroeconomic impact. Development expenditures are expected to begin to have an impact about a year after they are made, and are modeled as following a 20-year path to their full effect. These assumed lags are important in part because they imply that only development expenditures have the potential to affect economic outcomes during the so-called 10-year budget window, which represents the current fiscal year and each of the 10 subsequent years, and a time period over which information is often provided to Congress by CBO and other agencies

In contrast with these estimates, our assessment of the literature is that federally funded R&D appears to generate returns on a shorter time horizon, including within the 10-year budget window. Both the micro-evidence in Azoulay et al. (2019) and the timing of the impulse response function estimates in Fieldhouse and Mertens (2023) allow these lags to be measured directly, and suggest shorter time lags between non-defense R&D shocks and outcomes including labor productivity, total factor productivity, and potential output as well as intermediate indicators which, as expected, show changes on shorter time horizons (such as patents, researchers, and publication of technology-related books).

*II(d). How do state and local governments respond to additional federally funded R&D?*

CBO (2016) notes that in CBO's assessment one-third of an increase in federal investment is generally offset by a decrease in investment by states and localities (and, to a lesser extent, by private entities). Footnote 6 in that report solely cites papers analyzing federal highway funding as the basis for that assessment.

In contrast with that assumption, our assessment of the literature is that federally funded R&D appears to be a complement – rather than a substitute – with private investment, and is unlikely to substantially affect state and local R&D investments.

In 2025, only around 3% of government-funded R&D in the US was funded by non-federal government institutions (NSF 2018, Table 4-3). Moreover, a not insignificant share of this state and local spending was made through noncompetitive matching policies such as the Small Business Innovation Research (SBIR) program (Myers and Lanahan 2022). Taken together, this implies that the quantitative size of any response by state and local governments to changes in federal R&D policies is likely to be small in magnitude relative to the level of federally funded R&D, and if anything may be a complement with federally funded R&D by construction due to matching policies.

Federally funded R&D appears to have a small but not economically insignificant positive effect on private R&D spending (De Lipsis et al. 2023; Fieldhouse and Mertens 2023). CBO (2007) focuses on evidence from Guellec and van Pottelsberghe de la Potterie (2003), which estimates based on cross-country panel regressions that a dollar of government R&D induces private firms to spend 70 cents of private R&D. Fieldhouse and Mertens (2023) estimate a smaller but nonetheless substantial complementarity, estimating that an increase in federal R&D spurs an increase in private R&D roughly 20 percent as large. In our view, the literature here (see, e.g., David et al. 1999) is sufficient to provide a reasonable central estimate across papers over the intervening two decades. In interpreting this literature, it is important to note that papers vary in whether these follow-on / indirect effects are included or excluded from their returns estimates, which is an important factor to account for when cross-comparing returns estimates across studies.

## III. Applications: Cost estimates, revenue estimates, and baseline projections

Building on the discussion in Section II, in this section we discuss how and where this evidence from the research literature could potentially inform three additional applications: CBO's cost estimates of legislative provisions related to federally funded R&D, the staff of the Joint Committee on Taxation (JCT)'s revenue estimates of R&D-related tax provisions, and modeling of R&D in baseline budgetary and economic projections such as the total factor productivity projections generated by the Federal Reserve and by CBO.

### *III(a). Cost estimates of legislation affecting federally funded R&D*

For legislative proposals that have been approved by a Congressional committee, CBO produces "cost estimates" which provide public estimates of how the legislation would affect the federal budget, relative to a counterfactual represented by CBO's baseline projection of budgetary and economic outcomes that would occur under current law. For bills that would alter the tax code, CBO incorporates "revenue estimates" produced by the staff of the Joint Committee on Taxation (JCT), which also independently publishes some of their revenue estimates.

A technical but important distinction that is central to cost estimates of R&D-related legislation is the distinction between discretionary spending bills and mandatory spending bills. Historically, nearly all federal funding for investment activities – including nearly all federal R&D investment – has been funded through annual discretionary appropriations acts. However, in recent years there have been important exceptions to that trend, such as the CHIPS and Science Act (117th Congress, H.R. 4346) which was legislation affecting mandatory (rather than discretionary) funding.

Although the distinction between discretionary and mandatory funding may be unfamiliar to most economists, this distinction matters in the federal budget process for a number of reasons.[16] For appropriation acts, Congress asks CBO to estimate the spending obligations (outlays) that would result from the budget authority provided in the bills. That is, the appropriators provide the budget authority amounts (the funding) and CBO estimates the amount and timing of the resulting spending (outlays).[17] As an example, consider Title VIII of the American Recovery and Reinvestment Act (ARRA) of 2009 (111th Congress, H.R. 1). This legislative provision provided the US National Institutes of Health (NIH) with approximately $10 billion in discretionary spending that was available for obligation for two years, through September 2010. A statement from the NIH's then-acting director Raynard Kington in February 2009 noted that NIH expected to spend as much of this stimulus spending as possible in fiscal year 2009.

Consistent with the NIH Director's statement, in CBO's cost estimate for this discretionary spending provision (CBO 2009) outlays for this provision were estimated to be fully obligated within the two years and spent over several years, perhaps reflecting the five-year length of the core R01 grants which are the bread and butter of NIH's extramural research support.

In contrast, for some mandatory spending bills – so-called "major legislation" – Congress asks CBO to provide more extensive information on the economic and budgetary impacts of the legislative provisions. In Washington DC budget parlance, "major legislation" is eligible for dynamic scoring as opposed to conventional scoring. The key distinction between conventional

[16] We refer interested readers to CBO's Frequently Asked Questions about CBO Cost Estimates: https://www.cbo.gov/about/products/ce-faq and Frequently Asked Questions: https://www.cbo.gov/faqs.
[17] Budget authority allows government agencies to incur obligations (for example, signing a contract for provision of goods) that may lead to current or future outlays (for example, payments on delivery as specified in the contract). While some discretionary budget authority is estimated, those are the exceptions.

and dynamic scoring is that the former excludes – by design – any impacts on labor, capital, productivity, and output. While dynamic scoring has most frequently been discussed for tax legislation, the House of Representatives currently requires, under the House rules for the 118th Congress, CBO and JCT to provide dynamic estimates, to the extent practicable, for all bills (that is, not just tax bills) that exceed a threshold size (in terms of gross budgetary effects) in any year of the budget window, or legislation that has been designated as "major" by the chair of the House Budget Committee or of the Ways and Means Committee (Congressional Research Service 2023); some version of that rule has been in effect for much of the past decade.

Elmendorf et al. (2024) provide a detailed discussion of dynamic scoring, and note that in practice the major legislation rule has directed CBO to provide Congress with dynamic cost estimates in a vanishingly small number of cases. Of note here is that, to the best of our knowledge, R&D-related legislative provisions have never qualified for dynamic scoring under the major legislation rule. However, our understanding is that there is no rule that would prevent CBO from conducting and reporting this type of more extensive, dynamic analysis for federally funded R&D-related provisions in the text of cost estimates for either mandatory spending bills or in the text of cost estimates for annual appropriations acts, either at the request of the Chairman or Ranking Member of the House Budget Committee or the Senate Budget Committee, or if e.g. the Labor, Health and Human Services, Education, and Related Agencies (Labor HHS) appropriations bill would qualify for dynamic analysis via the "major legislation" rule.

Let us end by briefly commenting on two additional issues. First, CBO's framework for federal investment (CBO 2021b) that we focused on in Section II does not explicitly account for potential changes in the US population which could arise as a result of changes in federal R&D. At a conceptual level, this issue arises because the *performers* for a large share of federally funded R&D are universities, non-profit organizations affiliated with universities, non-profit research institutions, and government research institutions for which – unlike for private firms – visas for foreign nationals are effectively uncapped. Two concrete examples are H-1B visas, for which these institutions are exempt from the H-1B cap that applies to private firms, and J-1 exchange visitor visas which are also uncapped (Nice forthcoming).[18] Given that a substantial

[18] Glennon (2024) provides a discussion of partnerships between firms and such cap-exempt entities – such as through the Open Avenues Foundation, a non-profit organization that partners with universities – to exploit this arbitrage opportunity by matching cap-exempt employers with cap-subject employers. She

share of federally funded R&D is spent on labor (such as training graduate students and post-docs), and that a substantial share of graduate students and post-docs are foreign nationals[19] who express (in surveys[20]) a desire to stay in the US post-graduation if allowed to do so, it seems plausible that changes in federally funded R&D could translate into changes in the US population if funding (rather than trained scientists) is the key constraint on the size of scientific labs at many universities and non-profits. In that case, changes in federal R&D could retain graduate students and post-docs in the US population for a longer time than they would have otherwise stayed in the country. Freeman and Van Reenen (2009) and Tham et al. (2024) provide some evidence for the empirical relevance of this effect: the former documents suggestive evidence that the doubling of NIH funding under the ARRA in 2009 generated an increase in foreign national biomedical researchers at US universities; the latter documents evidence that delays in NIH grant support induced by continuing resolutions result in some foreign national scientists leaving the US, as measured by non-presence in Census data. To the extent that changes in federally funded R&D induce changes in the US population (which are not accounted for in CBO's conventional cost estimates), that may have separate budgetary effects including changes in outlays for federally funded benefits and tax revenues (primarily income and payroll taxes).[21] In addition, as illustrated in CBO's recent work on immigration (CBO 2024), the agency models total factor productivity as changing with the number of immigrants who are STEM workers, which would also be a relevant follow-on effect to be modeled in this case.

Second, Elmendorf et al. (2024) discuss some practical issues that would arise in implementing more dynamic analysis of R&D in legislative provisions. Because federal R&D is generally denominated in standardized units (dollars) with effects that are likely to scale mostly linearly over relevant ranges, modeling the impact of such investment can be simplified. They give the example of a spreadsheet that would report estimated dynamic effects for each dollar of additional funding through different agencies (say, the National Institutes of Health versus the

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gives the creation of Microsoft Research (a separate nonprofit entity) as another example of how firms can create separate nonprofit entities to hire skilled immigrants not subject to the H-1B visa cap.

[19] See, for example, Smith et al. (2024), in a brief from the National Center for Science and Engineering Statistics (NCSES) presenting data from the NCSES Survey of Graduate Students and Postdoctorates in Science and Engineering (among other data sources), on trends in graduate enrollment and post-doctoral appointments by citizenship status.

[20] See Nice (forthcoming) for a discussion of the relevant literature, based on data from the National Science Foundation's Survey of Earned Doctorates and Survey of Doctorate Recipients.

[21] See Elmendorf and Williams (2024) for one analysis of the budgetary effects of changes in the US population of advanced degree holders in STEM (science, technology, engineering, and mathematics) fields.

National Aeronautics and Space Administration) and for different purposes (say, basic R&D versus applied R&D) that could be updated with each baseline and allow such effects to be included in legislative cost estimates on compressed timelines.[22]

*III(b). Revenue estimates of changes to the tax code affecting privately funded R&D*

Expensing of research and experimentation expenditures has been a central topic of policy discussions in recent years before, during, and after the implementation of the 2017 tax act (115th Congress, H.R. 1). As noted in Section III(a), the staff of the Joint Committee on Taxation (JCT) is responsible for producing revenue estimates for legislative provisions that would alter the tax code, while CBO is responsible for incorporating the agency's projections of both budgetary and economic outcomes under current law (including current tax law) in their baseline projections. Consistency would align both (1) JCT and CBO's frameworks for modeling the projected effects of tax provisions changing the after-tax price of private R&D, and (2) modeling of private R&D with the projected effects of changes in federally funded R&D, adjusting for the key differences between private R&D and federally funded R&D. An advantage of consistency is that Congress and the public would receive the same information from each agency about legislative provisions that would be equivalent in their budgetary and economic effects. A disadvantage of such alignment is that Congress and the public would not receive signals about divergence between the conclusions of the two agencies that can serve as checks and balances in the estimation process.

The standard methodology that economists have used to summarize how features of the tax system – and changes to those features – change the price of investing in an additional dollar of R&D is to construct a so-called "user cost of R&D" (see, for example, Appendix A in Hall and van Reenen 1999; CBO 2018b; Burnham and Carloni 2022). The tax system affects the cost of R&D investments in two ways: taxing the revenue earned from the investment, and reducing the cost of the investment to the firm by depreciation allowances and investment tax credits. The net present value of a tax credit will depend on features such as whether the credit applies to

[22] For example, the estimates in Dyevre (2023) Appendix C.2 illustrate how his descriptive facts vary across federal agencies: NIH (HHS)-funded patents are much more closely linked to basic science research than are NASA-funded patents, NASA-funded patents are much more likely to open new technological fields in the patent data than are Department of Transportation-funded patents, and NIH (HHS)-funded patents generate spillovers across a wider range of patent classes than do Department of Energy-funded patents. While not directly translatable into agency-specific dynamic effects, this conceptual approach and these types of estimates could form the basis for such tabulations.

total or incremental expenditures, and how the base level of expenditure is defined in the incremental case, among other factors.

Bloom et al. (2019) summarize the evidence on how R&D-related tax provisions affect various outcomes, and argue that – taking the macro and micro studies together – a reasonable overall conclusion would be that a 10 percent fall in the tax price of R&D results in at least a 10 percent increase in R&D. With such an estimate of the elasticity of R&D with respect to tax-adjusted user cost in hand, one could then draw estimates of the productivity effects of private R&D directly from the literature (for example, Dechezleprêtre et al. 2023 directly test how changes in R&D tax incentives affect firm-level productivity), or from the literature discussed in Section II. Combining these estimates would enable an estimate of the effect of changes in R&D tax provisions on productivity that would be consistent with the analogous effects that CBO would estimate for federally funded R&D as detailed in Section II.

*III(c). Accounting for R&D in baseline budgetary and economic projections*

To the extent that R&D affects total factor productivity – as suggested by the research literature – then it is natural to ask how R&D is currently accounted for in baseline budgetary and economic projections, such as the total factor productivity (TFP) projections generated by the Federal Reserve and by CBO.

A standard growth accounting framework calculates TFP growth as productivity growth minus the contribution from capital deepening and minus an adjustment for changes in the composition of the labor force. Before statistical agencies started capitalizing R&D in investment and capital measures, any effects of R&D would implicitly land in the TFP growth term. However, after statistical agencies changed to count R&D as a capital asset (which, as discussed in Section II, BEA did for the US starting in 2013), R&D then changed to be a type of capital that would be included in the contribution of capital deepening term subtracted off from productivity growth to calculate TFP growth.

A number of measurement questions naturally arise: is it reasonable to measure the stock of R&D by cumulating R&D spending with an adjustment for depreciation? BEA measures R&D expenditures based on NSF survey data, such as the NCSES *National Patterns of R&D Resources* survey of R&D performers. Given that roughly 60% of federally funded R&D goes to so-called “indirect” costs, there is a question of whether physical infrastructure (such as scientific labs) funded via indirect costs would show up as private infrastructure investments even if the returns to those private investments should potentially be attributed back to the public R&D support. Of the roughly 40% of federally funded R&D which goes toward direct costs, a substantial share pays for the labor (time) of faculty, post-docs, trainees, and students. While faculty salaries seem appropriate to model as R&D investment, analogous to wages of construction workers being modeled as physical investment, a question naturally arises of whether spending on training (of post-docs, trainees, students) should instead be modeled as human capital investments (with e.g. different estimates of depreciation), or parametrized directly in a TFP adjustment.

Setting these types of measurement issues aside, there is a separate question of how this type of measurement does currently or should ideally relate to how R&D (both private and federally funded) is accounted for in forecasts of TFP.[23] Standard TFP forecast approaches are historical, and solely backward looking, in which case even large changes in federally funded R&D would not affect the TFP forecast. For changes in R&D spending that are sufficiently different from the historical trend, relative to the size of the economy, one could parametrize an off-model adjustment to the TFP forecast; a natural basis for such an off-model adjustment would be the framework presented in Section III (from CBO 2021b).

Alternatively, and more speculatively, one could move to a more factor-based TFP forecasting model. To draw on an analogy, consider CBO’s current methodology for forecasting interest rates (see, for example, Appendix C of Gamber 2020). CBO identifies a historical benchmark period and a set of factors that economic theory has shown to be important in determining interest rates, calculates the averages of those factors over the historical benchmark period and estimates them over the projection period of interest, and then applies a set of parameters derived from a Cobb-Douglas production function and the research literature to estimate how the projected changes in each of the factors between the benchmark period and the projection period would affect interest rates. Of course, forecasting productivity rates and forecasting interest rates are two different problems that are perhaps difficult in different ways. In a recent *Journal of Economic Perspectives* article, CBO staff (2024) expressed interest in additional research on both topics.

[23] One point of awkwardness in the literature is that the standard Basu-Fernald-Kimball (2006) method of TFP forecasting uses quarterly growth rates of real government defense spending as instruments which is problematic if defense R&D directly affects TFP, as that would be a violation of the exclusion restriction.

## V. Conclusions

Many US federal agencies model the economic and budgetary effects of R&D investments as if R&D is the same as any other form of investment, such as physical capital investment. Our reading of the research literature is that a broad base of evidence suggests that such modeling may result in budgetary and economic projections that are not well-aligned with what would be expected based on the evidence in the economic literature. This paper examines how the research literature provides evidence about how changes to R&D tax and subsidy policies would be expected to affect economic and budgetary outcomes.

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