WORKING PAPER

Relative price effects and UK labour productivity growth

Authors

Diane Coyle[*], Jen-Chung Mei[*], Lucy Hampton[*]

[*] Bennett Institute for Public Policy, University of Cambridge, UK

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Abstract

We explore the role played by relative price changes in the well-documented slowdown in labour productivity growth in the UK. Using two alternative sectoral decomposition frameworks, we isolate the contribution from relative output price changes to aggregate labour productivity growth before and after 2008. We also compare the recent double deflated UK data with the counterfactual of the previous single deflated data to explore the role of input prices at the sector level. We find that relative price shifts contribute negatively to aggregate UK labour productivity growth, although to a differing extent depending on the decomposition chosen. We also find that the shift to double deflation of the data, adjusting input prices separately, makes a large negative contribution in one of the decomposition methods. However, the relative price effects differ between manufacturing and ICT, with more sensitivity to the choice of single or double-deflated data in the case of ICT.

Keywords: Labour Productivity, Prices, Sectoral Decomposition.
JEL: O47, L16, L60

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1. Introduction

Identifying the sources of labour productivity growth across industries and sectors is a useful diagnostic tool for exploring the well-known slowdown in UK productivity growth since the mid-2000s. While a number of studies, such as Tang and Wang (2004), Riley, Rincon-Aznar, and Samek (2018), Zhao and Tang (2018), Nishi (2019), Coyle and Mei (2023), Goodridge and Haskel (2023), and Lafond, Goldin, Koutroumpis, and Winkler (2022), among others, have previously explored sector-level performance, the extent to which relative price changes (i.e., changes in the sector or sub-sector output price relative to the aggregate output price) affect labour productivity growth has not yet been widely investigated. In a period when relative prices between sectors are changing, such shifts could contribute to observed productivity outcomes.[1,2]

To explore this requires the use of a decomposition framework that allows price effects to be identified. Several decomposition methods have been used in the literature. Some authors have used the Generalized Exactly Additive Decomposition (GEAD henceforth) method, which uses the product of sector relative prices and sector nominal value added shares as weights, favouring it because, as the name indicates, the sectoral productivity figures add up to the aggregate; the weights vary over time with price shifts to preserve additivity (regardless of base year), but the decomposition combines relative price shifts and nominal size. For instance, Tang and Wang (2004) find that in Canada and the US, the aggregate labour productivity growth gap was driven by the within-sector contribution in manufacturing and service sectors.[3] Similarly, Zhao and Tang (2018) examine China and Russia and find that China had higher growth in aggregate labour productivity (henceforth, ALP) growth through 1995-2008. Dumagan (2013) implements both the standard GEAD and an alternative TRAD method;[4] he finds that both approaches are exactly additive for constant price output, but only GEAD is exactly additive when output is the chained volume measure. Looking at productivity growth by sector and province in Canada over the period 1997-2014, Calver and Murray (2016) find that the GEAD and an alternative CSLS[5] decomposition developed by Sharpe (2010) lead to very different conclusions: according to GEAD, aggregate labour productivity growth was driven primarily by the reallocation of inputs to the mining and

[1] This is also the case where the national statistics (e.g., the UK ONS and Statistics Canada) do not recognise the relative price contribution to aggregate labour productivity since only the GEAD framework proposed by Tang and Wang (2004), is adopted. See https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/datasets/labourproductivitybyindustrydivision/apriltojune2021 for more details.

[2] ONS notes that moving from single to double-deflation methodology can result in higher (or lower) levels of activity and stronger (or weaker) growth rates in the chained volume measures of GVA. See three industry case studies: https://www.ons.gov.uk/economy/nationalaccounts/uksectoraccounts/articles/doubledeflation/methodsandapplicationtouknationalaccountsexperimentalstatistics#:~:text=Notes%20for%3A%20Implementing%20double%2Ddeflation,where%20KP%20represents%20constant%20price.

[3] Also see Almon and Tang (2011) and Tang and Wang (2015), who adopt a new framework for estimating industry contributions to aggregate labour productivity growth through demand-pull and supply-push while considering price effects in Canada and the United States. Although their framework allows output prices contributions to be estimated, it requires detailed data on industry gross output, intermediate inputs, and both gross output and intermediate input price deflators.

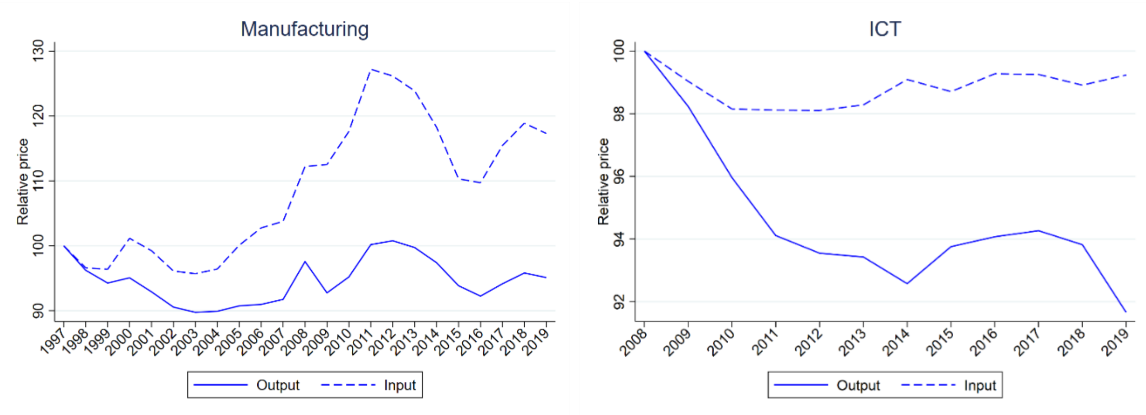
[4] TRAD is derived under the assumption that real output is calculated in constant prices using fixed-base Laspeyres quantity and Paasche price indexes, in which case real output is additive. GEAD and TRAD are identical when relative prices are constant.

[5] Like TRAD, CSLS is derived under the assumption that real output is calculated in constant prices. However, unlike TRAD, the CSLS decomposition uses shares of hours worked as sector weights.

oil and gas sectors and hindered by the manufacturing sector, whereas CSLS leads to the opposite conclusion.

However, as emphasised in De Avillez (2012) and De Vries et al. (2021), while the GEAD method generates sectoral contribution estimates that are perfectly additive irrespective of how real output is calculated, and also incorporates changes in relative output prices (unlike the alternative shift-share decomposition), it does not allow the contribution of relative output prices to be isolated.[6] One example in the existing literature that recognises the issue uses instead Diewert's (2015) extended GEAD framework, which defines labour productivity growth as the combined effect of relative price change, relative labour hours growth, and within-industry labour productivity growth; Nishi (2019) focuses on eight sectors of the Japanese economy from 1970-2010 and finds that relative price changes accounted for about 82% of productivity growth during the period 2005-2010.[7] In other words, the literature amply demonstrates the dependence of results on the choice of decomposition.

In previous work, Coyle and Mei (2023) implemented the Tornqvist decomposition (using nominal value-added shares as weights) to explore the slowdown in aggregate labour productivity (ALP) growth in the UK. They found that the within-sector component is the main contributor to the aggregate UK slowdown, driven by a small number of high-value sectors – parts of manufacturing (also see, Fernald and Inklaar, 2022), and information and communication (ICT). While useful, and also not imposing constant relative prices, the decomposition did not focus on the role of price changes in affecting sector output, for example by driving demand shifts.[8]



[6] Both the Tornqvist and shift-share approaches are commonly used in the literature, e.g., De Vries, Erumban, Timmer, Voskoboynikov, and Wu (2012), McMillan, Rodrik, and Verduzco-Gallo (2014), De Vries et al. (2021) employ the shift-share method, while Goodridge, Haskel, and Wallis (2018) and Coyle and Mei (2023) apply the Tornqvist approach. Note that although Tornqvist allows for relative prices to vary across industries (i.e., not assuming constant relative prices), shift-share does not, and neither allows the contribution of price changes to growth to be extracted. See Appendix II in Coyle and Mei (2023) for the comparison of different decomposition approaches.

[7] Nishi (2019), under the Diewert's GEAD framework, finds that the total labour productivity growth rate for the period 2005-2010 is 4.679%. Of this, 0.816 percentage points, 3.857 percentage points, and 0.006 percentage points are from within productivity, relative price effect, and labour reallocation, respectively.

[8] The Tornqvist decomposition is non-additive in levels of real output: sector levels will not sum to the aggregate where the latter is nominal output deflated by an aggregate price index. But by defining aggregate value-added growth as a weighted average (the weights being two-period nominal value added) of industry value added growth rates, it has the advantage of relaxing the assumption of an identical value-added function across industries. (Goodridge et al., 2018; De Vries et al., 2021).

Figure 1. Relative Input and Output Prices: Manufacturing (left) and ICT (right)
Notes: 1997 is rebased to 100. Input and output prices in manufacturing and ICT are relative to the whole economy implicit GDP deflator.
Sources: ONS for manufacturing (input BFO column and output prices AYF column: https://www.ons.gov.uk/economy/inflationandpriceindices/datasets/producerpriceindexstatisticalbulletindataset) and aggregate deflator (https://www.ons.gov.uk/economy/grossdomesticproductgdp/timeseries/ybgb), Annual Business Survey for ICT, and Authors' calculation.

In this study, we extend both the Diewert (2015) and Coyle and Mei (2023) frameworks to identify the contribution stemming from sector-level relative price changes using sectoral data for the UK for 1998-2019. When the (quality adjusted) price of a sector's output declines relative to the rest, the component identified as its price contribution to aggregate output and labour productivity growth will also decline, all else equal, and conversely. This may seem counter-intuitive, as we think of falling quality-adjusted prices as a signal of productivity gains; but it must be remembered that decompositions are a series of period by period snapshots of a dynamic process. In subsequent periods, the employment and nominal output shares of a dynamic sector will increase. To look at the role played by input prices, we compare double and single deflated UK data. If a sector's input prices rise relative to the rest, all else equal, we would expect its price contribution to aggregate labour productivity growth to decline when using the GEAD framework. The UK has seen substantial shifts in relative prices. Figure 1 shows that in ICT and manufacturing, relative input prices mainly rose for manufacturing up to 2008 but remained flat for ICT from 2008 onwards; while relative output prices have been broadly stable for manufacturing but declined for ICT.[9]

We calculate aggregate and sector-level labour productivity growth using the most recent double deflated data, introduced by ONS in the 2021 national accounts; and also as a counterfactual the previous single deflated data. Double deflation involves deflating disaggregated inputs and outputs separately, whereas until the change was introduced in 2021 both had been deflated using output prices in the UK data. We are therefore applying two lenses to the question of to what extent relative price shifts contribute to the productivity slowdown: a decomposition of the data with sector input and output prices deflated separately compared with the decomposition of data that – due to single deflation – assumed away any relative price shift between sector inputs and outputs; and extended versions of two alternative decompositions namely Tornqvist and GEAD. For extended GEAD, we would expect that if the relative price of a sector's output increases enough then it will make a positive price component contribution to that period's ALP growth; and conversely if the relative price falls, for reasons such as quality and technology improvements, the sector's price contribution to that period's ALP growth will be negative. We would expect that if its input prices increase relative to the rest this will reduce its price contribution to ALP growth in the current double deflated compared to the counterfactual single deflated figures.

We can account for price effects under both the extended Diewert (2015) (henceforth, extended GEAD) and extended Coyle and Mei (2023) (henceforth, extended Tornqvist) frameworks and show how relative price changes should affect the results. For reasons we set out below, the two approaches give different results. Extended GEAD finds a negative price contribution to aggregate ALP growth in both pre- and post-2008 periods in the double deflated data; relative

[9] Appendix I Figure AI 1 shows the changing employment shares for the two sectors – steadily up for ICT and down for manufacturing.

price changes make a negative contribution to UK growth of ALP of 0.905 and 0.124 percentage points over the periods 1998-2008 and 2008-2019 respectively. But the price contribution is positive when using the older vintage, counterfactual data. Using the alternative Extended Tornqvist decomposition, the price component is substantially negative in both double deflated and counterfactual datasets, contributing to reducing ALP growth by 2.408 and 1.776 percentage points in the earlier and later period respectively in the double deflated data. The figures are similar in the counterfactual single deflated data using this decomposition.

Disaggregating further for the UK to the ONS division-level data, while the earlier Coyle and Mei (2023) result that high value-added and high productivity growth sectors, manufacturing and ICT, made the biggest contributions to the aggregate productivity slowdown is confirmed, our new results show how the alternative decompositions produce different labour productivity growth patterns that are sensitive to relative price changes over time. The ALP growth pattern under the extended GEAD, but not the extended Tornqvist, framework is substantially affected by double deflation. In other words, we find that there is a clear ALP slowdown under the extended Tornqvist approach with both double and single deflated data for both sectors, but there is no consistent ALP slowdown under the extended GEAD framework with both the single and double deflated data for the two sectors. Additionally, we find that the impact of prices in ICT is more varied and sensitive to the data and measurement we employed. When using extended GEAD, we find that price contribution is positive in many years with single-deflated data but not with double-deflated data. By contrast, when using extended Tornqvist approach we find that price contribution is relatively more consistent (and stable) and positive in both datasets, though the growth pattern of price in ICT still slightly varies through the two datasets. Our findings suggest that input and output price differences play a significant role that determines the labour productivity growth pattern.

This paper proceeds as follows. Section 2 describes the extended GEAD and Tornqvist decomposition methodologies, and Section 3 describes the data used. Section 4 presents our results. Section 5 provides robustness checks and Section 6 discusses the results and concludes.

2. Methodology

The aggregate labour productivity figures familiar from the large literature on the productivity slowdown use aggregate deflators to calculate real output. The construction of deflators is therefore important to understanding the evolution of productivity, and different sectoral decompositions are likely to vary depending on the selection of weights. In order to develop a decomposition that isolates the effect of sectoral relative price changes, we start with an extended framework of the Generalized Exactly Additive Decomposition (GEAD) approach set out by Diewert (2015). Define aggregate relative price and labour hours-weighted labour productivity (henceforth, ARPLP) growth $g(X_t)$ between times t and $t-1$ as $g(X_t) = \frac{X_t - X_{t-1}}{X_{t-1}}$, where

$$X_t = \frac{\sum_i Q_t^i}{P_t L_t} = \frac{\sum_i V_t^i P_t^i}{P_t L_t} = \sum_i \frac{V_t^i}{L_t^i} \frac{P_t^i}{P_t} \frac{L_t^i}{L_t} = \sum_i p_t^i l_t^i X_t^i. \tag{1a}$$

Upper case X_t^i refers to the real value added (V_t^i) per hour (L_t^i total hours worked) for sector i, weighted by its output price relative to the aggregate deflator (p_t^i) and by labour hours as a share of the total (l_t^i). That is, Q_t^i refers to nominal value added for sector i at time t, $p_t^i = P_t^i / P_t$ is the sector i price relative to the aggregate and $l_t^i = H_t^i / H_t$ is the labour input share (hours worked), and $x_t^i = X_t^i / X_t$ is the sector's labour productivity level relative to the ARPLP level at time t. ARPLP growth can then be expanded as:

$$g(X_t) = \sum_i x^i_{t-1} \frac{P^i_{t-1}}{P_{t-1}} \frac{L^i_{t-1}}{L_{t-1}} \frac{X^i_t - X^i_{t-1}}{X^i_{t-1}} + \sum_i x^i_{t-1} \left(\frac{P^i_t}{P_t} \frac{L^i_t}{L_t} - \frac{P^i_{t-1}}{P_{t-1}} \frac{L^i_{t-1}}{L_{t-1}} \right) + \sum_i x^i_{t-1} \left(\frac{P^i_t}{P_t} \frac{L^i_t}{L_t} - \frac{P^i_{t-1}}{P_{t-1}} \frac{L^i_{t-1}}{L_{t-1}} \right) \frac{X^i_t - X^i_{t-1}}{X^i_{t-1}}$$
$$= \sum_i s^i_{t-1} \frac{X^i_t - X^i_{t-1}}{X^i_{t-1}} + \sum_i s^i_{t-1} \frac{p^i_t - p^i_{t-1}}{p^i_{t-1}} + \sum_i s^i_{t-1} \frac{l^i_t - l^i_{t-1}}{l^i_{t-1}} + \sum_i s^i_{t-1} \frac{X^i_t - X^i_{t-1}}{X^i_{t-1}} \frac{p^i_t - p^i_{t-1}}{p^i_{t-1}}$$
$$+ \sum_i s^i_{t-1} \frac{X^i_t - X^i_{t-1}}{X^i_{t-1}} \frac{l^i_t - l^i_{t-1}}{l^i_{t-1}} + \sum_i s^i_{t-1} \frac{l^i_t - l^i_{t-1}}{l^i_{t-1}} \frac{p^i_t - p^i_{t-1}}{p^i_{t-1}} + \sum_i s^i_{t-1} \frac{X^i_t - X^i_{t-1}}{X^i_{t-1}} \frac{p^i_t - p^i_{t-1}}{p^i_{t-1}} \frac{l^i_t - l^i_{t-1}}{l^i_{t-1}} \quad (1b)$$

where $s^i_{t-1} = \frac{p^i_{t-1} V^i_{t-1}}{\sum_i p^i_{t-1} V^i_{t-1}}$ is the product of sector i share of aggregate real value added with sector i price at $t-1$. Rearranging Eq. (1) gives:

$$g(X_t) = \underbrace{\sum_i s^i_{t-1} g(X^i_t)}_{Within\ contribution} + \underbrace{\sum_i s^i_{t-1} g(p^i_t)}_{Price\ Gcontribution} + \underbrace{\sum_i s^i_{t-1} g(l^i_t)}_{Labour\ contribution}$$
$$+ \underbrace{\sum_i s^i_{t-1} g(X^i_t) g(p^i_t) + \sum_i s^i_{t-1} g(X^i_t) g(l^i_t) + \sum_i s^i_{t-1} g(l^i_t) g(p^i_t) + \sum_i s^i_{t-1} g(X^i_t) g(p^i_t)\, g(l^i_t)}_{Sum\ of\ Interaction\ terms} \quad (2)$$

Equation (2) expresses the aggregate percentage growth rate of labour productivity decomposed into four components. The first component $s^i_{t-1} g(X^i_t)$ is the contribution of 'within' labour productivity growth in sector i. The second $s^i_{t-1} g(p^i_t)$ is the contribution of relative price changes between sectors.[10] The third $s^i_{t-1} g(l^i_t)$ captures labour input reallocation. The last component consists of four interaction terms. The weights are the sector shares of aggregate nominal value added.

Although Eq.(2) shows the price contribution to the weighted ARPLP growth, a feature of this extended GEAD framework is that the aggregate productivity growth rates are affected by changes in industry's relative input and output prices even when all industries' productivity levels and labour input shares remain constant (Diewert, 2015; Calver and Murray, 2016), which runs counter to the common intuition that productivity growth is driven by technological factors (Reinsdorf, 2015; Calver and Murray, 2016). This comes from the definition in Eq. (1a). Additionally, the labour reallocation contribution is also affected by price; it will increase in magnitude with an increase in the price of the outputs or fall in the prices of the intermediate inputs in $t-1$. To avoid this and derive a more intuitive framework that untangles the effect of changes in relative prices, it is necessary to subtract the relative price term (and its interaction terms) from Eq.(2) as follows:[11]

$$g(ALP_t) = g(X_t) - \sum_i s^i_{t-1} g(P^i_t) - \tfrac{1}{2} \sum_i s^i_{t-1} g(X^i_t) g(p^i_t) - \tfrac{1}{2} s^i_{t-1} g(l^i_t) g(p^i_t)$$
$$- \tfrac{1}{3} \sum_i s^i_{t-1} g(X^i_t) g(l^i_t) g(p^i_t)$$
$$= \sum_i s^i_{t-1} g(X^i_t) + \tfrac{1}{2} \sum_i s^i_{t-1} g(l^i_t) g(X^i_t) + \tfrac{1}{2} \sum_i s^i_{t-1} g(p^i_t) g(X^i_t) + \sum_i s^i_{t-1} g(l^i_t)$$
$$+ \tfrac{1}{2} \sum_i s^i_{t-1} g(l^i_t) g(X^i_t) + \tfrac{1}{2} \sum_i s^i_{t-1} g(l^i_t) g(p^i_t) + \tfrac{2}{3} \sum_i s^i_{t-1} g(X^i_t) g(l^i_t) g(p^i_t) \quad (3)$$

Hence, we have[12]

[10] Note that Diewert (2015) defines the relative price effect $g(AP_t)$ as the mixed change $\sum_i s^i_{t-1} g(p^i_t) + \sum_i \frac{1}{2} [s^i_{t-1} g(p^i_t) g(X^i_t)] + \sum_i \frac{1}{2} [s^i_{t-1} g(p^i_t) g(l^i_t)] + \sum_i \frac{1}{3} [s^i_{t-1} g(p^i_t) g(X^i_t) g(l^i_t)]$ and shows that the overall contribution of this term in each industry is small. While this is also the case for the UK at the whole economy level, it will still affect the overall growth of ARPLP.

[11] When the price deflator does not explicitly capture quality changes, excluding the price contribution from the growth measure can prevent true productivity developments from being masked by price effects (Reinsdorf, 2015).

[12] Note that we only define aggregate price term $g(AP_t)$ in the main context, but there are still two terms included in the ARPLP: the aggregate within change (i.e., the aggregate growth of real value added per hour)

$$g(ALP_t) = \underbrace{g(X_t)}_{\text{ARPLP Growth}} - \underbrace{g(AP_t)}_{Relative\ Price\ Growth} \quad (4)$$

where

$$g(AP_t) = \sum_i s_{t-1}^i g(P_t^i) + \frac{1}{2}\sum_i s_{t-1}^i g(X_t^i) g(p_t^i) - \frac{1}{2} s_{t-1}^i g(l_t^i) g(p_t^i) - \frac{1}{3}\sum_i s_{t-1}^i g(X_t^i) g(l_t^i) g(p_t^i), \quad (5)$$

Here we define aggregate price growth $g(AP_t)$ as consisting of the sum of relative price changes and three interaction terms with labour hours and real value added per hour. Eqs (3) and (4) thus show how the economy wide ALP growth rate is affected by relative price changes. If the relative price for sector i's output increases enough then it will make a negative contribution to ALP growth; and if the relative price falls enough, there will be a positive price contribution to ALP growth.

While Eq.(4) is informative about the relative price contribution to labour productivity growth, it is difficult to interpret because of the use of weights (and also interaction terms) that themselves still involve relative prices. So as an alternative, here we also extend Coyle and Mei (2023), using the Tornqvist decomposition to isolate the price contribution to aggregate labour productivity growth. We extend the framework by decomposing the 'within' component into *Nominal VA Growth*, *Price Growth*, and *Labour Growth.* We do so by expressing nominal value added per hour as follows:

$$\begin{aligned}
\Delta\, ln(V/H) &= \sum_j [0.5(w_{j,t} + w_{j,t-1})] \Delta\, ln(V_j / Hj) + \sum_j [0.5(w_{j,t} + w_{j,t-1})] \Delta\, ln(H_j / \sum_j H_j) \\
&= \sum_j \bar{w}_j \Delta\, ln(V_j / Hj) + \sum_j \bar{w}_j \Delta\, ln(H_j / \sum_j H_j) \\
&= \sum_j \bar{w}_j [\Delta\, ln(\frac{NV_j}{P_j} \times \frac{1}{H_j})] + R \\
&= \sum_j \bar{w}_j [\Delta\, (ln\, NV_j - lnP_j - lnH_j] + R \\
&= \underbrace{\sum_j \bar{w}_j \Delta\, ln\, NV_j}_{Nominal\ Growth} - \underbrace{\sum_j \bar{w}_j \Delta lnP_j}_{Price\ Growth} - \underbrace{\sum_j \bar{w}_j \Delta\, ln\, H_j +}_{Labour\ Growth} \underbrace{R}_{Labour\ Reallocation}
\end{aligned} \quad (6)$$

where the change in V is the weighted aggregate of changes in real industry value-added V_j and weights $\bar{w}_j$ are shares of nominal value-added, averaged over two periods to form a Tornqvist index. We can now define the aggregate labour productivity growth decomposition (in logs) as:

$$\Delta\, ln(V/H) = \sum_j \bar{w}_j \Delta\, ln\, NV_j - \sum_j \bar{w}_j \Delta lnP_j - \sum_j \bar{w}_j \Delta\, ln\, H_j + R \quad (7)$$

Note that this decomposition framework has the advantage that it allows value-added functions (nominal share-weighted real value added for all industries) and output prices to differ across sectors/industries (also see, Goodridge, Haskel, and Wallis, 2018; Goodridge and Haskel, 2023). In what follows, we will compare the two decompositions, and apply them to both current double deflated and counterfactual single deflated data.

$g(AX_t) = \sum_i s_{t-1}^i g(X_t^i) + \frac{1}{2}\sum_i s_{t-1}^i g(X_t^i) g(p_t^i) + \frac{1}{2}\sum_i s_{t-1}^i g(X_t^i) g(l_t^i) + \frac{1}{3}\sum_i s_{t-1}^i g(X_t^i) g(l_t^i) g(p_t^i)$; and the aggregate labour hours growth $(AL_t) = \sum_i s_{t-1}^i g(l_t^i) + \frac{1}{2}\sum_i s_{t-1}^i g(l_t^i) g(p_t^i) + \frac{1}{2}\sum_i s_{t-1}^i g(X_t^i) g(l_t^i) + \frac{1}{3}\sum_i s_{t-1}^i g(X_t^i) g(l_t^i) g(p_t^i)$.

3. Data

We use the same data as Coyle and Mei (2023), with sectoral and division[13] level data on nominal value added, real value added, and labour input (total hours worked). Prices at the sector level are implied by the nominal and real value added series. For real value added, we use the double deflated Office National Statistics (ONS) data for the UK, first introduced in October 2021. ONS provides Standard Industrial Classification 2007 (SIC07) data, dividing the whole UK economy into 20 (A-T)[14] sectors.[15] We also collected the previous single deflated real value added data for the UK from the ONS national accounts dataset published prior to October 2021.

4. Results

4.1 Aggregate UK results using double and single deflated data

To contextualize our proposed decomposition framework, we first demonstrate the sensitivity of the growth pattern of ARPLP (the relative price and labour hours-weighted productivity) to relative prices by showing results for both single and double deflated data.[16] Figure 2 illustrates how the 20 sectoral aggregated ARPLP, which is the labour productivity decomposition used by

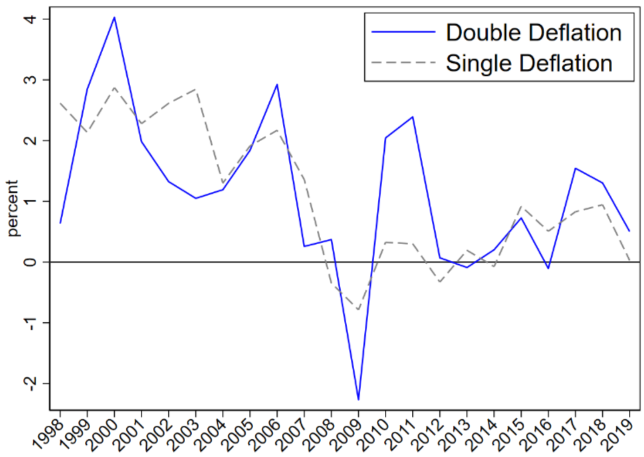


Figure 2. Whole economy aggregate relative price labour productivity growth 1998-2019
Notes: ARPLP growth calculated using Eq.(2).

[13] A division in the manufacturing sector is, for instance, manufacture of food products, beverages and tobacco (CA 10-12), manufacture of textiles, wearing apparel and leather products (CB 13-15), manufacture of wood and paper products, and printing (CC 16-18), etc. The division level dataset can be accessed here: ONS division.

[14] The 20 A-T sectors include A Agriculture, B Mining and quarrying, C Manufacturing, D Electricity, gas, steam and air conditioning supply, E Water supply; sewerage, waste management and remediation activities, F Construction, G Wholesale and retail trade and repair of motor vehicles and motorcycles, H Transportation and storage, I Accommodation and food service activities, J Information and communication, K Financial and insurance activities, L Real estate activities, M Professional, scientific and technical activities, N Administrative and support service activities, O Public administration and defence; compulsory social security, P Education, Q Human health and social work activities, R Arts, entrainment and recreation, S Other service activities, T Activities of households as employers.

[15] The low level GDP data file can be accessed here: ONS Low level GDP Dataset.

[16] Single deflation applies a single (output) deflator to both inputs and outputs, while double deflation deflates inputs and outputs separately.

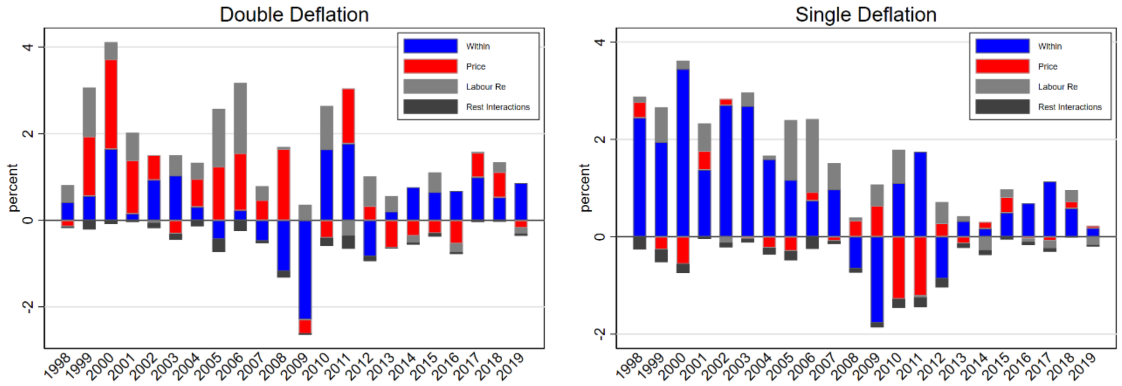


Figure 3. Whole Economy Aggregate Relative Price Labour Productivity Growth Components, Extended GEAD, 1998-2019
Note: ARPLP growth decomposed using Eq.(2).

the UK ONS,[17] varies between the single and double deflated data. The two series differ, sometimes substantially, while both trending down. Figure 3 then shows the same Extended GEAD decomposition of ARPLP growth into its components. The relative price effect (red bar) is larger using double deflated data, particularly pre-2008 when it generally makes a positive contribution, whereas in the counterfactual data the 'within' component stands out. Thus the aggregated productivity growth rates are indeed sensitive to changes in relative input and output prices. Recall that this ARPLP productivity growth measure can grow even if all industries' productivity levels and labour input shares remain unchanged.

While treating a change in the input prices that an industry pays, or in the output price that it receives, as a contribution to aggregate productivity growth in itself is as noted inconsistent with the traditional intuition about the technological drivers of productivity growth,

Figure 4. Whole economy aggregate labour productivity growth 1998-2019
Notes: Labour productivity growth rates for 20 industries.

[17] These differ very slightly from the official series due to the lack of granularity in the publicly-available industry data: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/labourproductivity/datasets/labourproductivity (column GI)

an appropriate price deflator may still allow the ARPLP to capture movement in the production possibility frontier caused by improvements in technology (i.e., the 'true' difference between the change in the quantity of output and inputs). However, constructing such a 'perfect' price deflator is difficult because the selection of weights can greatly affect the index, especially when the economy is changing (Abdirahman et al., 2020, 2022), so failing to separate price contributions from aggregate productivity can cause 'true' productivity developments to be masked by the price effects (Reinsdorf, 2015). Additionally, it can produce aggregate productivity growth that differs from other approaches; for example, De Vries et al. (2021) compared the differences in aggregate productivity growth constructed with different methods for the UK and found that the growth rate is somehow larger with the GEAD decomposition than other methods.[18]

Figure 4 (left) shows that ALP growth aggregating the 20 sectors using the extended Tornqvist framework, after accounting for price effects, is broadly consistent between the single (dash line) and double (solid line) deflated data, although there is still a gap. By contrast, in the extended GEAD framework (Figure 4, right) there is a larger gap between the double deflated current (solid line) and the counterfactual older data (dashed line), particularly pre-2008. Additionally, we find that both decompositions give similar results to each other when single deflated data is used (dashed lines) but differ substantially when double deflated data is employed (solid lines). The Tornqvist framework provides a more consistent pattern between double and single deflated data so is less sensitive to relative input price changes.

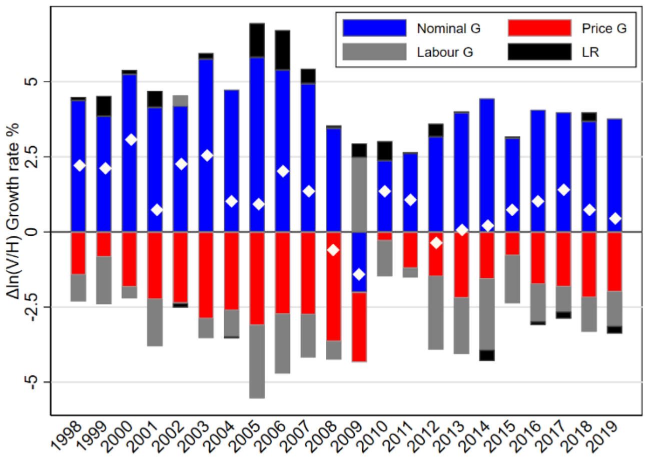


Figure 5. UK Labour productivity growth extended tornqvist decomposition

Notes: White dots show the whole economy labour productivity growth rate, blue for nominal value added growth, red for relative price change, gray for total hours worked growth, and black for the reallocation. Both price and hours increase in absolute terms, over time; negative terms are subtracted from the nominal growth rate in order to obtain the labour productivity measure.

[18] De Vries et al. (2021) find somewhat larger reallocation effects in GEAD than in other methods, suggesting that the aggregate labour productivity growth rate in GEAD would be larger than what is typically expected in other methods. While De Vries et al. (2021) employed the standard GEAD framework instead of the extended GEAD framework, both frameworks would yield the same aggregate labour productivity growth rate. However, we emphasize that only the extended GEAD framework allows researchers to isolate the price effects from the overall labour productivity growth. Our proposed framework is then to subtract the price contribution when extended GEAD method is adopted.

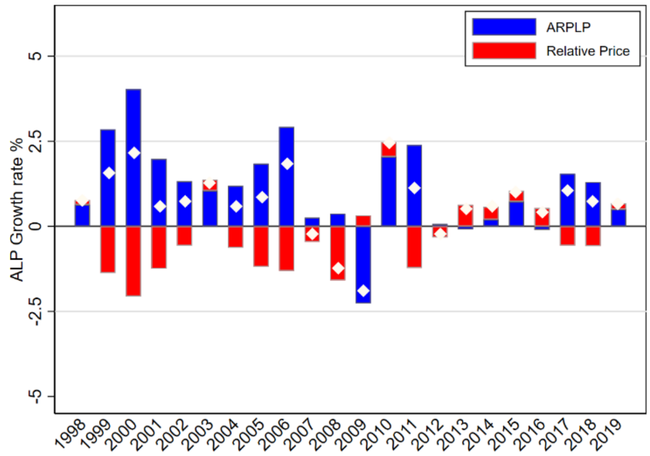


Figure 6. UK labour productivity growth, extended GEAD decomposition
Notes: White dot for whole economy labour productivity growth rates, blue for aggregate relative price labour productivity growth and red for relative price growth. Price growth should be interpreted in absolute terms. Negative terms are subtracted from the ARPLP growth to obtain labour productivity.

Figures 5 and 6 focus on the decompositions using double deflated data only. Figure 5 shows aggregated ALP growth (white dots) using the Extended Tornqvist decomposition (Eq. 10). Both the relative price (red) and hours worked (gray) make a negative contribution to ALP growth. In both Tornqvist and GEAD, the price contribution falls in magnitude over time, partially offsetting the posy-2008 slowdown, while the nominal gross value added (blue) component contributes to it (i.e., it becomes smaller post-2008). The labour reallocation term is small. Figure 6 shows the Extended GEAD decomposition (Eq. 4), where the aggregated ALP growth pattern (white dots) during the pre-2008 is quite similar to Figure 5 once the relative price is subtracted from the ARPLP (i.e., the white square dot).

Table 1 shows in detail the aggregated ALP growth rates using the extended GEAD decomposition in columns 1-3 and extended Tornqvist in columns 4-9. Panels A to C provide

Table 1. Labour productivity growth 1998-2019

	Eq.(4), Extended GEAD			Eq.(7), Extended Tornqvist				
	ALP	ARPLP	ARP	ALP	ANV	AP	AL	R
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
				Double Deflation (Panels A-C)				
Panel A: 1998-2019								
# Whole Economy	0.677	1.126	-0.448	1.040	3.869	-2.007	-1.070	0.248
Panel B: 1998-2008								
# Whole Economy	0.772	1.677	-0.905	1.632	4.720	-2.408	-1.087	0.409
Panel C: 2008-2019								
# Whole Economy	0.433	0.557	-0.124	0.350	3.055	-1.776	-1.015	0.086
				Single Deflation (Panels D-F)				
Panel D: 1998-2019								
# Whole Economy	1.211	1.118	0.093	1.174	3.797	-1.800	-1.081	0.259
Panel E: 1998-2008								
# Whole Economy	2.028	1.977	0.051	1.985	4.667	-2.003	-1.096	0.417
Panel F: 2008-2019								
# Whole Economy	0.307	0.209	0.098	0.277	2.935	-1.729	-1.028	0.099

Notes: Data are average growth rates per year for 1998-2019. Sum columns (2) to (3) equal to column (1) for each row, subject to rounding. Sum columns (4) to (8) equal to column (4) for each row, subject to rounding. For columns (1) to (3), ALP refers to aggregate labour productivity growth, ARPLP refers to aggregate relative price labour productivity growth, ARP refers to aggregate relative prices growth. For columns (4) to (8) then, ALP is aggregate labour productivity growth, ANV is aggregate nominal gross value growth, AP is aggregate prices growth, AL is aggregate hours growth, and R is the reallocation.

results based on the current double deflated figures, whereas Panels D to F provide results based on the (counterfactual) single deflated data. As before, the extended GEAD decomposition differs considerably between the current and counterfactual data. Our preferred extended Tornqvist decomposition is similar between the two data sets. Following Coyle and Mei (2023) and Goodridge and Haskel (2023), we also show results in Appendix I when industry real estate activities (labelled as L), public administration (labelled as O), Education (labelled as P), and human health (labelled as Q) are excluded. The aggregate productivity decomposition is significantly affected by whether or not real estate and the non-market sectors are excluded, pointing to the need to explore further price and volume measurement in these cases where the measurement issues are challenging.

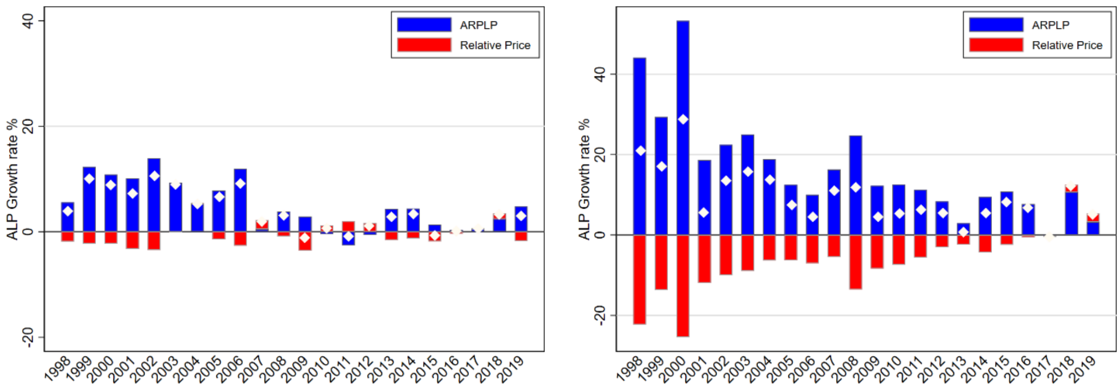
5. Manufacturing and ICT

We showed in Coyle and Mei (2023) that a small number of high-value sectors, manufacturing and ICT contributed the most to the UK labour productivity growth slowdown after 2008. Here we disaggregate the data to the ONS division level to diagnose look at how the price effects under alternative decompositions affect the ALP growth patterns (and so the slowdown) in the two sectors. We define the ALP growth for manufacturing and ICT, respectively, as follows:

$$g(X_t^j) = g(ALP_t^j) = g(X_t^j) - g(AP_t^j) + g(AL_t^j) \qquad (8)$$

Panel A: Double deflation

Manufacturing ICT



Panel B: Counterfactual (single) deflation

Manufacturing ICT

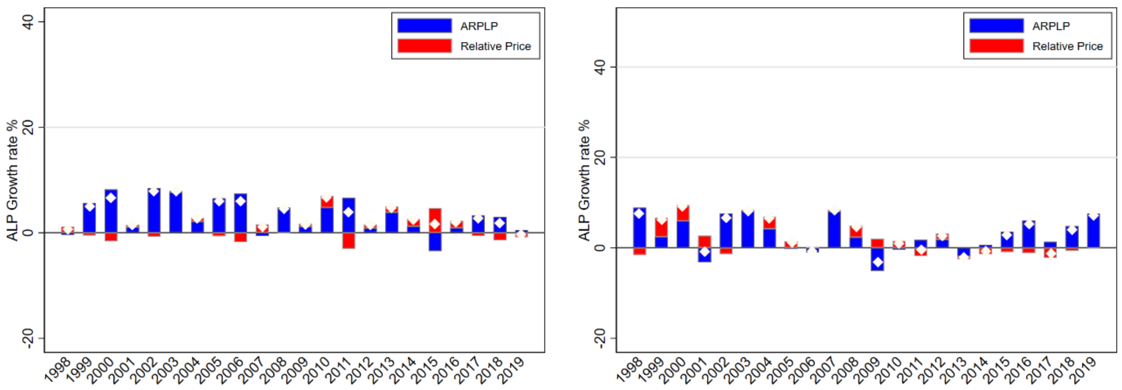


Figure 7. Cumulative labour productivity growth (Extended GEAD)
Notes: White dot for sector labour productivity growth rates, blue chart for aggregate relative price labour productivity growth and red for relative price growth. Price growth should be interpreted in absolute term, i.e., price term grows overtime. Negative terms are subtracted from the ARPLP growth in order to obtain the labour productivity measure ALP.

and

$$ln(V_j/H_j) = \sum_n \bar{w}_n \Delta \ln NV_n - \sum_n \bar{w}_n \Delta lnP_n - \sum_n \bar{w}_n \Delta \ln H_n + R_j \qquad (9)$$

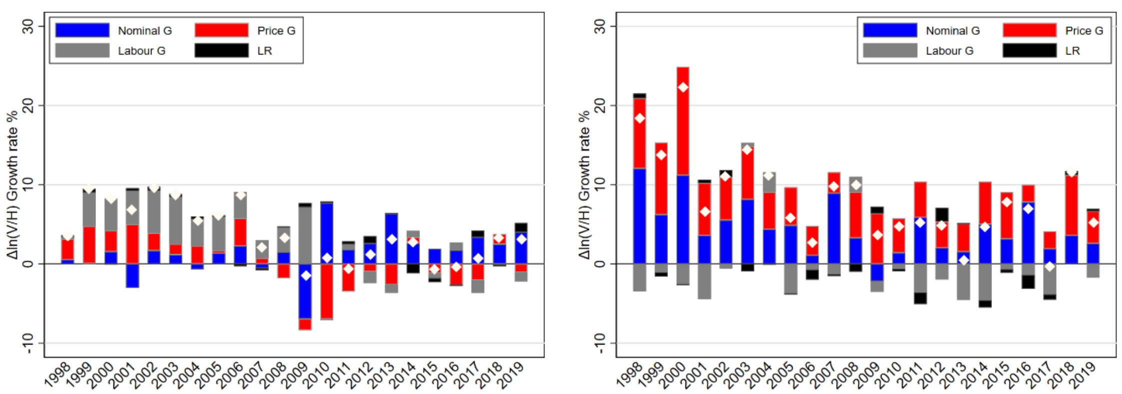
where superscript n refers to each ONS division within sector j (i.e., $n = 10, 11, \ldots, 18$ for manufacturing, and $n = 34, 35, \ldots, 39$ for ICT).

Figures 7 and 8 plot growth rates (white dots) and the contribution of each growth component over time for the Extended GEAD and Extended Tornqvist decompositions respectively. Each employs both double deflated (actual) and single deflated (counterfactual) data. As before, the results indicate that the extended GEAD framework (Figure 7) is substantially affected by double deflation in both sectors. By contrast, the extended Tornqvist approach (Figure 8) provides broadly more consistent results.

When comparing the results of both sectors in Figures 7 and 8 under the two different decompositions, we find that the price effects in the case of ICT are more varied and also sensitive

Panel A double deflation

Manufacturing ICT



Panel B counterfactual (Single) deflation

Manufacturing ICT

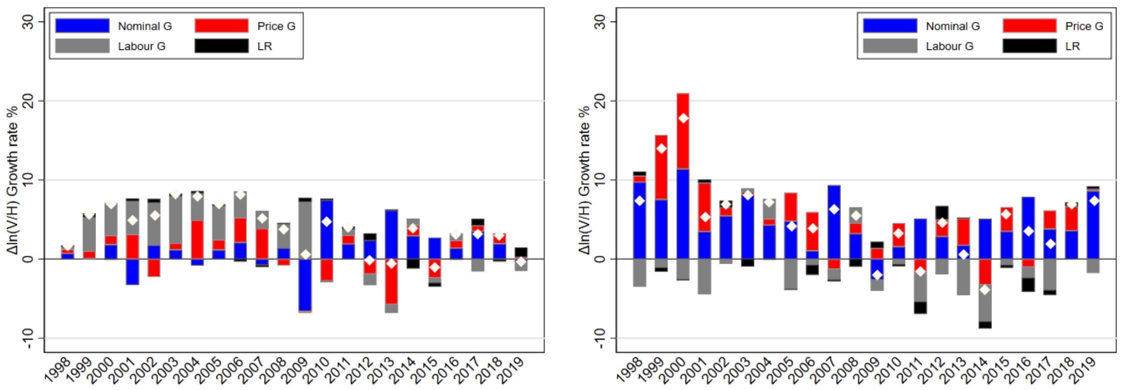


Figure 8. Cumulative labour productivity growth (Extended Tornqvist)

Notes: White dots for sector labour productivity growth rates, blue for nominal value added growth, red for relative price change, gray for total hours worked growth, and black for the reallocation. Both price and hours increase in absolute terms over time; negative terms are subtracted from the nominal growth rate in order to obtain the labour productivity measure ALP.

to the dataset, although less so when using the extended Tornqvist method. In particular, using extended GEAD (Figure 7), the price contribution becomes positive in many years with single-deflated data, but the ARPLP term (blue bars) becomes significantly smaller and the overall growth rate is smaller in ICT. The slowdown is also much clearer when double deflated data is used. Although there is a more consistent slowdown pattern under the extended Tornqvist approach no matter which dataset is used, the price contribution varies, being more consistently positive and not slowing as much in the actual as opposed to counterfactual data. Nevertheless, the growth patterns of the ICT's ALP (represented by the white dot) and prices are found to be significantly different when analysed using double and single deflator data, assuming all other factors remain constant. When double deflator data is used, we consistently observe positive contributions from price effects to ALP growth, whereas single deflator data show little effect, except for the years 1999, 2000, and 2001, where we observe positive contributions to ALP growth.

Table 2. Difference-in-differences through double and single deflation with ALP

	ALP growth 1998-2008 VS. 2008-2019	
	Extended GEAD Eq. (8)	Extended Tornqvist Eq. (9)
	(1)	(2)
γ (Double)	-0.029	-0.014
	(0.045)	(0.040)
β (Post)	-0.019	-0.068***
	(0.015)	(0.018)
δ (Double*Post)	0.020*	0.014
	(0.011)	(0.009)
θ (MIT)	-0.032	0.029
	(0.030)	(0.027)
μ (MIT*Post)	-0.003	-0.031***
	(0.011)	(0.010)
ρ (MIT*Double)	0.113***	0.048
	(0.048)	(0.043)
π (MIT*Post*Double)	-0.062***	-0.024
	(0.018)	(0.016)
Constant	0.053***	0.066***

	(0.010)	(0.026)
R-squared	0.141	0.185
Year FE	Yes	Yes
Industry FE	Yes	Yes
Observations	900	900

Notes: This table reports the estimates based on the model specification in Eq. (10). The dependent variable is ALP based on Eqs (8) and (9), respectively. Robust standard errors are reported in parentheses. *, **, and *** represent significance levels at the 10%, 5% and 1% respectively.

6. Robustness: Counterfactual estimates of difference-in-difference-in-differences

As a robustness check, we combine both single and double deflated data and allocate single deflated data into the control group while treating double deflated data as the treatment group in a regression analysis. We set pre-2008 as pre-period and post-2008 as post-period. This allows us to examine how the introduction of double deflation affected the decomposition of ALP growth. To do so, we estimate the following specification:

$$g(ALP_t^j) = \alpha + \gamma Double_t^j + \beta Post_t^j + \delta Double_t^j \cdot Post_t^j + \theta MIT_t^j + \mu MIT_t^j \cdot Post_t^j + \rho MIT_t^j \cdot Double_t^j + \pi MIT_t^j \cdot Post_t^j \cdot Double_t^j + \varphi d_t + \varepsilon_{j,t} \quad (10)$$

where $g(ALP_t^j)$ refers to the labour productivity growth measure defined by Eqs. 8 and 9, respectively. $Double$ is a dummy equal to 1 when the industry data is double deflated and 0 otherwise. $Post$ is also a dummy variable, equal to 1 for the post-2008 period and 0 otherwise. MIT is a dummy variable equal to 1 for *Manufacturing* and *Information and Communication* industries and 0 otherwise. We add this control into the specification as Coyle and Mei (2023) highlight that both industries contribute substantially to the UK ALP growth slowdown. d_t is a year fixed effect, and $\varepsilon_{j,t}$ is a zero mean error term.

As in Stiroh (2002), the coefficient α captures the mean within-industry labour productivity contribution for the control group (i.e. single deflated data, non-MIT industries) in the period prior to 2008, $\alpha + \gamma$ is the mean within-industry labour productivity contribution for treated industries prior to 2008, β measures acceleration/deceleration for the control group after 2008 (including $t = 2008$), $\beta + \delta$ is then the acceleration/deceleration for the treated group after 2008. The notation highlights that δ is the differential labour productivity growth contribution of double deflation relative to single deflation. Similarly, $\alpha + \theta$ is the mean within-industry labour productivity contribution for MIT industries prior to 2008, $\theta + \mu$ is then the acceleration/deceleration for MIT industries after 2008, $\theta + \rho$ is then the acceleration/deceleration for MIT industries after double deflation. The notation π then captures the average treatment effect of double deflation post-2008 on ALP growth in Manufacturing and Information and Communication. Table 2 confirms that neither single deflation nor double deflation affects the pattern of contributions to labour productivity growth between MIT and $non - MIT$ under the Tornqvist framework (π insignificant, reported in Table 2 column 2) but does under the extended GEAD framework (π is -0.062 at the 1% significance level).

6. Conclusions

Existing studies that decompose aggregate labour productivity growth performance have not accounted for the role of relative output price shifts between sectors, whereas if these are sizeable they will affect different components of the growth decomposition. In this paper, we address this by comparing extended GEAD and Tornqvist approaches, on double and single deflated UK data, to isolate the impact of the change in industry relative output and input prices from the more usual within and labour reallocation components of a productivity decomposition.

Comparing the two decomposition methods and performing the exercise on both the current double deflated data and the counterfactual, older single deflated data, we find the relative price component makes a negative contribution to ALP growth both pre- and post-2008 in the double deflated data under the *extended GEAD* framework of 0.905 and 0.124 percentage points respectively. The relative price contribution is also substantially negative in both double deflated and counterfactual datasets under the *extended Tornqvist* approach, and more so in the later period, contributing to reducing ALP growth by 2.408 and 1.776 percentage points in the earlier and later period respectively in the double deflated data. We do not find evidence that changing sectoral relative prices made a more negative contribution to the aggregate slowdown when double (not single) deflated data is used – on the contrary, they become less negative in both decomposition methods.

Disaggregating further to division-level data with a specific focus on manufacturing and information and communication industries, the alternative decompositions produce results that are sensitive to the price changes over time; the extended GEAD framework is substantially affected by double deflation in both sectors, whereas the extended Tornqvist approach provides broadly more consistent results. The price effects in ICT are confirmed to be more varied and sensitive to the data, although less so using the extended Tornqvist. By contrast, the manufacturing industry decomposition produces more similar results across both decomposition methods and data sets.

What picture of the productivity dynamics in the economy can we take from this decomposition exercise? While all decompositions are a series of snapshots of a dynamic phenomenon, by introducing the contribution of shifts in relative prices, this paper first confirms the need to focus on high value manufacturing, and ICT in particular, in exploring further the sources of the UK's aggregate productivity slowdown. Importantly, this paper also raises questions about how to interpret the effect of relative price changes in productivity dynamics. As discussed in Abdirahman et al. (2020, 2022) in the context of telecommunications, it is challenging to 'correctly' assign economic value added or productivity when the alternative (volume or revenue) weights diverge, as the choice of nominal or real share weights will substantially affect the results.

This issue is likely to occur in dynamic sectors such as ICT; Coyle and Hampton (2023) find that using a volume-based deflator (i.e., the cost per unit of computation as a basic unit for all products) in ICT produces price declines substantially larger than the official semiconductor PPI. Our results suggest that while the various decompositions consistently indicate that manufacturing and ICT both contribute significantly to the aggregate labour productivity growth slowdown in the UK post-2008, there are different phenomena in the two sectors. In manufacturing the 'pure' labour productivity (within and reallocation) elements are more prominent, consistently across decompositions and data sets. In ICT – consisting of computer software and services and telecommunications services – the relative price contributions we isolated play a larger part, and one that varies depending on method and data. This points to the need for further consideration of the measurement of quality adjusted input and output prices in the sector.

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Appendix I

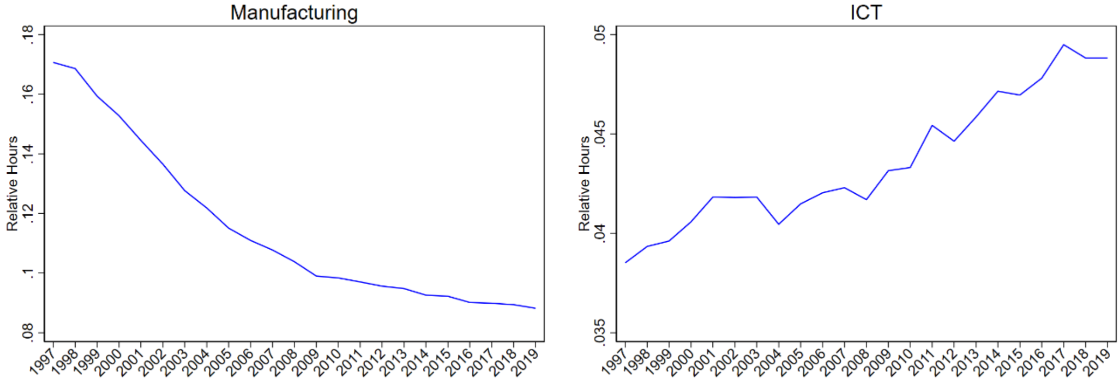

Figure AI 1. Relative hours worked over time 1997-2019

Notes: Total hours worked in manufacturing and ICT relative to the whole economy.

Sources: ONS and Authors' calculation.

Table AI 1. Labour productivity growth 1998-2019

	Eq.(4), Extended GEAD			Eq.(7), Extended Tornqvist				
	ALP	ARPLP	ARP	ALP	ANV	AP	AL	R
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
				Double Deflation (*Panels A-C*)				
Panel A: 1998-2019								
# Whole Economy	0.677	1.126	-0.448	1.040	3.869	-2.007	-1.070	0.248
# L Excluded	0.637	1.139	-0.502	0.818	3.426	-1.820	-0.585	-0.202
# O, P, Q Excluded	0.912	1.115	-0.203	0.978	3.056	-1.384	-0.861	0.168
Panel B: 1998-2008								
# Whole Economy	0.772	1.677	-0.905	1.632	4.720	-2.408	-1.087	0.409
# L Excluded	0.841	1.740	-0.899	1.502	4.206	-2.076	-0.391	-0.236
# O, P, Q Excluded	1.127	1.649	-0.522	1.719	3.661	-1.530	-0.814	0.403
Panel C: 2008-2019								
# Whole Economy	0.433	0.557	-0.124	0.350	3.055	-1.776	-1.015	0.086
# L Excluded	0.268	0.535	-0.267	0.048	2.636	-1.677	-0.742	-0.168
# O, P, Q Excluded	0.549	0.640	-0.091	0.179	2.466	-1.359	-0.874	-0.053
				Single Deflation (*Panels D-F*)				
Panel D: 1998-2019								
# Whole Economy	1.211	1.118	0.093	1.174	3.797	-1.800	-1.081	0.259
# L Excluded	1.241	1.265	-0.024	0.920	3.365	-1.656	-0.583	-0.204
# O, P, Q Excluded	1.480	1.098	0.382	1.065	2.998	-1.240	-0.873	0.180
Panel E: 1998-2008								
# Whole Economy	2.028	1.977	0.051	1.985	4.667	-2.003	-1.096	0.417
# L Excluded	2.137	2.176	-0.039	1.698	4.132	-1.806	-0.380	-0.247
# O, P, Q Excluded	2.468	1.953	0.515	1.943	3.630	-1.274	-0.823	0.412
Panel F: 2008-2019								
# Whole Economy	0.307	0.209	0.098	0.277	2.935	-1.729	-1.028	0.099
# L Excluded	0.239	0.234	0.005	0.060	2.548	-1.577	-0.748	-0.161
# O, P, Q Excluded	0.381	0.177	0.204	0.107	2.359	-1.323	-0.887	-0.040

Notes: Data are average growth rates per year for 1998-2019. Industry L is real estate activities, O is public administration, P is Education, and Q is human health. Sum columns (2) to (3) equal to column (1) for each row, subject to rounding. Sum columns (4) to (8) equal to column (4) for each row, subject to rounding. For columns (1) to (3), ALP refers to aggregate labour productivity growth, ARPLP refers to aggregate relative price labour productivity growth, ARP refers to aggregate relative prices growth. For columns (4) to (8) then, ALP is aggregate labour productivity growth, ANV is aggregate nominal gross value growth, AP is aggregate prices growth, AL is aggregate hours growth, and R is the reallocation.

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