Estimating the budgetary and economic effects of research investments

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Introduction

Both researchers and policy makers have long recognized innovation as the key driver of long-term economic growth. From a policy perspective, one of the key ways in which developed country governments aim to promote innovation is through subsidizing research and development (R&D) investments, either through providing direct funding for R&D or via tax provisions that aim to change the rate and/or direction of privately funded research investments.

When Congress wants to understand the budgetary impacts of such policies, they request budget estimates from the Congressional Budget Office (CBO) and the staff of the Joint Committee on Taxation (JCT). For R&D spending, traditional or so-called conventional cost estimates from CBO tabulate the spending (outlays) associated with such policies. Notably, such conventional cost estimates do not attempt to take into account how such policies could potentially affect productivity and growth in the US economy; such effects are included in so-called dynamic cost estimates but not in conventional cost estimates.

In 2018, CBO published a discussion of how the agency assesses the specific effects of changes in federal subsidies for R&D, and highlighted areas in which additional research would enhance the agency's capacity to evaluate the macroeconomic effects of R&D spending (CBO 2018) – effects that would be relevant for CBO's baseline modeling but also for dynamic cost estimates of R&D-related legislation. Since that writing, the economics literature has made notable progress in building out empirical evidence – at both the micro- and macro-level – on the economic effects of federally funded research investments. Particularly given that this progress in the academic literature is coincident with active Congressional interest in both federally funded research (such as the CHIPS and Science Act, H.R. 4346) and research-related tax incentives (such as the R&D expensing provisions in the TCJA, H.R. 1), it is a natural time to take stock of how CBO and the staff of the JCT currently estimate the budgetary and economic effects of R&D-related legislation, and to discuss potential updates they may wish to consider based on these recent advances in the literature.

We first discuss these recent advances in the literature, placing them in the context of the past literature. Building on this body of evidence, we then present an illustrative dynamic analysis of federally funded R&D investments. Because CBO has traditionally modeled the macroeconomic and budgetary effects of federal investment in physical capital, education, and R&D in a unified framework (see, for example, CBO 2013 and CBO 2016), it is natural for our

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analysis to build directly on CBO's 2021 report that provides an illustrative dynamic analysis of how increases in physical infrastructure spending would affect private-sector productivity and economic growth. The bottom line that emerges from us applying that framework to the case of federally funded R&D is clear: the estimated budgetary impacts of legislative proposals changing federally funded R&D are substantially different – during the 10-year budgetary window – when effects on productivity and growth are included (as in dynamic cost estimates) versus excluded (as in conventional cost estimates). Taking that – albeit, tentative – conclusion as a starting point, we then proceed to discuss practical implications for budgetary analysis at CBO and JCT.

Evidence on the economic effects of federally funded R&D

In the 1950s, two strands of the economics literature emerged that tackled different aspects of the relationship between innovation and growth. Solow (1956) and Swan (1956) published – nearly simultaneously – neoclassical aggregate production function-based models of long-run economic growth. One particularly notable consequence of the Solow-Swan model is that (simply stated) in the absence of improvements in the state of technology, there would be no sustained economic growth. However, the Solow model generates growth only by introducing an exogenous rate of technological progress (exogenous in the sense of being independent of economic forces). Essentially, the model is driven by a technological "black box," with no microfoundations for what factors drive technological progress. 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 – early estimates indicated ~85 percent, although subsequent statistical refinements and modifications of the model reduced the size of that estimate. Subsequent work suggested that the bulk of this "Solow residual" could be explained by technological progress. Hence, both theoretical approaches and empirical (accounting) approaches suggested that innovation was key to economic growth.

Subsequent work focused on innovation-based endogenous growth models (e.g., Romer 1990, Aghion-Howitt 1992, Grossman-Helpman 1991). Neoclassical models such as the Solow-Swan framework have the implication that growth is pegged to the exogenous rate of technological change. In contrast, the key feature of these so-called endogenous growth models was that they 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 set-up 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: namely, because ideas are public goods, in the sense of being both non-rival and non-excludable, we would expect new ideas to be under-provided by the private market (see, for example, Nelson 1959 and Arrow 1962). Even with a well-designed intellectual property rights system in place, ideas are

generally perceived as being promiscuous, in the sense that the benefits of new ideas are typically difficult to fully monetize.

That said, economic theory also suggests that research investments in a market economy could be either too high or too low, depending on the net size of such knowledge spillovers relative to what are often referred to as product market spillovers. The key idea behind product market spillovers is that a new invention may steal market share from other firms without necessarily generating any social benefit. A classic example is the case of pharmaceuticals, where one firm may spend billions of dollars to develop a drug that is only incrementally better than a drug produced by a rival firm – a "me too" drug. However, the small improvement in therapeutic value may allow the second firm to capture nearly the entire market. In cases where "me too" drugs are therapeutically indistinguishable from the products that they replace (and setting aside the possibility that such drugs may generate benefits such as price-cutting competition), this dynamic potentially generates a large private benefit for shareholders of pharmaceutical firms with little gains for patients.

In practice, the empirical evidence suggests that – even after accounting for business stealing effects – the social returns to R&D are much higher than the private returns. Bloom, Schankerman, and Van Reenen (2013) leverage cross-state variation in R&D tax credits combined with cross-firm variation in technology space (patenting) and product market space (sales activity) to separately identify knowledge spillovers and product market spillovers; their estimates suggest the social returns to R&D are 2-4 times as large as the private returns. Jones and Summers (2022) likewise argue, based on a more indirect approach, that the social rate of return to R&D is likely to be quite high.

This evidence suggests that knowledge spillovers exist, and are quantitatively important in magnitude – providing a justification for government-supported innovation policy. However, the challenge remains, as Griliches (1992) described, to "detect the path of the spillovers in the sands of the data." Governments can affect incentives for innovation through a variety of different policy levers – federally funded R&D, tax policy, intellectual property policy, competition policy, immigration policy – and the question of which of these policies are effective in generating knowledge spillovers and productivity growth in practice is an empirical question.

In the last decade, several empirical papers made important progress on this question by unpacking the role of federally funded R&D in generating knowledge spillovers. 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 – and, importantly, are observed

within the 10-year budget window. For example, Figure 5 of Azoulay et al. (2019) suggests that roughly 35 percent of NIH grants are cited in a patent relevant to an FDA approved drug within 10 years. 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 very similar conclusions which, together with the evolution of the literature described above, increases our confidence in the economic magnitude of 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, and apply that data to structurally estimate the returns to federally funded R&D. Their estimates imply returns of 150-300 percent, and suggest that federally funded R&D is responsible for around 25 percent of post-war productivity growth in the US. Because the Fieldhouse and Mertens framework is similar to CBO's workhorse frameworks, the estimates from this paper will be most central to our illustrative dynamic analysis.

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, and notes (see footnote 11) that his implied elasticities are close to those reported by Fieldhouse and Mertens (2023).

In our illustrative dynamic analysis, we will also rely on estimates from a recent paper by Kantor and Whalley (forthcoming), who use historical data on federal R&D spending during the Space Race to estimate local and national fiscal multipliers of that spending. Their estimated local fiscal multiplier is around 2.4-3.8 (with a similar national multiplier), which is notably larger than the consensus estimates cited in recent surveys by Chodorow-Reich (2019) and Ramey (2011), who support estimates of 1.8 and 0.5-2.0 respectively.

Finally, it is worth relating this evidence to two specific aspects of CBO's current or past modeling of R&D as exposited in CBO (2018). First, CBO 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 recent literature generally provides support for such a distinction. For example, Fieldhouse and Mertens (2023) 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 (2021) – who focus exclusively on defense R&D – estimate smaller productivity effects.

Second, CBO notes that in the absence of other evidence, they estimate 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. Notably, estimates from the literature discussed above – 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. In our work, as we will describe, we will parametrize the expected timing of effects based on Fieldhouse and Mertens' (2023) impulse response function estimates.

An illustrative dynamic analysis of the budgetary and economic effects of federally funded R&D

Our illustrative dynamic analysis of the budgetary effects of federally funded R&D builds closely on CBO's 2021 report that provides an illustrative dynamic analysis of how increases in physical infrastructure spending would affect private-sector productivity and economic growth.

The key components of this framework – and notes on modifications (where relevant) that we make in order to apply this framework to the case of federally funded R&D – are the following:

1. **How state and local governments respond to additional federal funding.** In the context of R&D, state and local R&D spending is negligible. However, an important analogous issue is complementarity or substitutability of public R&D with private R&D. CBO (2018) notes that, in CBO's judgment, federal spending for R&D has a small but noticeable positive effect on private R&D spending. The recent literature continues to support this conclusion. For example, Fieldhouse and Mertens (2023) note that increases in private R&D are relatively small, particularly in response to nondefense shocks. To be conservative, we assume this effect is negligible.
2. **How quickly funding leads to outlays.** For the provisions we model, we follow two past examples of CBO's assumed schedules of the relationship between funding and outlays.
    a. We first model the provision in Title VIII of H.R. 1, the American Recovery and Reinvestment Act of 2009, which provided the US National Institutes of Health (NIH) with approximately $10 billion that was available for two years, through September 2010. A statement from the NIH's Director in February 2009 noted that they expected to spend as much as possible in fiscal year 2009. CBO's (conventional) cost estimate for this bill (CBO 2009) estimated the outlays for this

provision in a way that presumably reflects – consistent with the NIH Director's statement – allocation of the funds early in the budget window, but continuing for 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. An advantage of modeling this provision is that this "shock" to the NIH budget aligns analytically with the thought experiment because the impulse response functions estimated in Fieldhouse and Mertens (2023).

   b. Second, we model the outlay schedule associated with a constant per-year increase in federally funded R&D, following the analysis in CBO's 2021 report.

3. **How quickly outlays increase productivity.** CBO's 2021 report assumes that for every $1 billion increase in infrastructure spending, $400 million would fully affect the private sector's productivity in the first year after the spending, $800 million would fully affect productivity in the second year after the the spending, and the entire amount of spending would have affected productivity seven years after the spending. We replace this assumed schedule of how outlays affect productivity with Fieldhouse and Mertens (2023)'s impulse response function estimated relationship between their R&D shocks and total factor productivity (Figure 6).
4. **How much outlays increase productivity.** CBO's 2021 report estimates a gross return on publicly funded infrastructure of 12.4 cents for every dollar of spending; they assume a depreciation rate of those assets to be 3.2%, implying a net return of 9.2 cents for every dollar of spending. Fieldhouse and Mertens (2023) apply a higher depreciation rate for R&D of 16% (rather than 3.2%), which they describe as the average depreciation rate for government R&D calculated by BEA. After applying that higher depreciation rate, their estimated net return on publicly funded R&D is $2 for every dollar of spending.
5. **How outlays are financed.** We follow CBO's 2021 report in modeling two scenarios: one scenario in which this research spending is financed by spending cuts elsewhere in the budget, and a second scenario in which this research spending is debt financed.

In the second (debt financed) scenario, we also consider the local multiplier effect that comes from government spending stimulating economic activity before the long term productivity effects of R&D kick in. In the first scenario, since we are offsetting this spending program with decreases elsewhere in the federal budget, this effect nets out to zero if the local multiplier effects of federally funded R&D are similar to the local multiplier effects that would have occurred from whatever spending program was reduced. Given the evidence from Kantor and Whalley (forthcoming) who estimate a local fiscal multiplier for federally funded R&D of 2.4 during the Space Race and 3.8 after the Space Race, local multiplier effects from federally funded R&D in practice appear to be higher than the consensus estimates cited in recent surveys by Chodorow-Reich (2019) and Ramey (2011), who support estimates of 1.8 and 0.5-2.0 respectively.

In its own work, CBO frequently translates estimated changes in GDP into budgetary changes using its budgetary feedback model (Frentz et al. 2020). For our purposes, we simplify and assume the government collects a fixed fraction of GDP as revenues, which we approximate

based on CBO's reported estimates of how changes in GDP relate to changes in the deficit. That approximation suggests that each dollar of GDP decreases deficits by about 10 cents.[2]

Given these assumptions, we can estimate the budgetary effects of an assumed schedule of outlays under both conventional and dynamic approaches. Our paper will present and compare these estimates.

Accounting for the economic effects of R&D in CBO's budgetary and economic estimates

By default, CBO's baseline projections are fully dynamic, so would already incorporate – up to any updates from the new literature – the effects illustrated above.

However, CBO's cost estimates – by default – are conventional, and would not include the dynamic effects illustrated above. Historically, the lion's share of direct federal funding for R&D is provided through annual appropriations bills.[3] CBO provides formal estimates of appropriation acts, but those estimates take the form of data runs that provide estimates of the spending (outlays) that would result from the budget authority provided in the bills (that is, the appropriators provide the Budget Authority amounts and CBO estimates the spending/outlays). Some discretionary Budget Authority is estimated, but those are the exceptions.

However, our understanding is that there is no rule that would prevent CBO from conducting a dynamic analysis of federally funded R&D-related legislation either at the request of the Chairman or Ranking Member of either 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.

Accounting for the economic effects of R&D in JCT's budgetary and economic estimates

According to tabulations by the US Treasury, the tax credit for increasing research activities has been, in recent years, one of the twenty largest US tax expenditures in terms of total projected revenue effects – roughly 25 billion dollars in 2023. Expensing of research and experimentation expenditures has also been a central topic of policy discussions in recent years after the TCJA temporarily allowed full expensing (that is, 100% bonus depreciation) through 2022, phasing down through the end of 2026.

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[2] While this is obviously quite a rough approximation, the implied estimates are similar to those reported in an earlier CBO report on federal investments (CBO 2016). In that report, CBO considers four policies, which vary in amounts, schedules, and financing. One of the four policies is similar to the deficit neutral investment modeled in CBO's 2021 report. Given that we are fundamentally interested in the "exchange rate" between an additional dollar of GDP and the government's balance sheet, we divide the column of yearly decreases in the federal deficit by the matching column of yearly increases in GDP and obtain an average of .12, which is roughly similar to the .1 figure derived above.

[3] More recently – say, the past four years – much of the funding provided for federal projects has been direct/mandatory spending rather than discretionary/annual appropriations.

In a recent article in the *Journal of Economic Perspectives*, Bloom, Van Reenen, and Williams (2019) summarize the evidence on the effectiveness of different policy levers in spurring research investments. They categorize R&D tax credits as one of only two areas (along with high skilled immigration) where the quality and conclusiveness of the evidence is quite clear, 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 in the long run. Stated differently, the absolute elasticity of R&D with respect to its tax-adjusted user cost appears to be unity or greater.

With such an estimate of the elasticity of R&D with respect to tax-adjusted user cost in hand, if one is willing to make assumptions about the relative fiscal multiplier and productivity effects of federally funded R&D relative to private R&D (for example, CBO traditionally estimates that federal nondefense R&D yields about three-fourths of the effect on output that private investment yields[4]), one could start with the academic literature's estimates of how federally funded R&D affects productivity and translate those estimates into the implied productivity effects of tax expenditures from provisions related to private R&D investments (both credit and expensing provisions).

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[4] See CBO (2018): "*CBO estimates that federal nondefense R&D yields about three-fourths of the effect on output that private investment yields (from all types of investment, including R&D). CBO bases that productivity estimate primarily on researchers' estimates of the productivity of investment in public physical capital because there are few estimates of the direct effect on output of federal investment in R&D.*"

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