SUPPLEMENTAL APPENDIX to
AI as an Innovation in the Method of Innovation:
Implications for Productivity Growth

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This appendix has three sections. The first reviews the measurement of software R&D; the second discuss the selection of software-producing industries, and the third reports the detailed table referred to in the "Empirical Results" section of the main paper.

1 Software R&D investment: Sources and Estimation Methods

Statistics on software R&D are collected through surveys conducted by the Census Bureau and sponsored by the National Center for Science and Engineering Statistics (NCSES) of the National Science Foundation. These data are obtained from survey questions on R&D by "technology focus" or "technology area," and have been published in the data tables of the Business Enterprise Research and Development Survey (BERD, previously BRDIS) and its predecessor, the Survey of Industrial Research and Development (SIRD), beginning with the tables for R&D expenditures in 2001.

Collecting and assembling these data in a consistent times series involves several steps, including retrieval of archived statistics and reconciliation of definitions and conceptual frameworks. Many of these procedures follow Moris (2019). Specifically, raw data from BERD are used from 2013 onward. Series from 2002 to 2012 are constructed using the available SIRD data, supplemented with estimates. Prior to 2002, software R&D estimates are based on information on the cost of developing software originals from the national accounts as reported in Crawford et al. (2014) and in BEA's fixed asset accounts. The final results are adjusted to be consistent with the measures of business R&D investment in national accounts as discussed below.

1.1 Survey definition

As reported in (Moris, 2019, pages 5-6), Software Product and Embedded Software R&D has been defined in the BERD survey since 2013 as follows: "R&D activity in software and Internet applications refers to activities with an element of uncertainty and that are intended to close knowledge gaps and meet scientific and technological needs." Further, respondents are instructed that "R&D activity in software includes

- Software development or improvement activities that expand scientific or technological knowledge
- **Construction of new theories and algorithms in the field of computer science R&D activity in software** and excludes:
  - Software development that does not depend on a scientific or technological advance, such as supporting or adapting existing systems, adding functionality to existing application programs, and routine debugging of existing systems and software
  - Creation of new software based on known methods and applications
  - Conversion or translation of existing software and software languages
  - Adaptation of a product to a specific client, unless knowledge that significantly improved the base program was added in that process"

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For the years 2007 to 2012, the survey asked respondents to report software product R&D and embedded software R&D separately; for these years the survey did not consistently collect information on sources of funding, and data by technological focus for 2009 were not published. From 2001 to 2006, the survey asked companies to report their costs of "software product development."

1.2 Software R&D vs. AI R&D

With the 2021 BERD survey, NCSES began reporting expenditures on AI R&D. Respondents are told that AI is defined as: "Artificial Intelligence (AI) is a branch of computer science and engineering devoted to making machines intelligent. Intelligence is that quality that enables an entity to perceive, analyze, determine response, and act appropriately in its environment." The 2022 survey reported that business expenditures on AI R&D were $37,014 million (all sources of funding) and $33,416 (paid for by the company). By contrast, expenditures on software R&D paid for by the company in that year were *larger by a factor of eight*.

The new question on AI R&D was added to the section of the survey that requests information on the "technological focus" of R&D activities. With this addition, the technological focus categories now include Software Product and Embedded Software, Biotechnology, and Nanotechnology, and Artificial Intelligence. The survey instructions for the R&D-by-technology-focus section note that "you may report the same R&D in multiple areas [of technological focus]." While this design allows the survey to capture embedded software R&D within areas such as biotechnology and nanotechnology, it also implies potential overlap between software R&D and AI R&D.

In addition, as noted in the preceding subsection, beginning in 2013 the survey instructions explicitly directed respondents to include the "construction of new theories and algorithms in the field of computer science" in software R&D. This guidance suggests that activities currently classified as AI R&D were partially captured in earlier BERD software R&D statistics. To reflect this consideration and to avoid potential double counting arising from overlapping classifications, one-half of the reported AI R&D expenditures for 2021 and 2022 is reflected in the software R&D series used in this paper.

1.3 Measurement Concept

International BERD surveys are conducted in accordance with the OECD's Frascati Manual (OECD, 2015), which specifies that R&D expenditures include capital expenditures. The United States does not follow this convention in its headline BERD-based R&D measures. Instead, NCSES reports and analyzes US domestic R&D expenditures on a current-cost basis. Under this treatment, expenditures on capital assets and land are excluded, while consumption of fixed capital (such as computers and laboratories) is included as a current cost. Capital expenditures related to R&D are reported separately for purposes of international comparability.

Estimates of business investment in R&D in national accounts are developed from the BERD survey's current-cost measures of R&D funded by the business sector. These estimates differ from R&D performance measures, which include funding from other sectors of the economy. In a comprehensive revision issued in 2018, the Bureau of Economic Analysis (BEA) incorporated the value of capital services into its estimates of R&D investment to better reflect economic theory and international standards for the imputation of own-account production (Kelly, McCulla and Wasshausen, 2018). This procedure replaces the survey-based measures of consumption of fixed capital are replaced with estimates of capital income, which imputes a return to R&D assets.

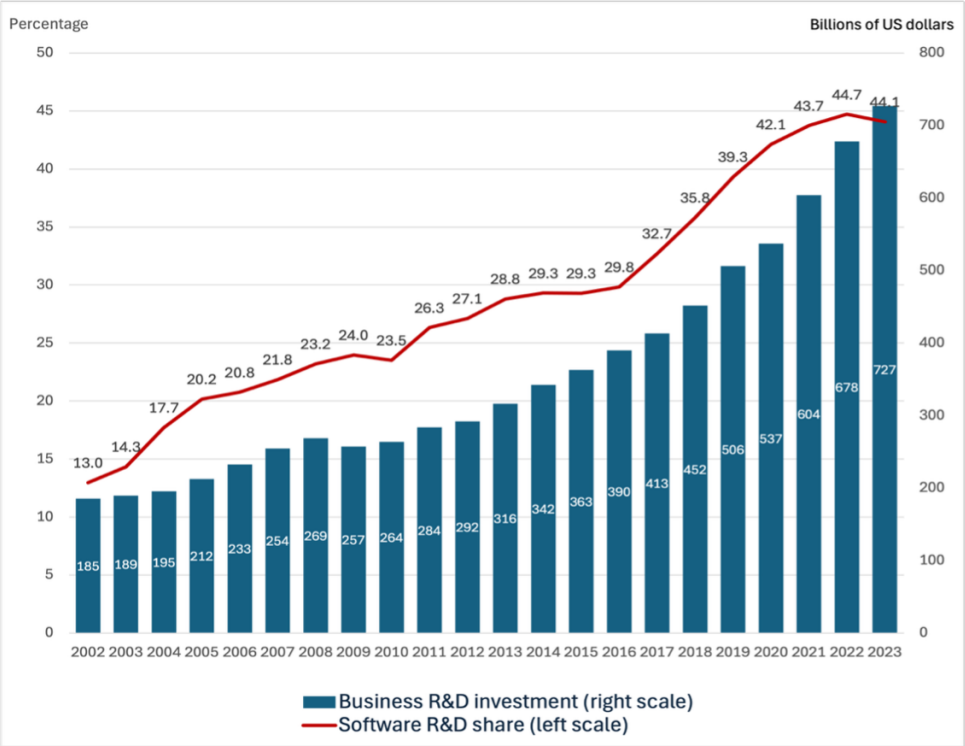
To construct a final time series consistent with the national accounts estimates of business investment in R&D, the ratio of software R&D funded by the business sector to total R&D funded by the business sector is used to allocate the BEA's estimates of business investment in R&D. The share of the resulting software R&D investment series attributable to software-producing industries is derived in a similar manner, with ratios based on NCSES data used to allocate the national accounts–consistent estimate of total software R&D.

1.4 Results

The resulting national accounts–consistent estimates indicate that software R&D represents a substantial component of business R&D investment. In 2022, the BEA series for business R&D investment—that is, R&D funded by domestic U.S. businesses—totaled $678 billion, of which nearly 45 percent ($303 billion) reflected software R&D. Of this amount, almost 60 percent ($178 billion) was performed within the three software-producing industries identified below. These estimates indicate both that software-producing firms devote substantial resources to the development of software products and internet-based software services, and that software R&D embedded within other R&D projects is quantitatively important.

The latter category totaled approximately $125 billion in 2022, with a large component reflecting software R&D embedded in the conduct of R&D on guidance and control systems.

Figure A1 presents these national accounts–consistent estimates. The figure shows that software products R&D as a share of total business R&D increased sharply beginning in 2017. Over the same period, total business R&D accelerated, growing at an average annual rate of 9.9 percent from 2017 to 2023, compared with growth of 5.9 percent in nominal U.S. GDP. As the share of software R&D increased concurrently, software R&D grew at an average annual rate of 15.5 percent, while software R&D performed by software-producing industries increased at an average annual rate of 16.3 percent.



Appendix Figure 1: Business R&D Investment and the Software R&D Share

Sources: U.S. Bureau of Economic Analysis, "Table 5.6.5. Private Fixed Investment in Intellectual Property Products by Type (accessed July 21, 2025). Software R&D shares, this paper.

2 Software Industries for Estimating the Production Effect

The Bureau of Labor Statistics (BLS) publishes annual estimates of total factor productivity (TFP) for the US nonfarm business sector, along with data on output, inputs and TFP by detailed industries. These data provide a natural starting place for measuring the production of software capital, which as explained in the main text comprises both software products and software R&D. The BLS system, following BEA which is the source for much of its underlying data, is coded using the 2017 North American Industrial Classification System (NAICS).

Identifying industries that specifically produce "software capital" in productivity data is not straightforward. The closest groupings in the BLS dataset include NAICS 511, 518-519, and 5415. However, these industries also generate various products and services in addition to software. For instance, Industry 511 encompasses both newspaper and print publishing as well as software product publishing. Industries 518-519 create platforms for data storage, internet publishing, cloud computing and infrastructure services, and numerous SaaS offerings. Industry 5415, which focuses on computer systems design, covers consulting, system management services, and custom software development. Importantly, all three of these industries are heavily involved in software R&D, accounting for 60 percent of the sector's total research and development efforts.

The inclusion of newspaper and magazine publishing in this grouping is potentially problematic. Classifying software with print media publishing at the three-digit NAICS level may have been reasonable at an earlier point in time, but continuing to combine these activities within a single industry in productivity statistics is increasingly outdated and difficult to justify in the AI era. That said, while the inclusion of print media may suggest that our measured software-producing sector is too broad, this concern is partly offset by the secular decline of print media, whose inclusion likely dampens measured TFP growth for the sector. Consequently, when the production effect is measured as the sector's production share multiplied by its TFP growth, these biases may partially offset one another.

3 Software Capital and Productivity Growth: Detailed Table

The following table provides the information on shares and breakouts by asset type discussed section IV of the main paper.

Appendix Table 1. Software Production, Use, and Software Capital Major Asset Types

	US Nonfarm Business Sector	2012 to 2017 (1)	2017 to 2024 (2)	Acceleration (3)
Production and Use of Software				
	Production (software industries)			
1.	Share of aggregate value added[1]	.052	.063	.01
2.	Total factor productivity (TFP) growth[2,4]	2.5	5.6	3.1
3	*Contribution to labor productivity growth*[3,4]	.13	.35	.23
	Use (software capital)			
4.	Share of aggregate rental payments[1]	.049	.069	.02
5.	Capital deepening[2,3]	5.9	9.8	3.9
6.	Contribution to labor productivity growth[3,4]	.29	.67	.38
	of which:			
	Software capital use in software industries			
7.	Share of rental payments[1]	.016	.025	.01
8.	Capital deepening[2,4]	5.0	8.5	3.6
9.	Contribution to labor productivity growth[3,4]	.11	.24	.14
Use of Software Capital Major Asset Types				
	IPP software capital			
10.	Share of aggregate rental payments[1]	.030	.035	.00
11.	Capital deepening[2,3]	5.6	9.3	3.7
12.	Contribution to labor productivity growth[3,4]	.17	.32	.15
	of which:			
13.	Contribution of software industries	.04	.08	.03
	Software R&D capital			
14.	Share of aggregate rental payments[1]	.019	.033	.01
15.	Capital deepening[2,3]	6.3	10.7	4.4
16.	Contribution to labor productivity growth[3,4]	.12	.35	.22
	of which:			
17.	Contribution of software industries	.06	.16	.10

Notes: Software industries are the NAICS 2017 511, 518-9, and 5415 industries. Software capital refers to the software products and software R&D. Shares are Divisia shares. TFP is reported on a value-added basis.
1. Percentage 2. Percent change 3. Percentage points 4. Based on natural log differences/points
Sources: Authors' elaboration of BLS productivity data files. Software R&D refers to estimates developed for this paper. BLS data last accessed June 4, 2024; NSF data last accessed June 25, 2025.

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