Accounting for the slowdown in UK innovation and productivity

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Abstract

This paper conducts a comprehensive sources-of-growth analysis for the UK non-farm market sector, 2000 to 2019, using the latest ONS data including: new estimates of intangible investment; double deflated value-added; and updated price indices. All estimates are constructed bottom-up from data for 40 industries. The decomposition incorporates contributions from intangible capital, including both assets currently capitalised and uncapitalised in national accounts. We use these data to comment on the contribution of innovation to UK growth and account for the productivity slowdown. The data show that the slowdown in UK labour productivity growth can largely be attributed to a slowdown in innovation, where innovation is defined as the contributions of intangible capital deepening and TFP growth. Our main findings are that: a) the level of labour productivity in 2019 is 27 log points (31 percentage points) less than it would have been had it continued to grow at its 2000-07 rate; b) reallocation of labour made no contribution to the slowdown, rather the slowdown is within industries; c) capitalisation of the full range of intangible capital explains 5% of the slowdown due to the adjustment to growth in value-added; d) 35% is explained by a slowdown in the contribution of capital deepening (of which 25% tangible and 10% intangible) and 78% is explained by a slowdown in TFP growth; e) the slowdowns in labour productivity and TFP growth are largest in the more intangible-, knowledge-, technology- and digital-intensive industries; and f) less than one-tenth of the UK TFP slowdown can be explained by exceptionally fast UK TFP growth in the pre-crisis period.

1. Introduction

UK labour productivity growth has slowed sharply since the financial crisis, to the extent that the level of labour productivity in 2019 was barely above that observed before the onset of the Great Recession. Naturally, the slowdown and its proximate causes have been the subject of a considerable amount of research. In terms of a standard sources-of-growth framework, some explanations point to a negative contribution from labour reallocation, that is, reallocation of labour to lower-productivity industries (see for example Sainsbury (2020)), others suggest it is due to capital shallowing (Goldin et al., 2021; Pessoa & Van Reenen, 2014), while some attribute the slowdown to lacklustre Total Factor Productivity (TFP) growth (Goldin et al., 2021; Goodridge et al., 2016). In examining whether the UK experience is unusual, Fernald & Inklaar (2022) argue that the UK slowdown is consistent with the slowdown observed in the US frontier.

We use the latest UK data to examine these arguments. We present a comprehensive sources-of-growth analysis for the non-farm market sector, 2000-2019, constructed bottom-up from data for 40 industries. The dataset incorporates new improved ONS estimates of investment in intangible assets currently uncapitalised in national accounts and complementary price indices. We combine these with the latest national accounts which includes new estimates of double deflated gross value-added (GVA) and GVA price indices, as published in Blue Book 2021 (BB21).

Our primary contribution lies in the comprehensive nature of the dataset, which allows us to address questions around: i) reallocation and structural change; ii) the contribution of innovation (or knowledge) to growth; and iii) contributions to the UK productivity slowdown following the financial crisis and Great Recession. In doing so, we implement the framework set out in Corrado, Hulten & Sichel (CHS, 2005, 2009) and build on previous work in Goodridge, Haskel & Wallis (2016; 2016).

First, we present the latest ONS intangible investment data and document intangible-intensity in industries where measured national accounts gross fixed capital formation (GFCF) and capital compensation only includes tangible assets and capitalised intellectual property products (IPPs).

Second, we integrate these within UK national accounts using the CHS framework. Capitalisation of the broader suite of intangibles enables us to investigate questions that could either not be addressed without these data or all relegated to the TFP residual. Capitalisation changes measures of both input and GVA output. Thus, we can use these data to answer questions around productivity performance and the contributions of labour, tangible and intangible capital, and the TFP residual, pre- and post-crisis, at detailed industry-asset level, to account for the productivity slowdown.

We find that, first, the level of UK labour productivity in 2019 was 27 log points[1] less than had it continued to grow at its 2000-07 rate. Second, reallocation of labour made no contribution to the slowdown. Rather the slowdown is within industries. Labour composition also did not contribute to the slowdown. In fact, the contribution sped up. Third, capitalisation of the full range of intangibles changes estimated labour productivity growth, explaining around 5% of the slowdown. Fourth, 35% (25% tangible and 10% intangible) of the slowdown is explained by a slowdown in the contribution of capital deepening and 78% is explained by a slowdown in TFP growth. Together, these results

[1] We work in log points in this paper, defined as 100 times the natural log difference between two numbers, which ensures that our decomposition is entirely additive. The estimate of 27 log points translates to approximately 31 percentage points. Our estimate of a 27 log point gap is based on estimates of value-added adjusted for capitalisation of all CHS intangibles. Using national accounts definitions of output and capital, the level of labour productivity is 28 log points (or 33 percentage points) less than it would have been had it continued to grow at its 2000-07 rate.

suggest that (78+10=)88% of the slowdown can be broadly attributed to a slowdown in innovation, defined as the contributions of intangible capital and TFP growth.

Fifth, on the slowdown in TFP, we find that some of the UK slowdown could be explained by the slowdown in TFP growth (innovation) observed in the US frontier, but this is conditional on a number of assumptions. We find that less than one-tenth of the UK TFP slowdown can be explained by exceptionally strong UK TFP growth in the pre-crisis (2000-07) period.

On industry contributions, we find that slowdowns in labour productivity and TFP growth are largest in more intangible-, knowledge-, technology- and digital-intensive industries, using a number of definitions, which we think is new finding. Coyle & Mei (2022) similarly report labour productivity slowdowns in unexpected industries, considered to be advanced, high value-added sectors. In particular, we find that TFP slowdowns in finance (SIC K64t66) especially, but also IT and information services (J62t63), manufacture of transport equipment (C29t30), manufacture of machinery and equipment (C28), pharmaceuticals (C21), manufacture of ICT equipment (C26), and publishing and broadcasting activities (J58t60) all substantially contribute to the aggregate TFP slowdown. Overall, we find that the TFP slowdown in intangible-intensive industries almost entirely explains the aggregate TFP slowdown. In terms of industries, the UK TFP slowdown is deeper and more broad-based than that observed in the US.

Finally, we document a slowdown in knowledge accumulation, which we conjecture might be related to the TFP slowdown via reduced absorptive capacity and knowledge diffusion/spillovers. We intend to use this dataset to explore this question further in future work

The rest of this paper is set out as follows. The next section sets out our model and section three describes our data. Sections four to seven present our results on intangible investment, the contribution of labour reallocation to the slowdown, the contribution of output mismeasurement and inputs, and the contribution of industries to the TFP slowdown. Finally, section eight concludes.

2. Model

We account for the productivity slowdown (V/H) in terms of capital deepening (K/H), labour composition (L/H) and TFP including industry contributions. But we also have a new set of capital assets, non-national accounts intangibles, which implies new measures of value-added (denoted Q) and new capital inputs (R^{oth}). So we must also account for how much of the slowdown is due to the gap between growth in V and Q. The following model sets out the relation between: (a) growth in V and Q; and (b) the industry components of growth and the aggregate market sector.

We start with data for different types of capital and labour. In this paper, capital services includes both tangible (K^{tan}) and intangible (R) asset types. Intangible assets include those already capitalised in national accounts (naintan: R^{na}) and those currently uncapitalised in national accounts (othintan: R^{oth}). For each asset, we first build a real capital stock via the perpetual inventory method whereby for any capital asset a, the stock of that asset in each industry j evolves according to:

$$K_{a,j,t} = I_{a,j,t} + (1 - \delta_a)K_{a,j,t-1} \qquad a \in K^{tan}, R^{na}, R^{oth} \tag{1}$$

Where I is real investment in that asset over the relevant period and δ the geometric rate of depreciation/deterioration. Real investment is nominal investment deflated by an investment price index. The investment price is converted into a rental price using the Hall-Jorgenson relation, with an industry-specific net rate of return estimated such that capital compensation is exhausted,[2] see for example Oulton & Wallis (2016) and Oulton & Srinivasan (2003).

In constructing composition-adjusted capital and labour services, we aggregate across different types: for labour, we use, education and industry; for capital, different types of tangible and intangible assets, all by industry. Denoting capital and labour types a and b we construct capital and labour services for each industry j:

$$\Delta \ln K_j = \sum_a \overline{s}_{a,j} \, \Delta \ln K_{a,j} \qquad a \in K^{tan}, R^{na}, R^{oth}$$

$$\Delta \ln L_j = \sum_b \overline{s}_{b,j} \, \Delta \ln H_{b,j} \qquad b \in High, Medium, Low\ (educational\ attainment)$$

$$where: s_{a,j} = \frac{P_{Ka,j}K_{a,j}}{\sum_a P_{Ka,j}K_{a,j}}, s_{b,j} = \frac{P_{Lb,j}L_{b,j}}{\sum_b P_{Lb,j}L_{b,j}}, \overline{s} = 0.5 * (s_t + s_{t-1}) \qquad (2)$$

Capital and labour produce (value-added) output Q_j in industry j. Thus, for each industry, we have the following value-added defined $\Delta lnTFP_j$:

$$\Delta ln(Q/H)_j \equiv \overline{w}^Q_{K,j} \Delta \ln(K/H)_j + \overline{w}^Q_{L,j} \Delta \ln(L/H)_j + \Delta lnTFP^Q_j \qquad (3)$$

$$where: w_{K,j} = \frac{P_{K,j}K_j}{P_{Q,j}Q_j}, w_{L,j} = \frac{P_{L,j}L_j}{P_{Q,j}Q_j}, \overline{w} = 0.5 * (w_t + w_{t-1}),$$

$$and: \quad P_{K,j}K_j = \sum_a P_{Ka,j}K_{a,j}, \ P_{L,j}L_j = \sum_b P_{Lb,j}L_{b,j}$$

Where terms in w are shares of factor costs (the sum of factor payments over capital or labour types in industry j) in industry nominal value-added, averaged over two periods.

Changes in aggregate real value added are defined as a Tornqvist-weighted sum of changes in industry real value added:

$$\Delta \ln Q \equiv \sum_j \overline{v}^Q_j \Delta \ln Q_j \qquad v^Q_j = \frac{P_{Qj}Q_j}{\sum_j P_{Qj}Q_j}, \overline{v} = 0.5 * (v_t + v_{t-1}) \qquad (4)$$

Thus the relation between economy-wide real value added growth and its industry contributions is:

$$\Delta \ln Q = \left(\sum_j \overline{v}^Q_j \overline{w}^Q_{K,j} \Delta \ln K_j\right) + \left(\sum_j \overline{v}^Q_j \overline{w}^Q_{L,j} \Delta \ln L_j\right) + \sum_j \overline{v}^Q_j \Delta lnTFP^Q_j \qquad (5)$$

Which says that the contributions of K_j and L_j to whole-economy value added growth depend upon the share of Q_j in total Q ($\bar{v}_j$) and the shares of K_j and L_j in industry value-added ($\overline{w}^Q_j$). The contribution of $\Delta lnTFP_j$ also depends on $\bar{v}_j$.

2.1. Labour reallocation

Working with industry data that is aggregated using value added weights introduces a wedge between "top-down" $\left(\Delta \ln(Q/H) = \sum_j \overline{v}^Q_j \Delta \ln(Q)_j - \Delta \ln \sum_j H_j\right)$ and "bottom-up" measures of aggregate productivity growth $\left(\sum_j \overline{v}^Q_j \Delta \ln(Q/H)_j\right)$, given by $R^{H,Q}$:

[2] In calculating rental prices we set the capital gain terms for buildings to zero to avoid generating negative user costs for buildings, as described in Statistics New Zealand (2010).

$$\Delta\, ln(Q/H) = \sum_j \overline{v}_j^Q \Delta\, ln(Q/H)_j + \sum_j \overline{v}_j^Q \Delta\, ln\, H_j - \Delta\, ln \sum_j H_j \quad (6)$$
$$= \sum_j \overline{v}_j^Q \Delta\, ln(Q/H)_j + \sum_j \overline{v}_j^Q \Delta\, ln(H_j / \Sigma_j H_j)$$
$$= \sum_j \overline{v}_j^Q \Delta\, ln(Q/H)_j + R^{H,Q}$$

The reallocation term, $R^{H,Q}$, is therefore a result of the "bottom-up" aggregation of hours using value added weights, whereas "top down" simply sums hours (which can be done since they are in natural units). Aggregate value added per hour can therefore grow via growth in industry value added per hour (within effect) but also with reallocation of hours to higher-productivity industries (between effect). Thus, we can write "top-down" industry productivity growth as "bottom-up" industry productivity growth, which is accounted for by K, L and TFP and the reallocation term:

$$\Delta\, ln(Q/H) = \sum_j \overline{v}_j^Q \overline{w}_{K,j}^Q \Delta\, ln(K/H)_j + \sum_j \overline{v}_j^Q \overline{w}_{L,j}^Q \Delta\, ln(L/H)_j + \sum_j \overline{v}_j^Q \Delta lnTFP_j^Q + R^{H,Q} \quad (7)$$

We comment on the relation of this term to "shift-share" reallocation terms below.

2.2. Intangibles

What is the effect of adding non-national accounts CHS intangibles (othintan)? We undertake the decomposition in equation (7) both with and without non-national accounts intangibles. The former gives a new measure of value-added, Q, relative to that corresponding to national accounts, V; an additional capital input, R^{oth}, new shares and hence new R^H and TFP (which is a residual). In what follows we shall present two versions of (7), and show that they are quite similar, at least in terms of the productivity slowdown. We can also show the relation between the two since for each industry:

$$\Delta\, ln\, Q_j = \Delta\, ln\, V_j + \overline{u}_{Q_j}^{\ I^{othintan}} \left(\Delta\, ln\, I_j^{othintan} - \Delta\, ln\, V_j\right) \quad (8)$$

$$where: u_{Q,j}^{I^{othintan}} = \frac{P_{I^{othintan},j} I_j^{othintan}}{P_{Q,j} Q_j},\ \overline{u} = 0.5 * (u_t + u_{t-1})$$

Where V_j is measured value-added (i.e. omitting non-national accounts intangibles) and $\overline{u}_{Q_j}^{\ I^{othintan}}$ is the Tornqvist share of non-national accounts intangible (othintan) investment in non-national accounts inclusive value-added, Q. Summing over all industries, using V weights (i.e. measured value-added), gives:

$$\sum_j \overline{v_j^V} \Delta \ln(V/H)_j = \sum_j \overline{v_j^V} \Delta \ln(Q/H)_j - \sum_j \overline{v_j^V}\, \overline{u}_{Q_j}^{\ I^{othintan}} \left(\Delta\, ln\, I^{othintan}{}_j - \Delta\, ln\, V_j\right) \quad (9)$$
$$= \sum_j \overline{v_j^Q} \Delta \ln(Q/H)_j + \sum_j (\overline{v}_j{}^V - \overline{v}_j{}^Q) \Delta \ln\, (Q/H)_j -$$
$$\sum_j \overline{v_j^V}\, \overline{u}_{Q_j}^{\ I^{othintan}} \left(\Delta\, ln\, I^{othintan}{}_j - \Delta\, ln\, V_j\right)$$

We can therefore write DlnV/H, which is top-down measured productivity growth excluding non-national accounts intangibles, as:

$$\Delta \ln\, (V/H) \equiv \sum_j \overline{v_j^V} \Delta \ln(V/H)_j + R^{H,V} \quad (10)$$
$$= \left(\sum_j \overline{v_j^Q}\, \overline{w}_{K,j}^Q \Delta \ln(K/H)_j + \sum_j \overline{v_j^Q}\, \overline{w}_{L,j}^Q \Delta \ln(L/H)_j + \sum_j \overline{v_j^Q}\, \Delta lnTFP_j^Q \right)$$

$$+\sum_j (\overline{v}_j{}^V - \overline{v}_j{}^Q)\Delta\ln(Q/H)_j - \sum_j \overline{v_j^V}\,\overline{u}_{Q_j}{}^{I^{othintan}}\left(\Delta \ln I^{othintan}{}_j - \Delta \ln V_j\right) + R^{H,V}$$

In sum, top-down, aggregate V/H growth is: (a) bottom up Q/H growth due to K, L and TFP; (b) the gap between aggregate V and Q due to different value-added weights; (c) the gap between V and Q due to not capitalising some intangibles; and (d) reallocation.

3. Data

3.1 Time period

Since we work with UK national accounts, much of our industry data begins in 1997. To reduce uncertainty around capital stock starting values, and based on an analysis of cyclical factor utilisation, we carry out our growth-accounting analysis over the period 2000-2019, with estimates presented for the 2000-2007 (pre-crisis) and 2007-2019 (post-crisis) periods.[3]

3.2. Industries

We work with 40 non-farm market sector industries as set out in Table 1. The level of industry detail is made possible by recent ONS publication of very detailed estimates of intangible investment by industry-asset-year (Fotopoulou, 2021). Our industry breakdown is more detailed than for instance EUKLEMS (Lab of European Economics, 2021), where professional, scientific and technical activities (SIC07 M) and administrative and support activities (N) are aggregated into two broad industries.

As we are estimating for the market sector, we exclude public administration & defence (O), education (P) and health (Q). We exclude real estate (L) since dwellings are not part of the productive capital stock and industry output largely consists of actual and imputed rents for occupation of dwellings. Due to the presence of large subsidies and uncertainty around measured output and capital compensation, we exclude agriculture (A). Finally, we exclude employment agencies (N78) due to the presence of knowledge workers that are estimated as undertaking intangible capital formation in agencies rather than the industry they actually work in.[4]

Using data for 40 industries, we estimate for the aggregate non-farm market sector, constructed bottom-up. Aggregation of nominal variables is by addition. Aggregates of real variables are share-weighted superlative indices for changes, benchmarked in levels to 2019 nominal data. All growth rates are estimated as changes in the natural log.

[3] Estimates of factor utilisation based on the change in the natural log of hours per worker (as in Basu et al. (2006)) show local peaks in 2001, 2007 and 2019. We therefore estimate peak-to peak between these years. Data on hours per worker are shown in Appendix A. Estimates for growth and sources-of-growth contributions are average log changes. Therefore, for the first period, averaging log changes for 2001-07 means that the value in 2001 incorporates growth from 2000. Similarly averaging changes for 2008-19 incorporates growth from 2007. Our periods of analysis are therefore 2000-07 and 2007-19.

[4] Estimates of own-account intangible investment are predominantly based on data from the Annual Survey of Hours and Earnings (ASHE). ASHE data are a 1% sample of national insurance numbers used in the PAYE system. Say there is a designer that is registered with an employment agency but working in another industry, manufacturing for instance. If that designer is selected for the sample, the ASHE form will be sent to the employer that pays their wages: the employment agency. As a result, the output of the designer will correctly be included in estimates of own-account design capital formation, but in the wrong industry i.e. in employment agencies rather than manufacturing. Estimates of own-account investment are therefore over-estimated for employment agencies and under-estimated in industries which use agency labour. We therefore exclude employment agencies (N78) from our analysis. We thank Eurydice Fotopoulou of ONS for relaying this information.

Table 1: Industries: non-farm market sector definition

No:	SIC	Description	SIC section
1	B5t9	Mining and Quarrying	B
2	C10t12	Manufacture of food, beverages & tobacco	
3	C13t15	Manufacture of textiles, wearing apparel & leather products	
4	C16t18	Manufacture of wood & paper products; printing and reproduction of recorded media	
5	C19	Manufacture of coke and refined petroleum products	
6	C20	Manufacture of chemicals and chemical products	
7	C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	
8	C22t23	Manufacture of rubber, plastic and non-metallic mineral products	C: Manufacturing
9	C24t25	Manufacture of basic & fabricated metals	
10	C26	Manufacture of computer, electronic and optical products	
11	C27	Manufacture of electrical equipment	
12	C28	Manufacture of machinery and equipment n.e.c.	
13	C29t30	Manufacture of transport equipment	
14	C31t33	Manufacture of furniture; other manufacturing; repair and installation	
15	D35	Electricity, Gas, Steam and Air Conditioning Supply	D
16	E36t39	Water Supply; Sewerage, Waste Management and Remediation Activities	E
17	F41t43	Construction	F
18	G45	Wholesale and retail trade and repair of motor vehicles and motorcycles	
19	G46	Wholesale trade, except of motor vehicles and motorcycles	G: Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles
20	G47	Retail trade, except of motor vehicles and motorcycles	
21	H49	Land transport and transport via pipelines	
22	H50	Water transport	
23	H51	Air transport	H: Transportation and Storage
24	H52	Warehousing and support activities for transportation	
25	H53	Postal and courier activities	
26	I55t56	Accommodation and Food Service Activities	I
27	J58t60	Publishing activities; Motion picture, video and television programme production, sound recording and music publishing activities; Programming and broadcasting activities	
28	J61	Telecommunications	J: Information and Communication
29	J62t63	Computer programming, consultancy and related activities; Information service activities	
30	K64t66	Financial and Insurance Activities	K
31	M69t70	Legal and accounting activities; Activities of head offices; management consultancy activities	
32	M71	Architectural and engineering activities; technical testing and analysis	
33	M72	Scientific research and development	M: Professional, Scientific and Technical Activities
34	M73	Advertising and market research	
35	M74t75	Other professional, scientific and technical activities	
36	N77	Rental and leasing activities	
37	N79	Travel agency, tour operator and other reservation service and related activities	N: Administrative and Support Service Activities
38	N80t82	Security and investigation activities; Services to buildings and landscape activities; Office administrative, office support and other business support activities	
39	R90t93	Arts, Entertainment and Recreation	R
40	S94t96	Other Service Activities	S

Notes to table: Industries are the 40 industries included in our non-farm market sector definition: A (Agriculture); L (Real Estate); N78 (Employment Agencies) and O-Q (Public Admin & Defence, Education, Health) are excluded.

3.3. Output, tangible capital and labour input

For labour composition we use data produced at the Bank of England,[5] estimated from Labour Force Survey (LFS) microdata. In order to maintain sufficient sample cell sizes for our narrow industry definitions, the only composition groups used are education (highest qualification attained) and industry. Education is split into three groups: high, medium, and low. The volume of hours worked are ONS productivity hours.[6] Changes in total labour services by industry are therefore the sum of changes in labour composition and changes in hours worked. Hours worked are annual person-hours, with persons including the employed, self-employed and those with two jobs.

For output, we use the latest ONS data (BB21) on industry GVA at current basic prices and double deflated real values.[7] Data on labour income, that is compensation of employees plus a proportion of mixed (self-employed) income,[8] are from ONS Supply Use Tables (SUTs).[9] Capital compensation is

[5] We thank Douglas Rendle of the Bank of England for producing these estimates.

[6] https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/datasets/compendiumofdatarelatedtolabourproductivitybylowlevelindustry

[7] https://www.ons.gov.uk/economy/grossdomesticproductgdp/datasets/ukgdpolowlevelaggregates

[8] We thank ONS for providing estimates of mixed income at detailed industry-level.

estimated residually as nominal GVA less labour compensation so that capital and labour compensation sum to GVA by construction. We of course amend GVA and capital compensation to incorporate intangible investment.[10]

Gross fixed capital formation[11] (GFCF) in tangible assets and intellectual property products (IPPs), and their price indices,[12] are from ONS. Initial capital stocks are re-based estimates from EUKLEMS 2019 (Stehrer et al., 2019). Tangible capital data are disaggregated into the following types: buildings; computer (IT) hardware; telecoms (CT) equipment; (non-ICT) plant & machinery; and transport equipment.[13] We exclude dwellings as they are not capital for purposes of productivity analysis. We incorporate tax adjustment factors for all assets, tangible and intangible, estimated from corporate tax data in Hanappi (2018) and OECD (2021) for all assets except R&D.[14] For R&D we use the OECD B-index.[15] These data update values in Goodridge et al. (2016) based on Wallis (2016).

3.4. Details of measurement of intangible Assets

Estimates of intangible investment are from ONS (Fotopoulou, 2021).[16] ONS work in this area goes beyond that of most other national statistics institutes with regular estimates released as part of their ongoing work programme (Lewis, 2021; Martin, 2019; Martin et al., 2018). ONS publish estimates by asset-industry-year for all CHS assets, for 58 industries, 1992-2019.[17]

ONS categorisation of intangible investment is from CHS (2005), which includes IPPs capitalised in national accounts and other intangibles currently uncapitalised in the System of National Accounts (SNA; European Commission et al., 2009). IPPs in national accounts are: software and databases; literary, entertainment and artistic originals; R&D; and mineral exploration and evaluation. These estimates form part of ONS GFCF. Other CHS assets not currently capitalised in the SNA are: other innovative property, which includes design and financial product innovation; and economic competencies, which includes firm-specific training, branding (advertising and market research) and organisational capital.

ONS data and methods build on those in CHS and previous UK research (Goodridge et al., 2016; Goodridge et al., 2014; Goodridge et al., 2012; Dal Borgo et al., 2011; Haskel et al., 2011b; Gil et al., 2008; Giorgio Marrano et al., 2009), summarised below and in Appendix B. Details are drawn from fuller descriptions in Goodridge (2022)[18] in turn drawn from Martin (2019), Martin et al. (2019),

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[9] https://www.ons.gov.uk/economy/nationalaccounts/supplyandusetables/datasets/inputoutputsupplyandusetables

[10] To preview our results, Table 7, Table 8 and Figure 7 include data on growth in real output (or productivity) as measured in national accounts and real output (or productivity) adjusted for capitalisation of all intangibles.

[11] Acquisitions less disposals of fixed assets, available at https://www.ons.gov.uk/releases/annualgrossfixedcapitalformationbyindustryandasset1997to2020

[12] Asset-specific (but not industry-asset-specific) price indices are from the ONS capital services dataset: https://www.ons.gov.uk/economy/economicoutputandproductivity/output/datasets/capitalservicesestimates

[13] We effectively exclude cultivated biological resources as we exclude the agricultural (A) sector.

[14] We thank Tibor Hanappi of OECD for sharing these data.

[15] https://stats.oecd.org/Index.aspx?DataSetCode=RDSUB

[16] https://www.ons.gov.uk/economy/economicoutputandproductivity/output/datasets/investmentinintangibleassetsintheukbyindustry

[17] The ONS data do not include an industry breakdown for training investment at the time of writing. Instead our industry estimates for training are based on ONS market sector values and industry shares of UK training investment from EUKLEMS (Lab of European Economics, 2021). Industries M and N are aggregated in EUKLEMS. We therefore disaggregate estimates for M and N using ONS industry shares in nominal intangible investment for non-training assets.

[18] Published alongside this working paper.

McCrae & Roberts (2019), Chamberlin et al. (2006, 2007), Ker (2014), OECD (2010), Haskel et al. (2011), among others.

3.4.1. Intangible investment in the national accounts: Intellectual Property Products (IPPs)

International recommendations for measurement of GFCF in IPPs are set out in OECD (2010). Our estimates for UK investment in: software and databases; R&D; artistic originals; and mineral exploration; are taken from the ONS GFCF dataset. We disaggregate estimates for software and databases into own-account and purchased components according to data in Fotopoulou (2021). Table 2 provides a summary of ONS data and methods used in estimation. Fuller details are provided in Appendix B and Goodridge (2022).

Table 2: Summary of ONS methods in estimating GFCF in intellectual property products (IPPs)

Asset	Method	From	Price index
Software & databases	***P:*** Surveyed expenditure: QCAS ***O:*** modelled estimates: sum of costs (ASHE)	1970	***P:*** Adjusted version of US BEA pre-packaged software price index ***O:*** SPPI: Computer Services (K8UK)
R&D	Modelled estimates: sum of costs (BERD and other R&D surveys)	1955	Share-weighted input cost index: wages and PPIs for intermediate and capital goods
Artistic originals	**Film:** Sum of costs extrapolated using UK production indicator (BFI)	1970	SPPIs: Sound recording and music publishing services (K8UF) and Book publishing services (K8TV)
	TV & Radio: Sum of costs (OFCOM, BBC & S4C)		
	Music: Total cross-sectional royalty income (industry data incl. collecting societies)		
	Books: Total cross-sectional royalty income (industry data incl. collecting societies), advances and own-account costs (for in-house publications e.g. textbooks) (Publishers Association)		
	Misc. Art: modelled estimates: sum of costs (ASHE)		
Mineral exploration	Surveyed expenditure (incl. own-account): QCAS	1950	SPPI: Technical testing and analysis (K8WD)

Source: Goodridge (2022)

Note to table: Bold italic letters ***P*** and ***O*** refer to purchased and own-account respectively. Column 1 is the IPP in national accounts. Column 2 summarises ONS methods for estimating nominal GFCF. QCAS is the Quarterly Acquisitions and Disposals of Capital Assets Survey. ASHE is the Annual Survey of Hours and Earnings. BERD is the Business Enterprise Research and Development Survey. BFI is the British Film Institute. Column 3 is the year for which estimates of GFCF begin (in ONS capital services data rather than GFCF data, which begin in 1997). Column 4 provides details on the asset price index. SPPIs are Services Producer Price Indices. Codes in column 4 are ONS series identifiers.

3.4.2. Intangible investment in assets outside national accounts definitions of GFCF

In the SNA, assets are defined as entities that provide economic benefits to owners and make repeated contributions to production over more than one accounting period (year) (European Commission et al., 2009). In the economics literature, savings and investment are a means of sacrificing current consumption to increase future consumption, making the appropriate definition the devotion of current resources to the pursuit of future returns (Hulten, 1979; Weitzmann, 1976).

Consistent application of these definitions makes clear that there exist other forms of (knowledge or intangible) asset that repeatedly contribute to production, outside those in the SNA. A comprehensive categorisation of the full range of intangible capital which firms invest in is provided in CHS (2005), summarised in Table 3.

Forms of intangible capital not capitalised in national accounts include: design, financial product innovation; (firm-specific) training; brand (or reputational) capital; and organisational capital. ONS have produced regular estimates of investment in these assets since 2018 (Fotopoulou, 2021; Lewis, 2021; Martin et al., 2018, 2019). Data and methods are summarised below in Table 4. Fuller descriptions are provided in Appendix B and Goodridge (2022). Latest developments include improvements to methods for nominal investment and work to develop suitable price indices.

Table 3: Categories of intangible capital (CHS, 2005)

Category	Asset	Included in nat. accounts
Computerised information	Software and databases	✓*
Innovative property	R&D (incl. non-scientific R&D)	✓
	Artistic originals	✓
	Mineral Exploration	✓
	Design	✕
	Financial product innovation	✕
Economic competencies	Firm-specific training	✕
	Branding (advertising and market research)	✕
	Organisational capital	✕

Source: CHS (2005)

Notes to table: Column 1 is the category in CHS. Column 2 are assets in each category identified in CHS. Column 3 indicates whether the asset is already capitalised in national accounts. *In national accounts, databases are capitalised but activities in the creation of analysable data and data analytics are not. Research on measuring activity in data capital formation and its contribution to growth presented in Goodridge et al. (2021), Goodridge et al. (2015), Goodridge & Haskel (2015b, 2015a) and Statistics Canada (2019a, 2019b).

Briefly, estimates for design, branding and organisational capital include purchased and own-account components. Estimates for purchased investment are largely based on the SUTs. Estimates for own-account are based on the (time-use adjusted) labour input of occupations assumed engaged in knowledge capital formation, observed from the Annual Survey of Hours and Earnings (ASHE). Estimates for financial product innovation are similarly based on ASHE. Estimates for training are based on the Investment in Training module of the Employer Skills Survey (ESS).

The largest category of uncapitalised intangible investment is organisational capital. Purchased investments in organisational capital are based on purchases of management consulting services. Own-account investment is estimated as a proportion of managerial labour input, based on the assumption that managerial occupations spend 20% of their time making long-lived improvements to business processes and organisational structure. Estimates therefore rely heavily on the time-use factor used in estimation, but the review in Martin (2019) does provide evidence to support this assumption, noting that it is relatively consistent with a range of managerial time-use studies.

Table 4: Summary of ONS methods for CHS assets outside national accounts definition of GFCF

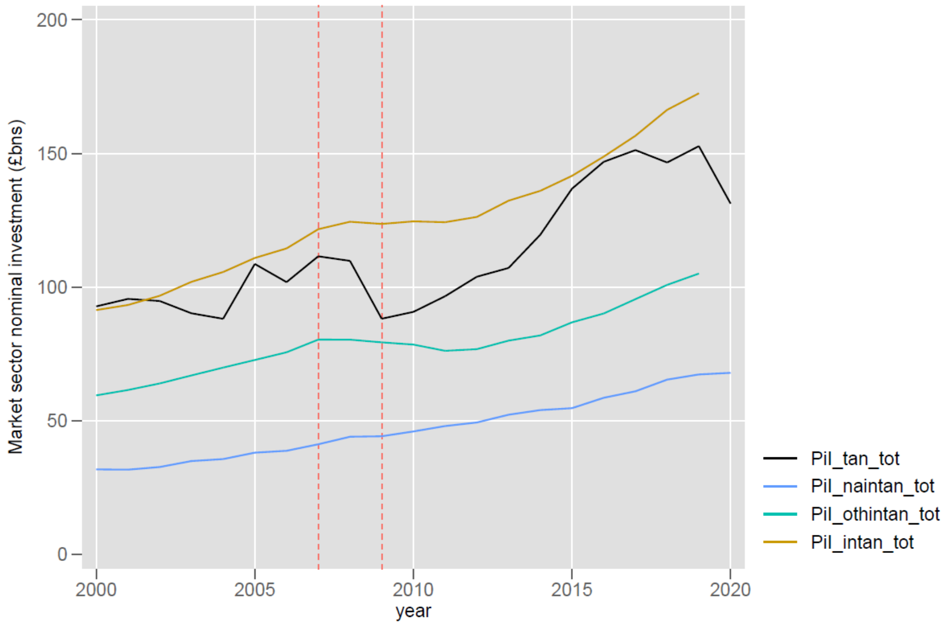
Asset	Method	Cap. factor	From	Price index
Design	***P:*** SUT data: purchases of arch. & eng. services (prod 71) plus output of specialist design industry (SIC 74.1) ***O:*** modelled: sum of costs (ASHE & NES)	0.5	1992	***P:*** SPPIs and Experimental Industry Deflators ***O:*** implied deflator derived using volume index for hours worked
Financial Product Innovation	Modelled estimates: sum of costs (ASHE & NES)	1	1992	Implied deflator derived using volume index for hours worked
Training	Sum of costs. From 2007: ESS and NESS. Pre-2007: modelled estimates	1	1985	Index of Labour Costs per Hour (ILCH) extended using ASHE pay data
Branding (advertising and market research)	***P:*** SUT data: purchases of adv & mr services (prod 73) ***O:*** modelled: sum of costs (ASHE & NES)	***P:*** 0.6 (adv) and 0.8 (mr) ***O:*** 0.3 (adv) and 0.8 (mr)	1992	***P:*** SPPIs ***O:*** implied deflator derived using a volume indices for hours worked
Organisational capital	***P:*** purchases of mgt cons services (MCA) apportioned to industries using SUT data on purchases ***O:*** modelled: sum of costs (ASHE & NES)	***P:*** 0.8 ***O:*** 1	1992	***P:*** SPPIs and Experimental Industry Deflator ***O:*** implied deflator derived using volume indices for hours worked

Note to table: Bold italic letters ***P*** and ***O*** refer to purchased and own-account respectively. Column 1 are intangible assets from CHS (2005) that are uncapitalised in national accounts. Column 2 summarises the ONS method in estimating nominal investment. NES is the New Earnings Survey. ESS is the Employer Skills Survey and the NESS its predecessor (National Employer Skills Survey). MCA is the Management Consultancies Association. Column 3 is a capitalisation factor, that is an assumption on what proportion of expenditure or output represents formation of long-lived assets. Column 4 indicates the year for which estimates begin. Column 5 describes the price index used to estimate real investment. SPPIs are Services Producer Price Indices.

4. Intangible investment

Figure 1 presents data on total market sector nominal tangible and intangible investment. Data for tangibles are to 2020 and for intangibles to 2019.[19] Intangible investment (intan) is broken down into intangibles capitalised in national accounts (naintan) and other CHS intangibles not capitalised in national accounts (othintan). Nominal tangible investment (tan) was slightly greater than intangible in 2000, at £93bn and £91bn respectively, before diverging. Intangible investment has remained greater than tangible since then. Following the financial crisis, intangible investment slowed while there was a sharp fall in tangible investment. Tangible investment then recovered at a faster rate than intangible, but has stagnated in more recent years while intangible investment has grown. Tangible investment fell sharply in the recent pandemic.

Figure 1: Total intangible and tangible investment, £bns, non-farm market sector, 2000-2020



Note to figure: Total nominal investment in tangible (tan, black line) and intangible (intan, gold line) assets in the non-farm market sector. Intangible investment broken out into national accounts intangibles (naintan, blue line) and other CHS intangibles (othintan, green line). Estimates in £ billions. Red lines mark the financial crisis in 2007 and the end of the recession in 2009. ONS estimates of intangible investment uncapitalised in national accounts are currently only to 2019.

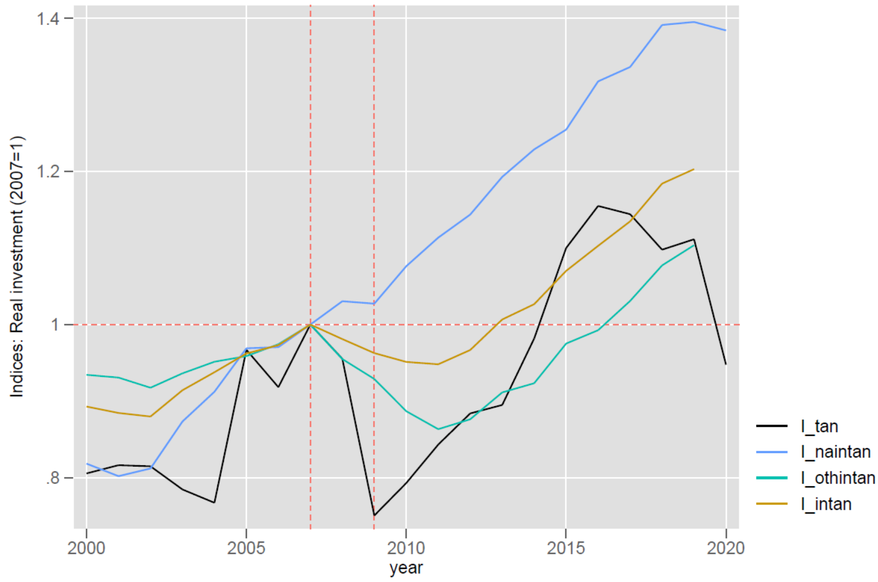
Figure 2 presents indices of real investment for total tangibles (tan), national accounts intangibles (naintan), other CHS intangibles (othintan) and total intangibles (intan), all set to 2007=1. Real investment in national accounts intangibles stayed above its pre-2007 level during and following the financial crisis. Indices for tangible, other intangible and total intangible investment all exhibit a decline with recovery later.

Figure 3 presents data on total nominal intangible investment by asset. In 2019, the largest categories were: software and databases (£35.4bn); organisational capital (£35.2bn); training (£31.3bn); branding (£26.3bn); and R&D (£24.6bn). Note that three of the four largest categories are not currently capitalised in national accounts.

Data for most assets show a stagnation immediately following the financial crisis but growth thereafter. Data for training however show a sharp fall in years following the crisis. It has since recovered somewhat but remains slightly below the estimate observed in 2007.

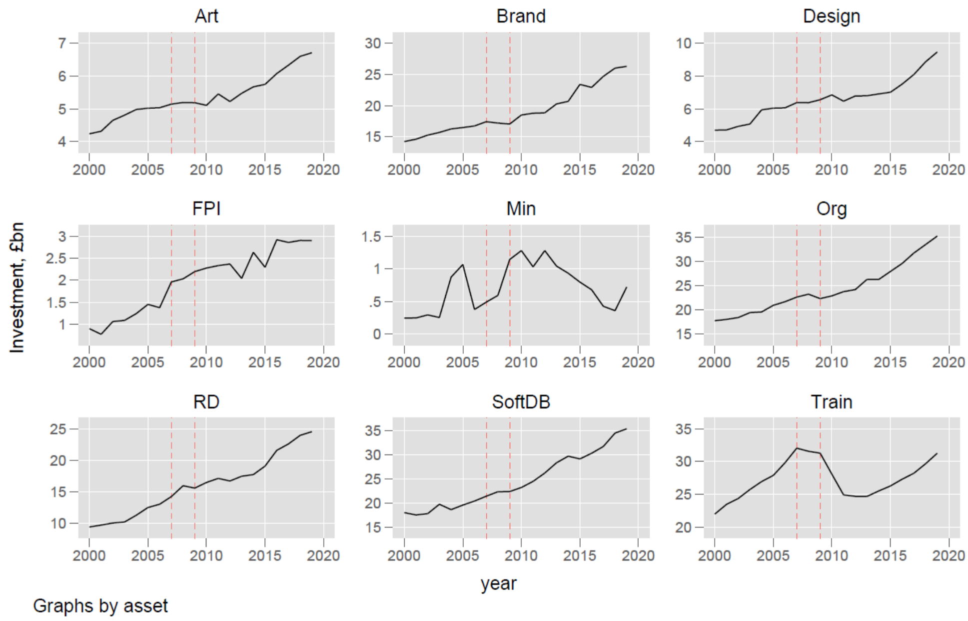
[19] Except for the sub-category of national accounts intangibles which are also to 2020.

Figure 2: Indices of real intangible and tangible investment, 2007=1, UK non-farm market sector, 2000-2020



Note to figure: Indices (2007=1) of real investment in tangible (tan, black line) and intangible (intan, gold line) assets in the non-farm market sector. Intangible investment broken out into national accounts intangibles (naintan, blue line) and other CHS intangibles (othintan, green line). Red vertical lines mark the financial crisis in 2007 and the end of the recession in 2009. ONS estimates of intangible investment uncapitalised in national accounts are currently only to 2019.

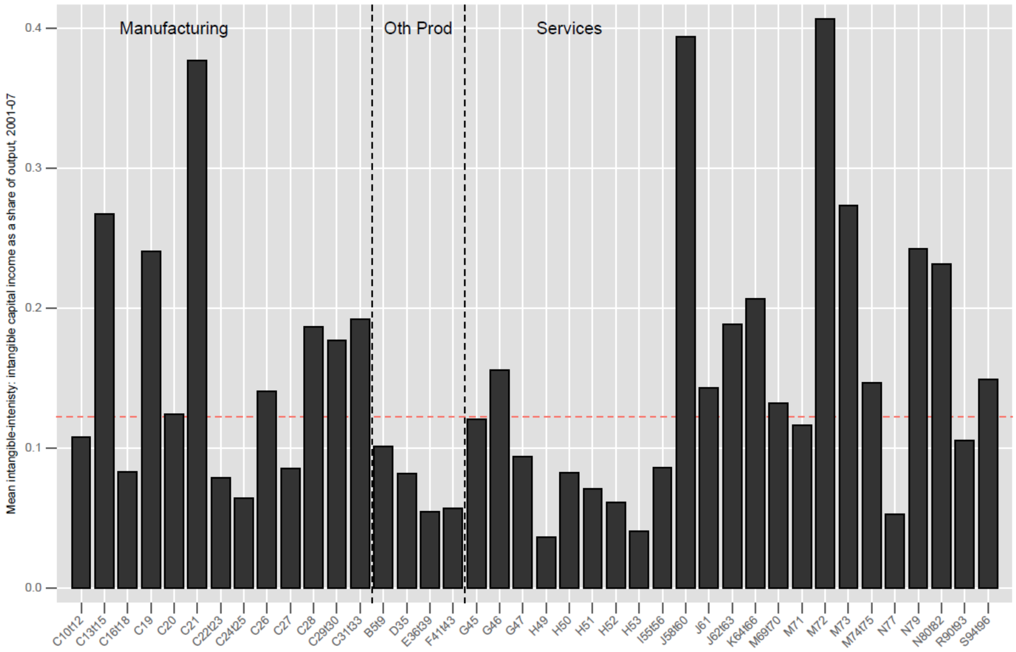
Figure 3: Nominal intangible investment by asset, £bns, non-farm market sector, 2000-2019



Note to figure: Nominal intangible investment for non-farm market sector, by asset. Data in £ billions. Red lines mark the financial crisis in 2007 and the end of the recession in 2009. Data for branding, design, organisational capital and software & databases are the sum of purchased and own-account components.

One way of estimating intangible- (or knowledge-) intensity in each industry is to calculate the ratio of intangible investment to value-added. Alternative methods are to use data on the share of intangible capital income, either within total capital income or total income (output). The advantage of using capital income is that it incorporates information on intangible capital accumulation in prior years rather than just the flow of investment in the current year. Figure 4 presents data on the share of intangible capital income in (adjusted) industry output (Q), constructed as an average for the pre-crisis 2001-2007 period. The red line marks the median industry value.

Figure 4: Mean intangible-intensity: intangible capital income as a share of adjusted industry output, by industry, 2001-2007



Note to figure: Mean intangible-intensity by industry, 2001-07. Intangible-intensity estimated as the share of intangible capital compensation in industry output (Q), where output is adjusted for capitalisation of intangibles. Red line is the median value (12.2%). Black vertical lines separate industries into sectors: Manufacturing, Other Production; and Services.

Using this measure, the most intangible-intensive (above median) industries are, in descending order, industries listed in Table 5. The three most intangible-intensive industries are Scientific research and development (M72) with intangible capital compensation accounting for 41% of industry output; followed by; Publishing, audio-visual and broadcasting activities (J58t60, 39%); and Manufacture of basic pharmaceutical products and pharmaceutical preparations (C21, 38%).

Table 5: Intangible-intensive industries: above-median share of intangible capital income in industry value-added (2001-07)

SIC	Description	Intangible-intensity
M72	Scientific research and development	0.41
J58t60	Publishing, audio-visual and broadcasting activities	0.39
C21	Basic pharmaceutical products and pharmaceutical preparations	0.38
M73	Advertising and market research	0.27
C13t15	Textiles, wearing apparel, leather and related products	0.27
N79	Travel agency, tour operator and other reservation service and related activities	0.24
C19	Coke and refined petroleum products	0.24
N80t82	Security and investigation; services to buildings and landscape; office administrative and business support	0.23
K64t66	Financial and insurance activities	0.21
C31t33	Other manufacturing; repair and installation of machinery and equipment	0.19
J62t63	IT and other information services	0.19
C28	Machinery and equipment n.e.c.	0.19
C29t30	Transport equipment	0.18
G46	Wholesale trade, except of motor vehicles and motorcycles	0.16
S94t96	Other service activities	0.15
M74t75	Other professional, scientific and technical; veterinary activities	0.15
J61	Telecommunications	0.14
C26	Computer, electronic and optical products	0.14
M69t70	Legal and accounting; head offices and management consulting	0.13
C20	Chemicals and chemical products	0.12

Note to table: Industries with a share of intangible capital income in industry value-added in 2001-07 greater than the median industry (0.122).

In our growth-accounting analysis we shall use this measure to estimate decompositions for intangible-intensive industries.[20] Research for the US has shown that a TFP slowdown in durable manufacturing made a substantial contribution to the post-2005 slowdown in US TFP growth (Sprague, 2021). The durability of goods is a consumption goods characteristic. We will explore whether the UK slowdown is related to a production characteristic, intangible-intensity, in both production and service sectors. Table 6 shows that there is some overlap between UK intangible-intensive manufacturing industries and those that produce durable goods. Of the six manufacturing industries in our dataset which produce consumer durable or capital goods, four have a share of intangible capital compensation in industry output that is above the market sector median value.

Table 6: Definitions: durability and intangible-intensity, manufacturing industries

	Manufacturing	Durables	Intangible-intensive (above MS median)
C10t12	Manufacture of food, beverages & tobacco		
C13t15	Manufacture of textiles, wearing apparel & leather products		✓
C16t18	Manufacture of wood & paper products; printing and reproduction of recorded media		
C19	Manufacture of coke and refined petroleum products		✓
C20	Manufacture of chemicals and chemical products		✓
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations		✓
C22t23	Manufacture of rubber, plastic and non-metallic mineral products		
C24t25	Manufacture of basic & fabricated metals	✓	
C26	Manufacture of computer, electronic and optical products	✓	✓
C27	Manufacture of electrical equipment	✓	
C28	Manufacture of machinery and equipment n.e.c.	✓	✓
C29t30	Manufacture of transport equipment	✓	✓
C31t33	Manufacture of furniture; other manufacturing; repair and installation	✓	✓

Note to table: Columns 1 and 2 are manufacturing industries. Column 3 indicates whether the industry produces consumer durable or capital goods, as defined by OECD at https://www.oecd.org/sdd/prices-ppp/43905313.pdf. Column 4 indicates whether the industry is intangible-intensive, defined as having a share of intangible capital compensation in adjusted industry output (Q) greater than the median market sector value.

5. The contribution of reallocation to the labour productivity slowdown

5.1. Basic findings

Table 7 sets out decompositions of market sector labour productivity growth showing bottom-up labour productivity growth ($\Sigma w_j \Delta \ln(V/H)_j$, "within effect") and labour reallocation (R^H, "between effect"). We present alternative decompositions based on i) national account definitions of capital and value-added (V, top panel) and ii) expanded definitions of value-added (Q) and capital which include all CHS intangibles (bottom panel).

Table 7: UK productivity slowdown: within and between effects

	2000-07	2007-19	$\Delta^{07-19} - \Delta^{00-07}$	*Memo: 2019-20*
$\Delta\ln(V/H)^{na}$	2.46%	0.12%	-2.34%	*3.13%*
$\Sigma w_j \Delta\ln(V/H)_j^{na}$	2.69%	0.14%	-2.55%	*0.18%*
$R^{H,na}$	-0.23%	-0.02%	0.21%	*2.95%*
$\Delta\ln(Q/H)^{ii}$	2.32%	0.10%	-2.22%	-
$\Sigma w_j \Delta\ln(Q/H)_j^{ii}$	2.55%	0.14%	-2.42%	-
$R^{H,ii}$	-0.24%	-0.04%	0.20%	-

Note to table: Panel 1 uses national accounts definitions of capital and value-added (V, na). Panel 2 uses expanded definitions of capital and value-added (Q) including all CHS intangibles (ii). In each panel, row 1 is aggregate market sector labour productivity growth, row 2 is the contribution of (Tornqvist value-added-weighted) industry labour productivity growth (within effect) and row 3 is the contribution of labour reallocation (R^H, between effect). Column 1 are data for 2000-07 and column 2 for 2007-19. Column 3 is acceleration: $\Delta\Delta = \Delta^{07-19} - \Delta^{00-07}$. A negative value represents a slowdown.

[20] We note above that there are other alternative potential methods to estimate intangible-intensity, such as using intangible capital compensation as a share of total capital compensation and intangible investment as a share of industry output. Our findings reported below are robust to using these alternative methods.

Memo item in column 4 is data for the pandemic period, 2019-20. Memo item not presented in panel 2 as intangible investment data for assets uncapitalised in national accounts are only to 2019. Growth rates calculated as changes in the natural log.

Using national accounts (na) definitions of GVA and capital, the data show a slowdown in top-down aggregate labour productivity growth of -2.34% pa. The slowdown in the within effect overexplains the aggregate slowdown, estimated at -2.55% pa. Thus labour reallocation does not contribute to the slowdown as its contribution speeds up by 0.21% pa. Incorporating all CHS intangibles in output and capital, as in panel 2, does not alter the conclusion. Absolute values for labour productivity growth are less, as real intangible investment grows slower than measured real value-added in both periods.[21] However, the slowdown values are similar.

We note that in the pandemic period (2019-20), measured aggregate labour productivity growth is strongly positive at 3.13% pa, reflecting a large contribution from labour reallocation of 2.95% pa, driven by the collapse in output and hours in lower-productivity industries during the pandemic, where workers were less able to continue working from home.[22]

It is therefore correct to state that labour reallocation has made a negative contribution to labour productivity growth. Pre-crisis (2000-07), labour reallocation dragged down labour productivity growth by as much as -0.24% pa, a not insubstantial amount. It also made a negative contribution post-crisis (2007-19) (-0.02% pa using national accounts definitions and -0.04% pa using adjusted GVA (Q)). But that negative contribution was less than in the pre-crisis period meaning that reallocation did not contribute to the slowdown.

5.2. Robustness to numbers of industries and to a different method

Since reallocation is estimated residually, estimation depends on the value for the within effect: weighted (Tornqvist shares of nominal value-added) growth in industry labour productivity. Therefore, it could be argued that estimates of the contribution of reallocation depend upon which industries one chooses to aggregate over. Table 7 is estimated bottom-up from data for 40 industries. Figure 5 presents an annual comparison of the reallocation estimate from Table 7 with a term estimated from data for 14 SIC sections.[23] Aggregating over alternative sets of industries makes little difference to estimated within and between effects.

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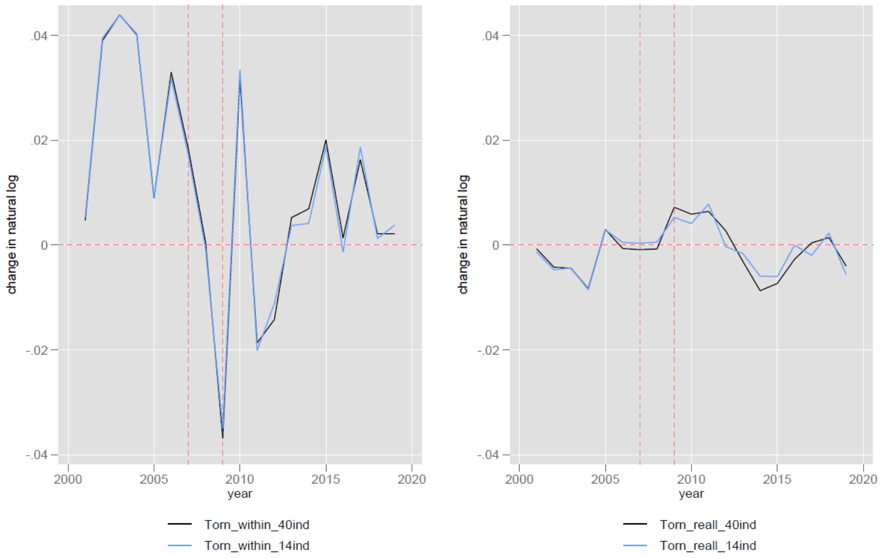
[21] In other words, the capitalisation effect set out in equation (8) is negative. In previous work we have found this term to be positive with real (uncapitalised) intangible investment growing faster than real measured value-added (V) in the pre-crisis period (Goodridge et al., 2016). However, that work largely relied on using the implied price of value-added as a proxy for the price of intangible assets. This work uses the latest ONS deflators for intangible assets and revised estimates of nominal investment using updated methods.

[22] We don't present estimates including intangibles for the 2019-20 period as ONS intangible investment data for uncapitalised intangibles only extend to 2019 at the time of writing.

[23] As in column 3 of Table 1. For simplicity, we only use national accounts definitions of output and capital here but incorporating intangibles does not affect our conclusions.

Figure 5: Labour productivity growth decomposition, within and between effects, 2001-2019, 40 industries vs 14 industries



Note to figure: Left panel is the within effect for alternative 40- (black line) or 14-industry (blue line) aggregations. Right panel is the reallocation (between) effect for 40- (black line) or 14-industry (blue line) aggregations. Estimated using Tornqvist aggregation. A positive reallocation term means that reallocation is adding to labour productivity growth. Growth rates calculated as changes in the natural log. Red vertical lines mark the financial crisis in 2007 and the end of the recession in 2009.

Turning to differences in method, we have used the Tornqvist aggregation method to estimate the reallocation term. An alternative approach is to use the shift-share aggregation method. As set out in De Vries et al. (2021), another way of estimating market sector labour productivity growth is to assume an aggregate production function such that real GVA can be summed over industries and the level of labour productivity is:[24]

$$V_t/H_t = \sum V_{jt}/\sum H_{jt} \tag{11}$$

Growth in aggregate labour productivity can then be decomposed into a within effect (first right-hand side term) and two other terms which are static (second term) and dynamic reallocation effects (third term) respectively:

$$\frac{\Delta(V_t/H_t)}{V_{t-1}/H_{t-1}} = \frac{\sum\left((H_{jt-1}/\sum H_{jt-1})\Delta(V_{jt}/H_{jt})\right)}{V_{t-1}/H_{t-1}} + \frac{\sum((V_{jt-1}/H_{jt-1})\Delta(H_{jt}/\sum H_{jt}))}{V_{t-1}/H_{t-1}} + \frac{\sum(\Delta(V_{jt}/H_{jt})\Delta(H_{jt}/\sum H_{jt}))}{V_{t-1}/H_{t-1}} \tag{12}$$

Figure 6 presents a comparison of within and between effects using Tornqvist and shift-share aggregations, based on a national accounts definition of value-added (V), aggregated bottom-up. The shift-share reallocation effect is the sum of static and dynamic effects. Estimates are similar[25] for both methods.[26]

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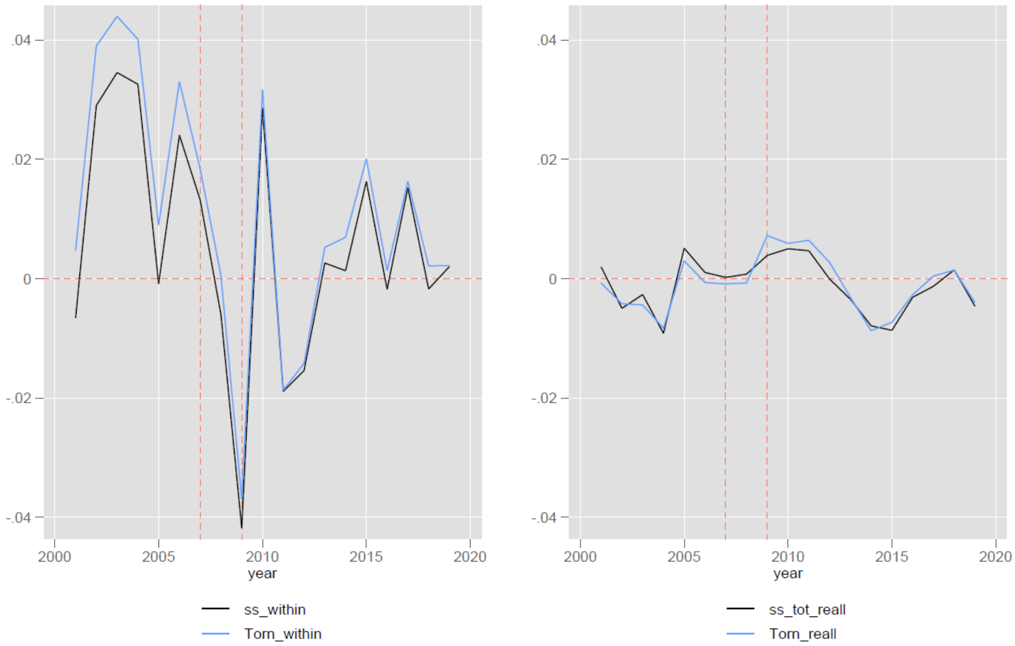
[24] This assumes a common production function such that we can sum different types of real value-added across industries. It assumes that value-added functions across industries are identical up to a scalar multiple (Jorgenson et al., 2005), which is a very strong assumption. For this reason, we prefer the Tornqvist aggregation method.

[25] Interestingly, for the within effect, the difference between estimates seems to be larger for earlier years furthest from the base year (2019 in our data), suggestive of a growing implicit error in adding real quantities of differently priced output the further one moves from the base year.

[26] We note however that there are other methods to estimate reallocation effects including Tang & Wang (2004) which takes account of changes in the price of industry value-added relative to the implied price of aggregate value-added.

Figure 6: Labour productivity growth decomposition, within and between, 2001-2019, Tornqvist aggregation vs shift-share aggregation



Note to figure: Left panel is the within effect estimated from Tornqvist (blue line) and shift-share aggregation (black line). Right panel is the reallocation effect using Tornqvist (blue line) and shift-share aggregation (black line). Shift-share reallocation effect is the sum of static and dynamic terms. A positive reallocation term means that reallocation is adding to labour productivity growth. Vertical axis is the change in the natural log for the Tornqvist aggregation and a growth rate for the shift-share aggregation. Red vertical lines mark the financial crisis in 2007 and the end of the recession in 2009.

Therefore, we conclude that the UK labour productivity slowdown is not due to reallocation of labour between industries. Rather it is a slowdown within industries.

6. The contributions of output mismeasurement and inputs

6.1. Output measurement

Before presenting data on industry and factor contributions to the slowdown, we first examine to what extent capitalisation of the full range of intangibles affects our sources-of-growth decomposition. Table 8 presents a decomposition based on national accounts definitions of value-added (V) and capital (na) and expanded definitions (Q) with all intangibles capitalised (ii), for pre- (2000-07) and post-crisis (2007-19) periods.

In the pre-crisis period, capitalisation of the full range of intangibles lowers aggregate market sector labour productivity growth (row 1) from 2.46% pa to 2.32% pa, and in the post-crisis period from 0.12% pa to 0.1% pa. Reallocation terms (row 2) are similar in the two scenarios.

Row 3 is bottom-up weighted labour productivity growth. In the pre-crisis period, labour productivity growth is less when the full of intangibles are capitalised, since real growth in other (i.e. uncapitalised in national accounts, othintan) intangible investment is less than real growth in measured value-added (V). This is shown in row 5, where the effect of capitalisation lowers labour productivity growth by -0.19% pa. Row 4 shows that the effect from changes in output shares is small. In the ii column, if we take bottom-up measured labour productivity growth in row 3, add row 4 (share effect) and subtract row 5 (output capitalisation effect), as in equation (9), we get measured labour productivity using national accounts weights, as reported in row 3 of the na column. Capitalisation of intangibles therefore explains a small proportion of the slowdown since pre-crisis growth is lower when intangibles are capitalised. The labour productivity slowdown is therefore less than when estimated using measured national accounts data.

Table 8: UK sources of growth, pre- and post-crisis: national accounts (na) and including CHS intangibles (ii), 2000-19

		2000-07		2007-19	
		na	ii	na	ii
1	Market sector: $\Delta\ln(V/H)$ or $\Delta\ln(Q/H)$	2.46%	2.32%	0.12%	0.10%
2	R^H	-0.23%	-0.24%	-0.02%	-0.04%
3	Bottom-up: $\Sigma v_j^V \Delta\ln(V/H)_j$ or $\Sigma v_j^Q \Delta\ln(Q/H)_j$	2.69%	2.55%	0.14%	0.14%
4	Share effect: $\Sigma(v_j^V - v_j^Q)\Delta\ln(Q/H)_j$		-0.05%		-0.02%
5	Output effect: $\Sigma v_j^V u_j^Q(\Delta\ln I_j^{othintan} - \Delta\ln V_j)$		-0.19%		-0.03%
6	$w_L\Delta\ln(L/H)$	0.18%	0.17%	0.26%	0.24%
7	$w_K\Delta\ln K/H^{tan}$	0.67%	0.62%	0.06%	0.07%
8	$w_K\Delta\ln(R/H)^{naintan}$	0.20%	0.18%	0.13%	0.11%
9	$w_K\Delta\ln(R/H)^{othintan}$		0.14%		-0.01%
10	$\Delta\ln TFP$	1.64%	1.44%	-0.31%	-0.28%
Memo:	*Row 9 + Row 10*	*1.64%*	*1.59%*	*-0.31%*	*-0.28%*

Note to table: Growth-accounting decomposition for UK non-farm market sector. Column 1 are estimates for the pre-crisis (2000-07) period and column 2 for the post-crisis (2007-19) period. Each column presents decompositions based on national accounts definitions of output (V) and capital (na) and expanded definitions (Q) including all CHS intangibles (ii). Row 1 is market sector labour productivity growth. Row 2 is labour reallocation. Row 3 is bottom-up industry labour productivity growth. Row 4 is the effect of capitalising other intangibles (othintan) on industry value-added shares. Row 5 is the effect of capitalising other intangibles in real output growth. In the ii column, row 3 plus row 4 minus row 5 gives measured bottom-up labour productivity growth, as reported in row 3 of column na. Row 6 is the contribution of labour composition. Row 7 is the contribution of tangible (tan) capital deepening. Row 8 is the contribution of capital deepening for intangibles capitalised in national accounts (naintan). Row 9 is the contribution of capital deepening for other CHS intangibles (othintan). Row 10 is TFP growth. Memo item is the contribution of other intangible capital deepening (row 9) plus TFP growth (row 10), highlighting how much of TFP is explained when other intangibles are capitalised.

The remaining rows present sources-of-growth contributions to labour productivity growth. In row 6, the contribution of labour compensation is less when intangibles are capitalised, since the labour income share is lower. In rows 7 and 8, the contributions of tangible (tan) and national accounts intangible (naintan) capital deepening are generally less when intangibles are capitalised, with the exception of tangible capital deepening in the post-crisis period. Row 9 presents the contribution of other intangible (othintan) capital deepening and row 10 is TFP growth. TFP growth in the pre-crisis period is lower when intangibles are capitalised, since some part of TFP is explained by the additional capital contribution. Interestingly however, if we sum the contributions of other intangible capital deepening and TFP growth as in the memo item in the final row, the decomposition looks remarkably similar across na and ii definitions. Capitalisation of intangibles therefore does not substantively change the decomposition or conclusions.[27]

Table 8 shows that labour productivity growth slowed sharply post-crisis. Figure 7 presents log point indices to highlight the implied labour productivity gap, estimated as the difference between the level of labour productivity in 2019 and the level that would have been reached had labour productivity continued to grow at the rate observed in 2000-07.

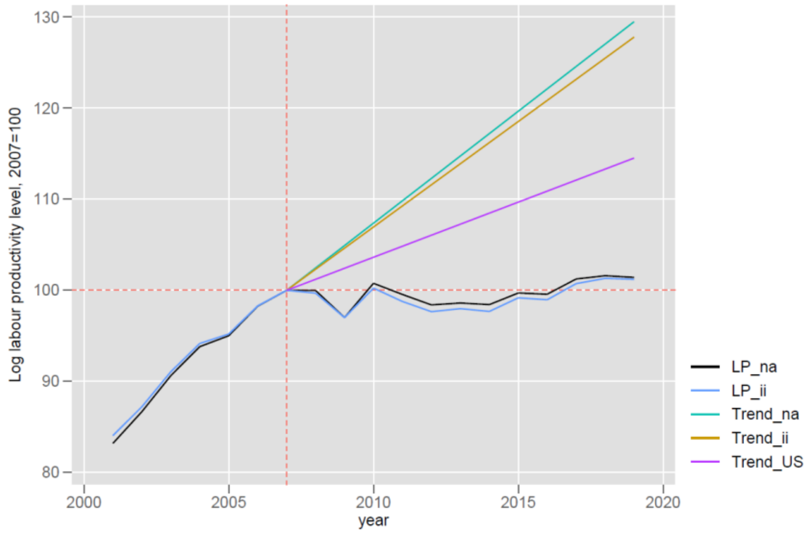
Using national accounts definitions of output and capital (na), we estimate a productivity gap in 2019 of 28.1 log points. The gap is less when we incorporate all intangible investment in output and

[27] The results of the decomposition are also robust to altering depreciation rates for intangibles that are currently uncapitalised in national accounts (othintan). If we double the depreciation rate for all those assets, TFP growth (ii model) changes from 1.44% pa to 1.47% pa in the pre-crisis period and from -0.28% pa to -0.29% pa in the post-crisis period.

capital (ii, 26.6 log points). Capitalisation of intangibles therefore explains ((28.1-26.6)/28.1=)5% of the labour productivity gap.

We also present an index based on labour productivity growth observed in the US, 2007-19, as reported in Fernald & Inklaar (2022). The UK productivity outcome (including intangibles, ii) is 13.3 log points less than it would have been had it grown at the US rate.

Figure 7: Labour productivity gap: trend vs outcome, 2000-2019, log points



Note to figure: Y-axis in log points. LP_na is an index of labour productivity based on national accounts definitions. LP_ii is an index of labour productivity incorporating all CHS intangibles. Trend_na is national accounts defined labour productivity had it continued to grow at its 2000-07 rate. Trend_ii is labour productivity (adjusted for capitalisation of all intangibles) had it continued to grow at its 2000-07 rate. Trend_US is an index based on labour productivity growth in 2007-19 in the US (1.21% pa, taken from panel 2 of Table 1 in Fernald & Inklaar (2022)).

6.2. Input contributions

Having noted that capitalisation of intangibles accounts for a small proportion of the productivity gap, from this point we will account for the slowdown with all intangibles capitalised (ii model). In Table 9 we estimate how much of the gap is explained by sources of growth contributions.[28] Market sector labour productivity growth slowed from 2.32% pa pre-crisis to 0.1% pa post-crisis, resulting in a productivity gap of 26.6 log points. Neither labour reallocation or labour composition explain any of the gap, since they speed up, increasing the gap to be explained by 3.3 log points (12%).

35% of the gap is explained by a slowdown in the contribution of capital deepening, which slowed from 0.94% pa pre-crisis to 0.17% pa post-crisis. Of that 35%, 25% is explained by a slowdown in the contribution of tangible capital deepening, which is broad based with a slowdown observed for all tangible assets. The largest contribution to the slowdown among tangible assets is from ICT hardware equipment, which slowed from 0.22% pa to 0% pa, explaining 10% of the gap.

The remaining 10% of the slowdown in the contribution of capital deepening is from intangible assets, the contribution of which slowed from 0.33% pa to 0.11% pa. Of that 10%, 6% is explained by training, the contribution of which slowed from 0.03% pa to -0.09% pa. Organisational capital, R&D, software and databases, design and other IPPs (artistic originals and mineral exploration) also contribute to the slowdown in the contribution of intangible capital deepening.

[28] In this Table we carry out the decomposition with all CHS intangibles capitalised. We present a version of the table based on national accounts definitions of capital and output (V) in Appendix C.

Table 9: Accounting for the UK slowdown, 2000-2019, log points

		1	2	3	4
		Before (00-07)	**After (07-19)**	**Implied gap**	***% of gap explained***
	$\Delta\ln(Q/H)$[ii]	**2.32%**	**0.10%**	**26.59**	**100%**
1	**Labour reallocation**	**-0.24%**	**-0.04%**	**-2.41**	**-9%**
2	**Contribution: Labour Composition**	**0.17%**	**0.24%**	**-0.86**	**-3%**
3	**Contribution: Capital deepening**	**0.94%**	**0.17%**	**9.23**	**35%**
	Tangibles	**0.62%**	**0.07%**	**6.59**	**25%**
	Buildings	0.23%	0.08%	1.84	7%
	Other Machinery and Equipment	0.10%	-0.05%	1.79	7%
	Transport Equipment	0.07%	0.03%	0.40	1%
	ICT (hardware) equipment	0.22%	0.00%	2.57	10%
	Intangibles	**0.33%**	**0.11%**	**2.63**	**10%**
	R&D	0.05%	0.01%	0.39	1%
	Software and databases	0.13%	0.10%	0.35	1%
	Other IPPs (mineral exploration & artistic originals)	0.01%	0.00%	0.09	0%
	Design	0.02%	0.00%	0.20	1%
	Financial Product Innovation	0.01%	0.02%	-0.12	0%
	Training	0.03%	-0.09%	1.50	6%
	Branding	0.02%	0.03%	-0.13	-1%
	Organisational	0.06%	0.03%	0.35	1%
4	**TFP**	**1.44%**	**-0.28%**	**20.64**	**78%**
Ind contributions:	Manufacturing	0.93%	0.16%	9.24	35%
	Other production	-0.51%	-0.41%	-1.22	-5%
	Services	1.02%	-0.03%	12.61	47%
K64t66	Financial and insurance activities	0.49%	-0.22%	8.55	*32%*
G46	Wholesale trade, except of motor vehicles and motorcycles	0.17%	-0.02%	2.29	*9%*
J62t63	IT and other information services	0.11%	-0.05%	1.83	*7%*
C29t30	Transport equipment	0.13%	-0.02%	1.75	*7%*
C28	Machinery and equipment n.e.c.	0.11%	-0.01%	1.46	*6%*
C10t12	Food products, beverages and tobacco	0.10%	-0.01%	1.25	*5%*
C21	Basic pharmaceutical products and pharmaceutical preparations	0.07%	-0.03%	1.20	*5%*
C26	Computer, electronic and optical products	0.14%	0.05%	1.06	*4%*
C16t18	Wood and paper products; printing and reproduction of recorded media	0.10%	0.03%	0.87	*3%*
J58t60	Publishing, audio-visual and broadcasting activities	0.07%	0.00%	0.80	*3%*
R90t93	Arts, entertainment and recreation	0.03%	-0.03%	0.78	*3%*
M72	Scientific research and development	0.02%	-0.04%	0.71	*3%*
C31t33	Other manufacturing; repair and installation of machinery and equipment	0.07%	0.01%	0.70	*3%*
C13t15	Textiles, wearing apparel, leather and related products	0.09%	0.03%	0.68	*3%*
M71	Architectural and engineering; technical testing and analysis	0.01%	-0.05%	0.67	*3%*
C27	Electrical equipment	0.05%	0.01%	0.54	*2%*
C22t23	Rubber and plastics products, and other non-metallic mineral products	0.06%	0.02%	0.47	*2%*
H49	Land transport and transport via pipelines	0.00%	-0.04%	0.47	*2%*
M69t70	Legal and accounting; head offices and management consulting	0.01%	-0.02%	0.42	*2%*
B5t9	Mining and quarrying	-0.16%	-0.18%	0.26	*1%*
M73	Advertising and market research	0.01%	-0.01%	0.22	*1%*
H51	Air transport	0.02%	0.01%	0.15	*1%*
5: Memo	***Memo: US TFP 2007-19****	***1.44%***	***0.10%***	***16.13***	***61%***
	Memo: pre-crisis UK TFP 1970-2007**	***1.30%***	***-0.28%***	***18.91***	***71%***

Source: authors' calculations.

Note to table: Sources-of-growth decomposition for UK non-farm Market Sector (incorporating all CHS intangibles) comparing period before the recession (2000-2007) to the period after (2007-19). Columns 1 and 2 are per annum log difference rates. The implied gap, column 3, is the difference in log points between the level realised by the twelve year

growth rate in the post-crisis second column and the level predicted by the twelve year growth rate in the pre-crisis first column. So for instance, the TFP gap (row 4) is 21 log points. Column 4 presents the percentage of the gap explained, calculated as a proportion of the total labour productivity gap (26.6 log points). Decomposition carried out at industry-level. Industry TFP estimates are value-added weighted contributions.
*First memo item uses an estimate of market economy US TFP growth of 0.1% pa in 2007-19 (column 2) as reported in Table 2 of Fernald & Inklaar (2022), and the realised UK growth rate in 2000-07 (column 1), thus estimating the size of the gap had UK TFP grown at the rate observed in the US in the post-crisis period.
**Second memo item uses a long-run estimate of UK *market sector* (the basis most comparable to our estimates) TFP growth of 1.3% pa (1970-2007) for the pre-crisis period (column 1), taken from the ONS Multi-Factor Productivity dataset,[29] thus estimating the size of the gap had pre-crisis TFP grown at this lower long-run rate.

The remaining 78% of the gap is explained by a slowdown in TFP growth, from 1.44% pa pre-crisis to -0.28% pa post-crisis. Panel 4 breaks that TFP slowdown into industry contributions.[30] Of the 75% of the gap explained by weakness in TFP: 47% is explained by a TFP slowdown in services, the contribution of which slowed from 1.02% pa to -0.03% pa; and 35% by a slowdown in manufacturing, the contribution of which slowed from 0.93% pa to 0.16% pa. The contribution from Other Production was negative in both periods, but actually sped up from -0.51% pa to --0.41% pa.

To summarise, 35% of the labour productivity slowdown is due to a slowdown in the contribution of capital deepening (25% tangible, 10% intangible) and 78% due to a slowdown in TFP.[31] Goldin et al. (2021) also report that the slowdown can be explained by slowdowns in capital deepening and TFP, with the latter being the larger component. TFP growth implicitly includes a number of effects, but generally is a measure of technology, knowledge diffusion and the efficiency with which labour and capital are combined in the generation of output. Broadly speaking, it is a measure of innovation. Investments in knowledge are investments in innovation. If we define the contribution of innovation to growth as the sum of contributions from knowledge capital deepening and TFP growth, we find that 88% of the slowdown is due to a slowdown in innovation.

7. The industry TFP slowdown

Having documented that much of the overall slowdown is in TFP, we explore the industry TFP slowdown in more detail.

7.1. Intangible-intensity and the productivity slowdown

The bottom part of Panel 4 in Table 9 presents industry contributions to TFP growth at a more detailed level, including all industries which contributed to the TFP slowdown.[32] There are data for 22 industries meaning that (22/40=)55% of the industries in our dataset experienced a TFP slowdown post-crisis.

As the table shows, of the 47% of the productivity gap explained by slower TFP growth in services, as much as 32% is due to a TFP slowdown in financial services (K64t66); 9% is due to a slowdown in wholesale (G46); 7% is due to a slowdown in computer programming and information services (J62t63); 3% is due to a slowdown in publishing, audio-visual and broadcasting activities (J58t60); and 3% is due to a slowdown in arts, entertainment and recreation.

Of the 35% of the productivity gap due to a TFP slowdown in manufacturing: 7% is due to a slowdown in the manufacture of transport equipment (C29t30, which includes aerospace); 6% is due

[29] https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/datasets/multifactorproductivityexperimentalestimatesreferencetables

[30] Where the contribution of each industry is the product of industry TFP growth and the Tornqvist share of nominal industry value-added in the aggregate.

[31] In Appendix C we show that, using national accounts definitions of output and capital, 29% is explained by the slowdown in capital deepening and 83% by the slowdown in TFP.

[32] Industries not presented experienced a speed-up in their TFP contribution between periods.

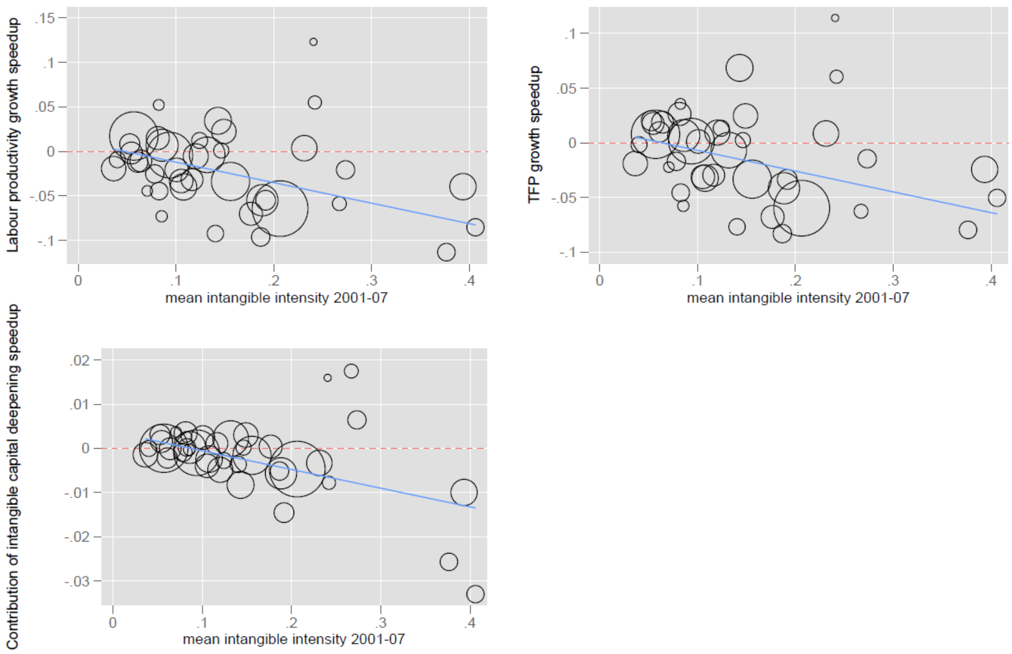
to a slowdown in the manufacture of other machinery and equipment (C28); 5% is due to a slowdown in pharmaceuticals (C21); 4% is due to a slowdown in manufacture of computers, electronic and optical products (C26); and 3% is due to a slowdown in manufacture of wood and paper products; printing and reproduction of recorded media (C16t18).

Other manufacturing or service industries which contribute to the slowdown include: research and development (M72); architecture and engineering (M71); manufacture of electrical equipment (C27); legal and accounting; head offices; management consulting (M69t70), and advertising and market research (M73).

A casual glance at the list shows that industries which contribute to the slowdown are perhaps surprising in many cases, a finding echoed in Coyle & Mei (2022). The list includes industries generally thought of as "high-technology", "knowledge-intensive", "high-productivity" industries. Part of the problem in establishing this hangs on what the definition of high-tech, high-knowledge etc. is. In this section we explore this more formally using our intangible (and other) measures.

Figure 8 shows scatter charts and (size-weighted) line of best fit between acceleration in i) Dln(Q/H), ii) DlnTFP and iii) w_Q^RDln(R/H) (the contribution of intangible capital deepening) against a measure of mean "knowledge intensity" in the base period (2001-07). "Knowledge intensity" is measured as intangible intensity $\left((P_{R^{na}}R^{na} + P_{R^{oth}}R^{oth})/P_{Q,j}Q_j\right)$, i.e. industry payments to the full list of intangible capital as a proportion of (adjusted) industry value added, as in Figure 4. Each has a negative correlation meaning that for every measure the slowdown was greater in more intangible-intensive industries.

Figure 8: Correlations between intangible-intensity and accelerations in labour productivity growth, TFP growth and the contribution of intangible capital deepening, 2000-19



Notes to figure: scatters of industry mean intangible-intensity (2001-07, x-axis) and acceleration (y-axis) in: i) labour productivity growth (top left); ii) TFP growth (top right); and iii) the contribution of intangible capital deepening (bottom left). Acceleration estimated as the change in mean values between periods: $\Delta(\Delta \ln X) = \Delta \ln X^{07t19} - \Delta \ln X^{00t07}$. A negative correlation means that the slowdown was greater in more intangible-intensive industries. Growth rates calculated as changes in the natural log. Each data point is an industry. Size of bubble determined by industry weight in nominal (adjusted) value-added. Appendix Figure E1 presents a version labelled by industry SIC code.

Table 10 confirms that the negative correlations between Δ(Δln(V/H)) (or Δ(ΔlnTFP)) and intangible-intensity as in Figure 8 are statistically significant and hold for a number of different measures (more detailed information on these measures and further decompositions are set out in Appendix D).[33] We report results for a series of robust least squares regressions. Each row presents the results of a separate regression. The dependent variable for regressions in column (1) is Δ(Δln(V/H)). The dependent variable in column (2) is Δ(ΔlnTFP). The independent variable in row 1 is the mean value of intangible-intensity (2001-07). Independent variables in rows 2 to 6 are categorical variables defined (=1) according to whether: (2) industry intangible-intensity is above the median industry value; (3) industry intangible-intensity is above the mean industry value; (4) the industry aligns with the OECD definition of knowledge-intensive service activities (KISA) (OECD, 2006); (5) the industry is included in OECD knowledge-oriented industries (OECD, 2009); and, (6) the industry is in OECD-defined High- or High-medium digitally intensive industries (Calvino et al., 2018). In each regression the correlation is negative. The correlation is statistically significant in 7 of the 12 regressions.

Table 10: Regressions of Δ(Δln(V/H)) and Δ(ΔlnTFP) on intangible-, knowledge- or digital-intensity, 2000-19

	(1)	(2)
VARIABLES	Δ(Δln(V/H))	Δ(ΔlnTFP)
(1) Mean intangible-intensity (continuous)	-0.19***	-0.15**
	(0.064)	(0.063)
(2) Above median (categorical)	-0.021	-0.022*
	(0.013)	(0.012)
(3) Above mean (categorical)	-0.038***	-0.036***
	(0.012)	(0.011)
(4) KISA (OECD) (categorical)	-0.016	-0.016
	(0.017)	(0.016)
(5) Knowledge-oriented (OECD) (categorical)	-0.028**	-0.024*
	(0.014)	(0.013)
(6) Hi-/Hi-med digital intensity (OECD) (categorical)	-0.020	-0.021
	(0.014)	(0.013)
Observations	40	40
Standard errors in parentheses		
*** p<0.01, ** p<0.05, * p<0.1		

[33] In Appendix D we present sector decompositions of labour productivity growth for various definitions of technology-, digital- and knowledge-intensity, constructed as weighted averages using Tornqvist shares of value-added and data for underlying industries. First, we present results for definitions based on the share of intangible capital income in value-added in the base (2001-07, see Figure 4) period. Industries are categorised as knowledge-intensive if the estimated share is above the median or mean sector value, with results for the market sector, production and services. Second, we apply OECD definitions of: knowledge-intensive service activities (KISA) (OECD, 2006), knowledge-oriented sectors (OECD, 2009); high-tech manufacturing (OECD, 2009); and High-/High-medium digital intensity (Calvino et al., 2018). See Appendix D for details of industries included in each sector definition. We find that, in every case, for each alternative decomposition, slowdowns in labour productivity growth, TFP growth and the contribution of intangible capital deepening are all greater in the more technology-, digital- and knowledge-intensive sectors, with remarkable consistency in results regardless of definition. Of all the categories we present, the slowdowns in labour productivity growth and TFP growth are greatest in the high-technology manufacturing sector, which is a surprising finding. Naturally there is a considerable degree of overlap between these alternative definitions. However, the key point is that regardless of which way we cut the data, the conclusion is consistent.

Note to table: All rows are robust least squares regression using data for all 40 industries in our dataset. Dependent variable in column (1) is the acceleration in labour productivity growth and in column (2) the acceleration in TFP growth: $\Delta(\Delta \ln X) = \Delta \ln X^{07t19} - \Delta \ln X^{00t07}$. Independent variable in row: (1) is mean industry intangible-intensity (2001-07, continuous variable); (2) is a categorical variable with a value of 1 if industry mean intangible-intensity (2001-07) is above the median value for all industries and 0 otherwise; (3) is a categorical variable that is 1 if industry mean intangible-intensity (2001-07) is above the mean value for all industries and 0 otherwise; (4) is a categorical variable that is 1 if the industry maps to the OECD definition of knowledge-intensive services activities (KISA) and 0 otherwise; (5) is a categorical variable that is 1 if the industry is defined by OECD as knowledge-oriented and 0 otherwise; and (6) is a categorical variable that is 1 if the industry is defined as High- or High-medium-digitally intensive by OECD and 0 otherwise.

In fact, summing over industry contributions to the TFP slowdown for the twenty industries defined as above-median intangible-intensity, as in Table 11, we find that the TFP slowdown in intangible-intensive industries accounts for 18 log points of the 21 log point TFP gap in Table 9, almost entirely accounting for the aggregate TFP slowdown.

We have documented that the slowdown was greatest in the more intangible-intensive industries. Of course, as shown in the lower two rows of Table 11, the extent of the estimated slowdown in the intangible-intensive sector is affected not only by weakness in productivity growth post-crisis, but also by the strength of productivity growth pre-crisis. TFP growth in the intangible-intensive sector was 1.83% pa pre-crisis and 0.3% pa post-crisis, compared to -0.38% pa and -0.57% pa for industries outside the intangible-intensive sector. In the pre-crisis period, intangible-intensive industries contributed (1.83/1.44=)126% of aggregate TFP growth.

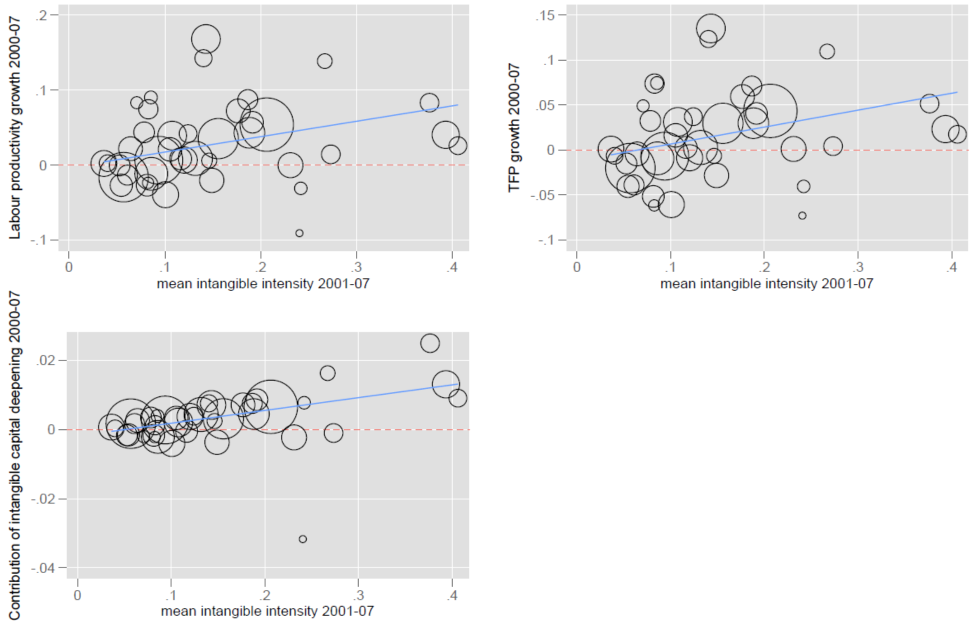
Table 11: Accounting for the UK TFP slowdown according to intangible-intensity, 2000-2019, log points

sector	2000-07	2007-19	Implied gap
Non-farm market sector (40 inds)	1.44%	-0.28%	20.64
Intangible-intensive (20 inds, above MS median)	1.83%	0.30%	18.37
Other (20 inds, below MS median)	-0.38%	-0.57%	2.27

Note to table: Column 1 is TFP growth in the pre-crisis (2000-07) period. Column 2 is TFP growth in the post-crisis (2007-19) period. Column 3 is the implied gap, that is, the difference in log points between the level realised by the twelve year growth rate in the post-crisis second column and the level predicted by the twelve year growth rate in the pre-crisis first column. Row 1 are data for the aggregate non-farm market sector, as reported in Table 9. Rows 2 and 3 break the market sector down into intangible-intensive and other industries. Intangible-intensive industries defined as those industries with a share of intangible capital compensation in (adjusted) industry output above the median market sector value.

Thus, the data show that the same industries that drove productivity growth pre-crisis are the same industries that contributed to the slowdown post-crisis, namely intangible- or knowledge-intensive industries. Figure 9 presents the correlation between intangible-intensity in 2001-07 and pre-crisis growth in: i) labour productivity (top-left); ii) total factor productivity (top-right); and iii) the contribution of intangible capital deepening. The positive correlation for each shows that for each variable, growth was stronger among more intangible-intensive industries, pre-crisis.

Figure 9: Correlations between intangible-intensity and growth in: i) labour productivity; ii) TFP growth; and iii) the contribution of intangible capital deepening, 2000-07



Note to figure: scatters of industry mean knowledge intensity (2001-07, x-axis) and pre-crisis (2000-07) growth (y-axis) in: i) labour productivity (top left); ii) TFP (top right); and iii) the contribution of intangible capital deepening (bottom left). A positive correlation means that pre-crisis growth was greater in more knowledge-intensive industries. Growth rates calculated as changes in the natural log. Each data point is an industry. Size of bubble determined by industry weight in nominal value-added.

7.2. The US and pre-crisis as counterfactuals

7.2.1. Aggregate measures

We have estimated the extent of the productivity slowdown based on the level in 2019 versus the level that would have been realised had the UK grown at its pre-crisis 2000-07 rate. However, it could be argued that the 2000-07 period is the wrong counterfactual. Labour productivity and TFP growth pre-crisis were strong, related to benefits from ICT capital accumulation and diffusion (Byrne & Sichel, 2017; Colecchia & Schreyer, 2002; Goodridge et al., 2016; Goodridge et al., 2016; Goodridge et al., 2019; Gordon, 2016; Stiroh, 2002; Timmer et al., 2007).

Therefore, in panel 5 of Table 9 we present two memo items. The first estimates the proportion of the gap explained had UK post-crisis TFP growth been the same as that observed in the US. Fernald & Inklaar (2022) argue that the UK post-crisis productivity performance is not unusual and can largely be explained by a slowdown in TFP in the US frontier. Panel 5 shows that had UK TFP grown at the US rate in the post-crisis period (0.1% pa, (Fernald & Inklaar, 2022)), that would explain 61% of the UK labour productivity slowdown and (61/78=)78% of the UK TFP slowdown. Therefore, as much as three-quarters of the UK TFP slowdown could potentially be explained by a slowdown in innovation in the frontier. What are the assumptions necessary for this to be a sensible counterfactual? They are either that: a) the UK had converged with the US frontier by the crisis such that the UK could not grow faster than the frontier; or b) that the UK had converged at a productivity level below the US frontier, where the gap is constant, so that the UK could not grow relative to the frontier. Fernald & Inklaar (2022) show that, by 2007, the level of productivity in UK market services had caught up to that in the US frontier but manufacturing had not. But for each the UK productivity gap relative to the US varies considerably suggesting that the UK is not necessarily behind the US by a constant gap. In their Table 2, Fernald & Inklaar (2022) present estimates of the level of UK TFP relative to the US. UK manufacturing TFP was 0.77 of US TFP(=1) in 2007 but was as much as 0.92 of US TFP in 1995. Market services was 1.02 of US TFP in 2007, but 0.87 in 1995. Therefore it does not seem that the UK-US productivity gap is constant. The above estimate relies on the assumption that the UK-US gap is fixed.

In the second memo item, we use an alternative pre-crisis counterfactual, based on market sector TFP growth of 1.3% pa in 1970-2007, as estimated by ONS.[34] If TFP in 2000-07 had grown at this long-run rate, the TFP slowdown would explain approximately 18.9 log points of the total slowdown. Put another way, (20.64-18.9=)1.73 log points, 8%, of the TFP gap, is explained by exceptionally strong UK TFP growth in the pre-crisis (2000-07) period. Thus according to these data, market sector TFP growth in the pre-crisis (2000-07) period was not substantially greater than it had been in the prior three decades. Therefore exceptionally fast growth pre-crisis is not a particularly significant factor in explaining the slowdown.

7.2.2. Industry measures

Fernald & Inklaar (2022) argue that the slowdown in UK TFP growth is consistent with that in the US. We currently do not have US industry data consistent with our dataset. We do however have access to the latest data from EUKLEMS (Lab of European Economics, 2021) with data and methods harmonised across countries. In Figure 10 we present the results of a cross-country comparison using EUKLEMS data for the UK and US.

Figure 10: UK and US: TFP growth acceleration between periods vs weight in value-added in pre-crisis period, 12 industries, 2000-18

Source: Lab of European Economics (2021)

Note to figure: Black dots are data for the UK and blue crosses are data for the US. Y-axis is acceleration in TFP: $\Delta(\Delta \ln TFP) = \Delta \ln TFP^{07t18} - \Delta \ln TFP^{98\text{-}07}$. Growth rates calculated as changes in the natural log. X-axis is the industry share in value-added (Q), where value-added is adjusted for capitalisation of all intangibles. Industries above red line experienced a TFP speed-up and below red line a slowdown.

Each data point is an industry, with the US in light blue crosses and UK in black dots. The graph shows TFP growth acceleration (i.e. TFP growth 2007-18 less TFP growth 2000-07) plotted against the value-added weight of each industry, averaged 2000-07. There are two main points to note from Figure 10.

[34] https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/datasets/multifactorproductivityexperimentalestimatesreferencetables

First, one might think that much of the change in TFP growth might be accounted for by different industrial structure. In fact, comparison of the horizontal axis shows that industrial structure is relatively similar in the UK and US in terms of shares for each industry in market sector value-added (which is the correct weight for value-added defined TFP growth). Transport (H) and construction (F) have a slightly larger share in the UK, while professional, scientific and technical activities (M), financial services (K) and manufacturing (C) have a slightly smaller share in the UK.

Second, the chart shows that the post-crisis TFP slowdown was more broad-based in the UK than in the US. The UK TFP slowdown was 1.2pppa more than the US on these data (UK 1.9%pa, US 0.7%pa), almost entirely due to the slowdown in each industry with a minuscule contribution of changing weights. Figure 10 shows that in the UK, only administrative and support services (N) experienced a speed up in TFP growth. The remaining eleven industries experienced a slowdown. In contrast, in the US, that same industry (N) plus four others experienced a speed-up in TFP growth. The remaining seven industries experienced a slowdown. Looking more closely at specific industries, TFP growth in US manufacturing slowed more than UK manufacturing, as did TFP growth in information and communication (J), administrative and support services (N), and Transport (H). For the other eight industries, the slowdown was greater in the UK, in particular in financial services (K), utilities (DE) and professional, scientific and technical activities (M).[35]

7.3. Potential explanations for the TFP slowdown

In Table 9 we report slowdowns in TFP growth and the contribution of intangible capital deepening, which we conjecture might be related. Corrado et al. (2017) and Goldin et al. (2021) note that a slowdown in knowledge capital accumulation might impact TFP via reduced knowledge spillovers (or knowledge diffusion). Fernald & Inklaar (2022) are sceptical of whether intangible capital can explain the TFP slowdown, pointing out that there has been little change in the intangible investment rate (investment as a share of value-added). However, it is knowledge accumulation (i.e. intangible capital services), rather than investment flows, which matter for potential spillovers. Table 12 presents data on mean values for the intangible investment rate, capital services growth and growth in capital deepening (capital services per hour worked), pre- and post-crisis. We present estimates for IPPs in national accounts (naintan), CHS intangibles not capitalised in national accounts (othintan) and total intangibles (intan).

Table 12: Intangible investment rate and capital services by period, 2000-19

period	**$(PiI/PqQ)^{naintan}$**	**$(PiI/PqQ)^{othintan}$**	**$(PiI/PqQ)^{intan}$**	**$DlnR^{na}$**	**$DlnR^{oth}$**	**$DlnR^{intan}$**	**$Dln(R/H)^{na}$**	**$Dln(R/H)^{oth}$**	**$Dln(R/H)^{intan}$**
2000-07	4.15%	8.04%	12.19%	3.10%	1.65%	2.21%	3.34%	1.71%	2.34%
2007-19	4.51%	7.25%	11.76%	2.85%	0.58%	1.51%	1.82%	-0.05%	0.72%
slowdown				*-0.24%*	*-1.06%*	*-0.70%*	*-1.52%*	*-1.76%*	*-1.62%*
Alt. period	**$(PiI/PqQ)^{naintan}$**	**$(PiI/PqQ)^{othintan}$**	**$(PiI/PqQ)^{intan}$**	**$DlnR^{na}$**	**$DlnR^{oth}$**	**$DlnR^{intan}$**	**$Dln(R/H)^{na}$**	**$Dln(R/H)^{oth}$**	**$Dln(R/H)^{intan}$**
2011-19	4.58%	7.10%	11.68%	3.11%	1.08%	1.93%	1.41%	-0.28%	0.42%
slowdown				0.01%	-0.57%	-0.28%	-1.93%	-2.00%	-1.92%

Note to table: Column 1 is the investment rate (investment as a share of GVA, where GVA is adjusted for capitalisation of intangibles (Q)) for national accounts intangibles (naintan), column 2 for other CHS intangibles not currently capitalised in national accounts (othintan) and column 3 for total intangibles (intan). Column 4 is growth in capital services for national accounts intangibles (R^{na}), column 5 for other CHS intangibles (R^{oth}) and column 6 for total intangibles (R^{intan}). Column 7 is growth in capital deepening (R/H) for national accounts intangibles (naintan), column 8 for other CHS intangibles (othintan) and column 9 for total intangibles (intan). Growth rates calculated as changes in the natural log. Panel 1 are data for the 2000-07 and 2007-19 periods. Panel 2 presents estimates for an alternative post-crisis period, 2011-19. The final row in each panel is: $\Delta(\Delta \ln X) = \Delta \ln X^{07t19} - \Delta \ln X^{00t07}$.

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[35] In Appendix F we show the correlation between pre-crisis growth and intangible-intensity for the UK and US. There is a positive correlation in both countries.

The data show a modest fall in the investment rate for total intangibles (column 3), underlying which is a rise in the investment rate for national accounts intangibles (IPPs, column 1) and a fall for other intangibles (column 2). For capital services, growth slowed by -0.24% pa for national accounts intangibles, -1.06% pa for other CHS intangibles, and -0.7% pa for total intangibles. Estimates of capital deepening show a more substantial slowdown. The capital services estimates do therefore suggest a slowdown in knowledge accumulation which may have implications in terms of reduced knowledge diffusion, absorptive capacity and spillovers.

The impact of reduced spillovers depends on the output elasticity of knowledge capital, where that elasticity incorporates social returns. Corrado et al. (2017) present estimates of an elasticity of around 0.2.[36] Goodridge et al. (2016) report an elasticity of a similar magnitude for R&D capital, depending somewhat on method. If we apply an estimated elasticity of 0.2 to a decline of -0.7% pa in knowledge accumulation, that would imply a fall of -0.14% pa in TFP. UK market sector TFP growth actually declined from 1.44% pa pre-crisis to -0.28% pa post-crisis, a slowdown of -1.72% pa. This calculation suggests that (-0.14/-1.72=) 8% of the TFP slowdown could be explained by reduced knowledge spillovers.

We note that the above values for capital service growth somewhat depend on the period chosen to average over. If we construct averages for the 2011-19 period, as in the lower panel, we find that there was no slowdown in capital services from national accounts intangibles (R&D, software etc.). Other intangibles and total intangibles slowed less in 2011-19 relative to 2000-07, at -0.57% pa and -0.28% pa respectively. Capital services per hour worked (capital deepening) show a larger slowdown in the 2011-19 period relative to the 2007-19 period. Of course these are averages for the market sector and therefore mask changes at industry level. We intend to explore correlations of knowledge capital flows between industries and industry productivity in future work.

A second potential hypothesis is that the financial shock imposed by the crisis had a larger impact in more intangible-intensive industries, possibly making access to capital for investment or market entry more difficult. Ikeda & Kurozumi (2018) suggest that financial shocks can lead to slowdowns in technology and knowledge adoption (innovation) which negatively impact TFP growth. In addition, adoption of knowledge and technology slows during periods when the economy is operating below potential. It is also notoriously more difficult to finance intangible capital investment than it is tangible. We therefore might expect negative effects on TFP growth to be larger in more intangible-intensive industries. In addition, a feature of intangible-intensive industries might be the presence of large intangible-intensive firms with considerable market power, potentially raising barriers to entry and reducing contestability, therefore reducing the degree of competition in the industry (Bajgar et al., 2021). We intend to use our dataset to explore these hypotheses in future work.

8. Conclusions

This paper uses the latest ONS data to conduct a comprehensive sources-of-growth decomposition for the UK non-farm market sector and account for the productivity slowdown. The level of labour productivity in 2019 is 27 log points less than it would have been had it continued to grow at its 2000-07 rate. We find that reallocation of labour made no contribution to the slowdown. Rather the slowdown is within industries. Similarly, labour composition did not contribute to the slowdown, in fact, the contribution sped up. Reallocation and labour composition therefore add to the gap we seek to explain. Instead, we find that 35% (25% tangible and 10% intangible) of the slowdown is explained by a slowdown in the contribution of capital deepening and 78% is explained by a slowdown in TFP growth. Together, these results suggest that (78+10=)88% of the slowdown can be

[36] Reported in columns 2 to 5 of their Table 3.

broadly attributed to a slowdown in innovation, defined as the contributions of intangible capital and TFP growth

On the slowdown in TFP, we find that less than one-tenth can be explained by exceptionally fast UK TFP growth in the pre-crisis period. In terms of industry contributions, we find that the slowdowns in labour productivity and TFP growth are largest in the more intangible-, technology- and digital-intensive industries, using a number of definitions, which we think is a new finding. In particular, slowdowns in TFP growth in finance (K64t66), IT and information services (J62t63), manufacture of machinery (C28), manufacture of transport equipment (C29t30), manufacture of ICT equipment (C26), publishing and broadcasting activities (J58t60) and pharmaceuticals (C21) all make substantial contributions to the aggregate TFP slowdown. The TFP slowdown in intangible-intensive industries almost entirely explains the aggregate market sector TFP slowdown. The UK TFP slowdown is deeper and more broad-based than that observed in the US.

Finally, we speculate on potential explanations for the TFP slowdown including first, the possibility of reduced knowledge diffusion or spillovers due to a slowdown in intangible capital accumulation, and second, a hypothesis that the effects of the financial shock imposed by the crisis were stronger in more intangible-intensive industries. We intend to use our dataset to explore these questions further in future work.

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Appendix A: Business Cycle: Factor utilisation

Appendix Figure A1: UK business cycle: changes in factor utilisation (market sector hours per worker), 1998-2019

Note to figure: estimates of factor utilisation for the non-farm market sector, estimated as the change in the natural log of hours per worker. Red vertical lines mark peaks in 2001, 2007 and 2019. We carry out growth-accounting for periods between these years.

Appendix B: Details of ONS measurement of intangible assets

B.1. Intangible assets in national accounts (Intellectual Property Products, IPPs)

Software and databases

GFCF in software and databases consists of purchased and own-account investment but cannot be separated into components for software and databases. Purchased investments are purchases of (pre-packaged or custom) software and databases estimated from business surveys.

Own-account (in-house) capital formation is modelled using the sum of costs method (OECD, 2010). Details are in Chamberlin et al. (2006, 2007) with updates described in McCrae & Roberts (2019) and Martin et al. (2019). The method is as summarised in the second line of equation (13). ONS identify occupations engaged in capital formation from the Standard Occupational Classification (SOC 2010 and predecessors) and form an estimate of wage costs from the Annual Survey of Hours and Earnings (ASHE). Wage costs are adjusted using factors for: non-wage labour costs (national insurance, pensions etc.); occupation-specific time-use (time spent on capital formation); intermediate costs; and capital services including net operating surplus (i.e. the net rate of return to capital). These adjustments approximately double wage costs. A further adjustment excludes the costs of producing software destined for final sale to avoid double counting with purchased GFCF.[37]

$$\begin{aligned} P_N N^{sfd-oa} &= \tau . P_L L^{SOC} + P_M M + P_K K \\ &= \lambda . \tau . w N^{SOC} \end{aligned} \qquad (13)$$

Where: $sfd - oa$ refers to own-account software and databases; $P_N N$ is nominal investment; $P_L L^{SOC}$ are total labour costs for selected occupations; τ is an occupation-specific time-use factor; $P_M M$ are nominal intermediate costs; $P_K K$ are nominal capital services; and wN are nominal wage costs. Non-wage labour costs, intermediates and capital services are incorporated in the cost adjustment factor,

[37] By not including some of the activity observed in selected industries, particularly the software industry.

λ, derived from Annual Business Survey (ABS) data for the software industry. The method has been updated to better capture database capital formation activity meaning that UK methods go further than most other European countries in estimating this growing activity (Goodridge et al., 2021).

In estimating real GFCF, ONS apply distinct price indices for purchased and own-account. The purchased index is the US Bureau of Economic Analysis (BEA) pre-packaged software price index.[38] The own-account index is the Services Producer Price Index (SPPI)[39] for Computer Services. In estimating software and database capital services, we assume a geometric depreciation rate of 0.33.

R&D

Details on ONS measurement of GFCF in R&D are in Ker (2014) and Abramsky (2014). Estimates consist of market output,[40] non-market output[41] and output for own final use. For each, output is estimated using the sum of costs method[42] (Ker, 2014):

$$P_N N^{rd} = P_L L + P_M M + P_K K \quad (14)$$

Where $P_L L$ are labour payments, $P_M M$ are intermediate payments and $P_K K$ are nominal capital services, including the net rate of return to capital used in R&D capital formation.[43] Estimates for each term are based on responses to R&D surveys. R&D expenditures related to development of software are excluded to avoid double counting.

The R&D price index is a modelled share-weighted input price index (Ker, 2014). To estimate R&D capital services, we assume a geometric depreciation rate of 0.2.

Artistic Originals

ONS data and methods for artistic originals have been revised and incorporated in UK national accounts since BB19 (Martin et al., 2019; McCrae & Roberts, 2019), building on research in Goodridge (2014) consistent with international recommendations in OECD (2010). Estimates are for the following types of originals: film; TV & radio; music; literary; and miscellaneous art. Film, TV & radio and miscellaneous art use a sum of costs approach. Music and books are based on observed royalty incomes earned from the stock of assets by owners. For fuller details, see Goodridge (2022).

ONS price indices for artistic originals are SPPIs for: 'Motion picture, video and television programme production services, sound recording and music publishing' and 'Original works of authors, composers and other artists, except performing artists, painters, graphic designers.' To estimate capital services, we assume a geometric depreciation rate of 0.2.

Mineral Exploration

Estimates of GFCF in mineral exploration include expenditure on physical activities, such as drilling and boring, and all complementary expenditures that make physical activities possible including surveys and other arrangements. GFCF does not include the value of assets discovered. Estimates

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[38] Exchange-rate adjusted.

[39] https://www.ons.gov.uk/economy/inflationandpriceindices/datasets/servicesproducerpriceindexsppi

[40] R&D sold in the market but excluding that: purchased by firms in the R&D services industry, which is counted as intermediate consumption; and sold outside the UK, which is an export.

[41] Including government and public R&D, as well as R&D in non-profit institutions serving households (NPISH), which include universities.

[42] For simplicity, ignoring adjustments for taxes and subsidies in production.

[43] In the case of market R&D output and output for own final use, but not in the case of non-market output where $P_K K$ only includes consumption of fixed capital (CFC, i.e. depreciation) by national accounting convention. In this paper we estimate for the market sector meaning that R&D data are for market output and output for own final use.

are valued on the basis of payments made to contractors and costs incurred on own account. Expenditures are included only where contractors are registered UK companies and are capitalised regardless of whether they result in successful discovery. Where operators work in a consortium, expenditures are allocated in proportion to shares. National accounts include three subcategories: a) mineral exploration other than oil and coal; b) continental shelf companies' exploration expenditure; and c) coal mineral exploration (Haskel et al., 2011a). The price index is the SPPI for Technical testing and analysis. In estimating capital services, we assume a geometric depreciation rate of 0.2.

B.2. Other CHS intangibles outside national accounts capital definitions capital

Design

Estimates for design include purchased and own-account components. Details are in Martin et al. (2018, 2019) and build on previous research (e.g. Goodridge et al. (2016) and Galindo-Rueda et al. (2008)). Purchased investment is purchases of Architectural and engineering services; technical testing and analysis services (product 71)[44] as recorded in the SUTs plus the sales of the specialist design industry (74.1). Inclusion of the latter is an update to the method (Lewis, 2021), which widens the scope of identified investment and improves consistency between definitions of purchased and own-account. Estimates exclude purchases made by the industry itself to avoid double counting, as some will include outsourcing and subcontracting arrangements. As in previous research, it is assumed that 50% of purchased expenditures are capital formation[45] (Galindo-Rueda et al., 2008).

Own-account investment is estimated using the software sum of costs method, as in equation (13), based on the time-used adjusted wagebill for relevant occupations[46] and cost adjustment factors derived from ABS data for the design industry. As with purchased, to reflect not all in-house design activity being long-lived, estimates incorporate a capitalisation factor of 50%.[47]

Estimates of real investment use separate deflators for purchased and own-account. The purchased price index is a share-weighted average of the SPPI for Architectural and Engineering Services; Technical Testing and Analysis Services and Experimental Industry Deflators[48] for SIC codes 71 (architectural and engineering activities; technical testing and analysis) and 74 (other professional, scientific and technical activities). The own-account deflator is an industry-specific implied price index derived from industry current price investment and volume indices of hours worked by occupations engaged in capital formation (Lewis, 2021). In estimating capital services, we assume a geometric depreciation rate of 0.2.

Financial Product Innovation

Estimates of financial product innovation measure own-account research and development of new long-lived products in financial services, based on the sum of costs method. Details are in Martin et al. (2019), Goodridge et al. (2016) and Haskel & Pesole (2010). ONS identify occupations engaged in capital formation in financial services (K64t66), estimate wage costs[49] and combine with assumptions on time spent on capital formation (50%) and a cost adjustment factor (λ). The deflator

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[44] Principally output from the architectural and engineering services industry (SIC 71).

[45] The other 50% is assumed to be (short-lived i.e. used up within the year) intermediate consumption. The factor of 50% is based on information from the Design Council Survey and Community Innovation Survey (CIS).

[46] Observed from microdata for ASHE and the New Earnings Survey (NES). For details on occupations assumed engaged in capital formation and time-use factors, see Goodridge (2022).

[47] Thus assuming that half of own-account output is short-lived and used up in current production, termed ancillary output in national accounts nomenclature.

[48] https://www.ons.gov.uk/economy/inflationandpriceindices/datasets/experimentalindustrydeflatorsuknonseasonallyadjusted

[49] Using ASHE and NES.

is an implied index derived from current price investment and a volume index of hours worked by relevant occupations in financial services. To estimate capital services, we assume a geometric depreciation rate of 0.2.

Training

Investment in firm-specific human capital, that is training provided by firms, is estimated using a variant of the sum of costs method. Details are in Martin et al. (2019) and Martin (2019), summarised in Goodridge (2022). The primary source is the Investment in Training module of the biennial Employer Skills Survey (ESS).[50] Importantly, the key feature of the survey is that it asks for information on direct training costs (in house training centres, fees for external providers etc.) and indirect costs i.e. the opportunity cost of employee's time spent receiving (or delivering) training and therefore not in current production.[51] Estimates for years prior to 2007 are modelled estimates of component terms for direct and indirect costs.

The price index is the industry-specific Index of Labour Costs per Hour (ILCH), which starts in 2000 and implicitly includes wages of both trainers and trainees, extended to earlier years using growth rates in employee pay in ASHE.[52] In estimating capital services, we assume a geometric depreciation rate of 0.4.

Branding

Estimates for branding consist of purchased and own-account components. Details on data and methods are in Martin (2019) and Martin et al. (2019). The method for purchased is as used in previous UK research (e.g. Goodridge et al., 2016), consisting of purchases of Advertising and market research services (product 73) from the SUTs. To avoid double-counting, estimates exclude purchases made from the industry by the industry itself. It is assumed that 60% of purchased advertising expenditure and 80% of purchased market research expenditure is long-lived, with evidence in Martin (2019) to support these assumptions.

Latest estimates for own-account incorporate significant methodological improvements and now include activity in both advertising and market research (Lewis, 2021). Estimates are constructed using the sum of costs method. For assumptions on occupations and time-use factors, see Martin (2019) or Goodridge (2022). As with own-account software, ONS incorporate sales adjustment factors to eliminate potential double-counting. Based on information from case studies, ONS assume that 30% of own-account advertising output and 80% of own-account market research output is long-lived capital formation (Martin, 2019).

ONS apply distinct price indices for purchased and own-account. The purchased index is a share-weighted average of SPPIs for Advertising and Market Research Services and Market Research and Public Opinion Polling Services. The own-account deflator is an industry-specific implied price index derived from current price own-account investment and volume indices of hours worked by relevant occupations. To estimate capital services, we assume a geometric depreciation rate of 0.6.

Organisational Capital

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[50] http://www.ukces.org.uk/ourwork/employer-skills-survey. Data for 2007-2011 is from the predecessor survey, NESS (National Employers Skills Survey) and is for England rather than the UK. Estimates for these years are scaled up to be representative of the UK. A separate survey has been run for Scotland since 2019.

[51] Firms are asked how many paid hours workers spend away from production whilst training and their hourly wage.

[52] Information provided by Melanie Lewis (ONS).

Organisational capital includes purchased and own-account. Details are in Martin (2019) and Martin et al. (2019). Estimates of purchased up to 2010 are based on data from the Management Consultancies Association (MCA).[53] Estimates apportioned to purchasing industries using shares of intermediate consumption of Services of head offices; management consulting services (product 70) in the SUTs. Estimates since 2010 are based on data from the ABS. It is assumed that 80% of expenditure represents long-lived capital formation.

Estimates of own-account are modelled using the sum of costs method, relying heavily on the original CHS assumption that managerial occupations spend 20% of their time making long-lived improvements to business processes and organisational structure. However, the review in Martin (2019) does provide evidence to support this assumption.

ONS apply separate deflators for purchased and own-account. The purchased index is a weighted average of SPPIs for: Services of Head Offices; Management Consulting Services; Business and Other Management Consulting Services; and the Experimental Industry Deflator for activities of head offices; management consultancy activities (M70). The own-account deflator is an industry-specific implied index, derived using current price estimates of investment and volume indices of hours worked by managerial occupations.

[53] These cover 70% of the industry. Estimates are scaled up to account for the remainder of the industry.

Appendix C: Slowdown accounting: national accounts definitions of output and capital

Appendix Table B1: Accounting for the UK slowdown, 2000-2019, log points: national accounts definitions of output and capital

		1	2	3	4
		Before (00-07)	**After (07-19)**	**Implied gap**	***% of gap explained***
	$\Delta\ln(V/H)^{na}$	**2.46%**	**0.12%**	**28.07**	**100%**
1	**Labour reallocation**	**-0.23%**	**-0.02%**	**-2.53**	**-9%**
2	**Contribution: Labour Composition**	**0.18%**	**0.26%**	**-0.91**	**-3%**
3	**Contribution: Capital deepening**	**0.87%**	**0.19%**	**8.12**	**29%**
	Tangibles	**0.67%**	**0.06%**	**7.24**	**26%**
	Buildings	0.25%	0.07%	2.12	8%
	Other Machinery and Equipment	0.11%	-0.05%	1.91	7%
	Transport Equipment	0.07%	0.04%	0.41	1%
	ICT (hardware) equipment	0.24%	0.00%	2.80	10%
	Intangibles	**0.20%**	**0.13%**	**0.88**	**3%**
	R&D	0.05%	0.02%	0.43	2%
	Software and databases	0.14%	0.11%	0.35	1%
	Other IPPs (mineral exploration & artistic originals)	0.01%	0.00%	0.09	0%
4	**TFP**	**1.64%**	**-0.31%**	**23.39**	**83%**
Ind contributions:	Manufacturing	1.02%	0.16%	10.32	37%
	Other production	-0.57%	-0.44%	-1.54	-5%
	Services	1.18%	-0.03%	14.61	52%
K64t66	Financial and insurance activities	0.54%	-0.22%	9.16	33%
G46	Wholesale trade, except of motor vehicles and motorcycles	0.20%	-0.02%	2.63	9%
J62t63	IT and other information services	0.13%	-0.05%	2.12	8%
C29t30	Transport equipment	0.14%	-0.02%	1.92	7%
C28	Machinery and equipment n.e.c.	0.12%	-0.02%	1.61	6%
C10t12	Food products, beverages and tobacco	0.11%	-0.01%	1.36	5%
C21	Basic pharmaceutical products and pharmaceutical preparations	0.08%	-0.04%	1.35	5%
C26	Computer, electronic and optical products	0.15%	0.05%	1.19	4%
R90t93	Arts, entertainment and recreation	0.04%	-0.04%	0.96	3%
C16t18	Wood and paper products; printing and reproduction of recorded media	0.11%	0.03%	0.95	3%
J58t60	Publishing, audio-visual and broadcasting activities	0.07%	0.00%	0.92	3%
C31t33	Other manufacturing; repair and installation of machinery and equipment	0.08%	0.01%	0.80	3%
M72	Scientific research and development	0.02%	-0.04%	0.78	3%
C13t15	Textiles, wearing apparel, leather and related products	0.09%	0.03%	0.74	3%
M71	Architectural and engineering; technical testing and analysis	0.01%	-0.05%	0.72	3%
C27	Electrical equipment	0.06%	0.01%	0.59	2%
C22t23	Rubber and plastics products, and other non-metallic mineral products	0.06%	0.02%	0.53	2%
H49	Land transport and transport via pipelines	0.00%	-0.04%	0.50	2%
M69t70	Legal and accounting; head offices and management consulting	0.02%	-0.02%	0.47	2%
B5t9	Mining and quarrying	-0.17%	-0.19%	0.20	1%
M73	Advertising and market research	0.00%	-0.02%	0.19	1%
H51	Air transport	0.02%	0.01%	0.18	1%
H53	Postal and courier activities	-0.01%	-0.01%	0.02	0%
5: Memo	***Memo: US TFP 2007-19****	**1.64%**	**0.10%**	**18.42**	**66%**
	Memo: pre-crisis UK TFP 1972-2007**	**0.42%**	**-0.31%**	**8.81**	**31%**

Notes to table: Sources of growth decomposition for UK non-farm Market Sector (national accounts definitions of output (V) and capital) comparing period before the recession (2000-2007) to the period after (2007-19). Columns 1 and 2 are per annum log difference rates. The implied gap, column 3 is the difference in log points between the level realised by the twelve year growth rate in the post-crisis second column and the level predicted by the twelve year growth rate in the pre-crisis first column. So for instance, the TFP gap (row 4) is 23 log points. Column 4 presents the percentage of the gap explained, calculated as a proportion of the total labour productivity gap (28 log points). Decomposition carried out at industry-level. Industry TFP estimates are value-added weighted contributions.

*First memo item uses an estimate of US TFP growth in 2007-19 (column 2) as reported in Table 2 of Fernald & Inklaar (2022) and the realised UK growth rate in 2000-07 (column 1), thus estimating the size of the gap had UK TFP grown at the rate observed in the US frontier.

**Second memo item uses a long-term estimate of UK TFP growth of 0.42% pa (1972-2007) for the pre-crisis period (column 1),taken from the whole economy TFP index in the EUKLEMS 2012 release (O'Mahony & Timmer, 2009).

Appendix D: Knowledge-, technology- and digital-intensity definitions

In Appendix Table D1 we present some decompositions of labour productivity growth for various categories according to definitions of intangible-, knowledge-, digital-, and technology-intensity. Estimates for each sector are constructed as weighted averages using Tornqvist shares of value-added and data for underlying industries. All estimates for all variables are in acceleration space so, for example, the estimate for labour productivity growth is: $\Delta(\Delta \ln(V/H)) = \Delta \ln(V/H)^{07\text{-}19} - \Delta \ln(V/H)^{00\text{-}07}$. Positive values represent a speedup and negative values a slowdown. The definition of each category in terms of industries included is in Appendix Table D2.

In panel 1, we present estimates for industries with mean intangible-intensity in the base period (2001-07, see Figure 4) above and below the median market sector value. Industries with intangible-intensity above the median value are defined as intangible-intensive. The data show that slowdowns in labour productivity growth, TFP growth and the contribution of intangible capital deepening are all greater in the intangible-intensive sector.

Remaining panels use alternative definitions. In panels 2 and 3, we present estimates for production and service industries with mean intangible-intensity above and below the median value for production and services respectively. In both panels the slowdowns in labour productivity growth, TFP growth and the contribution of intangible capital deepening are greater among intangible-intensive industries.

In panels 4 to 6, we present similar estimates to those in panels 1 to 3 but define intangible-intensity according to whether the industry value is above the mean sector value, rather than the median. We find the same pattern. Slowdowns in labour productivity growth, TFP growth and the contribution of intangible capital deepening are all greater among intangible-intensive industries.

In panels 7 to 10 we use a number of alternative definitions of knowledge-, technology- and digital-intensity from OECD. In panel 7 we define knowledge-intensive services according to the definition of knowledge-intensive service activities (KISA) in OECD (2006). Knowledge intensive service activities in OECD (2006) are activities rather than industries but map reasonably well to industries in the standard industrial classification (SIC).

In panel 8, we use the definition of knowledge-oriented sectors in OECD (2009), where knowledge-oriented sectors are defined as industries in high-tech manufacturing and knowledge-intensive services. Our industries do not exactly match those in the OECD definition, as we are unable to separate manufacture of air and spacecraft (C30.3) from manufacture of transport equipment (C29t30). We also exclude real estate (L), education (P) and health (Q) from our definition.

In panel 9 we categorise industries according to whether they are High- or High-medium digital intensive industries, as defined in Calvino et al. (2018). The taxonomy in Calvino et al. (2018) is presented for two periods: 2001-3 and 2013-15. Some industries move between High- and High-medium digital intensity between periods. Therefore, in our definition we use all industries classified as either High- or High-medium digital intensity.

Finally, in panel 10 we use the OECD definition of high-technology manufacturing (OECD, 2009) to compare with other manufacturing.

The estimates show a similar pattern to those in panels 1 to 6. That is, the slowdowns in labour productivity growth, TFP growth and the contribution of intangible capital deepening are all greater in the more knowledge-, technology- or digital-intensive industries. Of all the categories we present, the slowdowns in labour productivity growth and TFP growth are greatest in the high-technology manufacturing sector, which is a surprising finding.

Naturally there is a considerable degree of overlap between alternative definitions. However, the key point is that regardless of which way we cut the data, the conclusion is consistent.

Appendix Table D1: Growth-accounting decompositions by categories of technology and knowledge-intensity, all in slowdown space, % pa., 2000-19

	Category	Dln(Q/H)	s_KDln(K/H)	s_KDln(K/H)^{tan}	s_KDln(K/H)^{intan}	s_LDln(L/H)	DlnTFP
Panel 1: Intangible intensity	*Above median*	*-3.88%*	*-0.65%*	*-0.35%*	*-0.30%*	*0.08%*	*-3.31%*
	Below median	-0.98%	-0.61%	-0.57%	-0.04%	0.08%	-0.45%
Panel 2: Intangible intensity	*Above median in prod sector*	*-5.24%*	*-0.92%*	*-0.53%*	*-0.39%*	*-0.03%*	*-4.28%*
	Below median in prod sector	-0.28%	-0.60%	-0.65%	0.05%	0.14%	0.17%
Panel 3: Intangible intensity	*Above median in serv sector*	*-3.42%*	*-0.57%*	*-0.31%*	*-0.25%*	*0.10%*	*-2.96%*
	Below median in serv sector	-1.17%	-0.63%	-0.53%	-0.10%	0.06%	-0.59%
Panel 4: Intangible intensity	*Above mean*	*-4.83%*	*-0.63%*	*-0.27%*	*-0.37%*	*0.07%*	*-4.26%*
	Below mean	-0.78%	-0.63%	-0.59%	-0.04%	0.09%	-0.24%
Panel 5: Intangible intensity	*Above mean in prod sector*	*-6.35%*	*-1.13%*	*-0.58%*	*-0.55%*	*-0.05%*	*-5.17%*
	Below mean in prod sector	-1.00%	-0.60%	-0.60%	0.00%	0.11%	-0.51%
Panel 6: Intangible intensity	*Above mean in serv sector*	*-4.88%*	*-0.53%*	*-0.16%*	*-0.37%*	*0.08%*	*-4.42%*
	Below mean in serv sector	-0.54%	-0.64%	-0.59%	-0.05%	0.09%	0.01%
Panel 7: KISA (OECD)	*KISA inds*	*-4.32%*	*-0.97%*	*-0.51%*	*-0.46%*	*0.03%*	*-3.39%*
	Other non-KISA service inds	-0.73%	-0.60%	-0.48%	-0.12%	0.10%	-0.23%
Panel 8: Knowledge-oriented (OECD)	*Knowledge-oriented inds*	*-5.17%*	*-1.18%*	*-0.64%*	*-0.54%*	*0.04%*	*-4.03%*
	Other inds	-1.26%	-0.60%	-0.52%	-0.08%	0.09%	-0.75%
Panel 9: High & high-med digital intensity (OECD)	*Hi- & Hi-med digital intensity*	*-3.21%*	*-0.80%*	*-0.49%*	*-0.32%*	*0.05%*	*-2.46%*
	Other inds	-1.04%	-0.72%	-0.66%	-0.05%	0.11%	-0.44%
Panel 10: High-tech manufacturing (OECD)	*Hi-tech manuf*	*-8.79%*	*-1.34%*	*-0.58%*	*-0.76%*	*-0.19%*	*-7.26%*
	Other manuf inds	-3.36%	-1.03%	-1.02%	-0.01%	0.08%	-2.41%

Notes to table: Sources-of-growth by industry category. All estimates in slowdown space: $\Delta(\Delta \ln X) = \Delta \ln X^{07\text{-}19} - \Delta \ln X^{00\text{-}07}$. Growth rates calculated as changes in the natural log. Column 1 is (adjusted) GVA (Q) per hour. Column 2 is the contribution of capital deepening. Column 3 is the contribution of tangible (tan) capital deepening. Column 4 is the contribution of intangible (intan) capital deepening. Column 5 is the contribution of labour composition. Column 6 is TFP growth. Panel 1 compares estimates according to whether the mean industry value of intangible-intensity in the base period (2001-07) is above the median value in the market sector. Panel 2 compares estimates according to whether mean intangible-intensity (2001-07) is above the median value in the production sector. Panel 3 compares estimates according to whether mean intangible-intensity (2001-07) is above the median value in the service sector. Panel 4 compares estimates according to whether mean intangible-intensity (2001-07) is above the mean value in the market sector. Panel 5 compares estimates according to whether mean intangible-intensity (2001-07) is above the mean value in production. Panel 6 compares estimates according to whether mean intangible-intensity (2001-07) is above the mean value in services. Panel 7 compares estimates for services according to whether the industry aligns with OECD-defined knowledge intensive service activities (KISA). Panel 8 compares estimates according to whether the industry is knowledge-oriented, as defined by OECD. Panel 9 compares estimates according to whether the industry is included in the OECD definition of high and high-medium digital intensive industries. Panel 10 compares estimates for manufacturing according to whether the industry is included in OECD-defined high-technology manufacturing.

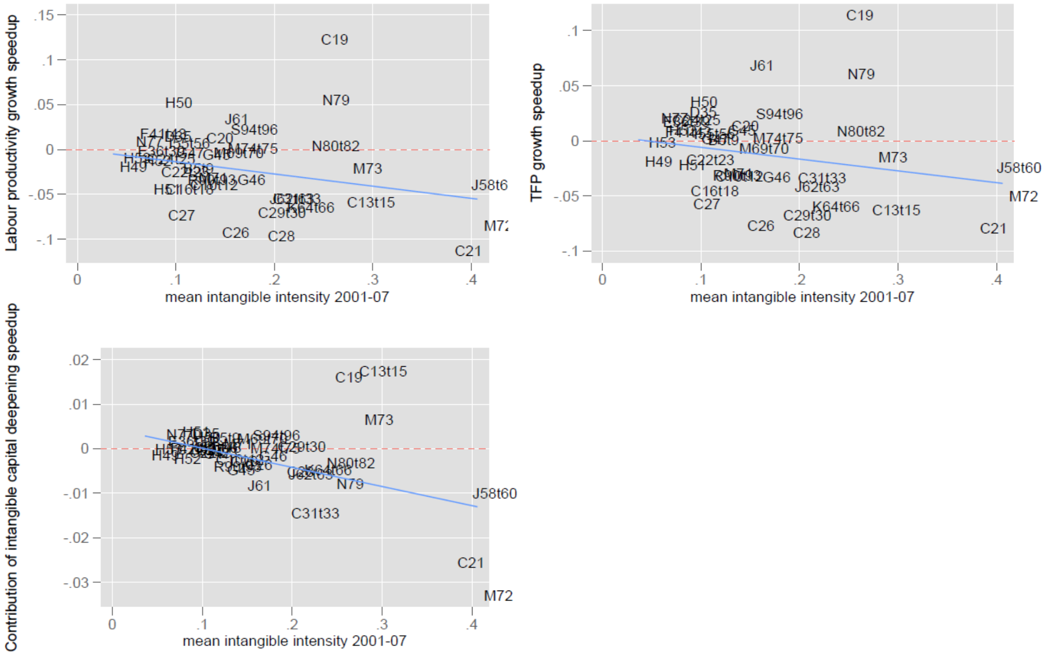
Appendix Table D2 presents industries included in each sector. Column: 1 are industries with mean (2001-07) intangible-intensity (intangible capital compensation as a share of industry GVA) above the median; 2 are industries with mean intangible-intensity above the median in the production sector; 3 are industries with mean intangible-intensity above the median in services; 4 are industries with mean intangible-intensity above the industry mean; 5 are industries with mean intangible-intensity above the mean in production; 6 are industries with mean intangible-intensity above the mean in services; 7 are knowledge-intensive industries based on the OECD definition of knowledge-intensive service activities (KISA); 8 are industries in OECD-defined knowledge-oriented industries; 9 are industries in OECD categories for High & High-medium digital intensity; and 10 are industries in the OECD-defined hi-tech manufacturing.

Appendix Table D2: Industries by category

sic	desc	Intangible intensity (above MS median)	Intangible intensity (above prod median)	Intangible intensity (above serv median)	Intangible intensity (above MS mean)	Intangible intensity (above prod mean)	Intangible intensity (above serv mean)	Knowledge-intensive service activites (KISA, OECD)	Knowledge-oriented (OECD)	High & high-medium digital intensity (OECD)	Hi-tech manufacturing (OECD)
B5t9	Mining and quarrying										
C10t12	Food products, beverages and tobacco		✓								
C13t15	Textiles, wearing apparel, leather and related products	✓	✓		✓	✓					
C16t18	Wood and paper products; printing and reproduction of recorded media									✓	
C19	Coke and refined petroleum products	✓	✓		✓	✓					
C20	Chemicals and chemical products	✓	✓								
C21	Basic pharmaceutical products and pharmaceutical preparations	✓	✓		✓	✓			✓		✓
C22t23	Rubber and plastics products, and other non-metallic mineral products										
C24t25	Basic metals and fabricated metal products, except machinery and equipment										
C26	Computer, electronic and optical products	✓	✓						✓	✓	✓
C27	Electrical equipment								✓	✓	✓
C28	Machinery and equipment n.e.c.	✓	✓		✓	✓				✓	
C29t30	Transport equipment	✓	✓		✓	✓			✓	✓	✓
C31t33	Other manufacturing; repair and installation of machinery and equipment	✓	✓		✓	✓				✓	
D35	Electricity, gas, steam and air conditioning supply										
E36t39	Water supply; sewerage; waste management and remediation activities										
F41t43	Construction										
G45	Wholesale and retail trade and repair of motor vehicles and motorcycles									✓	
G46	Wholesale trade, except of motor vehicles and motorcycles	✓		✓	✓		✓			✓	
G47	Retail trade, except of motor vehicles and motorcycles									✓	
H49	Land transport and transport via pipelines										
H50	Water transport								✓		
H51	Air transport								✓		
H52	Warehousing and support activities for transportation										
H53	Postal and courier activities								✓		
I55t56	Accommodation and food service activities										
J58t60	Publishing, audio-visual and broadcasting activities	✓		✓	✓		✓	✓		✓	
J61	Telecommunications	✓		✓				✓	✓	✓	
J62t63	IT and other information services	✓		✓	✓		✓	✓	✓	✓	
K64t66	Financial and insurance activities	✓		✓	✓		✓	✓	✓	✓	
M69t70	Legal and accounting; head offices and management consulting	✓		✓				✓		✓	
M71	Architectural and engineering; technical testing and analysis							✓		✓	
M72	Scientific research and development	✓		✓	✓		✓	✓	✓	✓	
M73	Advertising and market research	✓		✓	✓		✓	✓		✓	
M74t75	Other professional, scientific and technical; veterinary activities	✓		✓					✓	✓	
N77	Rental and leasing activities								✓	✓	
N79	Travel agency, tour operator, other reservation services	✓		✓	✓		✓			✓	
N80t82	Security and investigation; services to buildings; office administrative, support	✓		✓	✓		✓			✓	
R90t93	Arts, entertainment and recreation								✓	✓	
S94t96	Other service activities	✓		✓	✓					✓	

Appendix E: Correlation between slowdowns and intangible -intensity

Appendix Figure E1: Correlations between intangible-intensity and acceleration in i) labour productivity growth, ii) TFP growth and iii) the contribution of intangible capital deepening, 2000-19, with industry labels

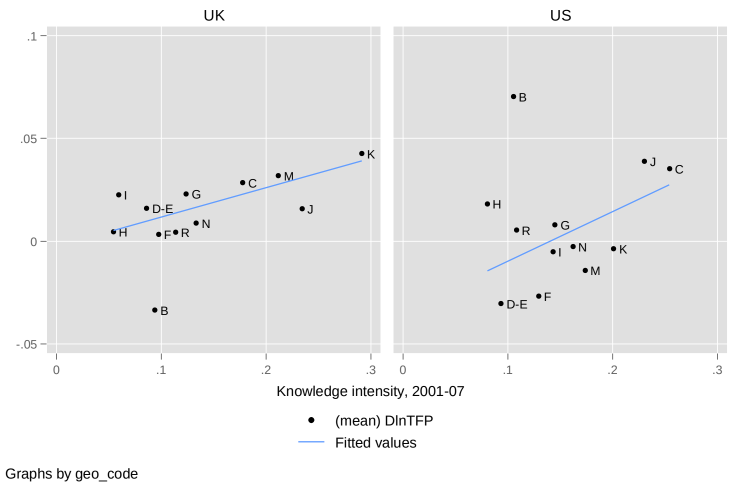


Notes to figure: scatters of industry mean intangible-intensity (2001-07, x-axis) and acceleration (y-axis) in: i) labour productivity growth (top left); ii) TFP growth (top right); and iii) the contribution of intangible capital deepening (bottom left). Acceleration estimated as the change in mean values between periods: $\Delta(\Delta \ln X) = \Delta \ln X^{07t19} - \Delta \ln X^{00t07}$. A negative correlation means that the slowdown was greater in more intangible-intensive industries. Growth rates calculated as changes in the natural log. Each data point is an industry.

Appendix F: Correlation between pre-crisis growth and intangible-intensity, 12 industries, EUKLEMS data, UK vs US

In Appendix Figure F1 we document the correlation between intangible-intensity (2001-07) and pre-crisis (2000-07) TFP growth in EUKLEMS data for the UK and US. In both countries, pre-crisis TFP growth was stronger in more intangible-intensive industries, with the correlation stronger in the US.

Appendix Figure F1: Correlations between pre-crisis intangible-intensity and TFP growth: UK and US, 2000-07



Note to figure: Y-axis is TFP growth in the pre-crisis (2000-07) period. X-axis is mean intangible-intensity (share of intangible capital income in total income), 2001-07. Growth rates calculated as changes in the natural log. Left-hand panel is data for the UK. Right hand panel is data for the US. Each data point is an industry (12 industries).