Intangible Capital, TFP Growth and Green Shoots in New Productivity Data

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Abstract

This article undertakes a comparative analysis of recent productivity growth in European economies, Japan, the United Kingdom, and the United States using the EU KLEMS & INTANProd database. The influence of intangible capital on productivity growth and insights from combining long historical time series for TFP with the current estimates in EU KLEMS & INTANProd are central features of our analysis. Our compara- tive analysis of growth decompositions before and after the productivity slowdown suggests that productivity growth in the 2014-2019 period in advanced economies has been relatively

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strong, consistent with a slew of the newer digital technologies (cloud, big data, AI) gaining wider use. Recent research finds that mechanisms governing knowledge diffusion are weaker recently than in the past—implying that advanced economies are not experiencing their full potential for productivity growth. Unless policies or voluntary industry actions create new platforms for technology extension and data sharing (e.g., open banking policies), the potential for spillovers to amplify intangible-investment induced innovations will be less strong than they have been in the past.

The slow productivity growth since the Global Financial Crisis (GFC) has been widely discussed, with some attributing its causes to the recession's aftermath (e.g. financial frictions, slowdown of international trade), others to structural factors (e.g. population aging, capital misallocations, decline in business dynamism). This article contributes to this debate using a new database for productivity analysis, the EU KLEMS & INTANProd dataset, to provide new estimates and undertake a comparative analysis of the productivity performance of European economies, Japan, the United Kingdom and the United States.

This database updates and extends previous editions of the widely used EU KLEMS database to incorporate measures of intangible investment from INTAN Invest.[2] This represents a significant advancement for productivity analysis and policymaking in that it is the first cross-country productivity database including all intangible assets as defined by Corrado, Hulten, and Sichel (2005, 2009) in a framework coherent with national accounts. As in previous editions of EU KLEMS, the Japanese module is kindly supplied by The Research Institute of Economy, Trade, and Industry (RIETI) and Hitotsubashi University.

The inclusion of all Corrado-Hulten-Sichel intangibles in EU KLEMS & INTANProd both modifies the asset boundary of existing national accounts and the interpretation of total factor productivity (TFP). As a result, this article examines how these first-order modifications affect the analysis of post-GFC productivity developments. In a nutshell, the article finds the oft-quoted magnitudes for the productivity slowdown in the United Kingdom and United States to be exaggerated, especially for the United Kingdom but that sustainable trends in TFP are a notch lower than in the past (as suggested by much recent literature). After reviewing and evaluating the slowdown, the article shifts focus to assessing the growth performance of advanced economies in the six-year period from 2013 to 2019 and finds evidence that productivity growth has been relatively strong—not strong enough in most countries to make up the shortfalls cumulative in the GFC and European sovereign debt crisis periods—but elevated by sus-

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[2] EU KLEMS & INTANProd is funded by the Directorate General for Economic and Financial Affairs (DG-ECFIN) of the European Commission. For information about past releases of EU KLEMS, see www.euklems.net, van Ark, O'Mahony and Timmer (2008), and Timmer, Inklaar, O'Mahony and van Ark (2010). The 2019 edition of EU KLEMS included intangibles, but the coverage was not comprehensive. For more information about INTAN Invest, see www.intaninvest.net and Corrado *et al.* (2012, 2013, 2016).

tained investments in innovation that seem to have paid off, especially when placed in the context of convergence and trend growth in intangibles-adjusted TFP at the frontier.

This article has five sections. The next section introduces our stylized "upstream/downstream" model of production with intangible capital, a framework we have used in previous works to address how innovation, intangibles and TFP are related in an economy. In the second section, we present the EU KLEMS & INTANProd dataset which offers many new features besides the inclusion of intangible capital. We examine how extending national accounts asset and production boundaries to include intangibles affects the EU KLEMS & INTANProd measures of investment and labour productivity. In the third section we use standard growth accounting techniques to analyze the contribution of intangible capital and TFP to labour productivity growth in the market-sector industries of nine EU economies (aggregated), Japan, United Kingdom, and United States.

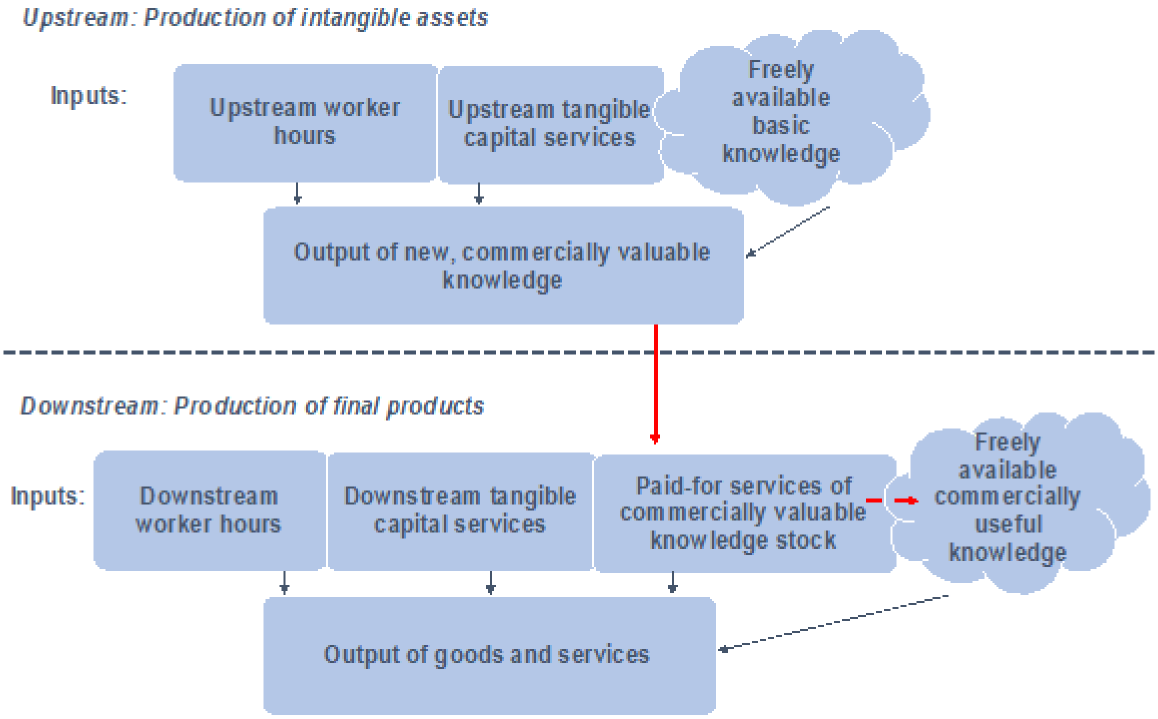
In the fourth section we provide a long-term perspective on TFP growth in the non-farm business sector of the US economy and analyze the impact of adjustments for mismeasurement of prices due to product quality change, This allows us to develop an estimate of intangibles-adjusted growth of TFP at the market sector frontier for the United Kingdom and United States. We find that the productivity slowdowns in the United Kingdom and the United States are exaggerated when measured using data starting in 1995 and that TFP growth in the United Kingdom, United States and Japan since 2013 is at or near the rate of intangibles-adjusted growth at the frontier of 0.5 to 0.8 per cent. TFP growth in the EU9 aggregate is less strong. A solid performance in the EU North region (Sweden, Denmark and Finland) only partially offset very weak TFP growth in France and Germany. We also find that investment in innovation after the GFC continued and that the contribution of intangible assets to labour productivity growth did not materially diminish. Nevertheless, TFP growth weakened in the aftermath of the GFC and period of the European sovereign debt crisis.

This seeming paradox—that investment in innovation-promoting intangibles was well maintained in the face of a slowdown in TFP growth—is examined in a fifth section. We find that the results from EU KLEMS & INTANProd support arguments that TFP growth has slowed due to weakened knowledge spillover mechanisms (Akcigit and Ates, 2021, Corrado *et al.*, 2024). This finding is consistent with firm-level/microdata studies showing that the acquisition of intangibles is associated with increased within-industry productivity dispersion (e.g. Corrado, Criscuolo *et al.* 2021; see also the discussion in Haskel and Westlake, 2018) and diminished competition (Bessen 2022, Aghion *et al.*, 2023, De Ridder, 2024).

Conceptual Framework

In the standard neoclassical production framework, changes in real output are proximately determined by changes in factor inputs and changes in TFP, with the latter attributed to structural (exogenous) factors or mismeasurement. In the concep-

Figure 1: Conceptual Framework for a Model with Intangible Capital



Source: Authors' illustration; from Chart 2 in Corrado *et al.* (2022)

tual framework of production with intangibles, intangible capital becomes an additional factor input and proximate determinant of TFP while also playing a growth-promoting role akin to R&D in endogenous growth theory. To explain, let us set out the intangible capital conceptual framework using a simplified model of the economy.

Model of an Economy with Intangible Capital[3]

In our simplified model of the economy, production activity is divided into two parts. The first is an "upstream" set of activities that produces innovations that can be commercialized, like a new system for organizing production or a software program adapted to the needs of the organization. The second is a "downstream" set of activities that uses the knowledge generated by upstream activities to produce final goods and services. By "final" we mean output for sale to consumers or for export or domestic investment; for simplicity, we ignore intermediate inputs. These two interlinked, yet distinct, production activities are depicted in Figure 1.

The outstanding stock of intangible capital in this framework, which might also be called "commercial knowledge," reflects the

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[3] This section is drawn from Corrado *et al.* (2022). For an algebraic formulation, see Corrado *et al.* (2023) and Corrado (2024), which are drawn from Corrado, Goodridge, and Haskel (2012) and based on the original Corrado-Hulten-Sichel intangible framework.

accumulation of upstream output, after adjusting for losses due to aging (or economic depreciation). Downstream producers acquire commercial knowledge much as they acquire 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 dashed arrow in the downstream sector.

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. So, while basic knowledge is an input to the production of commercial knowledge, it receives no factor payments because its services are assumed to be freely available. "Basic" knowledge in this model is not viewed as stemming solely from scientific breakthroughs. The idea of creating efficient supply chains relies on customer-determined product specifications and operational knowledge as well as practices with roots in engineering and information technologies. In fact, investments in branding and marketing, organization structure, and employer-provided training long have been modeled as complements with information technology.[4]

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. 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 upstream knowledge producers residing within larger organizations, and the internal payments to these innovation labs and strategy teams represent their contribution to total revenue.

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 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. Edison's Menlo Park innovation facility is another, more venerable, example.

Finally, the idea that innovators hold temporary product market power for their inventions is a common feature of economic

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[4] Brynjolfsson and Hitt (2000) and Corrado, Haskel, Jona-Lasinio (2017a) find justification for this in firm-level and cross-country macroeconomic data on intangibles, respectively.

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, which in the intangible capital framework of Figure 1 is treated as a price-taker for knowledge. Prices for other inputs are assumed to be competitive, as are final product prices (given the cost of producing new commercial knowledge). This implies that the first-order impact of market power is higher intangible asset prices, and if intangibles are not accounted for in firm-level or macroeconomic data, measures of market power such as price markups are biased.[5]

GDP and Labour Productivity with Intangible Capital

Without the capitalization of intangibles, spending on intangibles (and production in the upstream sector of the model sketched out above) is denoted $P^N N$ but is treated as a purchase of intermediate inputs. This GDP consists solely of downstream output, denoted $P^Y Y$.

When the definition of investment is expanded to include spending on intangibles, intangible investment becomes a final expenditure along with consumption and tangible investment. GDP is then $P^Y Y + P^N N$ and denoted $P^Q Q$. In our simplified model, which is closed, output is the sum of the production of intangibles and the production of all other final goods and services, or alternatively the sum of final expenditures:

$$P^Q Q = P^Y Y + P^N N \equiv P^C C + P^I I + P^N N \qquad (1)$$

Here, the P terms are prices, C is consumption, and I is investment in tangible capital K. Equation (1) shows that when investments in intangibles, N, are capitalized, GDP (the level of real output, previously Y, now Q) becomes larger—and so does real output per hour, the level of labour productivity.

In contrast, the impact on real GDP growth could be positive or negative. With intangibles capitalized, the growth rate of GDP equals a weighted average of the growth rates of previous GDP and the new investment. Denoting as the growth rates (defined as log-changes) of existing GDP, new GDP, and new investment by dy, dq, and dn respectively, and letting s_Q^N be the share of new nominal GDP accounted for by investment in intangibles in equation (1), this weighted average is:

$$dq = s_Q^N dn + \left(1 - s_{\mathrm{Q}}^N\right) dy \qquad (2)$$

The gap between true less measured GDP growth (dq-dy) is then given by

$$dq - dy = s_Q^N (dn - dy) \qquad (3)$$

which implies that the impact on labour productivity growth of capitalizing intangibles depends on the relative *growth* rate of *real* intangible investment.

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5 See Corrado *et al.* (2022, 2024) for further discussion.

Growth Accounting with Intangible Capital

As set out above, the upstream sector of this simplified economy produces N, real intangible investment, and the downstream sector produces all other final output Y, consumption and tangible investment. Each production sector uses labour L and tangible capital K inputs, whose prices P^L and P^K are competitive, but their production functions differ. The basic knowledge that the upstream sector uses is "free" whereas downstream producers pay P^R (per year) for their use of commercially valuable knowledge R.

The aggregate factor payments equation for this economy is written:

$$P^Q Q \equiv P^L L + P^K K + P^R R \qquad (4)$$

where P^R is the rental price of intangible capital. This refers to Jorgenson's user cost relationship (Jorgenson, 1963), which for intangibles is given by:

$$P^R = (r + \delta_R + dp^N_R)P^N \qquad (5)$$

where δ_R is the rate of depreciation of intangible assets and dp^e_R is their expected holding gain. The asset price P^N includes the Schumpeterian (monopolistic) returns to innovation as discussed above whereas the ex post calculated rate of return to capital r is a competitive return arbitraged over across all assets, tangible and intangible, in the economy.[6]

As in the Solow model, GDP growth in this model is decomposed into contributions from changes in inputs and from TFP, where TFP is residual growth not explained by input changes weighted by their income shares in (4). Let σ^X_Q be the combined factor income share for the conventional inputs L and K, dx the combined growth of these two inputs, σ^R_Q the factor income share attributed to intangible capital, and dr the growth of inputs of intangible capital. The sources-of-growth decomposition with intangibles is then:

$$dq = \sigma^X_Q dx + \sigma^R_Q dr + da \qquad (6)$$

which says that output growth consists of a contribution from conventional inputs $\sigma^X_Q dx$, a contribution from paid-for, commercially held knowledge $\sigma^R_Q dr$, and TFP growth da. The contribution of freely available knowledge, whether basic knowledge or commercial innovations able to be replicated at low cost, is included in da. What is different in the model with intangible capital is that paid-for, commercially valuable knowledge has become a proximate, measurable source of growth (rather than being relegated into TFP growth). That is, the services from the stock of intangibles becomes an input used in production while investment in new intangibles becomes one of the outputs.

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[6] In growth accounting with intangibles, the overall ex post calculated rate of return to capital is lowered and found to be generally aligned with calculations of the financial cost of capital; see Corrado *et al.* (2022) for further discussion and an illustration. For a discussion of how growth accounting with intangibles is consistent with Schumpeterian competition at the firm level, see Hulten (2010).

Now let da' be measured TFP when using $P^Y Y$, and let dx' be the contribution of conventional inputs (K and L) to the growth in dy, i.e. $da' = dy - dx'$. Combining that with equations (5) and (3), we have that:

$$da - da' = -[(\sigma_Q^R dr + \sigma_Q^X dx) - dx'] + s_Q^N (dn - dy) \tag{7}$$

as an expression of the difference between da as knowledge spillovers in the intangible capital model and measured TFP ignoring intangibles, da'.

Before we discuss the terms in equation (7) per se, it is important to underscore that theory provides some insight on the behavior of TFP when a new investment stream enters the picture. One is the J-curve effect of Brynjolfsson, Rock and Syverson (2021), which pertains to the impact on measured TFP (da') of the investment and income dynamics that take place in the early stages of a new technology. At first the output effect dominates, holding down da' relative to da because the new investments are not counted in real output. But eventually the income earned from the investments grows and boosts measured TFP, which by ignoring the capital created by the new investment stream exaggerates measured TFP growth, as in the upward "swoosh" of the letter J.

Theory also suggests that the contribution of investment to the output and input sides of (5) cancel out when the investment share of output (the savings rate) is equal to capital's share of income. This situation occurs on a "maximal" consumption steady-state growth path (Phelps, 1961), which in turn suggests that the addition of a new investment stream will eventually have little to no effect on measured TFP growth in advanced economies (Jorgenson 1966), i.e. the J-curve effect is a temporary dynamic.

Turning now to equation (7), it is a very simple statement of how TFP is affected when an investment stream is capitalized versus when it is not. The equation implies that there is an impact stemming from the difference in inputs growth rate (the first term in brackets) and an impact stemming from the difference in output growth rate (the second term). These impacts work in opposite directions, i.e. intangibles-adjusted TFP growth may be lower than the conventional calculation when the combined inputs grow faster than conventional input, which is the case when real intangible capital is growing faster than tangible capital. On the other hand, when real intangible investment is growing relatively rapidly, TFP growth is elevated relative to the conventional calculation, which may happen when intangible capital grows faster than tangible capital. But the dynamics of consumption and investment on the one hand and income on the other also enter the picture. All told, as an empirical matter equation (7) may be positive, negative, or essentially zero.

Finally, the intangible capital framework helps explain the origins of TFP growth. The knowledge embedded in intangible capital is inherently nonrival and only partially appropriable. Nonrival assets (such as a piece of software code) can be copied and used simultaneously in production by owners and non-owners alike, creating a situation where owner/developers do not capture the full returns to their investments. As in endogenous growth theory (e.g. models following Romer, 1990), these unappropriated returns are a source of TFP growth. The boost to TFP via the costless diffusion (or spread) of innovators' knowledge from one organization to another is a form of economic externality called "knowledge spillovers" discussed as an empirical matter below.

The EU KLEMS & INTANProd dataset

The EU KLEMS & INTANProd dataset covers 27 EU Member States, the United Kingdom, the United States and Japan across 38 NACE industries from 1995 to 2020.[7] NACE industries in EU KLEMS & INTANProd are listed in appendix table A1.[8] The project provides a portal for selective or bulk downloading of the EU KLEMS and INTANProd data, with LLEE (2023) the version used in this article. Bontadini *et al.* (2023) provide details on methods and estimation of variables in the database. Data and documentation for the Japanese intangible and productivity estimates are available from Japanese Industrial Database (2023).

For European countries, industry detail and coverage vary over time and across countries. In our analysis of intangible investment and labour productivity trends in this section, the coverage is sufficient to work with most of EU member states for the entire time span of the database. For our analysis requiring industry-level capital and labour inputs by detailed type, i.e. for examining trends in intangibles versus tangibles for the market sector and for the estimation of total factor productivity, EU country coverage over the database time span becomes more limited. The major EU KLEMS & INTANProd coverage variances are documented in Appendix Table A2.

Intangible Investment: Categories, Asset Types and Methods

Table 1 displays the intangible capital framework included in the EU KLEMS & INTANProd dataset. Compared with the prevailing national accounting framework, this approach expands the range of spending by firms that should be viewed as investment. It applies a fundamental economic criterion to define investment, namely, that business (or public) investment consists of outlays expected to yield a return in a future period. The categorization of assets in Table 1 indicates intangibles consist of a wide class of assets, from databases to business processes. These assets are instructive for understanding the performance of leading global companies, such as Apple, Microsoft and many others whose success is based on software, data, design, operations networks, and brand

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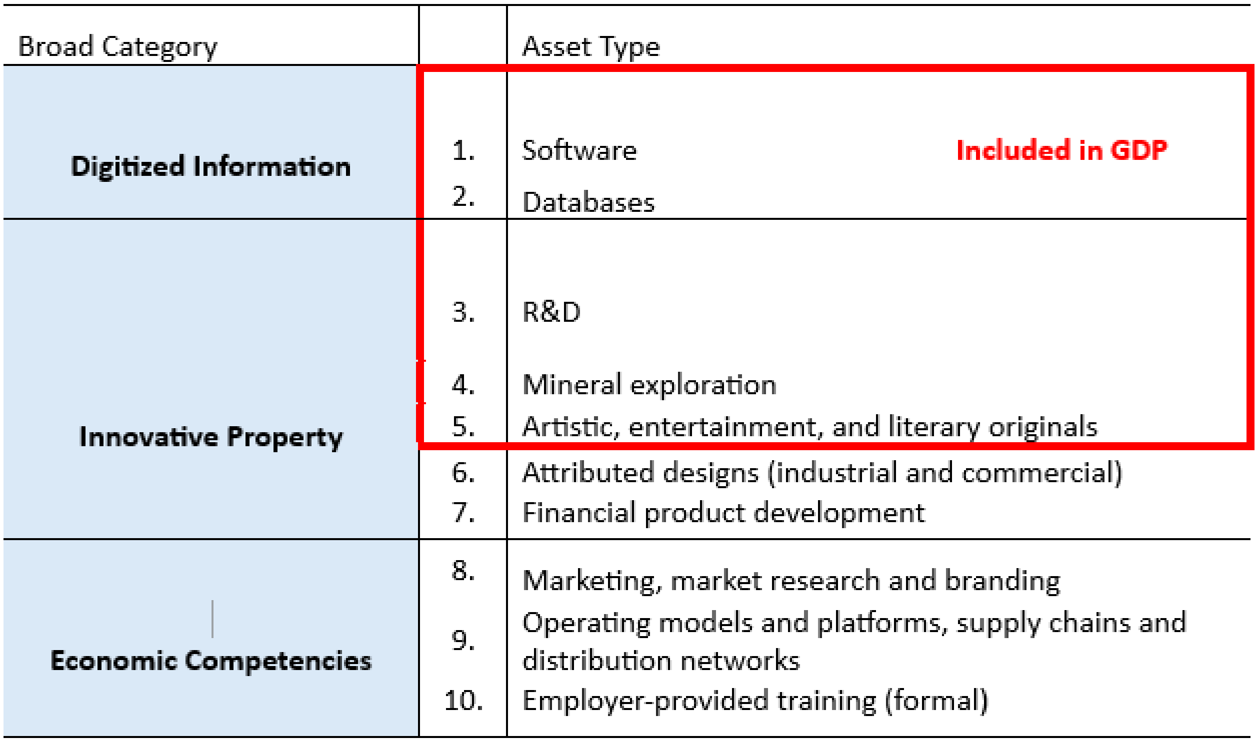
[7] NACE is the acronym (from the French 'Nomenclature statistique des activités économiques dans la Communauté européenne' - Statistical classification of economic activities in the European Community) used to designate various statistical classifications of economic activities developed by the European Union.

[8] All appendix tables are found at: https://csls.ca/ipm/46/Appendix$_C$*orrado.pdf*

Table 1: Corrado-Hulten-Sichel Typology of Intangible Capital: Broad Categories and Asset Types



Broad Category		Asset Type
Digitized Information	1.	Software
	2.	Databases
Innovative Property	3.	R&D
	4.	Mineral exploration
	5.	Artistic, entertainment, and literary originals
	6.	Attributed designs (industrial and commercial)
	7.	Financial product development
Economic Competencies	8.	Marketing, market research and branding
	9.	Operating models and platforms, supply chains and distribution networks
	10.	Employer-provided training (formal)

Note: Lines 1 to 5 (outlined in red) are included as investment in national accounts, though line 2 excludes purchases of data.
Source. Authors' elaboration of Corrado, Hulten and Sichel (2005, 2009).

and whose market capitalization greatly exceeds reported, mainly tangible assets.

The intangible capital framework in Table 1 is widely used. The OECD (2013) adopted the taxonomy, using "knowledge-based capital" to describe it. The European Union commissioned EU KLEMS & INTANProd as a vehicle for its policy work, and the World Intellectual Property Organization, an agency of the UN, is sponsoring the development of estimates for emerging economies using the Table 1 framework.[9]

There have been improvements in EU KLEMS & INTANProd in the measurement of intangible assets. Estimates for these assets now cover 38 NACE industries versus 18 industries in the previous editions of INTANInvest.[10] Nominal intangible investment by asset type covers all possible

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[9] The appendix to Corrado, Haskel, Jona-Lasinio, and Iommi (2022) summarizes the methods used to estimate intangible investment for assets that are not currently included as investment in GDP in national accounts; examples and data sources for a typical European country and the United States are provided. As noted in this source and on the EU KLEMS & INTANProd website, estimates of intangibles included in EU KLEMS & INTANProd for European countries and the United States incorporate significant improvements relative to previous editions of INTANInvest and EU KLEMS. The estimates for intangibles in Japan are not fully harmonized with these methods, but like the estimates for other countries, the Japanese estimates cover all Corrado-Hulten-Sichel assets, and the methods used are very close and generally aligned with those used for the other areas.

[10] Manufacturing is now disaggregated to cover 12 industries. Selected service sectors (wholesale and retail trade, transport, professional services, and health) also are expanded to provide more industry detail.

purchased and own-account activity and estimates are built from industry-level total expenditure when possible.[11] Japanese estimates do not include an own account component for brand or a purchased component for organizational capital.

Another important improvement is that real intangible investment now incorporates price deflators based on closely aligned services output. [12] One of the major changes is the incorporation of the dramatic drop in advertising media costs since 2009. To explain the relevance of this move, consider that a price deflator for investment in marketing, market research and brand needs to incorporate two major factors affecting costs: one cost element covers content development and production of original services, and the other is the cost of disseminating content via media.[13]

To measure the latter, a price index was developed from input price indexes for internet advertising versus traditional media from the BLS producer price index system. The dynamic of these relative prices was incorporated in the price deflator for brand deflator for European economies based on information on the internet share of advertising and domestic services prices for content development and production costs.[14]

Another change, affecting the US results only, is that the portion of purchased investments for IT organizational change, e.g. payments to external providers to organize a company's computing in the cloud, is deflated by the gross output deflator for the primary industry supplying these services.

The Structure of the Database

EU KLEMS & INTANProd consists of two modules. The **statistical** module is a repository of all the key variables for industry-level productivity analysis provided directly by the national accounts of individual countries. The **analytical** module complements these data with information on investment and capital stocks for intangible assets that are not included as investment in national account calculations of GDP.

The analytical module includes an intangibles submodule based on the constructs previously available via INTANInvest. This includes real industry-level value added adjusted to include the intangibles not currently included in official statistics as well as all key variables for industry-level growth accounting with intangibles. All told, the analytical module is the repository for ongoing improvements to estimates of intangibles and industry-level growth accounting with intangibles. Among the most recent developments included in its present version of the database are (a) cap-

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[11] Previously, there were no own account components for design or brand for European economies.

[12] for details on the prices used for each intangible asset for European economies and the United States (see Bontadini *et al.*, 2023).

[13] Branding and marketing are unique assets in that their value is based on information held by customers, which typically requires content dissemination.

[14] For further discussion of this deflator, see Corrado *et al.* (2024); for details on its construction from US PPIs, see the appendix in Corrado (2024).

ital stocks for all assets (tangible and intangible) based on geometric depreciation with harmonized age-price profiles, and (b) growth accounting results for selected aggregates are based on "bottom up" aggregations of industry-level output and factor inputs for countries with the requisite data. This is the standard approach in the productivity literature since Jorgenson and Griliches (1967).[15]

The bottom-up calculations reported on the website cover nine economies of Europe, Japan, the United Kingdom and United States with consistent, industry-level growth accounts from 1995 on (1997 for the United Kingdom); estimates for 11 member states are available from 2000 on, and for 14 member states from 2009 on. The calculations for each country are performed by building up from data on 19 NACE "letter" sector industries; for industries covered see Appendix Table A1.

Descriptive Results: Intangible and Tangible Investment

A feature of EU KLEMS & INTANProd is that intangible investment covering all Table 1 assets and all NACE industry activities are available for most EU member countries. Chart 1 uses these estimates to compare intangible and (nonresidential) tangible investment rates for the aggregate economy across eight economic areas/countries. The upper panels examine the EU (25 countries), Japan, United Kingdom and United States; the lower panels compare four regions within the EU.[16] In each panel, the solid red line plots investment in all Table 1 intangible assets as a share of gross value added (GVA) whereas the black line plots the share for tangible investment (nonresidential assets only). Investment in intangible assets included in national accounts is depicted by the dashed red line.

The panels of Chart 1 reveal variability across countries and EU regions in the rate of intangible investment. In the EU, total intangible investment was 8.5 per cent of GDP in 1995 and climbed 2.5 percentage points to 11 per cent by 2019. Investment rates in the United Kingdom and United States start at about 12 per cent and climb to 14.3 and 15.7 per cent, respectively. In Japan, the rate of intangible investment was 7.5 per cent in 1995, and while the rate rose 1.5 percentage points by 2009, it flat-

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[15] The initial EU KLEMS editions were built from the industry-level up, but the Commission's guidelines for the 2012 edition required the inclusion of the EU's new member states. The lack of industry and input detail for these countries necessitated calculating the growth accounting for the available industry coverage from corresponding quantities of labour (hours worked/number of employed) and capital (capital stocks). For continuity with previous editions (per commission guidelines), growth accounting results using this "direct calculation" approach are reported in both modules of EU KLEMS & INTANProd, but these estimates are not used in this article. As stressed in the productivity literature, growth accounting with aggregates implicitly assumes that the reallocation of capital and labour across industries does not contribute to aggregate growth, i.e., it requires perfect mobility of inputs across industries, that labour and capital earn the same compensation in all industries, and that all industries have the same value-added function. These assumptions are highly restrictive, and directly calculated TFP growth tends to overstates true TFP growth, which is best approximated using industry-level real output and inputs distinguished by type.

[16] The EU aggregate covers 25 EU member states excluding Austria and Ireland. These countries are excluded because the EU KLEMS & INTANProd estimates of total intangibles for these counties are understated. Owing to a lack of source data, they do not include own-account components of investment in certain asset types.

Chart 1: Intangible and Tangible Investment Rates as Share of GDP, all NACE Activities, 1995-2019

Note: Data for the United Kingdom start in 1997. European aggregates are formed using PPP-adjusted values for GVA. EU region country groupings. EU Centre: Belgium, Germany, France, Luxemburg, Netherlands. EU East: Czech Republic, Estonia, Croatia, Hungary, Lithuania, Latvia, Poland, Romania, Slovenia, Slovakia. EU North: Denmark, Finland, Sweden. EU South: Cyprus, Greece, Spain, Italy, Portugal; Malta. Note that tangible investment for Hungary, Poland, and Slovakia starts in 2000, affecting the start date for the EU East tangible investment aggregate.
Source: Authors' elaboration of data from EU KLEMS & INTANProd (LLEE, 2023).

tened and then edged down to 8.7 per cent by 2019.

The regional differences within the EU in 1995 are stark, with rates in 1995 ranging from around 6.7 per cent in EU South (the lowest) to around 11 per cent in EU North (the highest). But the expansion of intangible investment across the EU regions is somewhat uneven. Over the period shown, the EU Centre and EU North regions boost their intangible investment rates by 3 and 3.6 percentage points, respectively. By contrast, the rates for EU East and EU South show less change, 2.4 and 1.6 percentage points.

The area between the two red lines in each panel reflects the expansion of the production boundary for intangibles in the analytical module of EU KLEMS & INTANProd versus that in national accounts, i.e., the effect of adding the intangibles listed on lines 6 through 10 of Table 1 to those on line 1 through line 5. For the United Kingdom, including the additional intangibles more than doubles the rate of intangible investment based on averages for the years from 2017 to 2019; for the US the rate is exactly doubled for those years, and for the EU, the boost nearly doubles the rate of intangible investment, while for Japan, the expansion of investment is rather less.

Chart 2 reports investment rates for market sector industries of the countries and regions reported in Chart 1. This group of industries excludes real estate (which is dominated by the imputation for owner-occupied housing), public administration, education and health, and private households. In contrast to Chart 1, Chart 2 uses 17 EU member states to represent the EU, as it is necessary to exclude member states whose national accounts do not include industry-level information on investment by asset type. Thus, while a comparison of Chart 1 versus Chart 2 results mainly reflects the exclusion of nonmarket activity, some differences between the EU aggregates are due to the exclusion of countries. [17]

The patterns in Chart 2 are more market-driven than those in Chart 1. Accordingly, the rise in investment rates for intangibles is sharper and the rates for tangibles are more cyclical. As before, however, the trends for the rise in the investment rates for intangibles in the United States is sharper and the trends for the United Kingdom, United States and EU North are again strikingly similar—the market sector intangible investment rate stood between 17 and 18 per cent in these economic areas in 2019. The rate of intangible investment by market sector industries in EU Center countries remains lower than in these countries—it stood at 14.5 per cent in 2019. EU South looks relatively more dynamic here than in Chart 1, mainly due to the exclusion of laggard countries.

All told, the composition of investment, tangible versus intangible—and between intangibles included in national accounts versus those in Table 1's expanded list—varies across EU regions and across countries. Yet we see two major take aways

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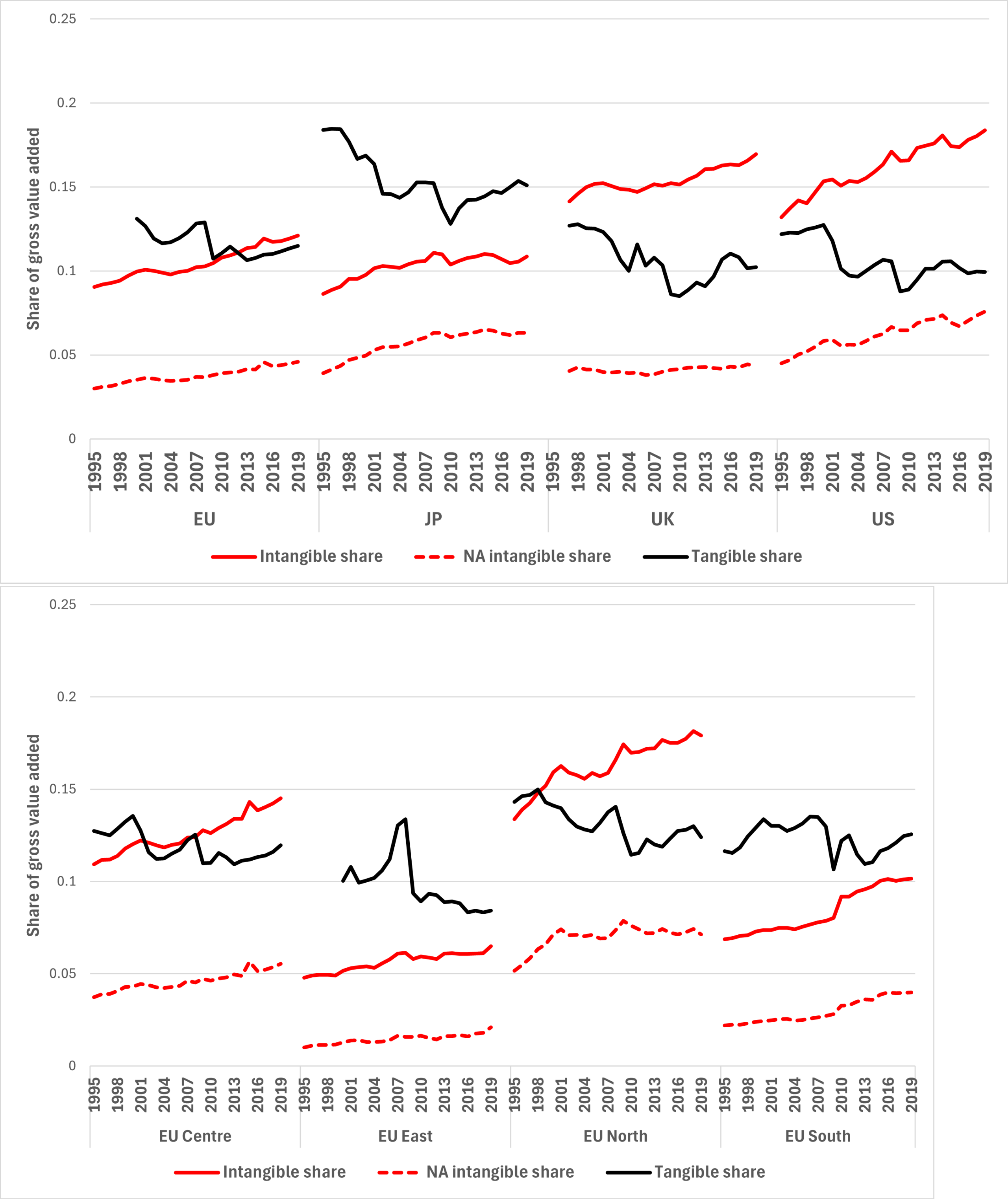
[17] The exclusions drop Luxembourg from EU Center; Cyprus, Greece, and Malta from EU South; and Estonia, Croatia, Hungary, and Poland from EU East.]

Chart 2: Intangible and Tangible Investment as Share of GDP, Market Sector Industries, 1995-2019



Note: Data for the United Kingdom start in 1997. European aggregates are formed using PPP-adjusted values for GVA. EU Country groupings. EU Centre: Belgium, Germany, France, Luxemburg, Netherlands. EU East: Czech Republic, Lithuania, Latvia, Romania, Slovenia, Slovakia. EU North: Denmark, Finland, Sweden. EU South: Spain, Italy, Portugal; Malta. Note that tangible investment for Slovakia starts in 2000, affecting the start date of the EU East tangible investment aggregate.
Source: Author's elaboration of data from EU KLEMS & INTANProd (LLEE, 2023).

Table 2: Labour Productivity with Expanded Intangible Investment, PPP-adjusted constant 2015 international dollars per hours worked, 2019

Country/ Region	Expanded	Official	Percent Difference (%) (1)-(2)/(2)	Percent of US in (1)	Percent of US in (2)	Change (p.p) (1)-(2)
	(1)	(2)	(3)	(4)	(5)	(6)
1) EU27	52.0	48.4	7.6	71.8	73.1	-2.1
2) JP	49.5	47.9	3.4	67.5	72.3	-4.8
3) UK	54.4	48.8	11.5	74.2	73.7	0.5
4) US	73.2	66.2	10.7	100.0	100.0	–
5) EU North	62.1	56.7	9.6	84.8	85.6	-0.8
6) EU South	46.5	44.0	5.6	63.5	66.5	-3.1
7) EU East	34.0	31.3	8.7	46.4	47.3	-0.9
8) EU Center	66.0	61.1	8.0	90.2	92.4	-2.3

Note: Calculations use gross value added for total industry expressed in constant 2015 units of local currency (i.e., real output in basic prices) adjusted to constant 2015 international dollars using PPPs. Sources: Authors' elaboration of labour productivity from EU KLEMS & INTANProd (LLEE 2023) and PPPs from the Eurostat database (2024).

from these data. First, for most countries and regions, the rate of intangible investment rises from 1995 to 2019, with the rise rather sharper for market-dominated industries than that for the total including all industries. A consequence of this finding is that, cutting through cyclicality, the rate of tangible investment tends to fall on balance. A notable exception to this is the pattern in Japan where the intangible investment rate remains flat after 2009. Second, for the United Kingdom and United States, the rate of intangible investment notably exceeds that for tangibles since at least 2000. In the EU North and EU Center regions, a similar pattern emerges (i.e. of intangible investment exceeding that of tangible investment), but it happens much later, by 2010 and 2015, respectively.

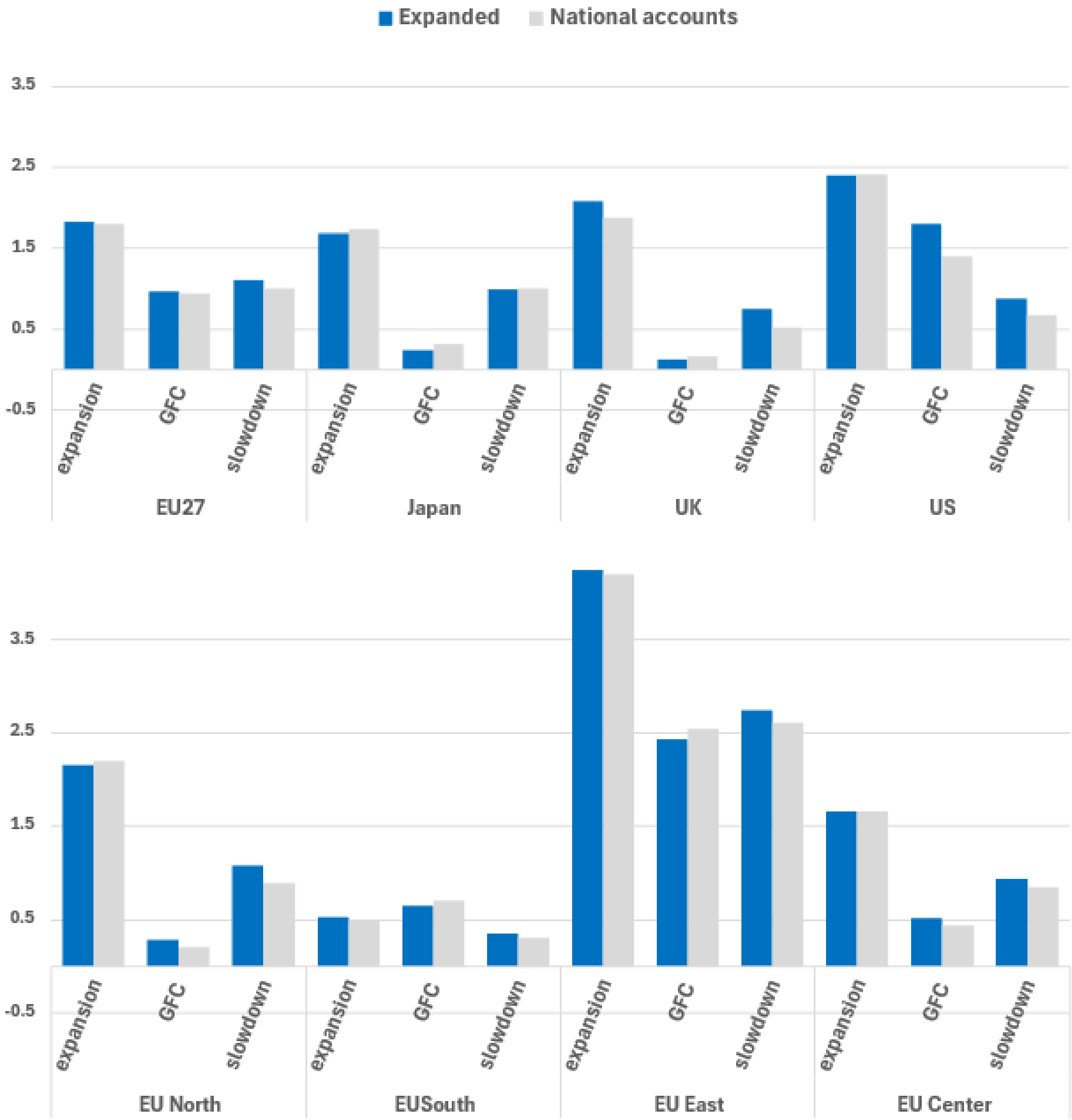
Expansion of Intangibles: Impacts on the Level and Growth of Labour Productivity

In the first section of the article we set out the simple algebra of the impact of capitalizing intangibles on GDP and labour productivity. Charts 1 and 2 have already suggested that the impact of capitalizing additional intangibles in the national accounts of an economy is an unambiguous boost to investment as a share of GDP (when measured for the aggregate economy) or Gross Value Added (when measured for a specific group of industries, such as the market economy. The move also boosts the level of real output and, consequently, the level of labour productivity for an economy. Expanding intangibles will also affect international comparisons of labour productivity levels.

A comparison of labour productivity levels for the major economic areas included in EU KLEMS & INTANProd is displayed in Table 2. Levels of labour productivity obtained from our "expanded" productivity accounts versus those obtained using the production boundary in "official" national accounts are shown using 2019 as the comparison year. The impacts on Japan and EU South are relatively the smallest.

The last set of columns in the table

Chart 3: Labour Productivity Growth with Expanded Intangible Investment in National Accounts, selected periods (all NACE activities), 1995- 2019



Note: The periods are as follows: Expansion is 1995 to 2007; GFC is 2007 to 2010; and slowdown is 2010 to 2019. For the United Kingdom, the expansion period begins in 1997. European aggregates are formed using constant PPP-adjusted values for real GVA.
Source: Authors' elaboration of EU KLEMS & INTANProd (LLEE 2023).

examine the expanded and official labour productivity levels relative to the United States. Looking at line 8, output per hour is relatively high in the EU Center countries, though the gap vis-à-vis the United States widens in the expanded measures. The level of labour productivity in EU North is affected less but still shows a widening of the gap with the United States. Only the United Kingdom moves closer to the United States in the expanded measure.

What about labour productivity growth? As also previously indicated, the impact of capitalizing additional intangibles depends in this instance on the relative growth rate of the new real investment—is it faster or slower than existing real GDP? The side-by-side bars of Chart 3 compare labour productivity growth after capitalizing all intangibles with labour productivity growth based on official GVA statistics for three periods in our data, which we label “expansion”, “GFC”, and “slowdown.” The definitions of these periods are spelled out in the note to Chart 3.

Chart 3’s side-by-side bars are generally very close to one another, though output per hour is boosted by more than 0.2 percentage points (rounded) in moving to an expanded boundary for intangible assets in some countries. For the United States and EU North this occurs in the post-crisis period when prices for intangible assets begin to fall in relative terms—and for these economic areas, the boost to labour productivity growth in the post-crisis period lessens the severity of the slowdown in labour productivity (defined as the difference between the pre- and post-crisis growth rates) by about 0.2 percentage points. In the United Kingdom, labour productivity growth is boosted in both the pre- and post-crisis periods, with little net effect on the slowdown measured by the difference in growth between these two periods.

Growth Accounting

This section focuses on analyzing productivity decompositions of the group of industries in the non-agricultural market sector of advanced economies, listed in detail in appendix table A1. This limits the country coverage of the EU to nine member states with industry-level production accounts including intangibles from 1995 on. The discussion below focuses primarily on the interpreting the productivity performance of the advanced economies included in the EU KLEMS & INTANProd dataset in the 12 years since the onset of the global financial recession, i.e. from 2007 to 2019. It also looks at more recent growth performance since 2019. The pandemic year 2020 is reported separately.

Labour Productivity Growth Decompositions

Labour productivity growth decompositions based on results in EU KLEMS INTANProd are summarized in Tables 3 and 4, where the first five lines for each country/economic area shows information for analyzing the slowdown over the 12 years since the onset of the GFC, and the second four show the slowdown calibrated against recent growth. Our analysis primarily focusses on Table 3, which displays results for a European aggregate, Japan, the United Kingdom and the United States. Table 4 shows the four major European countries included in the EU aggregate in Table 3, namely, France, Germany, Italy and Spain. Together they account for about 85 per cent of the combined market sector GVA of the nine countries in the aggregate. Labour productivity growth decompositions for the other five European countries are found on Appendix Table A4.

Basic Takeaways

Labour productivity for each aggregate economy (column 1) is calculated as the chained sum of value-added weighted real industry output divided by aggregate hours and includes a reallocation effect (column 2). The reallocation effect is positive when hours is relatively faster in higher value-added industries (or vice versa). This effect was a massive positive in the pandemic year 2020, when hours growth in many low value-added industries, e.g. hotels and restaurants, plummeted while many high salary office workers and professionals were able to telework. The 2020 reallocation effect was largely reversed in the following year (not shown). Scanning down column (2) and ignoring 2020, the reallocation of hours across industries generally does not play an important or sustained role in labour productivity developments for the advanced economies shown in Table 3.

The growth decompositions shown in the remaining columns of Table 3 reflect within industry changes in labour productivity as measured by value-added weighted labour productivity growth at the industry level. As may be seen in column (3) on the lines labeled “slowdown,” the average rate of growth of this labour productivity dropped dramatically in the United Kingdom and the United States (2.5 and 1.4 percentage points, respectively). The downshift is less in Japan, where labour productivity slowed 1.1 percentage point per year, and smaller still for the countries in the EU9 (0.7 percentage points). This cross-country variance in the severity of the slowdown in labour productivity stems largely from the variance in cross-country performance during the prior period used to calculate the slowdown. Once economic activity settled down after bubbles in some countries, convergence in others, and multiple crises, average labour productivity growth for the six years ending in 2019 (lines 7, 16, 25 and 34) varied less across the economic areas shown in Table 3, ranging from a low in Japan (0.75 per cent per year growth) to 1.1 per cent and 1.2 per cent for Europe and the United Kingdom, to 1.7 per cent per year in the United States.

Changes in labour composition (column 4) somewhat offset the slowdown in labour productivity in the EU9, but not elsewhere—indeed, the rate at which the within-industry composition of workers shifted to higher skilled (and higher paid) positions in other countries slowed. Moreover, the increased contribution of labour composition to labour productivity growth in Europe is widespread across its major countries (Table 4).

Let us make three additional points about the results shown on Table 3. First, more than half of the slowdown in labour productivity in Europe, United Kingdom and United States is directly accounted for by a slowdown in TFP (column 7). The TFP slowdown in Japan is both somewhat milder and accompanied by slowdowns in

Table 3: Decompositions of Labour Productivity Growth in the Nonagricultural Market Sector of the EU, Japan, UK and US (average annual change, selected periods)

				Contributions (p.p) to value added-weighted LP growth			
	Aggregate LP growth	Re-allocation	Value-added weighted LP growth	Labour Comp.	Tangible Capital Deepening	Intangible Capital Deepening	TFP
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
EU9							
1) 1996-2007	1.36	-0.15	1.51	0.10	0.71	0.42	0.28
2) 2008-2019	0.82	0.0	0.82	0.35	0.37	0.46	-0.35
3) 2020	1.61	2.1	-0.45	0.37	1.83	1.46	-4.10
Slowdown							
4) (lines 1-2)	0.54	-0.14	0.69	-0.25	0.34	-0.04	0.63
5) percent of col. (3)			100	-37	50	-6	92
6) 2008-2013	0.45	0.1	0.36	0.41	0.62	0.42	-1.09
7) 2014-2019	0.99	-0.2	1.14	0.25	0.13	0.44	0.32
Slowdown (recent growth)							
8) (lines 1-7)	0.38	0.01	0.37	-0.15	0.58	-0.03	-0.04
9) percent of col. (3)			100	-41	158	-7	-10
Japan							
10) 1996-2007	2.03	0.1	1.94	0.35	0.55	0.28	0.76
11) 2008-2019	0.78	0.0	0.81	0.11	0.21	0.15	0.35
12) 2020	-0.91	-0.2	-0.67	-0.93	1.02	0.87	-1.64
Slowdown							
(13) (lines 9-10)	1.25	0.1	1.13	0.24	0.35	0.13	0.42
(14) percent of col. (3)			100	21	31	11	37
(15) 2008-2013	0.79	-0.1	0.87	0.17	0.32	0.20	0.18
(16) 2014-2019	0.77	0.0	0.75	0.04	0.09	0.10	0.51
Slowdown (recent growth)							
(17) (lines 9-15)	1.54	0.10	1.19	0.30	0.46	0.18	0.25
(18) percent of col. (3)			100	25	39	15	21
United Kingdom							
(19) 1998-2007	2.91	-0.1	3.02	0.31	0.83	0.67	1.21
(20) 2008-2019	0.49	0.0	0.50	0.16	0.14	0.41	-0.22
(21) 2020	5.38	3.5	1.87	0.30	1.81	2.31	-2.55
Slowdown							
(22) (lines (18-19)	2.42	-0.10	2.52	0.15	0.69	0.25	1.43
(23) percent of col. (3)			100	6	27	10	57
(24) 2008-2013	0.05	0.3	-0.22	0.27	-0.06	0.35	-0.78
(25) 2014-2019	0.93	-0.3	1.22	0.05	0.35	0.48	0.34
Slowdown (recent growth)							
(26) (lines 18-23)	1.99	0.19	1.80	0.26	0.49	0.19	0.87
(27) percent of col. (3)			100	14	27	10	48
United States							
(28) 1996-2007	2.78	-0.1	2.87	0.34	0.91	0.72	0.90
(29) 2008-2019	1.47	0.0	1.49	0.24	0.36	0.79	0.11
(30) 2020	6.86	1.8	5.01	0.74	1.05	2.39	0.83
Slowdown							
(31) (lines 26-27)	1.31	-0.07	1.38	0.10	0.55	-0.06	0.79
(32) percent of col. (3)			100	7	40	-5	58
(33) 2008-2013	1.39	0.1	1.33	0.35	0.48	0.74	-0.24
(34) 2014-2019	1.54	-0.1	1.66	0.14	0.24	0.83	0.45
Slowdown (recent growth)							
(35) (lines 26-32)	1.24	0.03	1.21	0.21	0.66	-0.11	0.45
(36) percent of col. (3)			100	17	55	-9	37

Note: EU9 countries are CZ, DE, DK, ES, FI, FR, IT, NE, and SE. Annual changes are log changes multiplied by 100.
Source: Authors' elaboration of data from EUKLEMS & INTANProd (LLEE 2023)

Table 4: Decompositions of Labour Productivity Growth in the Nonagricutural Market Sector of Selected European Countries

				Contributions (p.p) to value added-weighted LP growth			
	Aggregate LP growth	Re-allocation	Value-added weighted LP growth	Labour Comp.	Tangible Capital Deepening	Intangible Capital Deepening	TFP
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
France							
(1) 1996-2007	1.77	-0.16	1.93	0.23	0.73	0.50	0.46
(2) 2008-2019	0.63	-0.01	0.64	0.45	0.29	0.61	-0.71
(3) 2020	2.02	1.96	0.06	0.63	1.44	2.33	-4.34
Slowdown							
(4) (lines 1-2)	1.14	-0.15	1.28	-0.22	0.43	-0.10	1.17
(5) percent of col. (3)			100	-17	34	-8	91
(6) 2008-2013	0.30	0.03	0.27	0.55	0.33	0.59	-1.19
(7) 2014-2019	0.96	-0.06	1.02	0.35	0.25	0.63	-0.22
Slowdown (recent growth)							
(8) (lines 1-7)	0.80	-0.10	0.91	-0.12	0.47	-0.12	0.68
(9) percent of col. (3)			100	-14	52	-14	75
Germany							
(10) 1996-2007	1.79	0.17	1.62	-0.04	0.46	0.24	0.96
(11) 2008-2019	0.87	0.01	0.86	0.26	0.17	0.30	0.13
(12) 2020	0.65	0.94	-0.28	0.00	1.10	0.93	-2.31
Slowdown							
(13) (lines 9-10)	0.92	0.16	0.75	-0.30	0.29	-0.07	0.83
(14) percent of col. (3)			100	-40	38	-9	111
(15) 2008-2013	0.37	0.02	0.35	0.38	0.18	0.25	-0.46
(16) 2014-2019	0.01	0.00	0.01	0.00	0.00	0.00	0.01
Slowdown (recent growth)							
(17) (lines 9-15)			1.60	-0.04	0.46	0.23	0.95
(18) percent of col. (3)			100	-3	29	15	59
Italy							
(19) 1998-2007	0.55	-0.03	0.57	0.19	0.71	0.23	-0.56
(20) 2008-2019	0.28	-0.06	0.34	0.39	0.27	0.27	-0.58
(21) 2020	4.17	2.04	2.14	0.47	2.84	1.51	-2.69
Slowdown							
(22) (lines (18-19)	0.27	0.03	0.23	-0.19	0.45	-0.04	0.02
(23) percent of col. (3)			100	-83	191	-16	9
(24) 2008-2013	0.04	0.03	0.01	0.41	0.52	0.29	-1.20
(25) 2014-2019	0.51	-0.16	0.67	0.36	0.02	0.26	0.04
Slowdown (recent growth)							
(26) (lines 18-23)	0.03	0.13	-0.10	-0.17	0.69	-0.02	-0.60
(27) percent of col. (3)			100	173	-721	24	624
Spain							
(28) 1996-2007	-0.34	-0.37	0.03	0.01	0.62	0.27	-0.87
(29) 2008-2019	1.10	-0.17	1.27	0.44	0.82	0.42	-0.40
(30) 2020	-2.75	2.52	-5.27	0.59	3.40	1.10	-10.36
Slowdown							
(31) (lines 26-27)	-1.44	-0.20	-1.24	-0.43	-0.19	-0.15	-0.47
(32) percent of col. (3)			100	35	16	12	38
(33) 2008-2013	1.63	-0.12	1.75	0.67	1.70	0.63	-1.24
(34) 2014-2019	0.57	-0.22	0.79	0.22	-0.06	0.20	0.44
Slowdown (recent growth)							
(35) (lines 26-32)	-0.92	-0.15	-0.76	-0.21	0.69	0.07	-1.31
(36) percent of col. (3)			100	27	-90	-9	172

Note: Annual changes are log changes multiplied by 100.
Source: Authors' elaboration of data from EUKLEMS & INTANProd (LLEE 2023)

the other proximate factors, including in the contribution of intangible capital deepening.

Second, the contribution of tangible capital deepening slows dramatically in Europe, United Kingdom and United States, primarily reflecting the large slowdowns in TFP growth in these countries because of the endogeneity of capital to TFP, but also an apparent substitution away from equipment towards intangible assets (e.g. big data, AI tools).

Third, despite the slowing in TFP, the contribution of intangible capital deepening was maintained in the entire post-GFC period (except for the slowing in Japan between 2008-2013 and 2014-2019). This is not the flipside of the substitution point made immediately above. If there are increasing returns to intangibles in the form of social returns via diffusion, TFP growth would not be expected to slow in the face of steady rates of investment in intangibles and increases in intangible capital deepening (all else equal), a topic discussed later in this section.

The TFP Slowdown Relative to Trend Growth at the Frontier

This section reviews topics that help us interpret the recent slowdown in TFP growth. We have already suggested that one must look at the contribution of intangible capital in conjunction with TFP to "see" innovation in an economy. Here we focus almost entirely on TFP, though still through the lens of the framework set out in the first section.

The widespread slowdown in productivity growth since 2007 has been labeled a "puzzle" and a subject of a growing number of studies. A slowdown is a period of slower growth compared to a prior period of faster growth. The prior period we use in this study begins in 1995 because that is the first populated data point in the industry-level EU KLEMS & INTANProd database. The "period of slower growth" typically includes the years since the onset of the GFC in 2007, which as a cyclical event ended in 2009, so sometimes the period from 2010 on is used as the "slower period" for analysis of the slowdown. The sovereign debt crisis in Europe that began soon after recovery from the GFC and did not end until early 2014 was another disruption heightening global investment uncertainty and the productivity performance of advanced economies. The 6-year period from 2013 to 2019 that followed was relatively quiescent, however, and hence that period, too, can be used as a "slower period" for analysis of the slowdown.

A Long-Term Perspective on the TFP Trend Growth

But how does the recent slowdown in TFP growth compare to long-term trends? For this we must focus on the United States, which may be regarded as the frontier country of productivity. In the

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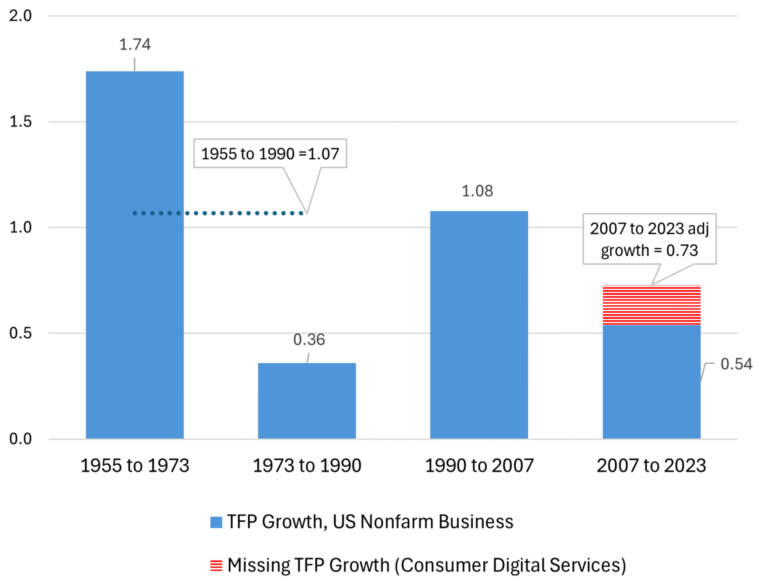
18 Fernald and Inklaar (2022) use this approach to analyze productivity developments in the United States. Consistent with this view, as they point out, the International Monetary Fund (2015, Box 3.2) finds a statistically significant link between changes in U.S. TFP growth and in TFP growth for other advanced economies using a cross-country panel data from 1970 to 2007. The peak effect occurs in three to four years.

Chart 4: Peak-to-peak Trends in Total Factor Productivity in the United States, Selected Periods (Average annual per cent change)



Note: The adjustment for mismeasurement in the 2007 to 2023 stacked bar applies to the years from 2007 to 2019.
Source: Authors' estimates and U.S. Bureau of Labor Statistics (2024).

neoclassical model of conditional convergence, TFP growth in the frontier country affects other countries with a lag.[18] Recall that in a model with intangible capital TFP is endogenous, driven by the costless spread of innovations (or knowledge diffusion) and affected both by innovation policies as well as the growth and composition of intangible capital. By contrast, an economy's TFP is viewed as influenced Models of conditional convergence view an economy's TFP as influenced

An estimate of TFP for the US non-farm business sector is available from 1948 to 2023 from the Bureau of Labor Statistics (BLS, 2024), which we use to estimate TFP growth at the frontier

Simple peak-to-peak estimates of US TFP growth are illustrated in Chart 4.[19] Peak-to-peak averages reduce noise in the underlying series by calculating changes that eliminate business cycle effects. The first bar on the left combines the 1955 to 1968 and 1968 to 1973 peak-to- peak periods, which were both characterized by very high TFP growth.[20] The second bar shows the "slump" period from 1973 to 1990, and the third, the 1990 to 2007 period, which includes the IT-driven productivity boom. The blue portion of the final bar shows measured US TFP growth since the onset of the GFC to 2023, with the red-striped portion depicting our estimate of missing TFP growth due to a misstatement of price changes in paid-for consumer digital services in the official BLS statistics. Impor-

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[19] "Peak" refers to cyclical peaks in the level of the estimated index number for TFP.

[20] 1955 is used as the first cyclical peak because the peak for the 1948 to 1955 expansion is indeterminate. Note also that 1955 to 1973 period comprises two peak-to-peak episodes in TFP, as does the 1973 to 1990 period.

tantly, this misstatement has an inflection point in 2007, which affects TFP growth in subsequent years (through 2019).[21]

The US long-term series implies that there has been some slowing in frontier TFP growth since 2007, but also that the slowdown is rather small though consistent in direction. The performance of the adjusted post-GFC TFP estimate is relatively robust (0.73 per cent per year) though 0.35 percentage points below the average 1.08 per cent from 1990 to 2007 (and 0.34 percentage points below the average for the entire period from 1955 to 2007, which is 1.07 percent per year).

Our EU KLEMS & INTANProd series starts in 1995, with average US TFP growth from 1995 to 2007 boosted by the US "bubble growth" years from 1995 to 2005. Using these years as a basis for calculating the slowdown after 2007 therefore exaggerates the drop in sustainable TFP growth—there is no solid ground for using what is closer to a trough-to-peak year calculation to gauge a sustainable trend in a famously cyclical (and noisy) series.

The TFP estimates from EU KLEMS & INTANProd correct for a "missing intangibles" effect in the more typical calculations of TFP based on national accounts intangibles, such as those as shown in Chart 4. The analysis of the impact of capitalizing additional intangibles on measured TFP growth, as discussed earlier in this article, suggested that the missing intangibles effect in EU KLEMS & INTANProd estimates of TFP is an empirical matter but that there were offsetting forces and that the effect is likely to be small. The precise size of the bias will differ across countries and the business cycle, so it is difficult to generalize. Corrado, Hulten, and Sichel (2009; Table 4), initially estimated that the inclusion of total intangibles lowered average US TFP growth by 0.25 percentage points per year from 1973 to 2003, with the average impact rising to 0.34 percentage points per year for the IT boom years, 1995 to 2003. Appendix A3 uses EU KLEMS & INTANProd to reexamine the missing intangibles effect and finds similar results, i.e. that capitalizing the missing intangibles per Table 1 lowers average TFP growth by 0.27 percentage points from 1995 to 2019.

All told, the estimates imply that the intangibles-adjusted growth trend in TFP at the frontier has been about 0.8 per cent per year but that growth of about 0.5 per cent per year may be more pertinent in the face of evidence that knowledge spillovers are presently weaker than in the past, which we will address in more detail later in this section.

The TFP Slowdown and Recent Growth: Redux

Though all countries/economic areas have seen a slowdown in TFP growth and

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[21] Official statistics miss major aspects of how consumers benefit from the digital economy. A primary example is the falling cost of consumer digital content delivery. 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 (a) very fast drops in prices for paid-for consumer digital services, especially for mobile data and streaming services, and (b) increased shares of consumer spending allocated to subscriptions for these services. See, for example, Byrne and Corrado (2020, 2021).

labour productivity, there is heterogeneity in severity of the TFP slowdown and little correlation between its magnitude and the subsequent growth in TFP.

As noted previously (Table 3), Japanese TFP continued to expand at a solid 0.5 per cent per year in 2014-2019. And though the EU9 did not have an especially large slowdown in TFP growth after the onset of the GFC (0.6 percentage points), the slowdown pushed the EU9 post-GFC average annual change in TFP well into negative territory (-0.4 per cent), with an especially large average drop during 2008-2013 (-1.1 per cent per year). Adding to this, both labour productivity and TFP in the EU took especially hard hits in 2020, the pandemic year. Based on the EU9 aggregate shown in Table 3, as the EU entered the pandemic, its 2019 level of TFP stood nearly 4.1 per cent below that in 2007.[22] There also was a large slowdown in TFP growth in the United Kingdom, pushing its post-GFC average annual change in TFP into negative territory and reducing the level of TFP in 2019 below that in 2007 by more than 2.5 per cent.

Productivity developments in the more recent—and more quiescent—period after 2013 are a relevant point of departure for assessing current trends and (possibly) revealing "green shoots" that hint at rates of future growth. Looking at the results on the lines showing the 2014-2019 average growth rates, we see that recent measured TFP growth for the countries and the EU aggregate shown in Table 3 are positive and clustered in a narrow range at or slightly below the lower bound of the intangibles-adjusted growth of TFP of 0.5 per cent at the frontier —from 0.32 per cent and 0.34 per cent in the EU and United Kingdom at the low end to 0.45 per cent and 0.51 per cent in the United States and Japan at the high end.

Consider again the heterogeneity in magnitudes of the calculated slowdown and the clustering in recent growth in terms of the earlier analysis of using 1995 to 2007 as a baseline for calculating the slowdown in TFP growth. This analysis and the availability of long histories of TFP permit a refined assessment of the productivity slowdown in the United Kingdom and United States, i.e. we can adjust the baseline period used for the calculation of the TFP slowdown.[23] We can also reassess measured TFP growth after 2007 to account for misstated price change for consumer digital services due to the availability of a largely comparable study of consumer digital series for the United Kingdom (Abdirahman *et al.* 2022) that obtained similar results to those found by Byrne and Corrado (2020) for the United States. We do not have a basis for adjusting the baseline for the productivity slowdown in the EU9 aggregate and Japan, though adjusting post-2007 TFP growth for price mismeasurement in the digital (services) economy also may be appropriate for these countries. There are no hard findings or

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[22] Calculated as the compound growth rate of the annual fall in TFP (-0.35 per cent) from 2008 to 2019.

[23] For the United Kingdom we use estimates of market sector TFP produced by its Office of National Statistics that span from 1970 to 2022 (ONS, 2023) to examine the representativeness of 1995-2007 TFP growth as a base period for calculating the productivity slowdown.

Table 5: Adjusted TFP Growth for the UK and US selected periods, average annual change

Period		UK	US
1.	Adjusted baseline	0.74	0.74
2.	2008-2019	0.03	0.36
	Slowdown:		
3.	(line 1 less line 2)	0.71	0.38
4.	2008-2013	-0.53	0.01
5.	2014-2019	0.59	0.70
	Post aftermath slowdown:		
6.	(line 1 less line 5)	0.15	0.04

Notes. Growth rates are log differences multiplied by 100. Line 3 and line 6 are point differences in growth rates. Adjusted baseline is growth in the period 1995-2007 from EUKLEMS & INTAN-Prod, adjusted to represent the longer prior cycle in each country as detailed in Appendix Section A5. Lines 2, 4 and 5 are adjusted for mismeasurement of prices for consumer digital services from Byrne and Corrado (2020) Sources. Authors' elaboration of data from EU KLEMS & INTAN-Prod (LLEE 2023); UK ONS (2023) and US BLS (2024).

available calibrations for these countries to determine a relevant magnitude of adjustment.

The adjusted results for the United Kingdom and United States are shown in Table 5. TFP growth remains very strong in the adjusted baseline (line 1) of both countries, and the productivity slowdown since then (line 3) is more moderate than shown in Table 3. That said, the slowdown for the United Kingdom is still large and exceeds that of other countries (United States, see Table 5,; EU9 and Japan, see Table 3). Nevertheless, amid the uncertainty prior to Brexit (line 4), its adjusted overall change does not dip into negative territory (line 2).

The fresh perspective on recent TFP growth in Table 5 underscores that there are indeed "green shoots" in recent productivity data. Adjusted average 2014-2019 TFP growth in the United Kingdom and the United States is estimated to have been 0.6 and 0.7 per cent per year, respectively, according to Table 5. Both rates of change are squarely within the estimated bounds of growth in intangibles-adjusted TFP at the frontier of 0.5 to 0.8 per cent per year. As noted previously the same can be said for recent growth in Japan (without adjusting the EU KLEMS & INTANProd estimates of TFP for possible misstated measured consumer price change in that country) as well as in Spain (Table 4) and the EU North countries in the EU9 aggregate (Appendix Table A4).

The softer results for recent TFP growth in the EU9 aggregate is a cautionary tale, however. Recent productivity growth in the economies of Germany and France are very weak (Germany) or negative (France)—and this follows a decline in their TFP over the years of multiple crises. France has been investing heavily in intangible assets, though, and perhaps returns to these investments are yet to come.

Innovation and TFP

The conceptual framework in the first

section suggests that the origins of TFP growth are commercial knowledge spillovers and basic knowledge used to develop innovations embodied in intangible capital. We found that market sector intangible capital deepening remained steady through the ups and downs of multiple crises and that, since 2013, TFP growth has been at an average pace consistent with steady gains from the use and diffusion of technologies in three of the four major economic areas economies studied in this article. That said, the newer technologies are not boosting growth sufficiently to make up the losses incurred during the GFC, the European sovereign debt crisis and their aftermaths.

To put recent TFP growth in perspective, consider the two sources of knowledge spillovers in our model. The diffusion of commercially valuable knowledge is the primary and endogenous determinant of TFP in the intangible capital framework, but new basic knowledge flowing into upstream production in the market economy—the exogenous "freely available knowledge" depicted in the upper right corner of Figure 1—also affects measured TFP.

The TFP we have measured and discussed reflects contributions from both production sectors in the upstream/downstream model depicted in Figure 1. In this model total factor productivity may be expressed in terms of its two production sectors as:

$$da = s_Q^Y da^Y + s_Q^N da^N \tag{8}$$

i.e. the share-weighted sum of total factor productivity growth in each sector, where the superscript Y denotes the downstream sector and N denotes the upstream sector. Ignoring trade and intermediates, the upstream production share s_Q^N is the market sector intangible investment rate displayed and analyzed in the previous section, i.e. it ranges from 8 to 18 per cent (Chart 3).

It is then natural to ask, which component of da in (8) might have slowed, and why? The concept of basic knowledge contributing to the production of commercially viable innovations is difficult to assess in its broadest meaning, but if we follow Bloom *et al.* (2020) and think of it as "ideas", and if such ideas really are harder to find, then da^N falls—indeed because of its relatively low share, it must collapse to have a significant direct effect on da. All else equal, along with the direct effect of lower da^N on da, a collapse in da^N also lowers the rate of real intangible investment. The data in EU KLEMS & INTANProd contradict this, as do AI indicators (Maslej *et al.*, 2023).

Another indicator of freely available knowledge flowing into upstream production activity, is the growth in availability of open-source software, which has been strongly positive over the period of the productivity slowdown (Robbins *et al.*, 2022). In addition, the increase in the use of big data in upstream production processes improves efficiency and lowers the cost of producing intangibles, e.g. big data "greases the wheels" of supply chain logistics, improves the precision of marketing goods and services to customers, and likely enhances the probability of success in new product development. In fact, Corrado *et al.* (2024) estimated that the boost to da^N from the use of big data in marketing and organization processes has been sufficient to exert downward pressure on the relative price of intangible assets that elevated labour productivity growth by about 0.1 to 0.2 percentage points since 2009.

On the other hand, a commonly used proxy for free basic knowledge is public R&D, which presents a mixed picture at first blush. Chart 5 illustrates comparative trends in non-market sector R&D from EU KLEMS & INTANProd. Non-market real R&D stocks in EU countries posted consistently strong growth over the last 20 years, whereas non-market R&D stocks elsewhere showed weak growth. In Japan, real stocks grew 0.7 per cent per year (a tad faster than the country's growth 0.5 per cent per year growth in real GDP). The United States and the United Kingdom posted little to no growth in R&D stocks in the aftermath of the GFC, largely in line with weak overall growth in economic activity in these countries.

It is of course unclear how the patterns shown in Chart 5 may have affected the flow of basic knowledge into the production of market sector intangibles. The production of market sector intangibles also includes the sector's conduct of own-funded R&D. In the United States, market sector R&D stocks (not shown) grew rapidly and relatively steadily from 2000 to 2020, and the measured flow of services from US total R&D stocks was apparently not affected by the period of slowdown in non-market stocks shown in Chart 5.

Recall that the full footprint of innovation in the market sector of an economy consists of the returns to market sector intangible capital (whose asset price will reflect gains in da^N, sign reversed) plus the "costless" gains due to commercial knowledge spillovers. Seen from this perspective, the contribution of innovation to growth reflects the combined contributions of intangible capital and TFP.[24] In terms of labour productivity growth, this contribution in the post-2013 period is illustrated by summing up the contribution of columns (6) and (7) in Tables 3 and 4. As may be seen, the portion due to intangible capital deepening is substantial and did not change much over the slowdown period in the face of weakness (and in some cases, decline) in TFP during the crisis years.

Our growth accounting results thus suggest that, while the social returns to market sector investments innovation (commercial knowledge spillovers) slowed after 2007, returns to private investments in innovation were generally maintained (on a per-hour basis). Moreover, as argued above, these returns were likely boosted by new efficiencies due to the increased use of data, open-source software and "free" knowledge about AI.

Reduced Commercial Knowledge Spillovers

Cross-country and firm-level econometric work has repeatedly estimated increasing returns, or knowledge spillovers, to market sector intangibles. In simple terms, the available works imply that the proportional relationship, $da \approx 0.2\,dr$ could

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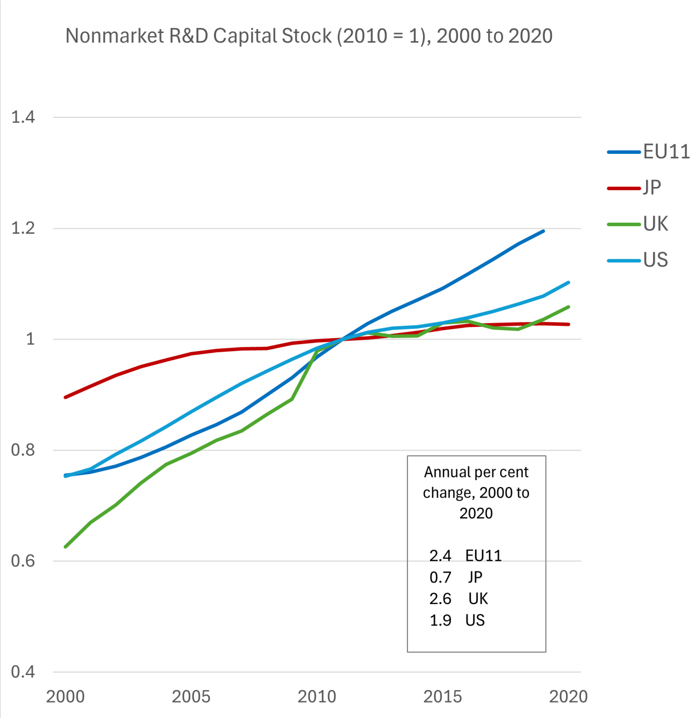
[24] For further elaboration see Goodridge, Haskel and Wallis (2012) and Corrado *et al.* (2024).

Chart 5: Nonmarket R&D Capital Stocks (in 2010=1), 2000 to 2020



Note: EU aggregate is through 2019.
Source: EU KLEMS & INTANProd (LUISS 2023).

be used to represent the costless diffusion of commercially valuable knowledge (dr) in market economies.[25] As *dr* per hour worked did not materially slow along with TFP, the logical (endogenous) explanation for the slowdown in measured *da* is that factors driving these increased returns ceased to operate as strongly as they previously had.[26]

The authors are engaged in an econometric study on productivity spillovers from market sector intangible capital and how they may have changed in recent years, but the study is incomplete, and results are preliminary. Chart 6 presents a story that we believe will emerge from that work. The blue dotted line in the chart shows a prima-facie association between the growth rates of TFP and intangible services, in line with the extant literature. But the figure also suggests that this relationship may have changed over time, with the slope of plot covering the more recent period (the red dots) lower than that of the plot for the pre-crisis period (the blue dots).

The flatter line for the 2014-19 period suggests there have been fewer productivity spillovers from intangible capital growth to

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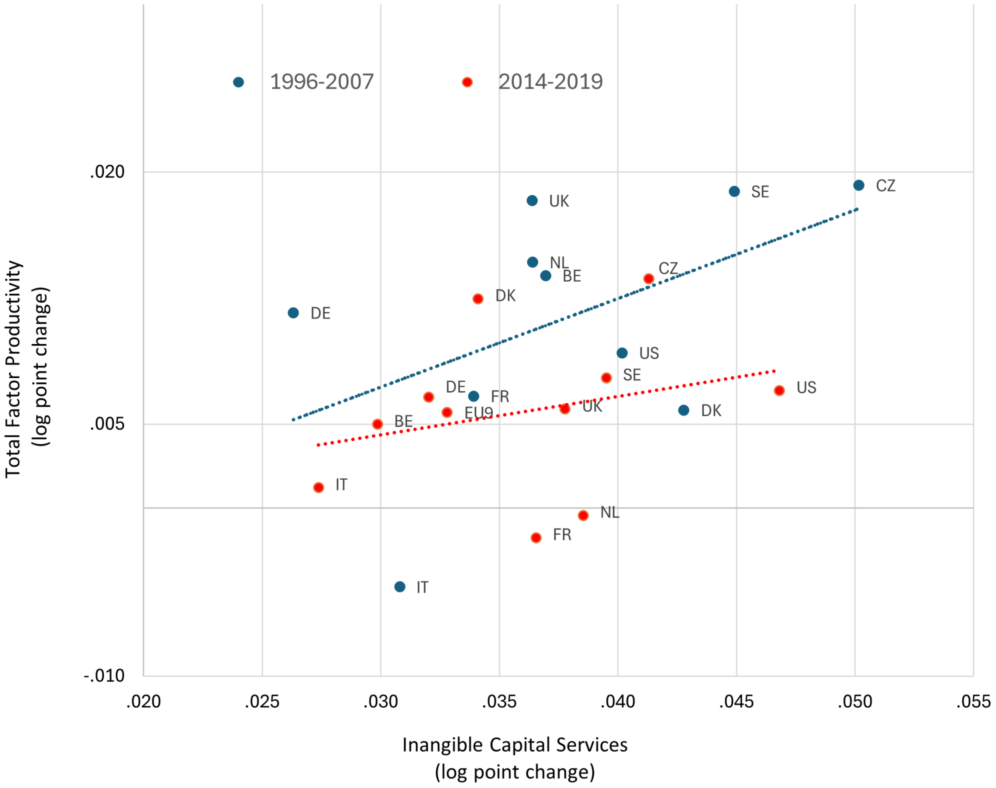
[25] This refers to the aggregate implications of estimates for R&D spillovers reported by Griliches for manufacturing (e.g. Griliches 1992) and for intangible capital spillovers (excluding R&D and software) reported by Corrado, Haskel, and Jona-Lasinio (2017a). The latter study used a cross-country dataset consisting of European economies and the United States from the late 1990s to the onset of the GFC.

[26] Though hours growth also slowed overall in the post-2007 years, hours growth during 2014-2019 was about the same as during 1996-2007 in the EU aggregate.

Chart 6: Changes in TFP and Intangible Capital, Selected Periods.



Note: Figures for post-2007 growth of TFP in the United Kingdom and the United States are adjusted for the misstatement of consumer digital prices.
Source: Authors' calculations from EU KLEMS & INTANProd database.

TFP growth in recent years. Why might this be? We have no definitive answers, but one possibility is around the commercial implementation of AI. As argued elsewhere (Corrado *et al.*, 2024), the large role that proprietary data play in the applications of AI technologies is consistent with a reduced pace of costless knowledge diffusion. Even if the AI algorithms are open source, the proprietary data companies use to train them for quantitative guidance deployed in business decisions are not. This creates a situation where new paid-for investments in data are needed for each replication of the technology, which slows its spread. The provision of more open data by governments and policies that promote industry data sharing are needed to overcome this.

What might the quantitative contribution of the fall in spillovers be? Excluding Japan from the analysis, the average growth of intangible capital services after recovery from the GFC ranged from 3.2 per cent in Europe, to 3.6 per cent in the United Kingdom, and 4.5 per cent in the United States. If we suppose that spillovers of intangible capital were half of what they were prior to the GFC, then using the previously mentioned proportional relationship, reduced spillovers likely shaved 0.3 to 0.4 percentage points off TFP growth—consistent with a lower prevailing intangibles-adjusted growth of TFP at the frontier. Referring to Tables 3 and 5, these are also large fractions of the measured TFP growth slowdowns. Further work on the hypothesis that spillovers have declined is worthwhile.

Summary and Conclusions

This article has used an updated and improved cross-country growth accounting dataset, EU KLEMS & INTANProd, to examine several macroeconomic performance issues. Before summarizing our results, let us put this workstream into context.

What is the point of integrating intangibles into macroeconomic data? Research has consistently indicated that (advanced) countries are increasingly investing in knowledge and relationship-style assets, or "intangible assets". Such assets are typically ill-measured in company accounts, where company accountants are reluctant to ascribe any asset value to an asset without a clear market price, which many intangibles lack. That they lack a market price is itself of interest: this could be because intangibles are indivisible from the company itself (e.g. reputation) or being internally generated for secrecy reasons (e.g. business process engineering).

National accountants are gradually moving towards capitalizing more intangibles in line with national accounts principles: for purchased intangibles, a market price is observable and for internally generated intangibles, a cost-of-production approach is adopted.[27] Thus, in our data, we treat intangible assets as a measured investment in the productive capital of an organization. When we include intangible assets in national accounts, we have more capital investment, changed measures for value-added output, capital income, and factor inputs. These changes have, in turn, consequences for calculations of the price-markup and the ex post rate of return to capital for economies.

In this article we first set out a framework for thinking about how the analysis of growth and productivity is affected by the inclusion of intangible capital. Intangible capital deepening not only becomes a source of growth in labour productivity in this framework, but also drives TFP growth via the diffusion of freely available, commercially valuable knowledge that the measure embodies.

The impact of the additional intangibles included in EU KLEMS & INTANProd on labour productivity levels and growth was calculated for the EU, EU regions, Japan, United Kingdom and United States, and we analyzed growth accounting results for the market sector. We also considered the impact on TFP growth of the misstatement of prices for consumer digital services and looked closely at comparative productivity growth in the relatively quiescent, recent period (2014-2019) for glimmers of an impact from newer technologies and implica-

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[27] The 2025 SNA will recommend that data be capitalized as an asset in national accounts, but the SNA's implementation guidance is unlikely to capture the breadth of what business analysts and technologists refer to as data assets, e.g., per discussions in Mayer-Schönberger and Cukier (2013) and Varian (2019). The conceptualization of data as an asset, its measurement, and its relationship to intangible capital is addressed in Corrado *et al.* (2024).

tions for the years ahead.

To put recent comparative developments as captured in the EU KLEMS database in perspective, we used an estimate of intangibles-adjusted TFP growth at the frontier, which we estimated to be between 0.5 and 0.8 percent per year—conditioned on recent trajectories for intangibles and knowledge spillovers. One of our most important findings is that recent TFP growth in Japan, and TFP growth in the United Kingdom and the United States adjusted for quantifiable price misstatement, are all within the range of growth at the frontier. TFP growth in Europe (unadjusted for price misstatement due to a lack or hard evidence) averaged 0.1 percentage point per year below the lower bound of the range. Nevertheless, these gains are not strong enough to make up for the accumulated shortfalls in TFP growth in Japan, United Kingdom, and Europe during 2008-2013.

In summary, while the story of the productivity slowdown in the intangible-intensive economies studied in this article is nuanced, intangible capital appears to have been well maintained throughout the ups and down of the post-2007 period. Our main message is that recent productivity growth suggests some green shoots from the combined contribution of intangible capital deepening and TFP growth, especially when taking into account adjustments for measurement error. This finding is consistent with gains from the take up of newer digital technologies, from moving computer and data processing to the cloud to incorporating AI into business processes—actions that have been accompanied by intangible investments.

The tempered enthusiasm regarding recent TFP growth comes from the fact that studies, including our own (Corrado *et al.* 2024), have found that the mechanisms that govern commercial knowledge diffusion are rather weaker since about 2010 than they have been in the past. We suggest that the impact of AI is weaker than generated by past waves of technical change, due in part to the fact that applications of AI in business processes rely on certain types of intangible assets (e.g., training data) that are held tightly and not replicable at low cost.[28] Other studies have documented diminished spillovers from R&D-based knowledge (Akcigit and Ates, 2021), an extraordinary concentration of advanced software tools in the hands of a few giant firms (Bessen, 2022) and evidence that protections of data ("compilations of information with commercial value"). This suggests that, unless polices to foster industry data sharing and digital technology extension restore the strength of prior diffusion mechanisms, the full potential of productivity growth-promoting spillovers from intangible capital will not be met.

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[28] Related, a recent study by Wang (2022) examined technology spillovers in the United States under the Uniform Trade Secrets Act (UTSA). The act protects data ("compilations of information with commercial value") as intellectual property but is adopted on a state-by-state basis. The study exploited this feature, finding that technology spillovers between local firms and from peers in other states were 27 to 50 per cent lower in states adopting the USTSA than in states that did not.

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