Journal of Economic Perspectives—Volume 36, Number 3—Summer 2022—Pages 3–28

Intangible Capital and Modern Economies

Carol Corrado, Jonathan Haskel,
Cecilia Jona-Lasinio, and Massimiliano Iommi

Every practitioner of economics, whether student or professional, will at some point be asked about growth, innovation, and economic performance. Why are many African countries so poor? How did Japanese car companies come to dominate world production? How did some firms like Walmart, Amazon, and Facebook get to be so big, while others like Sears, Webvan, and MySpace crashed and burned? At this point, the practitioner will recall the textbook account of a production function, in which output is a function of inputs of capital, labor, and technology. To make the abstractions concrete, most textbooks are peppered with examples from agriculture or manufacturing. In agriculture, capital is tractors, labor is farmworkers, and technology is the "know-how" of crop production. Technology or know-how is discussed broadly as advancing through research and development (R&D) and policies that govern the protection of patents and other forms of intellectual property.

■ *Carol Corrado is Distinguished Principal Research Fellow in Economics, The Conference Board, New York City, New York, and Senior Policy Scholar, Center on Business and Public Policy, Georgetown University McDonough School of Business, Washington, DC. Jonathan Haskel is Professor of Economics, Imperial College Business School, and an External Member of the Monetary Policy Committee, Bank of England, London, United Kingdom. Cecilia Jona-Lasinio is Senior Researcher at the Italian Statistical Institute (ISTAT) and Professor of International Economics at LUISS University, both in Rome, Italy. Massimiliano Iommi is a Senior Researcher, Italian Statistical Institute, and a Research Fellow, LUISS Lab of European Economics, both in Rome, Italy. Their email addresses are carol.corrado@conferenceboard.org, j.haskel@imperial.ac.uk, Cecilia Jona-Lasinio cjonalasinio@luiss.it, and Massimiliano Iommi miommi@luiss.it.*

For supplementary materials such as appendices, datasets, and author disclosure statements, see the article page at https://doi.org/10.1257/jep.36.3.3.

Table 1
The World's Largest Companies by Market Capitalization, March 31, 2021
(billions of US dollars)

Company name	*Market capitalization*	*Tangible assets*	*R&D assets*
Apple	2,051	344	75
Saudi Aramco	1,920	322	5
Microsoft	1,778	245	92
Amazon	1,558	330	137
Alphabet	1,393	300	105
Facebook	839	141	51

Source: PWC and company reports (market capitalization and tangible assets for 2020). R&D assets are authors' estimates of 2020 R&D stock based on time series of R&D spending from company reports.

But when this practitioner of economics encounters the real world, this basic production function approach exhibits some glaring holes. Table 1 sets out the world's leading companies by market capitalization in March 2021. Market capitalization refers to the total value of the company, based on stock market valuations. (It should be noted that some companies, like Saudi Aramco, remain primarily owned by the government of Saudi Arabia.) A first lesson from Table 1 is that the value of these companies is clearly not based on the textbook physical or "tangible" capital, which covers "property, plant, and equipment." The gap between tangible assets as reported in corporate annual reports and the market value of these companies is enormous, even though tangible assets do include, for example, Amazon's property, plant, and equipment in cloud server farms.

Perhaps then the value of these companies is more closely related to their "intangible" assets, that is, their "know-how"? The final column of Table 1 sets out an estimate of the capitalized value of spending on research and development by these companies, based on calculations by the authors that sum the value of past R&D spending by the firms and assume a depreciation rate of 15 percent. However, combining these figures with tangible assets does little to explain market capitalization.

In what follows, we will argue that understanding modern firms and indeed modern economies requires broadening the concept of capital beyond tangible assets to include intangibles, and that research and development spending is not the only way to capture intangible capital. Indeed, R&D spending is extraordinarily skewed by size of firm and by industry. The OECD (2017) reports, "In 2014, the top 10 percent of [the world's largest] corporate R&D investors (i.e., the top 200 companies with their affiliates) accounted for about 70 percent of R&D expenditure and 60 percent of . . . inventions patented in the [world's] five top IP offices." In the US economy, just four industry groups—chemicals, computer and electronic products, transportation equipment, and information services—accounted for more than 70 percent of R&D performed in 2018.[1] Many substantial industries including retail, finance, and most professional services—say, companies such as LinkedIn—do little or no R&D or patenting. But innovative firms do invest in other types of knowledge not classified as R&D: software tools, attributed designs, and strategies for improving brand awareness, business practices, services delivery, or managing after-sale services, and others.[2]

In what follows, we shall discuss intangible capital as reflecting investments in many types of knowledge-based, nonphysical assets. We begin by discussing what constitutes investment in knowledge-based assets and how accounting for such assets reshapes our thinking about macroeconomic data on investment. We then turn to issues of how intangible capital relates to growth theory and practical growth accounting. We consider how the growth and ownership of intangible capital may affect competitiveness across firms. We lay out some of the challenges underlying measurement of intangible capital and discuss how it affects estimates of productivity in the US and European economies in recent decades. Finally, we address the conundrum of why, despite a growth in intangible capital and what seems to be a modern technological revolution, productivity growth has slowed down since the Great Recession.

What Is Intangible Investment?

The potential importance of intangible investment in understanding the economy has deep roots in economics. For example, in the 1970s and 1980s, there were efforts to treat research and development as an intangible capital asset in both firm-level growth and neoclassical growth studies (Griliches 1973, 1979, 1986). The academic thinking about brand as strategic capital of the firm is rooted in the management/marketing literature that developed somewhat later (Farquhar 1989; Aaker 1991). But the significance of intangible investments in the structure of organizations and the macroeconomy did not emerge until the information technology-driven productivity "boom" of the late 1990s (Brynjolfsson and Hitt 2000; Brynjolfsson, Hitt, and Yang 2002). That boom was accompanied by a large widening gap between market valuation of firms based on equity markets and accounting valuations of firms based on the physical plant, property, and equipment—that is, gaps such as those shown in Table 1. Influential research from accounting underscored

[1] Based on our own calculations using figures reported by the US National Science Foundation at https://ncses.nsf.gov/pubs/nsf20316/.

[2] International standards for R&D surveys are set out in the Frascati Manual 2015 (OECD 2015) subtitled, *The Measurement of Scientific, Technological and Innovation Activities*. It defines R&D as activity that comprises "creative and systematic work undertaken to increase the stock of knowledge . . . [and] to devise new applications of available knowledge." R&D expenditure survey respondents are typically instructed to not include expenditures on efficiency surveys; management or organization studies; marketing research and consumer surveys; advertising or promotions; the payment for another's patent, model, production, or process; prospecting or exploration for natural resources; or research in connection with literary, historical, or similar projects (Moris 2018).

that brand names, new products, and intangible assets such as software-enabled procurement systems were key drivers of the financial outcomes of many of the nation's most innovative companies (Lev 2001). Indeed, Lev (2005) suggested that company reports consider new products/services development, customer relations, human resources, and organizational capital as assets. These observations and findings spurred measurement-oriented economists to pursue the notion that there was more to business investment than captured in standard macroeconomic measures (for example, Young 1998; Nakamura 1999, 2001).

The approach of Corrado, Hulten, and Sichel (2005, 2009) as summarized in Table 2 built upon these works. Their intangible assets approach expands the range of spending by firms that should be viewed as an investment. It applies a fundamental economic criterion that defines investment, namely, that business (or public) investments are outlays expected to yield a return in a future period.

The principle obviously applies to tangible spending and to research and development spending: for example, spending on a tractor or a robot is an investment, and so is R&D that yields a drug formula and software code that (say) guides a delivery truck more efficiently. In an economic sense, investments in industrial design, market development, employee training, organizational change, and even songs and film scripts likewise provide ongoing revenue. The categorization of intangible investment proposed by Corrado, Hulten, and Sichel (2005, 2009) suggests a wide class of intangible assets, from databases to business processes. The intangible assets listed in Table 2 are attractive for understanding the market capitalization of the companies in Table 1 because those companies tend to be based on software, data, design, operations networks, and brand.

The OECD (2013) has adopted the taxonomy in Table 2, using "knowledge-based capital" to describe it. The European Union, which since 2003 commissioned a series of studies of productivity accounts known as EU KLEMS—where the acronym stands for inputs of capital (K), labor (L), energy (E), materials (M), and services (S)—includes in its most recent version the complete list of intangible assets from Table 2 via an INTANProd production module for each country.[3]

Intangibles in Existing Data

To what extent do official macroeconomic and financial data incorporate intangible capital? The incorporation of intangibles into national accounts is moving, but slowly; their incorporation into company financial accounts has not progressed materially, and as matters now stand, the treatment of intangibles is conceptually inconsistent (for a recent self-assessment, see CPA Ontario 2021).

In official calculations of GDP, there has been a relatively recent recognition of certain intangible assets including R&D, mineral exploration, computer software (blended with internally produced databases), and entertainment, artistic, and literary originals—the assets "boxed" in Table 2. GDP arbiters have been hesitant

[3] The EU KLEMS & INTANProd database is available from the LUISS Lab of European Economics at LUISS University (https://euklems-intanprod-llee.luiss.it/).

Table 2
Intangible Capital: Broad Categories and Types of Investment

Digitized Information	• Software • Databases
Innovative Property	• R&D • Mineral exploration • Artistic, entertainment, and literary originals • Attributed designs (industrial) • Financial product development
Economic Competencies	• Market research and branding • Operating models, platforms, supply chains, and distribution networks • Employer-provided training

Currently included in GDP (boxed: Software; Databases; R&D; Mineral exploration; Artistic, entertainment, and literary originals)

Source: Authors' elaboration of Corrado, Hulten, and Sichel (2005, 2009).

to embrace the idea that the asset boundary of an organization encompasses intangible investments in industrial design, marketing and branding, management practices, and employer-provided training—the complete Table 2 approach—for some reasons we elaborate on below.

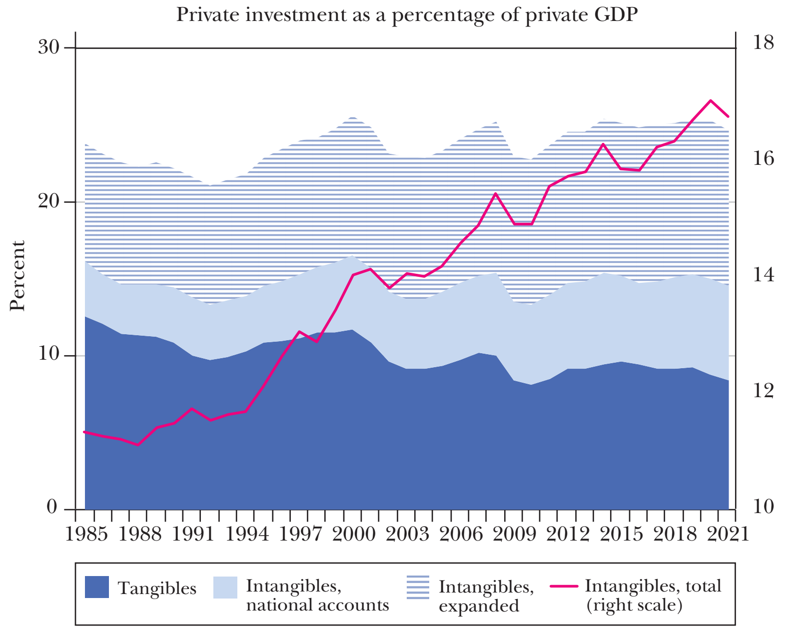
The standards for reporting intangibles into company accounts are problematic and asymmetric. For example, International Accounting Standard #38 on "Intangible Assets"[4] generally disallows the capitalization of most internally generated intangible assets, like most R&D, software, and brand/organization development costs, but it allows capitalization of externally generated intangible assets like patent portfolios and customer lists when acquired via merger activity. Researchers who use values for intangible assets on firms' balance sheets should be aware that they largely arise from acquisitions, not from production, thus creating a situation in which changes in reported assets do not reflect actual investment flows in an economy.

Intangible Investment in the Macroeconomy

Implementation of an expanded framework for investment and intangible capital provides a new view on the characteristics and performance of the

[4] Available at https://www.ifrs.org/issued-standards/list-of-standards/ias-38-intangible-assets/.

Figure 1
Rates of Private Nonresidential Investment in the United States, Tangible and Intangible, 1987 to 2021



Source: Authors' elaboration of data on investment by broad category from the US national accounts and US intangibles module of EU KLEMS & INTANProd.
Note: GDP includes all intangible investment.

macroeconomy. Figure 1 shows rates of private nonresidential intangible and tangible investment based on this framework for the US economy since 1985. Following Table 2, it separates intangible investment that is included in national accounts from the whole. The rate for tangible investment, the dark shaded portion at the bottom, drifts down 4 percentage points over the period shown, from about 12½ percent of private sector GDP in 1985 to about 8½ percent in 2021. Total investment in the economy, which adds investment in intangibles and is shown by the sum of the shaded areas, edges up by more than 1 percentage point, driven by growth in the relative importance of intangible investment. Indeed, the rate of total intangible investment (plotted separately as a line on the right scale) rises rather dramatically over the period shown and now stands at about 16¾ percent of GDP.

Another message from Figure 1 is that total investment in intangibles in the United States substantially exceeds components included in official statistics; the same can be said for the major economies of Europe. Practitioners analyzing macroeconomic trends, who may have been taught that research and development is a sufficient proxy for innovation effort, should be aware of the relative magnitudes displayed in Figure 1. Regarding private R&D, in cross-country data covering selected countries in Europe and the United States (described below), the correlation between growth in R&D capital and total intangible capital excluding R&D is 0.32. The correlation between the official components of intangible capital and the expanded components is 0.28. These correlations suggest that much is missing in official macroeconomic data on private investment.

Although the primary focus of this paper is on how intangible capital affects growth and competitive mechanisms in economies, some preliminary work suggests that the rise of intangible capital as a strategic factor input also has the potential for altering cyclical patterns. This includes patterns of investment and factor input demands, and perhaps the responsiveness of inflation to economic conditions in the short run. Research on the formulation of investment demand argues that intangibles are less sensitive to changes in interest rates than tangibles, reflecting their higher user cost and tendency to be less reliant on secured debt financing (for example, Crouzet and Eberly 2019; Haskel and Westlake 2018, chapter 8; Döttling and Ratnovski 2020). Figure 2 displays fluctuations in the intellectual property products (that is, intangibles already included in national accounts) as a share of private nonresidential investment, using quarterly data for the United States. Notice that during the recession periods (shown as shaded bars) these investments tend to keep rising, which suggests that these investments are the last category of capital spending cut during downturns.

Businesses may view the acquisition of software (and other intangibles) as moves to increase efficiency that dampen the impact of workforce layoffs and cutbacks in customer demand. The fact that intangible capital increasingly reflects knowledge built from the analysis of data likely explains the recent persistence of its relative strength; as an example, half of the respondents in global survey of companies administered by McKinsey & Company reported that the pandemic-induced economic downturn had no effect on their investments in artificial intelligence, while 27 percent reported increasing them (Zhang et al. 2021, p. 103). An implication is that intangible capital (or some forms of it) may help firms to adjust production relatively rapidly to changes in economic conditions.

Intangible Capital and Growth Theory

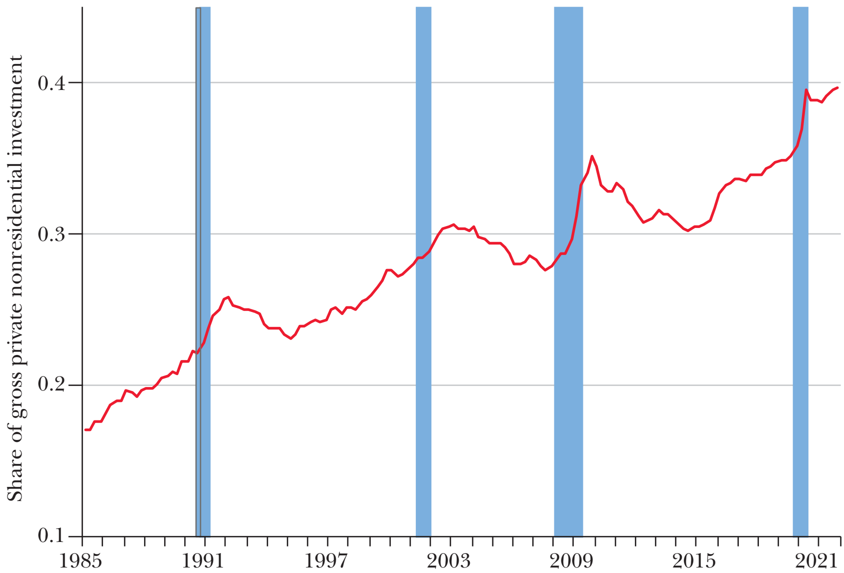
Here, we review how the intangibles approach relates to neoclassical and endogenous growth theory, as well as to strands of literatures concerning human capital, management, and business innovation.

How Does the Intangible Capital Approach Fit into Growth Theory?

The standard production function begins with output as a function of (quality-adjusted) inputs of capital and labor. The empirics of standard growth accounting are a powerful macroeconomic tool, so it is useful that the intangible capital framework augments standard growth accounting, rather than seeking to replace it.

One way of understanding how the intangible investment framework builds on the standard aggregate production function is to recognize that, as Milgrom

Figure 2
Intellectual Property Products Investment in the United States, 1985:I–2021:IV



Source: Authors' elaboration of quarterly data from the national income and product accounts.
Notes: Intellectual property products include software, R&D, and entertainment originals. Shaded areas are periods of business recession as defined by the National Bureau of Economic Research.

and Roberts (1990) have argued, the standard approach says nothing about what might be called the "coordination activities" within a firm required in production. A standard macroeconomic production function approach describes a set of possible production plans, but is not explicit about the costs of coordinating or managing their combination. Evaluating alternative plans, managing supply chains, and balancing competing interests in an organization is costly. If such costs are integral to generating ongoing returns, then such costs are investments. The intangibles approach accounts for "coordination activities" as long-lived investments in process efficiencies by grouping spending on new or reorganized business models under the heading of investment in organizational capital.

The standard production function approach also says little about "informative activities" that build long-lived demand, activities like marketing, market research, customer development, product promotion, and brand-building. The recognition of these activities as investment captures the insight that customer adoption of new products and new technologies typically is far from costless. Instead, such investments expand demand (and thus productive capacity) rather than change the production process (Hulten 2010, 2011). Though the introduction of demand-side considerations in growth analysis is a substantial departure from the neoclassical and endogenous growth paradigms, it leads to considering how accounting for intangible capital affects the analysis of market power and imperfect competition, a point to which we will return below.

Measuring and accounting for this broader notion of intangible capital in fact provides a bridge to Romer's (1990) endogenous growth theory. In his approach, the aggregate production function has (implicitly) constant returns to "objects" like capital and labor but adds "ideas" and the potential for increasing returns to ideas. Jones (2019, pp. 864–5) elaborates:

> Whereas Solow divided the world into capital and labor, Romer makes a more basic distinction: between ideas, on the one hand, and everything else (call them "objects") on the other. Objects are the traditional goods that appear in economics, including capital, labor, human capital, land, highways, lawyers, a barrel of oil, a bushel of soybeans . . . An idea is a design, a blueprint, or a set of instructions for starting with existing objects, and transforming or using them in some way. . . . Examples include calculus, the recipe for a new antibiotic, Beethoven's Fifth Symphony, the design of the latest quantum computer.

The source of the increasing returns to ideas is their nonrival property. Romer (1990) illustrated this property with the example of oral rehydration therapy. This simple formula, essentially requiring a packet of sugar, salt, and potassium to be mixed with water, cures diarrhea and has saved literally millions of lives in developing countries. Suppose there is one plant in the world producing such packets. If a rival set up an identical plant, what inputs would be needed to produce the same number of packets? Romer's insight was that a new firm would need to employ a second set of machines and workers but could freely use the existing "idea"—the formula for the treatment—because it's available on Wikipedia and would not have to be invented anew.[5] In this sense, the production function has constant returns to objects but increasing returns to ideas.

Returning to Table 1, consider trying to duplicate the "ideas" that are Apple. Until 2008, the leading cell phone manufacturer was the Finnish company Nokia. Their phones were among the first to have auto-correct texting, Wi-Fi connections, and games. Yet with the introduction of Apple's iPhone, Nokia's market share collapsed. The Apple smartphone featured innovation like a touch screen technology and an aesthetic design—ideas that could, at least in principle, be licensed or copied by rivals. But Apple also had remarkably efficient supply chain management. When Nokia launched new products, customers waited for months to acquire them, whereas Apple could provide millions of new phones essentially on launch day (Cuthbertson, Furseth, and Ezell 2015). Apple's supply chain management knowledge cannot be copied from Wikipedia, and Apple's brand and reputation for service and delivery, while in public view, cannot be "shared" or copied in the

[5] See https://en.wikipedia.org/wiki/Oral_rehydration_therapy.

same way as a recipe for oral rehydration therapy. A firm seeking to be the same as Apple would have to invest in capital and labor, but also to invest in the knowledge that constitutes Apple's supply chain and its reputation for product/service quality. Nokia could not "freely utilize" this kind of knowledge to duplicate Apple.

The nonrival nature of intangibles is of course important, but the fact that intangible assets are partially appropriable takes center stage in the intangible capital approach. Without some degree of appropriability, there are no incentives for private business to invest in innovation, and without potential for commercial use, to paraphrase a comment attributed to Thomas Edison, there is no value in an idea. Consistent with endogenous growth theory, however, economies with investments in intangibles should still display increasing returns to those investments. But the intangible capital approach holds that the phenomenon does not just apply to investments in R&D; the potential for knowledge spillovers also extends to investments in business models, marketing strategies, and industrial design (among other areas) in models of intangible capital.

Whether the knowledge spillovers and knowledge stocks related to intangible capital should be termed "ideas" or not is mostly a semantic argument. In any case, appropriable knowledge stocks are termed "intangible capital" in the approach using a production function written as $Y = A\,F(L, K, R)$, where A is the technology that applies to the entire production function F. Here, intangible capital R is an input to the production process with several relevant traits: (a) it provides a flow of enduring income-generating services (and so is capital and not an intermediate); (b) more of it may be required along with more capital K and labor L to avoid diminishing marginal returns; but (c) as R is fundamentally nonrival, there is potential for increasing returns as the innovations embodied in intangible investments diffuse across firms, industries, and economies.

Why Isn't Intangible Capital Just Part of Labor?

One concern over expanding the conventional notion of business investment is to argue that much of what we have described will be captured by human capital, and in particular the talents of managers, engineers, and designers, which are accounted for in labor input. Does adding intangible capital pose a risk of double-counting?

The issue boils down to ownership of (or command of) the insights and intellectual property the managers and others are paid to develop. When Apple's founder and chief executive officer Steve Jobs passed away in 2011, the value of Apple did not disappear. Rather, a large part of his value was embodied in Apple itself. Formal studies of executives who leave famous companies, such as GE, find that they are often unable to repeat that success in other corporations, suggesting that they do not carry the corporate knowledge they created with them (Groysberg, McLean, and Nohria 2006).[6] Additionally, studies based on linked employer-employee data suggest that the marginal revenue product of managers exceeds their compensation,

[6] Formal studies of the value of a firm when the owner dies tend to find small effects in large firms, but larger effects for smaller firms; see the discussion in Smith et al. (2019, p. 1722).

and Piekkola (2016) even finds magnitudes in line with Figure 1's estimates of organizational capital generated within firms.

The human capital created by employer-provided training is a related concern, but studies demonstrate that firm-specific training (like the apprenticeships discussed in Zwick 2007) generates net returns to the firm, over and above the costs of the training and additional wages paid to employees with enhanced skills. Thus, it seems plausible that the skills embodied in the business practices of a firm are in several ways separable from the individuals working at the firm.

Intangible Capital, Competition, and GDP

If a firm is to use and pay for intangible capital, the capital must be produced and its owners rewarded. How do the production of intangible assets and the accompanying flows of reward fit into an overall vision of the economy?

A Model of an Economy

In a simplified model of the economy, production activity can be divided into two parts: 1) an "upstream" or "innovation" sector that produces ideas that can be commercialized, like a new system for organizing production or a software program adapted to the needs of the organization; and 2) a "downstream" or "production" sector that uses the knowledge generated by the upstream sector to produce final output.[7] By "final" output we mean output for sale to consumers or for export or investment: for simplicity, we ignore intermediate inputs. Figure 3 depicts these two interlinked production functions.

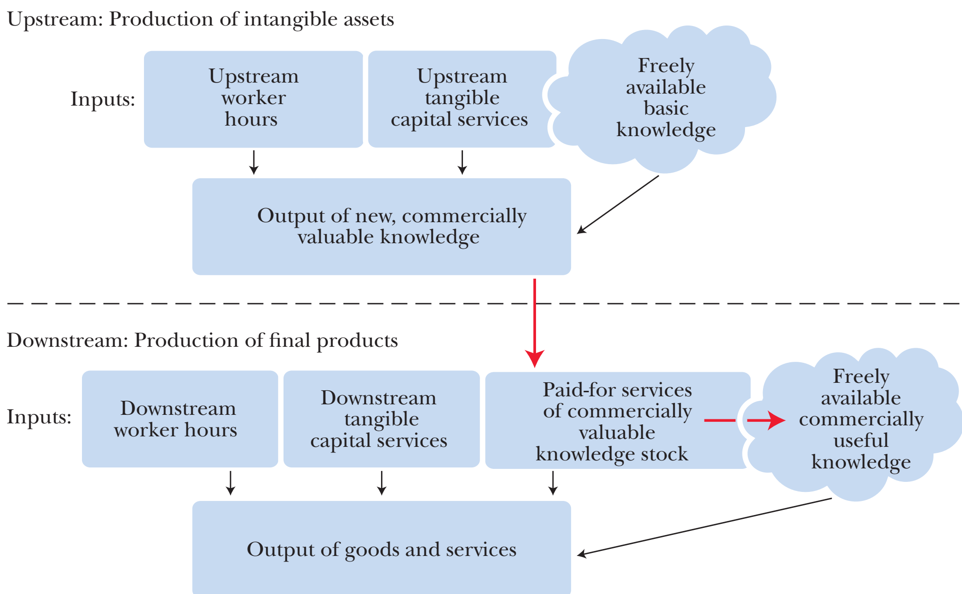
The outstanding stock of intangible capital in this framework, which might also be called "commercial knowledge," reflects the accumulation of upstream output, after adjusting for losses due to aging (the equivalent of depreciation). The production sector acquires commercial knowledge much as it acquires plant and equipment, via capital expenditure. But the stock of this knowledge is non-rival and only partially appropriable. The possible leakage from paid-for commercial knowledge to freely available useful knowledge is shown by the dotted arrow in the downstream sector.

The idea that innovators hold only temporary product market power for their inventions is a common feature of economic models of innovation. Such market power lasts for the time during which the innovator can sell or rent the knowledge for a monopoly price to the downstream sector, who in this framework is treated as a price-taker for knowledge.[8] We assume that prices for other inputs are competitive;

[7] The approach discussed here is based on Corrado, Hulten, Sichel (2005, 2009) as adapted in Corrado, Goodridge, and Haskel (2011).

[8] In this model the asset price for purchasing permanent use of commercial knowledge and the price of using this knowledge for a pre-set period of time (like a year) are linked via the Jorgenson (1963) user cost expression.

Figure 3
Conceptual Framework



Source: Authors' illustration.

final product prices are also competitive (given the cost of producing new commercial knowledge).

In contrast to this commercialized knowledge, "basic" knowledge, generated (say) via public funds for basic scientific research to universities, is assumed to be a free input in the upstream production function. Thus, while basic knowledge is an input to the production of commercial knowledge, it receives no factor payments to because its services are assumed to be freely available. "Basic" knowledge in this model is not viewed as stemming solely from scientific breakthroughs, though investments in branding and marketing, organization structure, and employer-provided training have long been modeled as complements with information technology equipment, as in Brynjolfsson and Hitt (2000); Corrado, Haskel, and Jona-Lasinio (2016) find justification for this approach in cross-country macroeconomic data.

This model's depiction of the two sectors captures some important aspects of business innovation in modern economies. The upstream sector would include firms that are almost fully reliant on the production of innovations in the form of new intangible assets—say, biotech startups producing new formulas for drugs—with the downstream sector comprising producers that acquire the use of the innovations via outright purchase or license agreements with annual payments. More generally, many innovating firms have their own internal "innovation labs" and "business strategy teams" that produce and commercialize new ideas for downstream production (for example, Alphabet's "X" research arm). In our model, these innovation labs and strategy teams are then upstream knowledge producers residing within larger organizations, and the internal payments to these innovation labs and strategy teams represent their contribution to total revenue. This depiction of innovation is not limited to production of new technologies. For example, consider the downstream firm Peloton, which wishes to purchase the rights to music that can be played while people exercise. The firm can make "rental" payments to musicians for use of music in Peloton video exercises (now around 3 cents per song, as reported by Pahwa 2021), or the company could pay for the right to use a song (legally) forever.

Further, the intuition of an upstream entity commercializing knowledge helps, we believe, relate economic theory and measurement to the interests of management and innovation scholars. Such scholars typically find the economist's use of total factor productivity to represent innovation hard to reconcile with their detailed and diverse case studies of the internal process by which firms develop new products and processes whereas the innovation divisions with firms ("skunk works") described by Greenstein (2016) are, collectively, upstream sector knowledge producers in our model.

Dynamic innovative economies will maintain a continuous flow of differentiated innovations via investments in intangible capital. In the long run, firms will compare the after-tax returns to investments in innovation that build intangible capital with the returns to alternative long-term investments that build tangible capital. In this setting, non-zero innovator profits can persist, manifest as higher prices for intangible assets; for further discussion, see Corrado et al. (2022).

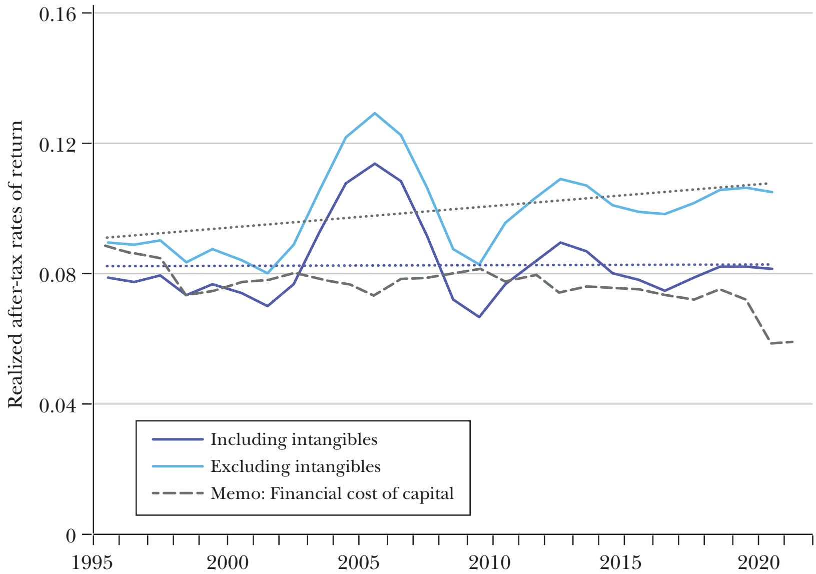
Implications for Measuring Market Power

The rewards that accrue to intangible investments are a part of business profits whether or not intangibles are measured or included in GDP, income, and fixed asset accounting. But if investments in intangible capital are not included, economies may appear to have abnormally high profits relative to the (mismeasured) capital employed—in fact, the higher the (uncounted) intangible investment, the greater the misperception. Using the investment data on tangible and intangible investment underlying the earlier Figure 1, Figure 4 shows that the after-tax rate of return implied by macroeconomic data is dramatically affected when investment is expanded to cover intangibles.

Figure 4 also shows a market-based cost of capital, calculated as a weighted average of the expected return on stocks and after-tax cost of debt. The gap between the financial cost of capital and realized (actual) returns to capital can serve as an indicator of market power, akin to the price markup discussed in much recent competition literature.

The message suggested by the (erroneous) gap based on the rate of return excluding intangibles is akin to the price markup calculated using (most) microdata sources. Firm-level databases based on company financial reports and/or microdata from official production surveys do not account for intangibles—and

Figure 4
Realized After-Tax Rates of Return, US Private Industries, 1995 to 2020



Source: Authors' elaboration of data from US national accounts, BEA, BLS, EU KLEMS & INTANProd, Federal Reserve financial accounts, and FRED databases.
Notes: Private industries exclude residential real estate and private households. Private capital includes fixed assets, inventories, and nonresidential land. Intangibles covers all assets listed in Table 2. The last point plotted for the financial cost of capital is 2021.

even miss the software and R&D components included in macrodata—and thus are difficult sources for depicting competitive developments accurately.

Implications for GDP and Growth Accounting

In the model of the economy depicted in Figure 3, measured GDP consists of output sold to consumers and investment goods. If the conventional measure of investment in final demand is expanded to include intangibles, then spending on intangibles is no longer treated as an intermediate expenditure, and measured GDP is larger. The rise in output is a first-order impact of capitalizing intangibles in GDP accounting.

In a standard growth-accounting framework, output growth can be decomposed into contributions from capital, from labor, and from total factor productivity growth. What is different in the model that includes intangibles is that there is both an expansion of output, as above, but also—another first-order implication—an expansion of inputs. The contribution of paid-for, commercially valuable knowledge becomes an additional accountable source of output growth, a *direct* contribution if you will. Because intangible capital is only partially appropriable, however, the augmented model also includes a way for intangible capital to explain changes in total factor productivity. The contribution via total factor productivity is not directly measured, but it reflects the impact of the diffusion, or spread, of innovations embodied in current and past vintages of intangible capital as they are freely copied and adopted across firms and industries in an economy.

As we will discuss later in this paper, this diffusion process, termed "knowledge spillovers" (or increasing returns), is usually modeled as driven by the growth of knowledge itself but may also be affected by institutional factors like the rules concerning patents, trade secrets, and intellectual property, as well as by specific characteristics of the intangible investments themselves.

Why Intangible Capital Is Difficult to Measure

The macroeconomic analysis of intangible capital set out in this paper is grounded in concepts and measures aligned with national accounts. For example, national accounts use investment flows and depreciation rates to derive asset stocks, asset values, and asset incomes. But seeking to apply this approach to a broad category of intangibles is challenging. In this section, we explore several issues.

First, it is often difficult to identify the investment flow, especially when intangible assets are co-produced along with primary products. Second, absent "arm's length" transactions in markets with prices, how can we calculate a price deflator for intangible assets, so that past investments can be expressed in real terms? Third, given that intangible assets lack "substance" (as financial accountants describe this asset class) how should we think of their capital consumption/economic depreciation? Finally, does partial appropriability provide a sufficient conceptual rationale for cumulating and aggregating real flows of intangible investment into capital stocks, as is typically done for tangible assets? This question is relevant for those who question how the competitive advantage of a single firm as reflected in, say, its marketing assets, can create aggregate value for an industry or market in a way that contributes to total factor productivity. These topics are reviewed with reference to "the perpetual inventory method" (PIM), a calculation that assumes depreciation of each asset is geometric and constant across all vintages of the asset and that asset investment flows may be cumulated to obtain measures of real asset stocks.[9]

Investment Flows

Intangible assets may in some cases be acquired via market transactions, like purchases of customer management software systems or of strategic management consulting advice. But more commonly, they are produced within an organization, as in the case of customized software to determine seating in the firm's open office

[9] More specifically, PIM measures the real stock R of individual asset a for a given industry at time t as $R_{(a,t)} = N_{(a,t)} + (1 - \delta_a^R)\ R_{(a,t-1)}$, where $N_{(a,t)}$ is the real investment flow for asset a in the industry. Once each $R_{(a,t)}$ for an industry is obtained, the usual procedures for aggregating over assets and industries are applied.

space or to manage its unique order book. The tendency toward in-house production of intangible capital contrasts with the typical "arm's length" production of most tangible capital. Very few firms make their own tangible assets: for example, UPS does not make its delivery trucks.

A *sum-of-costs* approach is used to estimate investment via in-house production in the macroeconomic data in national accounts. The idea is to imagine a firm, a bank, say, as having a "software factory" or "strategy factory" inside of it and the measurement challenge is to estimate the value of output produced by this hypothetical factory based on factor costs (labor, capital, and intermediates). The linchpin of this approach is identifying the occupations of the workers in the in-house "factory" and estimating their wages and employment from, for example, labor force surveys. From that, the total payments made to all factors used in the in-house production can be estimated. An important assumption in this estimation is the fraction of time spent by the identified workers on the relevant activity. This factor for own-account software investment in the macroeconomic data for many countries is about one half—that is, software developers are assumed to spend one-half of their work time creating new software that is long-lasting. However, this estimate varies within occupational categories, such that software managers are assumed to only spend 5 percent of time on creating long-lived capital.

Could own-account intangible investment be determined more accurately via a survey instrument? Collecting information via a survey instrument is already a proven approach for research and development, which is amenable to data collection via survey because it is well-defined as a business function. European countries gather regular information on firms' expenditures on formal employer-provided training, internal and external, reflecting the fact that training budgets are usually well-defined components of business expenditure. However, own-account investments in software are not well-defined as a separate business expenditure category, nor are the "skunk works" of divisions focused on internal innovation. Surveys of capital expenditures have attempted to collect information on software investments in several OECD countries, including the United States, but results have tended to yield implausibly small figures. Thus, software and databases, and the data series for industrial design, brand, and organizational capital all contain own-account components that are estimated based on the sum-of-costs approach. The series for new financial products consists solely of own-account production.

Asset Price Deflators

An asset price deflator is needed to express past investment in real terms. Because many intangible assets do have a purchased component, a common approach is to use a services output price as an asset price for the deflation of intangibles (for example, Martin 2019). In early empirical work, Corrado, Hulten, and Sichel (2009) used an overall business output price "as a placeholder" in the absence of information on intangible asset prices, noting that this essentially implies that upstream input costs and productivity are little different from downstream (or existing, measured business) sector costs and productivity.

A more sophisticated version of this approach is to identify upstream costs (which may differ substantially in composition from downstream production costs) and apply a productivity adjustment. This approach is in fact used to derive price deflators for business research and development in the US national income and product accounts. The US Bureau of Economic Analysis selected the approach after examining several alternatives (including available service price deflators for the R&D services industry, as discussed in Robbins et al. 2012). The productivity adjustment is a trend derived from the official estimates of nonfarm business sector total factor productivity as published by the US Bureau of Labor Statistics.

Research on hard-to-measure services prices typically does not address intangible asset-producing activities—like R&D labs, marketing teams, engineering design projects—nor are these activities typically viewed as hotbeds of rapid quality change missed by price collectors in assessments of productivity mismeasurement. But more recently, with the digital transformation of economies, the rise of digitally enabled business models, and the increased use of data in business more generally, the nature and efficiency of intangible asset-producing activities arguably have been transformed. This would be manifest in the upstream/downstream model as more rapid total factor productivity growth in the upstream sector, and competitive issues aside, lower prices of intangible asset. Recent developments in intangible asset prices are discussed in Corrado (2021) and analyzed in the context of data, intangibles, and productivity in Corrado et al. (2022).

Economic Depreciation

One might start by asking how knowledge-based intangible assets can even "depreciate": after all, the Pythagorean theorem (and even some Greek buildings!) seems to have lasted for a very long time. But because intangibles are non-rival and returns to investments are not fully appropriable, the value of the investment to the firm or innovator is limited to the returns that the owner/investor can capture. Partial appropriability implies, in stark contrast to the notion that the depreciation of intangible assets must be "slow" because ideas last a very long time, that the value of commercial knowledge declines rather rapidly. This pattern is documented in empirical studies (reviewed in de Rassenfosse and Jaffe 2017; see also Pakes and Schankerman 1984 and Martin 2019) and is supported by survey evidence that asks firms to report the average useful life of their intangible assets (Awano et al. 2010).

Economic depreciation is the reduction in value of an asset as it ages—a price concept that is unobservable and necessary to estimate for any type of capital, tangible or intangible. The definition of economic depreciation showcases the difficulty with textbook explanations of depreciation as physical decay or "wear and tear." Such explanations lose sight of the larger conceptual issue that assets tend to yield less revenue and lose productive value as they age, a loss that reduces value to the firm. All told, then, intangibles do decline in value as firms cease to appropriate benefits because commercialized ideas are replaced by new ones or copied by competitors.

Competitive Advantage and Aggregation

Should investments in marketing assets or brand development, which businesses undertake as a form of competition and to gain a competitive advantage, be conceptually viewed as "capital"? At their root, the question turns on two subsidiary issues. First, do the spending streams for these categories have the longevity that we typically expect of capital? Second, if competing firms both engage in marketing and brand management strategies, would it be more accurate to say that marketing and brand management efforts have some tendency to cancel each other out, rather than the spending by each firm adding up to an overall capitalization value? These topics are discussed in more detail in Corrado (2021), Haskel and Westlake (2019, pp. 49–52), and the paper in this symposium by Bronnenberg, Dubé, and Syverson.

The conceptual basis for treating spending on marketing and brand development as capital is grounded in signaling theory (Milgrom and Roberts 1986), supported by many structural modeling/competition studies, and consistent with the welfare-enhancing effects of product differentiation (Dixit and Stiglitz 1977). The key insight of this broad spectrum of works is that the appropriable revenue stream due to marketing and promotion is determined in general equilibrium via both price and quantity channels. An implication of this view is that product prices are not necessarily higher due to the costs of marketing and promotion. The available empirical evidence also suggests that promotion exhibits important scope economies (for example, it interacts with how a firm chooses to focus its R&D efforts) and that product advertising has, on average, long-lasting informative effects on economic activity in both product markets (as in Rauch 2013) and services industries (as in Kwoka 1984).

In addition, while the original context of much work on intangibles focused on technological innovation via investments in research and development, the analysis of intangibles also has roots in the industrial organization literature, which has focused on the supporting role of marketing in innovation (Hulten 2011). The complementarity between R&D and promotion, both theoretically and empirically, is an established characteristic of globally innovative pharmaceutical firms (Clarkson 1977; Vinod and Rao 2000), as well as other manufactures (for example, Clarkson 1996). In firm-level work on the growth drivers of the software company Microsoft, Hulten (2011) found an important supporting role for marketing in the company's innovation, and a firm-level study of retailers (Crouzet and Eberly 2018) argued that the growing value of brand supported the more efficient practices that spurred the expansion of large retailers in the United States.

In short, the argument that marketing, brand management, and similar activity are only a zero-sum battle breaks down in the presence of innovation and the realities of how modern companies create competitive advantage and differentiate their products. Perhaps a more pertinent question is why macroeconomic practitioners have not been persuaded by the corpus of research on these topics. After all, it is apparent that for marketing assets to have no net impact on aggregate economic activity via consumption as a component of net worth, investments in them must have zero impact on aggregate market capitalization, which would contradict the body of evidence that branding does influence market valuations of firms.

Productivity in Economies with Intangible Capital

We have already demonstrated that measuring intangible capital affects investment/GDP and rates of return. This section focuses on productivity, including remarks on the productivity slowdown and increased role of proprietary data in commercially valuable knowledge. Recent work that has approached measuring and analyzing data as an intangible asset reveals that data capital overlaps almost completely with intangible capital, both conceptually and empirically (Corrado et al. 2022). This change in the composition of intangible capital may have diminished its potential for increasing returns to the extent that the data capital of individual firms is unable to be copied for costless use elsewhere in economies.

To calculate productivity, we use the recently issued EU KLEMS & INTANProd database, which reports productivity estimates including harmonized investment streams for the intangible assets listed in Table 2 for most of Europe, as well as for the United States and Japan.[10] The investment and capital estimates for assets not regularly capitalized in national accounts are developed using methods consistent with national accounts (such as perpetual inventory models): the estimates are not calibrations of a model or developed from data in company financial reports. The methods used to develop the harmonized estimates of intangible investment are documented in Bontadini et al. (2022).[11]

In this section, we report and analyze estimates of total factor productivity that cover ten European countries and the United States from 1998 to 2018. The European aggregate consists of Austria, Germany, Denmark, Spain, Finland, France, Italy, Netherlands, Sweden, and United Kingdom. Future work may bring in more countries—EU KLEMS & INTANProd includes estimates of intangible investment for all 27 EU countries (though histories are short for some). The EU KLEMS & INTANProd data is updated as National Accounts data are released, and so the results here are a snapshot as of March 2022.

Growth Decompositions

The growth accounting reported below is in per hour terms—that is, it decomposes the growth in output per hour for both the European aggregate and the United States. The accounting for the European aggregate is developed at the country-industry level, where industries are aggregated to "market" sector aggregates for each

[10] This update/expansion is funded by the European Commission's Directorate General for Economic and Financial affairs (procurement procedure ECFIN/2020/OP/0001 – Provision of Industry level growth and productivity data with special focus on intangible assets – 2020/S 114-275561).

[11] Available on the EU KLEMS & INTANProd portal at https://euklems-intanprod-llee.luiss.it. Compared with previous estimates for Europe and the United States issued via the INTANInvest database and website (www.intaninvest.net), current figures reflect significant improvements to the own-account components of intangible investment and to intangible asset price deflators. Methods used to develop the current estimates of intangible investment are set out in the appendix to this paper. Regarding deflators for software and tangibles, as in our own previous work, the product quality change component of price deflators for information technology equipment and software is harmonized across countries. The harmonized IT equipment and software deflators are developed and kindly supplied by the OECD.

country and then weighted accordingly to form the European aggregate. Market sector aggregates exclude the public sector and majority-public industries, resulting in coverage across twelve industries that is broadly similar, though not identical, to the nonfarm business sector used for headline productivity statistics in the United States.[12]

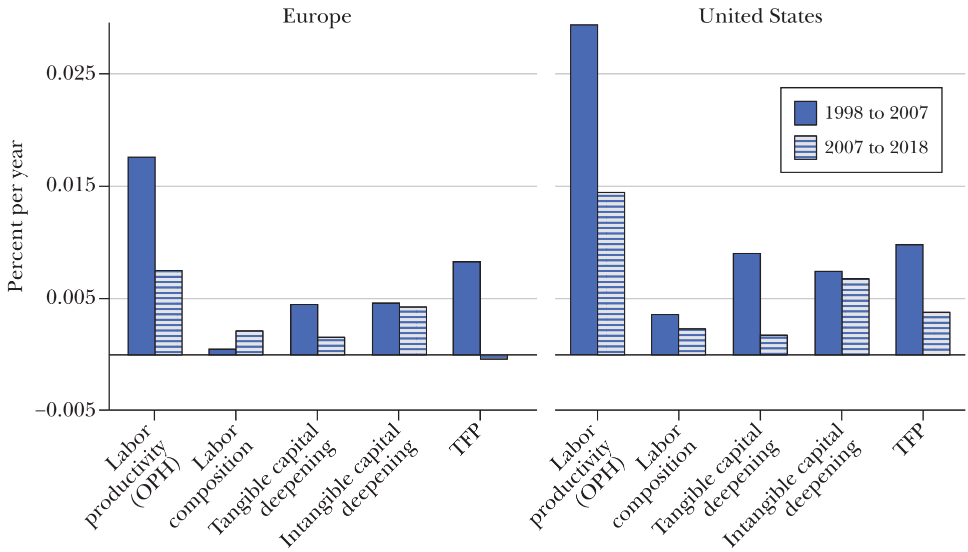
As is well-known, estimates of changes in country-level output per hour reflect both "within" and "between" industry sector effects. The reallocation of labor across sectors is the "between" effect. In lower-income countries, for example, the movement from agriculture to manufacturing is an important source of productivity growth. For high-income countries in recent decades, the main movement across sectors is from manufacturing to services. However, we find that the reallocation of hours across industry sectors has had a negligible impact on broad changes in market sector output per hour in Europe and the United States between 1998 and 2018. When labor productivity growth dropped precipitously in market-dominated industries of both regions with the onset of the global financial recession in 2008, it was almost entirely due to a "within" effect that reached across industries. (By contrast, labor productivity during the pandemic-affected years 2020–2021 is heavily driven by reallocation effects.)

Figure 5 sets out decompositions of industry-aggregated (that is, within-industry aggregates) of labor productivity growth for ten European countries and the United States for the decade leading up to the Great Recession, 1998–2007, and then for 2007–2018. The first pairs of columns for each area shows a substantial drop in labor productivity growth (output per hour) in both areas (-1.0 and -1.5 percentage points, respectively). The last pair of columns reports total factor productivity for each region; they show that the drop in growth of output per hour in Europe is largely accounted for by a substantial slowdown in total factor productivity growth of 0.9 percentage points; similarly, total factor productivity slowed 0.6 percentage points in the United States. The contribution of the second set of bars (labeled labor composition) reflects the per-hour contribution of increases in (employed) human capital, which reflects changes in the proportion of high-skilled/high-wage jobs in industries. Though this effect works in opposite directions in Europe and the United States, its contribution to explaining developments in productivity growth in these regions during the past 20 years is relatively small.

Capital deepening is part of the story of the slowdown in output-per-hour, directly and indirectly. A drop in the contribution of tangible capital deepening directly accounts for nearly one-third of the drop in output-per-hour in Europe and one-half of the drop in the United States. The contribution from the rate at which workers in both regions were equipped with intangible capital edged down only

[12] The market sector aggregates are formed using twelve individual industries that cover ten NACE letter level industry sectors: B (Mining), C (Manufacturing), D and E (Gas, Electricity, and Water), F (Construction), G (Wholesale and retail Trade; repair of motor vehicles), H (Transportation and storage), I (Accommodation and food services), J (Information and Communication activities), K (Finance and insurance activities), M (Professional, scientific, and technical activities), N (Administration and support activities) and R (Arts, entertainment, and recreation). NACE is an international system for industry classification used in Europe; for a concordance to the NAICS system used in North America, see the Bontadini et al. (2022) documentation on the EU KLEMS & INTANProd project portal.

Figure 5
Decompositions of Labor Productivity Growth



Source: Authors' elaboration of EU KLEMS & INTANProd (Bontadini et al. 2022), accessed March 23, 2022.
Note: Decompositions are derived from industry-level data; figures are reported in natural logarithms. See text for composition of the European aggregate. Labor composition and capital deepening columns are labor and capital payments share-weighted per-hour input growth rates. OPH stands for "output per hour." Total factor productivity (TFP) is a residual.

very slightly, however, and thus *directly* explains little of the drop in labor productivity. This finding—which should *not* be interpreted as suggesting that correcting for mismeasurement of intangibles deepens the productivity slowdown puzzle—is discussed further below.

Even though the focus of this article is that national accounts and productivity calculations are missing many intangible assets, the ongoing controversy that official statistics miss major aspects of how consumers benefit from the digital economy cannot be overlooked. For example, the falling cost of consumer digital content delivery—and thus the value that consumers obtain from their paid-for wireless data, internet, and video subscription services—is not well-reflected in GDP. Available research quantifies very fast drops in prices for consumer digital services, especially for mobile data and streaming services, and also increased shares of consumer spending allocated to subscriptions for these services. These are telltale signs that the missed price drops have an *increasing* deflationary impact on consumer price inflation.[13] The missed price drops are in fact estimated to have understated the

[13] The ways in which consumers benefit from free content delivered via their paid-for digital services, like value derived from user-generated content in social media, is a related matter. But however significant, these impacts fall outside the market activity scope of the productivity analysis reported in Figure 5.

deceleration in consumer price change by 0.3 percentage points per year from 2007 to 2018, which when translated to Figure 5, potentially explains one-third to one-half of the estimated drop in growth of total factor productivity. The aggregate estimate is from Byrne and Corrado (2020, 2021), which applies to the United States and covers mobile voice and data, internet access, cable TV, and video streaming. This estimate is consistent with results showing comparably rapid rates of price drops for mobile voice and data in the United Kingdom by Abdirahman, Coyle, Heys, and Stewart (2020) and for music streaming globally by Edquist, Goodridge, and Haskel (2021).

Diffusion of Commercial Knowledge and Increased Productivity Dispersion

The diffusion of commercially valuable knowledge is, logically, a primary determinant of total factor productivity growth according to the upstream/downstream model of Figure 3. The real world is more complex than the basic model, but a connection from intangible capital to productivity growth is a regularity in past productivity data, insofar as cross-country and firm-level econometric work have estimated increasing returns (or knowledge spillovers) to intangible capital. In simple terms, these works imply that a proportional relationship, such that about one-fifth of the growth of intangible capital translates into gains in total factor productivity.[14] The proportional relationship can be used to represent the costless diffusion of commercially valuable knowledge in an economy.

Spillovers are estimated to occur in proportion to the input, not the input-per-hour terms in Figure 5 (the spillovers from a phone network are from the existence of the network, not with the network per hour worked). Intangible capital input did slow in Europe after the financial crisis, from 4.2 percent per year from 1998 to 2007 to 3 percent in the post-crisis period. A spillover effect of one-fifth would predict a total factor productivity slowdown of 0.25 percent in Europe. So, a small part of the total factor productivity slowdown in Europe can be attributed to slower growth in intangible capital; in the United States, the impact is even smaller, less than 0.1 percent.

Another endogenous explanation for the slowdown in measured total factor productivity growth is that the drivers of these increased returns ceased to operate as strongly as they previously had. Why might this change have occurred? One possibility is that the potential for productivity spillovers to intangible investments is determined by an innovation ecosystem, including competition intensity and regulation, intellectual property rights and their enforcement, privacy laws, broadband access, and other factors. It is very difficult, however, to see how the workings of this system could change so seriously and suddenly on both sides of the Atlantic (for some evidence on this point, see Akcigit and Ates 2021).

An alternative possibility is that the composition of knowledge assets directly affects the strength of the diffusion process. Some forms of intangible capital—datasets,

[14] This underlying estimates here refer to the aggregate implications of estimates for R&D spillovers reported by Griliches (1992, 1994) for manufacturing and the similar estimates for non-R&D intangibles (especially, the industrial design, employer-provided training, and organizational capital components) by Corrado, Haskel, and Jona-Lasinio (2017).

certain formulas, and software code—tend to be regarded as trade secrets, intentionally undisclosed and difficult to replicate. The digital economy has boosted the share of investment in these forms, which arguably weakens mechanisms that generate increasing returns to intangible capital. As intangible capital has become, in effect, data capital, there also has been an increase in dispersion of firm-level productivities *within* industry groups attributed, at least in part, to increased investments in economic competencies by market services industries. This pattern was documented globally in Andrews, Criscuolo, and Gal (2016), who characterized the development as a worrisome decline in the global diffusion of new ideas and technologies since 2000. The growing relative importance of intangible assets was identified as a mechanism behind increased firm-level productivity dispersion in follow-on work (Corrado et al. 2021). This changed composition of intangible investment then may also have led to scale economies within *certain* firms, like data agglomeration effects in digitally enabled firms, that tended to reduce competition in those markets.

In the intangible capital framework, the maximum impact of these developments on market sector productivity is as follows: With post-2007 growth of intangibles averaging 3 percent per year in the European countries and about 3½ percent per year in the United States, and applying the approximation that one-fifth of this growth translates into a change in total factor productivity, a *complete* cessation of the diffusion mechanism would shave more than ½ percentage point per year off measured total factor productivity growth in these regions. Productivity growth via the costless replication of commercial knowledge is of course highly unlikely to have ceased entirely, and this brief analysis does not rule out other possible culprits behind the productivity slowdown. But the increased use of data and increasing overlap between data capital and intangible capital is an important development that is likely having an impact on productivity growth in modern economies.

Final Remarks

The framework for intangible capital presented here builds bridges between GDP measurement, growth accounting, and modern growth theory: because intangibles are also nonrival, productivity narratives using the intangible capital framework naturally embrace endogenous factors that modern growth theory emphasizes. In its focus on the partial appropriability of investments in innovation, the intangibles framework provides economists with a bridge to discussions of methods of business innovation in the management literature. Several key topics related to intangible capital have received no mention or only a very light touch here, such as how digital technologies like cloud computing and artificial intelligence affect productivity and how data assets are captured in the intangible capital framework studied elsewhere (Corrado, Haskel, and Jona-Lasinio 2021; Corrado et al. 2022), as well as the policy-related dimensions of intangible capital reviewed in Haskel and Westlake (2022).

The trendlines suggest that the intangible economy is only becoming more important. Policymakers, along with policy and business analysts, are already putting intangible capital into economic frameworks used for analysis: some examples with which we are familiar include central banks, the OECD, European Commission, Italian G20 Presidency, and business-oriented research organizations such as the Conference Board, McKinsey Global Institute, and NESTA (UK). As modern economies become more "knowledge-intensive," we believe that economic researchers should seek to include the full complement of intangibles in investment, profits, and productivity data. Continued movements in this direction by statistical agencies and data compilers will make business data much more representative of the intangible world around us.

References

Aaker, David A. 1991. *Managing Brand Equity*. New York: Free Press.

Akcigit, Ufuk, and Sina T. Ates. 2021. "Ten Facts on Declining Business Dynamism and Lessons from Endogenous Growth Theory." *American Economic Journal: Macroeconomics* 13 (1): 257–98."

Abdirahman, Mohamed, Diane Coyle, Richard Heys, and Will Stewart. 2020. "A Comparison of Deflators for Telecommunications Services Output." *Economie et Statistique* 517-518-519: 103–22.

Andrews, Dan, Chiara Criscuolo, and Peter Gal. 2016. *The Global Productivity Slowdown, Technology Divergence and Public Policy: A Firm Level Perspective*. Paris: OECD.

Awano, Gaganan, Mark Franklin, Jonathan Haskel, and Zafeira Kastrinaki 2010. "Measuring Investment in Intangible Assets in the UK: Results from a New Survey." *Economic and Labour Market Review* 4 (7): 66–71.

Bontadini, Filippo, Carol, Corrado Jonathan Haskel, Massimiliano Iommi, and Cecilia Jona-Lasinio. 2022. *The EUKLEMS & INTANProd Database: Methods and Data Descriptions*. Rome: LUISS.

Brynjolfsson, Erik, and Lorin M. Hitt. 2000. "Beyond Computation: Information Technology, Organizational Transformation and Business Performance." *Journal of Economic Perspectives* 14 (4): 23–48.

Brynjolfsson, Erik, Lorin M. Hitt, and Shinkyu Yang. 2002. "Intangible Assets: Computers and Organizational Capital." *Brookings Papers on Economic Activity* 1 (1): 137–99.

Byrne, David, and Carol Corrado. 2020. "The Increasing Deflationary Influence of Consumer Digital Access Services." *Economic Letters* 196 (109447): 1–4.

Byrne, David, and Carol Corrado. 2021. "Accounting for Innovations in Consumer Digital Services: IT Still Matters." In *Measuring and Accounting for Innovation in the Twenty-First Century*, Vol. 78, *Studies in Income and Wealth*, edited by Carol Corrado, Jonathan Haskel, Javier Miranda, and Daniel Sichel, 471–517. Chicago: University of Chicago Press.

Clarkson, Kenneth W. 1977. *Intangible Capital and Rates of Return: Effects of Research and Promotion on Profitability*. Vol. 138, *American Enterprise Institute Studies in Economic Policy*. Washington, DC: American Enterprise Institute for Public Policy Research.

Clarkson, Kenneth W. 1996. "The Effects of Research and Promotion on Rates of Return." In *Competitive Strategies in the Pharmaceutical Industry*, edited by Robert B. Helms, 238–68. Washington, DC: AEI Press.

Corrado, Carol. Forthcoming. "Measuring Intangible Capital: Implications for Growth and Productivity." Brookings Hutchins Center Working Paper.

Corrado, Carol, Chiara Criscuolo, Jonathan Haskel, Alexander Himbert, and Cecilia Jona-Lasinio. 2021. "New Evidence on Intangibles, Diffusion and Productivity." OECD Science, Technology and Industry Working Paper 2021/10.

Corrado, Carol, Peter Goodridge, and Jonathan Haskel. 2011. "Constructing a Price Deflator for R&D: Calculating the Price of Knowledge Investments as a Residual." The Conference Board Economics Program Working Paper 11–03.

Corrado, Carol, Jonathan Haskel, Massimiliano Iommi, Cecilia Jona-Lasinio, and Fillipo Bontadini. 2022. "Data, Intangibles and Productivity." Paper presented at the NBER/CRIW Conference on Technology, Productivity, and Economic Growth, Washington, DC, March 17.

Corrado, Carol, Jonathan Haskel, and Cecilia Jona-Lasinio. 2016. "Intangibles, ICT and Industry Productivity Growth: Evidence from the EU." In *The World Economy: Growth or Stagnation?*, edited by Dale W. Jorgenson, Kyoji Fukao, and Marcel P. Timmer, 319–346. Cambridge, UK: Cambridge University Press.

Corrado, Carol, Jonathan Haskel, and Cecilia Jona-Lasinio. 2017. "Knowledge Spillovers, ICT, and Productivity Growth." *Oxford Bulletin of Economics and Statistics* 79 (4): 592–618.

Corrado, Carol, Jonathan Haskel, and Cecilia Jona-Lasinio. 2021. "Artificial Intelligence and Productivity: An Intangible Assets Approach." *Oxford Review of Economic Policy* 37 (3): 435–58.

Corrado, Carol, Charles R. Hulten, and Daniel Sichel. 2005. "Measuring Capital and Technology: An Expanded Framework." In *Measuring Capital in the New Economy*, Vol. 66, Studies in Income and Wealth, edited by Carol Corrado, John Haltiwanger, and Daniel Sichel, 11–46. Chicago: NBER, University of Chicago Press.

Corrado, Carol, Charles R. Hulten, and Daniel Sichel. 2009. "Intangible Capital and U.S. Economic Growth." *Review of Income and Wealth* 55 (3): 661–85.

Corrado, Carol, and Charles Hulten. 2010. "How Do You Measure a 'Technological Revolution'?" *American Economic Review* 100 (2): 99–104.

CPA Ontario. 2021. *You Can't Touch This: The Intangible Assets Debate.* Toronto: Chartered Professional Accountants of Ontario.

Crouzet, Nicolas, and Janice C. Eberly. 2018. "Intangibles, Investment, and Efficiency." *AEA Papers and Proceedings* 108: 426–31

Crouzet, Nicolas and Janice C. Eberly. 2019. "Understanding Weak Capital Investment: The Role of Market Concentration and Intangibles." NBER Working Paper 25869.

Cuthbertson, Richard, Peder Inge Furseth, and Stephen J. Ezell 2015. "Apple and Nokia: The Transformation from Products to Services." In *Innovating in a Service-Driven Economy: Insights, Application, and Practice*, 111–29. London: Palgrave Macmillan.

de Rassenfosse, Gaétan, and Adam B. Jaffe. 2017. "Econometric Evidence on the R&D Depreciation Rate." NBER Working Paper 23072.

Dixit, Avinash K., and Joseph E Stiglitz. 1977. "Monopolistic Competition and Optimum Product Diversity." *American Economic Review* 67 (3): 297-308.

Döttling, Robin, and Lev Ratnovski. 2020. "Monetary Policy and Intangible Investment." IMF Working Paper 2020/160.

Edquist, Harald, Peter Goodridge, and Jonathan Haskel. 2021. "The Economic Impact of Streaming beyond GDP. *Applied Economics Letters* 29 (5): 403–8.

Erdem, Tülin, and Michael P. Keane. 1996. "Decision-making Under Uncertainty: Capturing Dynamic Brand Choice Process in Turbulent Consumer Goods Markets." *Marketing Science* 15 (1): 1–20.

Erdem, Tülin, Michael P. Keane, and Baohong Sun. 2008. "A Dynamic Model of Brand Choice When Price and Advertising Signal Product Quality." *Marketing Science* 27 (6): 949–1136.

Farquhar, Peter H. 1989. "Managing Brand Equity." *Marketing Research* 1 (3): 24–33.

Greenstein, Shane. 2016. "What Does a Skunk Works Do?" *IEEE Micro* 36 (2): 70–1.

Griliches, Zvi. 1973. "Research Expenditures and Growth Accounting." In *Science and Technology in Economic Growth*, edited by B.R. Williams, 59–95. London: Palgrave MacMillan.

Griliches, Zvi. 1979. "Issues in Assessing the Contribution of Research and Development to Productivity Growth." *Bell Journal of Economics* 10 (1): 92–116.

Griliches, Zvi, 1986. "Productivity, R&D, and the Basic Research at the Firm Level in the 1970's." American Economic Review 76 (1): 141–154.

Griliches, Zvi. 1992. "The Search for R&D Spillovers." *Scandinavian Journal of Economics* 94: S29–47.

Griliches, Zvi. 1994. "Productivity, R&D, and the Data Constraint." *American Economic Review* 84 (1):1–23.

Groysberg, Boris, Andrew N. McLean, and Nitin Nohria. 2006. "Are Leaders Portable?" *Harvard Business Review* 84 (5): 92–100.

Haskel, Jonathan, and Stian Westlake. 2018. *Capitalism without Capital: The Rise of the Intangible Economy.* Princeton: Princeton University Press.

Haskel, Jonathan, and Stian Westlake. 2022. *Restarting the Future: How to fix the intangible economy.* Princeton: Princeton University Press.

Hulten, Charles R. 2010. "Decoding Microsoft: Intangible Capital as a Source of Company Growth." NBER Working Paper 15799.

Hulten, Charles R. 2011. "How did Microsoft Become 'Microsoft'? Intangible Capital and the Endogenous Growth of the Firm." Unpublished.

Jones, Charles I. 2019. "Paul Romer: Ideas, Nonrivalry, and Endogenous Growth." *Scandinavian Journal of Economics* 121 (3): 859–83.

Jorgenson, Dale W. 1963. "Capital Theory and Investment Behavior." *American Economic Review* 53 (2): 247–59.

Kwoka, John. 1984. "Advertising and the Price and Quality of Optometric Services." *American Economic Review* 74 (1): 211–6.

Lev, Baruch. 2001. *Intangibles: Management, Measurement, and Reporting*. Washington, DC: Brookings Institution Press.

Lev, Baruch, and Suresh R. Radhakrishnan. 2005. "The Valuation of Organization Capital." In *Measuring Capital in the New Economy*, edited by Carol Corrado, John Haltiwanger, and Daniel Sichel, 73–110. Chicago: NBER, University of Chicago Press.

Martin, Josh. 2019. "Measuring the Other Half: New Measures of Intangible Investment from the ONS." *National Institute Economic Review* 249 (1): R17–29.

Milgrom, Paul, and John Roberts. 1990. "Bargaining Costs, Influence Costs, and the Organization of Economic Activity." In *Perspectives on Positive Political Economy*, edited by James Alt and Kenneth A. Shepsle, 57–89. Cambridge, UK: Cambridge University Press.

Milgrom, Paul, and John Roberts. 1986. "Price and Advertising Signals of Product Quality." *Journal of Political Economy* 94 (4): 796–821.

Moris, Francisco. 2018. "Definitions of Research and Development: An Annotated Compilation of Official Sources." Alexandria, VA: National Science Foundation.

Nakamura, Leonard. 1999. "Intangibles: What Put the *New* in the New Economy?" *Federal Reserve Bank of Philadelphia Business Review* (July/August): 3–16.

Nakamura, Leonard. 2001. "What is the U.S. Gross Investment in Intangibles? (At Least) One Trillion Dollars a Year!" Federal Reserve Bank of Philadelphia Working Paper 01-15.

OECD. 2013. *Supporting Investment in Knowledge Capital, Growth and Innovation*. Paris: OECD Publishing.

OECD. 2015. *Frascati Manual 2015—Guidelines for Collecting and Reporting Data on Research and Experimental Development*. Paris: OECD Publishing.

OECD. 2017. *OECD Science, Technology and Industry Scoreboard 2017: The Digital Transformation*. Paris: OECD Publishing.

Pahwa, Nitish. 2021. "How the Heck Is Peloton the Best-Paying Music Streaming Service?" *Slate*, July 12, https://slate.com/culture/2021/07/peloton-music-royalties-spotify-apple-music.html.

Pakes, Ariel, and Marcus Schankerman. 1984. "The Rate of Obsolescence of Patents, Research Gestation Lags, and the Private Rate of Return to Research Resources." In *R&D, Patents, and Productivity*, edited by Zvi Griliches, 73–88. Chicago: University of Chicago Press.

Piekkola, Hannu. 2016. "Intangible Investment and Market Valuation." *Review of Income and Wealth* 62 (1): 28–51.

Robbins, Carol, Olympia Belay, Matthew Donahoe, and Jennifer Lee. 2012 "Industry-level Output Price Indexes for R&D: An Input-cost Approach with R&D Productivity Adjustment." Unpublished.

Romer, Paul M. 1990. "Endogenous Technological Change." *Journal of Political Economy* 98 (5): S71–102.

Smith, Matthew, Danny Yagan, Owen Zidar, and Eric Zwick. 2019. "Capitalists in the Twenty-First Century." *Quarterly Journal of Economics* 134 (4): 1675–745.

Vinod, H.D., and P.M. Rao. 2000. "R&D and Promotion in Pharmaceuticals: A Conceptual Framework and Empirical Exploration." *Journal of Marketing Theory and Practice* 8 (4): 10–20.

Young, Alison. 1998. *Towards an Interim Statistical Framework: Selecting the Core Components of Intangible Investment*. Paris: OECD.

Zhang, Daniel, Saurabh Mishra, Erik Brynjolfsson, John Etchemendy, Deep Ganguli, Barbara Grosz, Terah Lyons, et al. 2021. *The AI Index 2021 Annual Report*. Stanford: Stanford University Human-Centered AI Institute.

Zwick, Thomas. 2007. "Apprenticeship Training in Germany? Investment or Productivity Driven?" ZEW Discussion Paper 07-023.