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An Analysis of Corona Pandemic-related Productivity Growth in Germany: Sectoral Aspects, Work-From-Home Perspectives and Digitalization Intensity

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Summary:

This paper considers labor productivity growth under the Corona pandemic setting in Germany in 2020 and the first two quarters of 2021 and thus is a complementary analysis to a study of Vries et al. (2021) which covers the US, France and the UK. Data from 63 industries is used within a shift-share analysis to analyze pure within-productivity growth in Germany, abstracting from reallocations of hours worked. Following the original approach of Vries et al. (2021), three taxonomies are applied to categorize industry-level data regarding similar types of activity (sector affiliation), working-from-home (WFH) intensity and digital intensity. We find that aggregate productivity growth in Germany was slightly negative in 2020, but saw a rather large positive growth in the second quarter of 2021. This is still true when looking at the pure-within industry productivity growth. The much-discussed hospitality and culture sector underwent only small within-productivity growth reductions. Most changes of within-productivity growth during 2020 and 2021 can be observed in the manufacturing sector. Even though high WFH industries performed better during 2020 in terms of within-industry productivity growth, the difference to medium- and low-WFH industries was very small. In the second quarter of 2021 both medium and low WFH industries outperformed high WFH industries. Above average digital-intensive industries showed higher within-industry productivity growth than below average digital-intensive industries at the beginning of the pandemic. However, below average digital-intensive industries caught up during the first two quarters of 2021. For almost all industries, rather large within-industry productivity growth can be observed in the second quarter of 2021.

Zusammenfassung:

Dieses Papier untersucht das Wachstum der Arbeitsproduktivität unter den Bedingungen der Corona-Pandemie in Deutschland im Jahr 2020 und in den ersten beiden Quartalen des Jahres 2021 und ist damit eine ergänzende Analyse zu einer Studie von Vries et al. (2021), die die USA, Frankreich und das Vereinigte Königreich abdeckt. Daten aus 63 Branchen werden im Rahmen einer Shift-Share-Analyse genutzt, um reines brancheninternes Produktivitätswachstum in Deutschland zu analysieren, wobei von Umschichtungen von Arbeitsstunden abstrahiert wird. In Anlehnung an den ursprünglichen Ansatz von Vries et al. (2021) werden drei Taxonomien verwendet, um die Daten auf Branchenebene in Bezug auf ähnliche Tätigkeitsarten (Branchenzugehörigkeit), die Heimarbeitsintensität und die digitale Intensität zu kategorisieren. Wir stellen fest, dass das gesamtwirtschaftliche Produktivitätswachstum in Deutschland im Jahr 2020 leicht negativ war, im zweiten Quartal 2021 jedoch ein recht hohes positives Wachstum verzeichnete. Dies gilt auch dann, wenn man das reine Produktivitätswachstum innerhalb der Branche betrachtet. Der vieldiskutierte Gastgewerbe- und Kultursektor verzeichnete nur geringe Rückgänge des brancheninternen Produktivitätswachstums. Die meisten Veränderungen des internen Produktivitätswachstums in den Jahren 2020 und 2021 sind im verarbeitenden Gewerbe zu beobachten. Obwohl Sektoren mit hohem WFH im Jahr 2020 beim brancheninternen Produktivitätswachstum besser abschnitten, war der Unterschied zu den Sektoren mit mittlerem und niedrigem WFH gering. Im zweiten Quartal 2021 übertrafen sowohl die Industrien mit mittlerer als auch mit niedriger WFH die Industrien mit hoher Heimarbeitsintensität. Überdurchschnittlich digital-intensive Branchen wiesen zu Beginn der Pandemie ein höheres brancheninternes Produktivitätswachstum auf als unterdurchschnittlich digital-intensive Branchen. In den ersten beiden Quartalen des Jahres 2021 holten die unterdurchschnittlich digitalintensiven Branchen jedoch auf. Für fast alle Branchen ist im zweiten Quartal 2021 ein recht hohes brancheninternes Produktivitätswachstum zu beobachten.

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1. Introduction

Labor productivity growth is a key variable in macroeconomics and plays a crucial role in collective bargaining as well as with regard to international competitiveness. The latter is influenced by relative international productivity developments as well as relevant technology shocks. The Corona pandemic-induced recession in OECD countries went along with massive output shocks related both to negative demand shocks and supply shocks (IMF, 2020, 2021). Both in the US and Europe, labor retention schemes have played a crucial role in 2020 and 2021 (Anderton et al., 2021). with such retention schemes still being operational in Germany in 2022. The labor retention schemes allow firms to technically shift the burden of wage payments for effectively laid-off workers to the government whose main motivation is the stabilization of aggregate demand during the recession. To some extent, such schemes slowed down the sectoral reallocation of labor. Another specific factor of the Corona recession has been the massive emphasis of firms on enhanced work-from-home (WFH) arrangements for workers.

Germany's Economic Council of Economic Advisors (SVR, 2021) has broadly discussed labor productivity issues, however not the aspects highlighted in this paper. Moreover, as regards the long-term stability of the Eurozone, the real effective exchange rate is crucial among Eurozone member countries and in this context labor productivity growth should naturally be considered. Productivity growth could also become relevant in the context of (high) inflation These aspects reinforce the relevance of our research. As regards the pandemic-related role of changing capital intensity, the European Central Bank (ECB) has presented preliminary research results (Bodnár et al., 2020). The ECB has also presented research on labor productivity changes in the Eurozone in the period prior to the pandemic, namely based on a shift and share analysis: with roughly 60% of labor productivity growth explained by total factor productivity growth in 1995-2019 and with a dominant role of intra-sectoral effects as opposed to cross-structural changes and interaction effects (Lopez-Garcia & Szörfi, 2020).

On the basis of quarterly data, Vries et al. (2021) have analyzed short-term Corona-shock related productivity changes in the US, the UK and France. Most innovative is the authors' WFH differentiation across sectors and the focus in different digital intensities where the authors pick up on previous related work. Moreover, the authors use a shift and share analysis as an approach for their short-term and rather static analysis (which assumes technologies and factor intensities at full employment as given). The approach is indeed useful for identifying short-term Corona-shock effects on labor productivity changes. The analysis is in line with older findings of the same authors (van Ark et al., 2019) according to which digital producing sectors strongly contribute to within-industry productivity growth effects in the US, but not so much in European Union (EU) countries such as the UK and France. The authors point out that medium WFH sectors contributed rather strongly to within-industry productivity effects in the US, UK and France. This suggests that special benefits from high WFH-intensity sectors are still to be exploited and indeed might need a longer learning-by-doing period in leading firms. It is important in this context to take an additional look at the EU's largest economy, Germany, and such an analysis is presented subsequently. An increase in work-from-home practices in the context of the Corona pandemic has been observed in leading OECD countries as well as in Eastern European countries, Turkey, Egypt and Australia (EBRD, 2021): Australia, the Netherlands and the UK were characterized – according to a survey – by about 40 percent of respondents working from home on three or more days, the US recorded a figure of close to 40 percent while in this category Germany only reached slightly more than 20 percent; and France less than 20%. Efficiency gains from work-from-home activities were expected by about one-third of respondents, with workers in sectors such as finance, banking, insurance and ICT services reporting that they are over 7 percent more efficient, while people in the education sector indicated only a 1 percent efficiency gain. While 39 percent of respondents in leading OECD countries in the age bracket 45 to 59 reported enhanced efficiency, only 26 percent of the respondents in the EBRD region (post-socialist countries of Eastern Europe and the former Soviet Union) reported efficiency gains. A rise of labor productivity figures in 2020 and 2021 in certain sectors – and countries – thus could reflect efficiency gains through more work-from-home activities.

The available economics literature on Covid-19 for Germany has pointed to Corona-related labor productivity growth (H. Schneider, 2020), as labor productivity has increased in the first half of 2020 – a puzzle as the author has put it (with a first look at the strong output contraction in the German economy when hit by the Corona pandemic). At that time, the German government offered a job retention scheme, liquidity support for selected firms and financial support for certain sectors, while intra-EU trade was facing initial distortions in the context of the various lock-downs in both Germany and other EU countries. Firms reacted in various ways to the Corona pandemic challenge, including efforts to use work from home arrangements. Such arrangements were possible in various sectors to different extents, obviously not so much in sectors such as construction or health care, but more in part of the services sector and manufacturing. Based on the follow-up survey to the 2018 BIBB/BAuA Employment Survey, in which over 17,000 complete interviews were conducted, persons employed were asked whether their job could, at least partly, be done in home office (Hall et al., 2020), about half of the workers who could work from home, did not do so prior to the pandemic. Alipour et al. (2020) estimate, based on this Employment Survey, that approximately 56% of all jobs in Germany are WFH feasible. With firms facing some international supply distortions – increasingly so during 2020/2021 – and reduced aggregate demand, reductions in terms of hours worked and reductions of the workforce employed were two options that could be used as an adjustment mechanism. As regards Germany’s worker retention scheme, one cannot rule out that the potential reallocation of resources across sectors was reduced through the fact that employees using the scheme obtain 60 percent of the previous wage income (67 percent if the parent/family had at least one child; see Bundesagentur für Arbeit, 2021) – the wage income replacement ratio is raised to 80 percent in the seventh month of layoff (87 percent if the parent/family had at least one child).

Analytically, this paper follows the categorization of industries suggested by Vries et al. (2021), where three taxonomies are emphasized: Similar types of activity (sector affiliation), WFH intensity and digital intensity. This allows a comparison of the findings for Germany with those for US, the UK and France. The analysis is organized as follows: Section 2 takes a closer look at certain theoretical aspects of labor productivity analysis. Section 3 introduces the applied methodology, data and the taxonomies on a detailed level. Section 4 presents the result of the statistical analysis. Section 5 presents policy conclusions and suggestions for further research.

2. Theoretical Aspects of Labor Productivity Growth

Labor input in sectoral production functions in western industrialized countries is heterogeneous, with skilled labor input being intensively used in sectors which use information and communication technologies (ICTs) intensively, as has been shown by ample empirical evidence (Pichler & Stehrer, 2021). Labor productivity can be measured as output per worker or as output per hour. The latter will be relevant subsequently as changes in labor input volume were significant during the Corona recession due to (partial) lockdowns and consumption reductions. In the context of linear-homogeneous production functions – generally considered as relevant for industrialized countries - labor productivity is a positive function of capital intensity (K/L). This is relevant in the Corona recession in two ways:

- Firms use labor retention schemes to reduce their workforce and costs for wages during the recession. The effective ratio K/L thus will increase as firms will effectively lay off those workers with relatively low labor productivity.

- The effective ratio K/L could increase not only in firms with higher ICT investment but also with strong WFH arrangements. If many households have their own ICT equipment at home (an option rather relevant for small and medium-sized companies), then households could effectively use this private IT equipment for work-related tasks. Therewith, an indirect increase of capital intensity could take place – an effect which is more likely in countries with rather high computer endowments per household. Here indeed, one finds considerable differences across OECD countries (Table 1)[1].

The second effect might be relevant in the tradables sector in particular - where skilled workers are more common and thus the opportunities for WFH arrangements are greater than in the nontradables sector. However, high-tech industries often require the use of tacit knowledge which can only fully be exploited by firms if staff members meet in person. Thus, there might be a natural limitation for WHF arrangements in high-tech firms. WHF arrangements also go along with some adjustment needs and learning effects on the side of workers.

During the Corona pandemic, many OECD countries, including the US, the UK, France and Germany, have adopted effective government deregulation, particularly in order to alleviate WFH opportunities. As more digital capital becomes available (e.g., the computers of private households and new IT investment on the part of firms) there will be sectors using the more abundant digital input factor intensively and those sectors' respective output will expand according to the Rybczynski theorem. The theorem states that if one factor endowment (here computers) rises exogenously, the sector using this endowment (here the tradeables sector) will expand relatively intensively. The other sector's output will decline in absolute terms. Thus, output in tradable sector using WFH arrangements and therewith its respective labor productivity should increase in the medium term. This assumes that some adjustment time is needed by firms, particularly in Germany where the reallocation of labor across sectors is

[1] For Germany, France, the UK and the US, the authors compared ITU data with the respective national data. The latest available data for all four countries was from 2017. We find that ITU and national data differs sometimes substantially (see Appendix Table A1). The same was found for other OECD countries in Table 1 when comparing the ITU data with OECD data (OECD, 2022).

relatively slow as the OECD Employment Protection Index (EPL) suggests (OECD, 2021)[2]. Germany's strong trade unions in the manufacturing sector may also play a role in the adjustment process.

[2] The EPL for Germany was at 2.6 in 2019, with just six OECD countries having higher employment protection levels in 2019. The OCED average was 2.06, the highest EPL at 3.61 (Netherlands) and the lowest available index in 2019 at 0.09 (USA) (OECD (2021).

Table 1: Computer endowment per household - selected OECD countries

Country	Percentage of households with a computer
Netherlands*	91.1
Germany (2017)#	92.9
Denmark*	88.9
United Kingdom (2017) *	87.5
Finland*	87.4
Poland*	83.1
United States*	83.1
Spain*	80.9
Israel*	79.5
Czech Republic*	77.9
France (2017) *	77.5
Lithuania*	76.7
Japan*	74.6
Korea (Rep. of) *	71.7
Italy*	66.2
Turkey*	55.3
Costa Rica#	49.9
Mexico*	44.3
Brazil#	39,4
Colombia*	37.2

Note: Data from the ITU and the OECD database was available for most countries as of 2019. If older data was used, the year is indicated in parenthesis.
Sources: *ITU World Telecommunication/ICT Indicators 2020 database, Households with a Computer by Urban-Rural Location and Household Composition (ITU World Telecommunication, 2020) . #OECD, Access to Computers from Home, accessed: 09.03.2022 (OECD, 2022).

An additional aspect in a multi-input production function context, including intermediate input, concerns the availability of critical international input factors – e.g., computer chips. To the extent that the availability of computer chips in 2020 was a major issue in the manufacturing industry in Germany and other OECD countries, labor productivity should be expected to stagnate or even fall in 2020. However, as the chip input bottlenecks were easing in 2021/2022, one should expect a medium-term increase in labor productivity in manufacturing in Germany. It is noteworthy that Germany's manufacturing sector is – measured relative to GDP – much bigger than in other large OECD countries such that the manufacturing sector's labor productivity growth performance will affect the aggregate labor productivity rather strongly.

In a nutshell: What should one expect in the context of a global pandemic shock with demand policies in place, monetary policy intervention, as well as liquidity support for firms?

(1) Strong adjustment of many firms at the same time. Some of the firms will face bottleneck problems, e.g. procuring laptops for thousands of workers to switch to WFH arrangements implies limitations to productivity growth in some sectors.

(2) Firms in certain sectors will additionally face sector-specific input bottlenecks.

(3) Some firms might try to take advantage of the “global crisis shock” by implementing restructuring reforms which otherwise would have faced much resistance from workers and trade unions. This might lead to a rise of sectoral labor productivity. The pressure for such behavior may be expected to be rather large in the tradables sector, as it faces more competitive pressure than the nontradables sector.

(4) The unemployment rate is naturally increasing during the Corona recession, the volume of labor hours – even when corrected for unemployment effects – could fall, but if it falls faster than output, it brings about a paradoxical rise of labor productivity.

(5) The innovation dynamics of firms could be weakened – a problem which will become visible only in the medium term. Services innovation could be reinforced to the extent that Corona-related digital modernization impulses could strengthen services innovation dynamics (on some key drivers of services innovations in the UK and Spain see: Wilson, 2007, Santamaría et al., 2012).

While many firms in leading OECD countries have pledged to realize more working from home opportunities in the post-Corona economic upswing, it remains to be seen whether or not innovative WFH arrangements could indeed be implemented in many sectors in a tailor-made way which raises firms’ productivity or the rate of product innovations – leading to higher relative prices in world markets.

One potential issue concerns the measurement of labor productivity. In data from the System of National Accounts (SNA), where inputs and outputs are recorded, pre- and post-COVID-19 output does not include prosumer-based value-added (e.g., households booking holidays from home – with effective labor input in the hospitality sector) which seems to have been rather large in the US and the UK and more modest in, e.g., Germany (Welfens & Perret, 2014). Given the increase of official und hidden unemployment rates, one may, on the other hand, assume that activities in the shadow economy in some OECD countries have increased in 2020/21; in some sectors more than others and in EU countries with weak fiscal policy more so than in others (e.g., UK, France and Italy). As regards the size of the shadow economy prior to the Corona recession, there are broad international estimates available (e.g., (F. Schneider, 2012, 2014). The subsequent analysis considers the official German SNA data and related measurement of hourly working data. Aspects of the shadow economy cannot be covered here.

3. Removing labor reallocation effects to measure pure industry productivity contributions – The shift-share aggregation method and data

In order to understand and quantify the productivity movements which were due to the pandemic, the shift-share approach is applied, following the original paper by Vries et al. (2021) who measure labor productivity (y_t) as the ratio of real value-added (Y_t) and the number of hours worked (H_t). The authors assume an aggregate production function such that both variables can be summed up over all sectors (i) to derive aggregate productivity and the number of hours worked. The aggregate labor productivity can then be stated as shown in equation (1).

$$y_t = \frac{Y_t}{H_t} = \frac{\sum Y_{i,t}}{\sum H_{i,t}} \tag{1}$$

The aggregate productivity level (Δy_t) is decomposed into

a pure within-industry productivity component: The change in the industry productivity weighted by the relative employment size of the industry in the previous period

$$s_{i,t-1} * \Delta y_{i,t}, \tag{2}$$

static shift-effect, which is the change in unemployment share weighted by the productivity level in the previous period

$$y_{i,t-1} * \Delta s_{i,t}, \tag{3}$$

a dynamic shift-effect, which is the product of changes in employment share and productivity level.

$$\Delta y_{i,t} * \Delta s_{i,t} \tag{4}$$

Such that the aggregate productivity growth ($\dot{y}_t$) can be stated as shown in equation (5).

$$\dot{y}_t = \frac{\Delta y_t}{y_{t-1}} = \sum \frac{s_{i,t-1} * \Delta y_{i,t}}{y_{t-1}} + \sum \frac{y_{i,t-1} * \Delta s_{i,t}}{y_{t-1}} + \sum \frac{\Delta y_{i,t} * \Delta s_{i,t}}{y_{t-1}} \tag{5}$$

The first term is thereby the pure, or within-industry effect, on which this approach focuses. It will be positive if labor productivity in an industry i increases, while the size of its influence on aggregate productivity depends on the relative of size of the respective industry in terms of employment, i.e., hours worked.

The second and third terms reflect the static and dynamic reallocation of workers and together they reflect the reallocation effect. The static shift-effect (second term) will be negative if employment shifts to sectors with lower relative productivity and sectors with higher productivity lose employment. The dynamic shift-effect (third term) captures the employment growth in sector i with respect to its productivity growth. If employment over all sectors tends to shift to sectors with higher productivity growth, then this term will be positive.

3.1.Data and data quality issues

The level of sector decomposition increases the amount of reallocation effects and therefore the accuracy of the analysis. Vries et al. (2021) state respectively: “At a higher level of industry grouping, the potential to pick up the effects of movements of output or employment across industries is less compared to a lower level of industry groupings" (Vries et al., 2021, p.552). For Germany, 63 industry groupings have been defined, which compared to the initial analysis from Vries et al. (2021) is a quite satisfying level of level of subdivision. Vries et al. (2021) defined 66 industry groupings for the UK, 50 for France and 48 for the US. All data from Germany was drawn from the German Statistical Office and are part of SNA. Appendix-Table A2 indicates the specific data tables within the SNA and the assumptions made for the derivation of the output and employment variables at an industry-level for all sectors were sufficient data was available for Germany.

The distribution of the output indicator, i.e. real value-added, had to be approximated through the distribution of turnover or, in some cases, the turnover index (with 100=2015), in order to obtain industry level data (i.e. 2-digit ISIC rev. 4 classification) per quarter. The respective revenue shares of 2-digit industries were then multiplied with the overall sector real value-added data. For instance; real value-added on a quarterly basis is available for the wholesale, transportation and hospitality sector (1-digit ISIC classes G-I). This sector is comprised of 10 industry-groupings (2-digit ISIC classes 45-47, 49-53 and 55-56). Real value-added on a quarterly basis (2-digit classes) is not available from the German National Statistical Office and neither is turnover data in monetary units. Therefore turnover-index data is taken to derive the turnover shares of each industry-grouping with respect to the turnover in the whole sector (G-I). These shares are then multiplied with real value-added on sector level (G-I). If turnover in monetary terms on a quarterly basis and on industry-level was available for a certain sector, then this output approximator was taken instead of the turnover index (since the conversion of the turnover index to monetary values required further assumptions, as explained below).

Quarterly or monthly hours worked on an industry-level (2-digit) were available in many cases and did not need further approximation. However, in some cases, the same approximation method as for the output indicator had to be applied for the input indicator, i.e., hours worked. The quarterly employment index (with 100=2015) served as an approximation in these cases.

This approach might introduce some inaccuracies, especially when only the turnover index (or employment index), instead of turnover in monetary terms (or hours worked), has to be used to approximate output (input) distribution among industry-groupings. The latest available turnover index and employment index data from the German National Statistical Office takes 2015 as a base year. However, turnover and employment data for 2015 on a 2-digit level is only available on annual rather than quarterly basis. Therefore, an additional assumption had to be made in these cases, namely that annual revenue and employment in 2015 is distributed equally across all quarters in each industry. As mentioned, this level of assumption only had to be made for some industry groupings, as indicated in Appendix Table A2.

The real estate industry (ISIC rev.4 class L) was excluded completely, following Vries et al. (2021). A large part of its value-added comes from owner-occupied dwellings, which do not relate to any workforce activity. Since this part of the real estate sector could not be identified, separated and removed, the whole real estate sector is excluded.

3.2.Taxonomies

Three taxonomies are applied in order to categorize the 63 industries that could be defined for Germany. The assignation of a specific industry to a certain taxonomy-category follows, in most cases Vries et al. (2021). All industry groupings and the respective taxonomy assignation can be found in Appendix Table A3. There are some differences to the categorization of the original approach, which are due to data availability affecting industry grouping. These deviations are marked within the table (*).

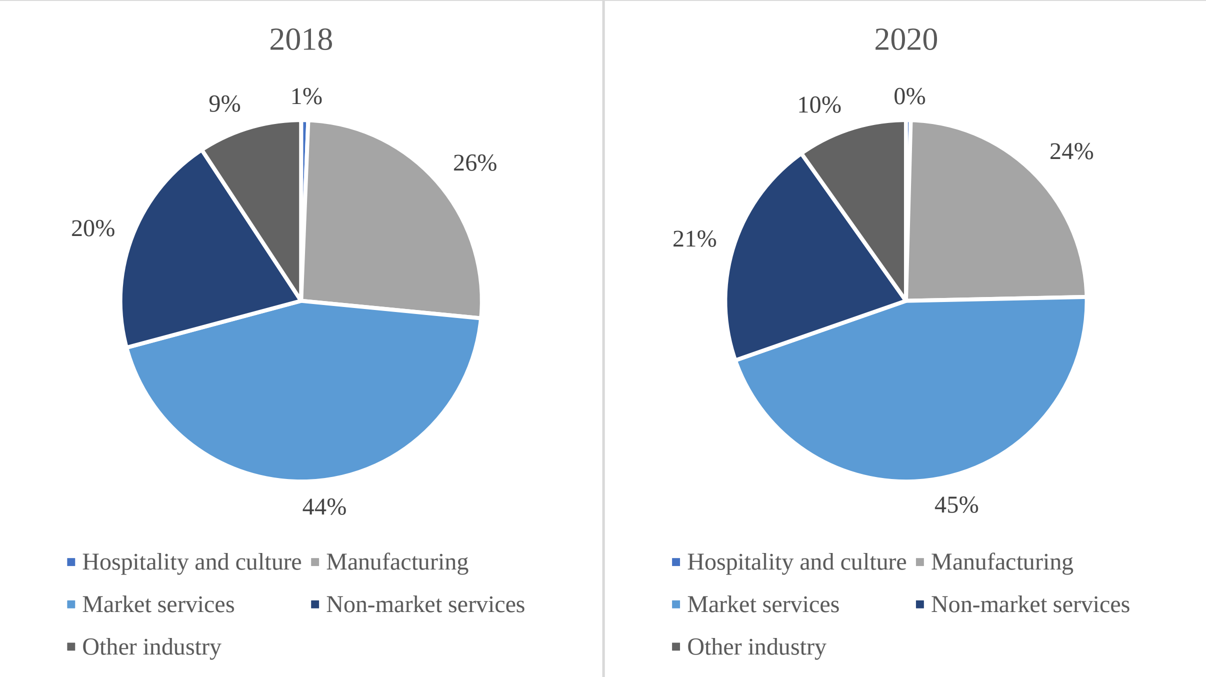
The first taxonomy groups industries in similar types of activities, which results in the distinction of five sectors: hospitality and culture, manufacturing, market services, non-market services and other industries. Market services exclude the hospitality and culture, as well as the real estate industry. Other industries include agriculture/forestry/fishing, mining and quarrying, electricity/gas/steam and air conditioning supply, water supply/sewerage/waste management and construction.

The second taxonomy clusters the work-from-home (WFH) intensity of an industry (high, medium, low). Again, the classification of Vries et al. (2021) is applied, which is based on data of the American Time Use Survey (ATUS) and averaged values of the prevalence of WFH between 2011-2019[3]. This follows the assumption that WFH patterns amongst industries are similar in Germany as in the US; Vries et al. (2021) make the same assumption for France and the UK. Only this way does cross-country data become comparable. However, for Germany, there is a second source for WFH intensity within industries. The High-frequency Online Personal Panel (IAB-HOPP) surveyed individuals from May 2020 to March 2021 regarding their work-life situation during the Covid-19 pandemic. The questionnaires included topics such as employment trends, short-time work (furlough schemes), working hours, home office and child care (Haas et al., 2021). As soon as the data of the survey are made accessible to the authors, its results will be compared to the WFH intensity categorization within this analysis.

The degree of digital intensity in an industry is categorized in the third taxonomy (above average, below average, digital producing). The categorization also follows Vries et al. (2021) who adopted the digital intensity taxonomy developed by OECD (Calvino et al., 2018) and have used it in earlier papers (van Ark et al., 2019; van Ark et al., 2021).

[3] For more information, see Vries et al. (2021), p.553

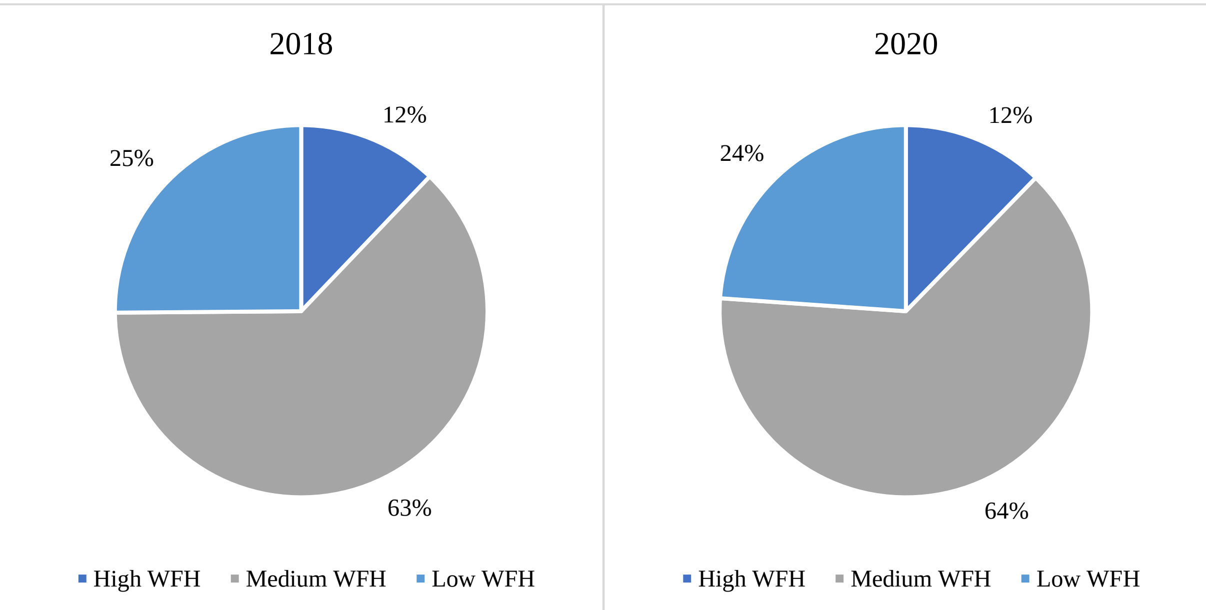
Figure 1: Taxonomy 1 (Sectors) - Distribution of value-added in €bn before and during the pandemic



Sources: Own calculation and representation based on Taxonomies of Vries et al (2021) value added data from Statistisches Bundesamt (Destatis) 2021) (for more information see Appendix Table A2).

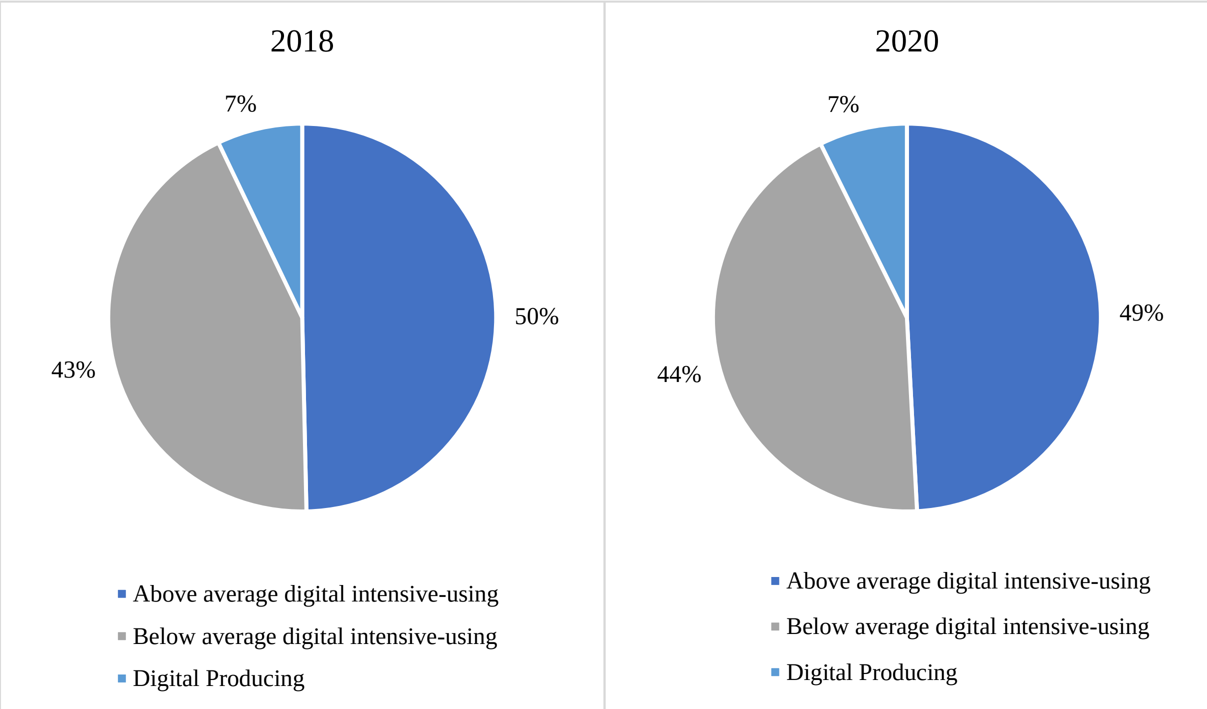
Figures 1, 2 and 3 display the respective value-added share for each taxonomy and respective category during, before and after the pandemic. Market services make up for the largest output share in Germany, even increasing over the course of the pandemic. Slight reductions of output market shares can be observed for the manufacturing sector and the hospitality and culture sector, which had also had by far the smallest market share before the pandemic.

Figure 2: Taxonomy 2 (WFH intensity) - Distribution of value-added in €bn before and during the pandemic



Sources: Own calculation and representation based on Taxonomies of Vries et al (2021) value added data from Statistisches Bundesamt (Destatis) 2021) (for more information see Appendix Table A2).

Figure 3: Taxonomy 3 (Digital intensity) - Distribution of value-added in €bn before and during the pandemic



Sources: Own calculation and representation based on Taxonomies of Vries et al (2021) value added data from Statistisches Bundesamt (Destatis) 2021) (for more information see Appendix Table A2).

Output in industries with differing WFH intensities did not change much during the course of the pandemic. As previously mentioned, it should be borne in mind that the WFH categorization was done through ATUS data collected between 2011 and 2019. Above average digital intensive-using industries accounts for the largest share of output production in Germany, somewhat reducing its value-added share in 2020. Surprisingly, the market share lost by above average digital intensive using industries was taken over by the below average digital intensive using industries over the course of the pandemic. The shift was so small however, that this might be due to common market fluctuations. Surprisingly, digital producing industries did not increase their value-added between 2018 and 2020. These first impressions regarding the taxonomies are further analyzed through the shift-share analysis.

4. Results

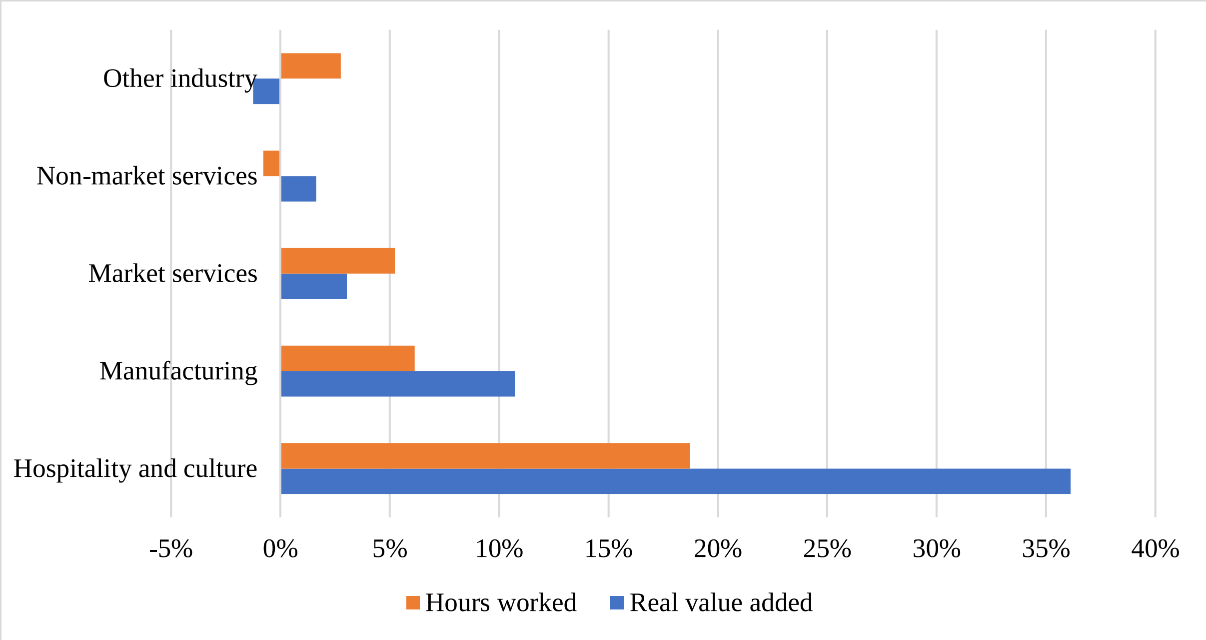
4.1. Sector-taxonomy results

Real value-added and hours worked shares are by far highest in the market services sector, productivity, however, is highest in the manufacturing sector which is largely representing the tradables sector. This confirms the commonly known strength of the German economy in manufacturing products with a high final value. There are only very small differences between the two pre-pandemic years. However, even in 2020 there are only minor, if any, reductions in market size or productivity across sectors. Between 2019 and 2020 productivity levels decreased - contrary to what might be expected - most in the manufacturing sector, followed by a reduction in the hospitality and culture sector and non-market services.

In 2021, however, the manufacturing sector recovered in terms of output, while the hospitality and culture sector kept decreasing output. Productivity in the market services sector and other industries even experienced a slight increase. In the much-discussed hospitality and culture sector productivity levels already decreased between the pre-pandemic years 2018 and 2019, even though a rather large reduction in market share and hours worked can be observed between 2019 and 2020, as well as in 2021. Hours worked only experienced an increase in other industries and non-market services between 2018 and 2021, while in all other sectors hours worked decreased between 2018 and 2020, with the hospitality and culture sector being the negative leader. Hours worked in manufacturing and market services increased again in 2021.

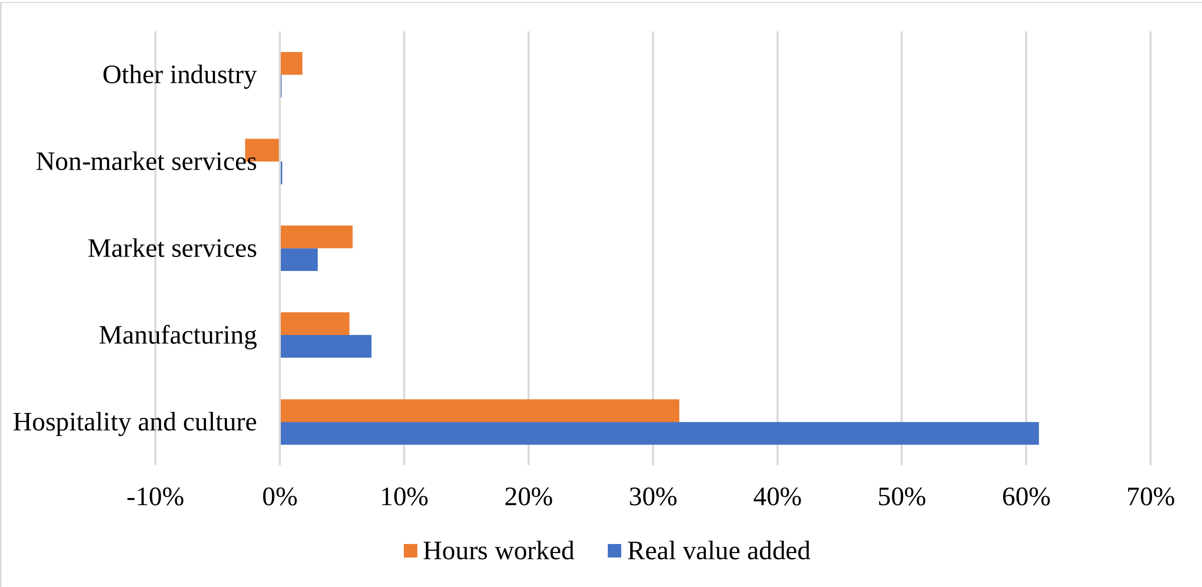
When looking at the development of the total values of real value-added and hours worked between 2018 and 2020 (Figure 4), as well as the comparison between the first quarter of 2018 and 2021, it becomes clear that the furlough programs of the German government might have contributed to a less severe reduction in hours worked. Between 2018 and 2020, three of five sectors experienced a less significant decrease of hours worked than value-added. The non-market services sector even saw an increase in hours worked, while reducing real value-added. Hours worked, however, decreased more than output in other industries, the market services sector and the manufacturing sector. Within the first half year of 2018 and 2021 the figures for the rates of decline are much larger than between the years 2018 and 2021, especially in the hospitality and culture sector. Again, hours worked in non-market services, manufacturing and the hospitality and culture sector decreased by less than real value-added, indicating the effectiveness of the German furlough programs.

Figure 4: Rate of decline of real value-added and hours worked between 2018 and 2020



Sources: Own calculation and representation based on Taxonomies of Vries et al (2021) value added data from Statistisches Bundesamt (Destatis) 2021) (for more information see Appendix Table A2).

Figure 5: Rate of decline of real value-added and hours worked between the first half year of 2018 and 2021



Sources: Own calculation and representation based on Taxonomies of Vries et al (2021) value added data from Statistisches Bundesamt (Destatis) 2021) (for more information see Appendix Table A2).

Compared to the productivity level results for France, the UK and the US in 2019 (Vries et al., 2021), Germany's productivity level in the manufacturing sector is higher than in all of the other three countries, while productivity levels in the hospitality and culture sector as well as for non-market services are lower. It should be noted that Vries et al. (2021) used nominal value-added as an indicator of market size, while the authors of this paper used real value-added, such that a comparison between different years, as done in Table 2, becomes viable. However, since inflation between 2018 and 2020 was still rather low, a country-wise comparison still seems reasonable.

In the pre-pandemic year of 2019, almost all sectors still showed small, positive within-industry productivity growth (see Table 3). Only in the manufacturing sector did within-industry productivity slightly decrease, mostly due to productivity losses in the coke and petroleum manufacturing industries. In 2020, three of the five sectors had a negative impact on total within-industry productivity, with the manufacturing sector being the negative leader. This was again mainly due to output reductions in the coke and petroleum manufacturing industries (while hours worked stayed somewhat constant), as well as productivity and hours-worked reductions in the manufacture of motor vehicles. The non-market services, namely public service providers, education and health industries, also performed negatively, as well as the hospitality and culture sector (due to large productivity losses in accommodation). In 2021, only the hospitality and culture sector continued to perform negatively, however to a smaller extent. Other industries, particularly the construction industries, at that time have also had a negative impact on total within-industry productivity. Even though the electricity, gas, steam and air conditioning supply industries contributed positively to within-industry productivity, the extent of hours worked reductions in the key construction industry seems to outweigh this positive performance.

The manufacturing sectors performed especially strikingly in 2021: While its within-industry productivity growth was large and negative in 2020, it increased to the largest positive number of all sectors in 2021. This was mainly due to the performance of the chemicals industry, where output increased while hours worked decreased. Moreover, the basic metal and the motor vehicle industries contributed positively to within-industry productivity. In the automotive sector, declining problems with imported chips seem to have supported productivity growth in 2021. Non-market services also recovered and showed a small positive within-industry effect.

Table 2: Output shares, hours worked shares and productivity levels in Germany (2018-2020) using taxonomies.

	Real value-added share (%)				Hours worked share (%)				*Productivity level (total economy = 1.0)*			
	2018	***2019***	***2020***	***2021[a]***	***2018***	***2019***	***2020***	***2021[a]***	***2018***	***2019***	***2020***	***2021[a]***
Sectors												
Hospitality and culture	0.6	0.6	0.4	*0.2*	4.5	4.4	3.8	*3.1*	0.14	0.14	0.11	*0.08*
Manufacturing	25.9	25.5	24.2	*25.4*	18.3	18.1	17.9	*18.1*	1.42	1.40	1.35	*1.40*
Market services [b]	44.3	44.6	45.0	*44.4*	43.0	43.0	42.6	*42.4*	1.03	1.04	1.06	*1.05*
Non-market services	19.9	20.0	20.5	*20.8*	24.5	24.8	25.8	*26.4*	0.81	0.81	0.79	*0.79*
Other industry [c]	9.3	9.2	9.8	*9.2*	9.7	9.6	9.9	*10.0*	0.95	0.96	0.99	*0.92*
Working from home (WFH) intensity												
High WFH	12.1	12.3	12.3	*12.2*	12.8	12.8	12.7	*12.5*	0.95	0.96	0.97	*0.97*
Medium WFH	62.8	62.9	63.8	*63.7*	58.9	59.0	60.1	*60.6*	1.07	1.07	1.06	*1.05*
Low WFH	25.1	24.8	23.9	*24.1*	28.3	28.1	27.2	*26.9*	0.89	0.88	0.88	*0.90*
Digital Intensity												
Above average digital intensive-using	49.6	49.8	49.2	*48.7*	44.0	43.8	43.1	*42.9*	1.13	1.14	1.14	*1.14*
Below average digital intensive-using	43.2	43.0	43.5	*43.7*	51.2	51.3	51.9	*52.0*	0.84	0.84	0.84	*0.84*
Digital Producing	7.1	7.2	7.3	*7.6*	4.8	4.9	5.0	*5.1*	1.50	1.47	1.47	*1.48*

Note: Productivity is measured as the ratio of real value-added and hours worked.

[a] At the time when this analysis was made, no data (real value-added and hours worked) were yet available for the last two quarter of 2021. In order to still evaluate the performance of the economy in 2021, at least in the first two quarters, the following assumption was made: Real value-added in each of the last two quarters (Q3 and Q4) of 2021 is equal to real value-added in 2021 (Q1+Q2) / 2. The same assumption was applied to hours worked.

[b] Market services exclude the hospitality and culture, as well as the real estate industry.

[c] Other industries include agriculture/forestry/fishing, mining and quarrying, electricity/gas/steam and air conditioning supply, water supply/sewerage/waste management and construction.

Sources: Own calculations based on data from Destatis (for more insight on the sources, see Appendix Table A2).

4.2. Working-from-home taxonomy results

Increasing WFH intensity was found to be an effective measure against the spread of the Covid-19 pandemic (Alipour, Fadinger, & Schymik, 2021; Gabler et al., 2021; Kriegel & Hartmann, 2021). The working population survey of the Hans Böckler Foundation which took place in four rounds between 2020 and 2021 showed that before the pandemic (here: January, 2020), only 4% of the working population in Germany worked exclusively from home and 13% changed between home office and other places of work (mobile or from the office). In April 2020, 27% of the working population reported working exclusively from home and 17% had changing places of work (Emmler & Kohlrausch, 2021). These numbers went down during the summer months of 2020 but increased again in January 2021. This was also the month in which the German government introduced the obligation to work from home, such that all employers had to offer the opportunity to workers to work from home if there were no operational reasons impeding it. This regulation was extended in November 2021 until March 2022. However, this regulation did not lead to a substantial increase of WFH within the German population, as three surveys show. Through its monthly business cycle survey, the ifo-Institute started a detailed survey (vgl. Alipour, Falck, et al., 2021) regarding the usage of home office by employees in February 2021, surveying approximately 7,600 firms (which together employ approximately 8% of all employees in Germany (Corona Datenplattform, 2021)). The infas Institute for Applied Social Sciences performed two surveys on WFH activity in Germany. Since the beginning of the pandemic, infas has performed monthly surveys on the home office activities including approximately 600 persons employed (Corona Datenplattform, 2021). Since March 2021, infas additionally started a larger home office survey, including approximately 7,000 persons employed (Corona Datenplattform, 2021). Regarding these three surveys, in February 2021 between 22-30% of the persons employed worked from home[4]. By January 2022 the ifo institute reported 28% of persons employed who work, at least partly, from home. Despite some variation during the summer of 2021, the work-from-home quota seems rather constant. The ifo institute, however, sees much more potential for the expansion of home office activities. As previously mentioned , Alipour et al. (2020) estimate that 56% of all jobs in Germany could be relocated from the office to the worker's home.

The home office quota differs substantially across industries, position and the level of education of the person employed (Alipour et al., 2020; Corona Datenplattform, 2021; Emmler & Kohlrausch, 2021). The share of high- and mid-level government officials ("Beamte im gehobenen und höheren Dienst") working from home in 2021 was, with 49%, the highest amongst all occupational groups, followed by employees in executive positions (32%) and simple employees (21%) (Corona Datenplattform, 2021). The monthly business cycle survey from the ifo institute from January 2022 shows that 39% of people employed in the services sector stated working, at least partly, from home, while this number amounts to 20% of both the manufacturing as well as the wholesale sectors, to 8% in the key construction sector and to 7% in the retail sector (ifo Institut, 2022).

Even though the shift-share analysis does not capture the extent of people who increased their working hours from home during the pandemic without changing their industry of work, it does

[4] The differing percentages result from a different definition of home office between the infas and ifo. The ifo survey asked employers about the percentage of employees that work at least partly from home. The infas survey asked employees if they work completely of mostly from home (Corona Datenplattform (2021)).

shed light on the productivity of industries with different extents of WFH intensities. It should be clear, however, that once industries were categorized to a certain WFH intensity (e.g., low WFH), it stays fixed throughout the whole observation period. What can be determined however is the productivity movements of industries with different WFH intensities.

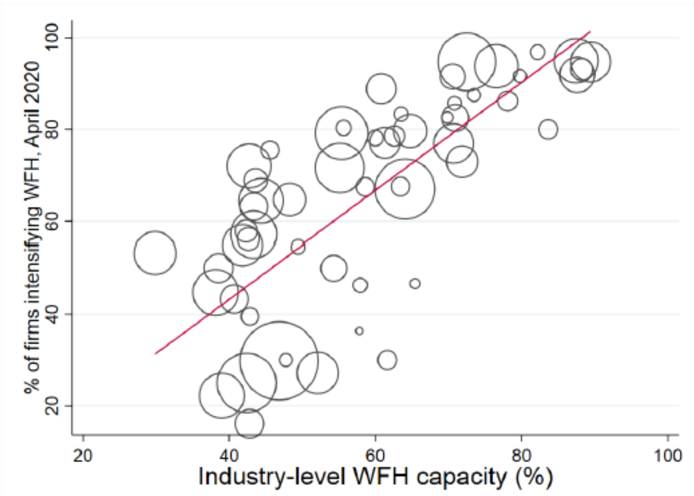
Medium WFH professions make up the largest share of output generation and hours worked in Germany, followed by low WFH. While low WFH and high WFH lost in terms of the share of hours worked each year between 2018 and 2021, medium WFH increased its share of hours worked. According to that, productivity levels decreased during the pandemic in medium WFH professions, while experiencing a slight increase in high WFH and low WFH professions. Especially in low WFH industries this might rather be a trend than an effect of the pandemic. In summary, it can be observed that the productivity level increased in high WFH industries, which might have been expected due to improved technology. However, the productivity increase is rather small.

In the pre-pandemic year of 2019, industries of all three taxonomies (high WFH, medium WFH and low WFH) contributed positively to total within-industry productivity growth, even though the effects where small (0-0.1%) (see Table 3). In 2020, productivity growth was then negative in both the medium WFH industries and low WFH industries, while it was very small but positive in high WFH industries. Within the low WFH industries, especially the manufacturers of motor vehicles contributed negatively, with a reduction in both productivity and hours worked. Furthermore, air transport, food and beverage services, accommodation and manufacturing of machinery and equipment contributed negatively to within-industry productivity growth among the low WFH industries. The construction sector, on the other hand, contributed positively. The medium WFH industries contributed even more to the overall negative performance of within-industry productivity in 2020 than the low WFH industries (especially travel agencies and tour operators, public service providers such as education and health, as well as manufactures of coke). The extent of the negative performance of the travel agency and tour operator industry was mainly due to a sharp reduction in productivity, while hours worked stayed almost constant between 2019 and 2020. The same applies for the manufacturer of coke. Only the public service providers (especially education and health) experienced a rather large drop in hours worked, additionally to a small decrease in productivity. The high WFH industries contributed a positive impact close to zero to the total within productivity effect, while there was also not much variation of the within-industry effect among the assigned industries. In 2021, within-industry productivity increased in all of the three groupings, showing the general recovery of most industries within the first two quarters of 2021 with vaccinations and extensive anti-Covid19 measures (such as distancing and masks) being used customarily. Especially in the low WFH industries within-industry productivity increased, showing the absence of lockdowns and input shortages, which were in place during the pandemic. Especially the manufacturers of vehicles, air transport, food and beverage services and accommodation recovered within this category.

4.3. Digital usage taxonomy results

When Alipour et al. (2020) estimated the WFH potential in Germany they found that there is a large variation in WFH capacity across industries. Among other factors, such as the level of urbanization or the density of population, the level of digitalization substantially influences the WFH capacity of industries. While the authors estimated the average WFH capacity in Germany at 56%, it amounts to almost 90% in the financial and insurance sector and to 85% in the ICT sector (both highly digitalized). However, before the pandemic, occasional or frequent WFH was mostly applied in the education and ICT sector. Alipour et al. (2020) continue their analysis by comparing WFH capacity estimates with actual WFH outcomes in the first wave of the pandemic in Germany in April 2020. The database for actual WFH outcome is the monthly ifo Business Survey, where approximately 9,000 managers of German companies are asked about the applied WFH intensity in their company. Figure 6 shows the outcome of the comparison of industry-level shares of firms relying on WFH in April 2020 against the estimated WFH capacity measure. The correlation is 0.76 and highly statistically significant. The capacity index explains around 58% of pandemic-induced WFH variation across industries (Alipour et al., 2020).

Figure 6: Industry-level WFH capacity vs. actual WFH intensity



Sources: Alipour et al., 2020, p.14, graph is used with kind permission of the authors

It might therefore to be expected that the shift-share analysis shows an increase in productivity in highly digitalized industries, especially those who already applied WFH before the pandemic, since they had less adjustment costs and the technology was already in place. One could also expect a shift of employment towards industries with higher WFH capacities, which however would only be reflected in an increase of hours worked. When looking at pure productivity and hours worked measures (Table 2), however, this development cannot be observed.

While above average digital-intensive using industries produce the largest share of value-added in Germany, hours worked are highest in below average digital-intensive using industries. This points to the substitution of technology for labor, independently of the effects of the pandemic. Digital-producing industries, however, had the highest levels of productivity between 2018 and 2021. Productivity in all categories stayed rather constant when comparing the pre-pandemic years with 2020 and 2021. Only the digital-producing industries experienced a reduction in the productivity share, however seeming to recover in 2021.

As regards transatlantic technology transfer from the US to the EU, one may point out that the ICT sector has been of particular relevance in the 1990s and hence the digital sectors are relevant here (Ark et al., 2003). Given the fact that transatlantic digital technology transfers between the US and the EU were not fully implemented then – and possibly in the decade after – there should be large opportunities for digital catching-up effects in Germany. This could, in turn, along with the Corona-deregulation-enhanced expansion of IT investment of firms (and households) explain the relatively strong productivity growth of the digitally-intensive sector. It should be noted in addition that, according to van Ark et al. (2008), the relative technology catching-up effect of the EU reached a peak in 1995. As regards sectoral transatlantic transfers, both industry and the service sector have played a crucial role (Ortega-Argilés et al., 2014). With respect to the impact of joint multinational R&D intensification in OECD countries, 2005 saw critical data after which innovation dynamics seem to have slowed down (Jungmittag, 2020).

Within-industry productivity (Table 3) was slightly negative in below average digital-intensive and digital-producing industries in the pre-pandemic year 2019. Digital-producing industries recovered in 2020 and 2021, generating positive productivity growth. The below average digital-intensive industries showed a sharp increase of within-industry productivity between 2020 and 2021. This was mainly due to the recovering of the electricity, gas, steam and air conditioning industry, as well as the public service providers, especially education and health. In both industries, productivity increased while hours worked decreased.

The above average digital-intensive industries did not outperform the other two categories during the pandemic as might have been expected. In 2020, within-industry productivity was even slightly negative, which was caused by negative within-industry productivity growth in the travel and tour operator industries in particular, as well as the manufacturing of motor vehicles and trailers. In 2021, above average digital-intensive industries showed positive growth. The finance and insurance industry stayed on its slightly positive within-industry growth path from 2020. However, the main drivers of the positive growth in this category were wholesale trade, other cooperate services[5] and the manufacturers of motor vehicles. Retail trade, on the other hand, decreased productivity and hours worked between 2020 and 2021, resulting in slightly negative within-industry productivity growth (though the largest decrease within the above average digital-intensive using industries). A survey among German firms has shown that the Corona pandemic has stimulated firms in all sectors to raise ICT investment (SVR, 2021).

From the within-industry growth analysis it becomes clear that digital-intensive using industries did not outperform industries with less digital intensity. In fact, below average digital-intensive industries performed better in 2021 than the above average digital-intensive industries. The advantage in experience in using digital tools and the already existing technical equipment did not seem to have been an advantage during the course of the pandemic. Digital-producing industries performed well throughout the pandemic, but there was no considerable productivity growth or variation in hours worked in any industry in this category. The digital-producing industry naturally has benefitted from the Corona-related digital expansion of the economy.

[5] Other cooperate services comprise activities of head offices and management consulting, scientific research and development, veterinary activities, rental and leasing activities, as well as services to buildings and landscape activities.

Table 3: Decomposition of within-industry productivity effects using three taxonomies, annual average (% change)

	2019	2020	2021[a]
Aggregate productivity growth	0.3	-0.6	2.2
Within industry productivity	**0.4**	**-0.8**	**1.7**
Static effect	-0.1	0.2	0.5
Dynamic effect	0.00	0.0	0.0
Sectors			
Total within-industry effect	**0.4**	**-0.8**	**1.7**
Hospitality and culture	0.0	-0.2	-0.1
Manufacturing	-0.2	-1.0	1.4
Market services [b]	0.5	0.5	0.6
Non-market services	0.0	-0.5	0.2
Other industry [c]	0.1	0.3	-0.5
Work-from-Home intensity			
Total within-industry effect	**0.3**	**-0.8**	**2.2**
High WFH	0.1	0.0	0.4
Medium WFH	0.1	-0.5	0.8
Low WFH	0.0	-0.3	1.0
Digital intensity			
Total within-industry effect	**0.3**	**-0.8**	**2.2**
Above average digital-intensive	0.5	-0.1	0.9
Below average digital-intensive	-0.2	-0.3	1.1
Digital producing	-0.1	0.0	0.2

[a] At the time when this analysis was made, no data (real value-added and hours worked) were yet available for the last two quarters of 2021. In order to still evaluate the performance of the economy in 2021, at least in the first two quarters, the following assumption was made: Real value-added in each of the last two quarters (Q3 and Q4) of 2021 is equal to real value-added in 2021 (Q1+Q2) / 2. The same assumption was applied to hours worked.

[c] Market services exclude the hospitality and culture, as well as the real estate industry.

[d] Other industries include agriculture/forestry/fishing, mining and quarrying, electricity/gas/steam and air conditioning supply, water supply/sewerage/waste management and construction.

5. Conclusion and economic policy outlook

Within-industry productivity growth is a strong analytic element in the Corona recession. If the comparison of the first and the second quarter 2021 is an indicator for the medium-term adjustment of the German economy under Corona, one may be rather optimistic with respect to productivity growth; although with an effective rehiring of workers many firms using government labor retention schemes will employ at the margin workers with a below-average productivity. If, however, the additional workers' input goes along with more hours worked of those already active – and often using WFH arrangements – productivity growth could still be considerable if there are sufficient digital network effects. Germany's net export performance in the medium term could benefit from this (and it also will benefit from the removal of bottlenecks in the field of intermediate products). It will be interesting to analyze in future research the performance of unit labor costs and hourly labor productivity growth in Germany's main trading partners in the EU.

As regards wage bargaining in Germany, the standard compromise formula between employer and trade unions is based on “productivity growth plus expected inflation rate”. To the extent that WFH goes along with short-term productivity growth but only modest medium- and long-term productivity growth, trade unions’ collective bargaining strategies could be too aggressive, since the role of rising working hours and rising employment is not adequately taken into effect. The unemployment rate could increase (an effect which, however, could be cushioned in the short and medium term by unexpected rises of the inflation rate and Philips curve effects, respectively). This risk should not be overestimated as a medium-term challenge, since below-average digital sectors generate relatively high productivity growth are not the key wage bargaining sectors in Germany. Rather, the above average digital sectors’ firms are the core players in collective bargaining.

The digital economic policy of both the German federal government and regional governments should consider the implications of the analysis presented. The shift-share analysis which is popular in regional economic analysis could certainly be used for regional economic sectoral analysis. This also applies to a potential comparative analysis of EU regions and questions related to the use of EU Corona funds.

The analysis has shown that not only highly digitized sectors generate high labor productivity growth in the Corona setting. One plausible conclusion is that medium digitalized sectors where pre-pandemic WFH arrangements were rather rare could take advantage of a naturally enforced pandemic-induced experiment and. Learning-by-doing effects could reinforce these effects in the medium-term. Long-term labor productivity growth from the pandemic-related expansion of WFH will allow part of firms to use less physical capital (office space) than in the pre-pandemic environment. However, it is not yet clear if new work-from-home activities will be a permanent arrangement in most professions or not. Survey figures for the US as well as theoretical analysis (Bick et al., 2022) allows one to expect that the adoption of new working arrangements will, to a certain extent, be persistent; the authors argue, based on a quantitative model matched to survey data, that about twice as many workers will realize work-from-home full-time in the post-pandemic period as compared to the pre-pandemic period and that roughly one in every five instead of seven workdays will be on a work-from-home basis in the future (the model’s predictions are fairly consistent with survey response evidence on workers’ own WFH-expectations in the future). As regards the latter aspects in a transatlantic perspective, one might expect some minor differences between the US and Germany: US subsidiaries in Germany can be expected to push for more WFH post-pandemic; certainly, in sectors with WFH-related efficiency gains in the United States. Moreover, German multinationals’ subsidiaries in the US will reflect positive experiences with more WFH activities in the United States. While some transatlantic differences in WFH preferences of workers cannot be ruled out without conducting further research, one may, however, point out that US workers with typically longer commuting times to the workplace at the office/factory stand to gain more in terms of welfare from more WFH activities than workers in, for example. Germany who on average have a somewhat shorter commute to and from work.

Comparing EU countries with the US could be an interesting aspect for future research since the higher US lay-off rate of workers should reinforce – compared to the EU – cross-sectoral labor re-allocation and thus labor productivity growth in certain sectors. As the IT-producing sector is positively affected by the rise of WFH arrangements under Corona conditions, the natural long-term winner of the Corona-related structural adjustment is the IT sector. This should hold both for Germany and other leading OECD countries. If WFH arrangements generate additional innovation dynamics in the services sector in the long run, countries with a relatively large service sector are bound to benefit relatively strongly from the recession. Here only further research can bring adequate findings.

At the bottom line, the productivity growth effects in Germany are not so much a puzzle in sectoral terms, rather the taxonomy used can partly explain the observed productivity patterns. It would be useful if the OECD could establish a broad international research project along these lines. As emphasized here, such a study could also be the starting point for future research on Corona effects and the Rybczynski theorem.

If one follows Bloom et al. (2020), the world economy and the digital sector have developed in such a way that the creation of new ideas and the related exponential growth rates are more difficult to find. In an increasingly digital economy, one may critically raise the question of output measurement: most of the highly valuable data generated in today's digital-intensive firms and the overall economy in OECD countries and newly industrializing countries are not covered as value-added in the traditional System of National Accounts.

Appendix

Appendix Table A1: Computer endowment in 2017 - national data vs. ITU data

Country	Percentage of households with a computer (national data)	Percentage of households with a computer (ITU)***
France	84*	78
Germany	93*	88
United Kingdom	92*	88
United States of America	91**	83

Sources: *Eurostat (dataset: ISOC_CI_CM_H). **US Census Bureau (American Community Survey). ***ITU World Telecommunication/ICT Indicators 2020 database (Households with a computer by urban-rural location and household composition)

Appendix Table A2: Data sources for the derivation of input and output approximations for each industry grouping

Industry	Output Approximation (for quarterly sector gross value-added)	Input Approximation (for quarterly sector hours worked)	Dataset
B-C	Revenue, monthly, 2019 2 industries missing (B-07 and B-09) B-05, no revenue available for 2020. Therefore, revenue in 2020 is assumed to be the same as in 2021. B-07 and B-09: revenues are assumed to be zero	Hours worked, monthly, 2019 2 industries missing (B-07 and B-09 B-05, no hours worked available for 2020. Therefore, hours worked in 2020 is assumed to be the same as in 2021. B-07 and B-09: hours worked are assumed to be zero	Destatis 42111-0004
D-E	Revenue, annual, 2019 → split into quarters (only firms with 20 or more employees included)	For D35 and E36: Hours worked, monthly (only for companies with from 20 employees and more) For E37-39: Employees, annual, 2019 Monthly hours worked per employee are assumed to be the same as in E36. The monthly hours worked for E37-E39 can therewith be derived. →aggregated to quarters (only firms with 20 or more employees included)	Output: 43221-0001 Input D35-E36: Destatis 43111-0002 Input E37-39: Destatis 43221-0001 + 43111-0002

F	Revenue, monthly, 2019-2021 for the key construction industries (F-41.2, F-42, F-43.1 and F-43.9) → split into quarters (only firms with 20 or more employees included) Revenue, quarterly, 2019-2021 for the subconstruction industry (F-43.2 and F43.2) (only firms with 20 or more employees included) Assumption: For 41.1 (developing industry) we assume the revenue to be zero over the examination period.	Hours worked, quarterly, 2019 for the key construction industries (F-41.2, F-42, F-43.1 and F-43.9) → split into quarters (only firms with 20 or more employees included) Hours worked, quarterly, 2019-2021 for the subconstruction industry (F-43.2 and F43.2) (only firms with 20 or more employees included) Assumption: For 41.1 (developing industry) we assume the hours worked to be zero over the examination period.	Bauhauptgewerbe (key construction industry): Destatis 44111-0004 Ausbaugewerbe (subconstruction industry): Destatis 44131-0001
G	Turnover index, quarterly, Q1-2019 to Q1-2021, Index: 100=2015, real. Annual turnover data in Mill. Euros from 2015 is taken as a basis to transform the turnover index into monetary values. Annual turnover data is divided by four to break it down to quarters. Assumption: In 2015, the annual revenue is distributed equally across all quarters in each industry.	Employment as a proxy for the quarterly distribution of hours worked. Quarterly employment index, 100=2015 for Q1-2019 to Q1-2021. Annual employment from 2015 is taken as a basis to transform the employment index into real values (people employed). Assumption: No quarterly variation in the number of people employed in 2015	Quarterly turnover index: G45: Destatis, 45214-0004 G46: Destatis, 45211-0004 G47: Destatis, 45212-0004 Quarterly employment index: G45: Destatis, 45214-0002 G46: Destatis, 45211-0002 G47: Destatis, 45212-0002 Annual turnover in Mill. Euro and employment for 2015: G45 and G46: Destatis, 45341-0001 G47: Destatis, 45341-0050
H	Turnover index, quarterly, Q1-2019 to Q1-2021, Index: 100=2015 (no real values available) Annual turnover data in Mill. Euros from 2015 is taken as a basis to transform the turnover index into monetary values. Annual turnover data is divided by four to break it down to quarters. Assumption: In 2015, the annual revenue is distributed equally across all quarters in each industry.	Employment as a proxy for the quarterly distribution of hours worked. Quarterly employment index, 100=2015 for Q1-2019 to Q1-2021. Annual employment from 2015 is taken as a basis to transform the employment index into real values (people employed). Assumption: No quarterly variation in the number of people employed in 2015	Quarterly turnover index: 47414-0001 Quarterly employment index: 47414-0008 Annual turnover in Mill. Euro for 2015: 47415-0009 Annual employment for 2015: 47415-0015

I	Turnover index, quarterly, Q1-2019 to Q1-2021, Index: 100=2015, real. Annual turnover data in Mill. Euros from 2015 is taken as a basis to transform the turnover index into monetary values. Annual turnover data is divided by four to break it down to quarters. Assumption: In 2015, the annual revenue is distributed equally across all quarters in each industry.	Employment as a proxy for the quarterly distribution of hours worked. Quarterly employment index, 100=2015 for Q1-2019 to Q1-2021. Annual employment from 2015 is taken as a basis to transform the employment index into real values (people employed). Assumption: No quarterly variation in the number of people employed in 2015	Quarterly turnover index: 45213-0004 Quarterly employment index: Destatis, 45213-0002 Annual turnover in Mill. Euro and employment for 2015: 45342-0001
J and M	Turnover index, quarterly, Q1-2019 to Q1-2021, Index: 100=2015 (no real values available) Annual turnover data in Mill. Euros from 2015 is taken as a basis to transform the turnover index into monetary values. Annual turnover data is divided by four to break it down to quarters. Assumption: In 2015, the annual revenue is distributed equally across all quarters in each industry.	Employment as a proxy for the quarterly distribution of hours worked. Quarterly employment index, 100=2015 for Q1-2019 to Q1-2021. Annual employment from 2015 is taken as a basis to transform the employment index into real values (people employed). Assumption: No quarterly variation in the number of people employed in 2015	Quarterly turnover index: 47414-0001 Quarterly employment index: 47414-0008 Annual turnover in Mill. Euro for 2015: 47415-0009 Annual employment for 2015: 47415-0015

* These categories were assigned by the author, deviating from the approach of Vries et al. (2021). This deviation from the original approach is caused by differences in the data availability on industry-grouping level.

Appendix Table A3:Industry groupings and taxonomies

ISIC rev. 4		Industry grouping	Sectors	Working from Home	Digital Intensity
A	01-03	Agriculture, forestry, fishery	Other industry	High WFH	Below average digital intensive-using
B	05	Mining of coal and lignite	Other industry	Medium WFH	Below average digital intensive-using
B	06	Extraction of crude petroleum and natural gas	Other industry	Medium WFH	Below average digital intensive-using
B	08	Other mining and quarrying	Other industry	Medium WFH	Below average digital intensive-using
C	10	Manufacture of food products	Manufacturing	Medium WFH	Below average digital intensive-using
C	11	Manufacture of beverages	Manufacturing	Medium WFH	Below average digital intensive-using
C	12	Manufacture of tobacco products	Manufacturing	Medium WFH	Below average digital intensive-using

C	13	Manufacture of textiles	Manufacturing	High WFH	Below average digital intensive-using
C	14	Manufacture of wearing apparel	Manufacturing	High WFH	Below average digital intensive-using
C	15	Manufacture of leather and related products	Manufacturing	High WFH	Below average digital intensive-using
C	16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	Manufacturing	Low WFH	Above average digital intensive-using
C	17	Manufacture of paper and paper products	Manufacturing	Low WFH	Above average digital intensive-using
C	18	Printing and reproduction of recorded media	Manufacturing	Low WFH	Above average digital intensive-using
C	19	Manufacture of coke and refined petroleum products	Manufacturing	Medium WFH	Below average digital intensive-using
C	20	Manufacture of chemicals and chemical products	Manufacturing	Medium WFH	Below average digital intensive-using
C	21	Manufacture of pharmaceuticals, medicinal chemical and botanical products	Manufacturing	Medium WFH	Below average digital intensive-using
C	22	Manufacture of rubber and plastics products	Manufacturing	Low WFH	Below average digital intensive-using
C	23	Manufacture of other non-metallic mineral products	Manufacturing	Low WFH	Below average digital intensive-using
C	24	Manufacture of basic metals	Manufacturing	Low WFH	Below average digital intensive-using
C	25	Manufacture of fabricated metal products, except machinery and equipment	Manufacturing	Low WFH	Below average digital intensive-using
C	26	Manufacture of computer, electronic and optical products	Manufacturing	Medium WFH	Digital Producing
C	27	Manufacture of electrical equipment	Manufacturing	Low WFH	Digital Producing
C	28	Manufacture of machinery and equipment n.e.c.	Manufacturing	Low WFH	Above average digital intensive-using
C	29	Manufacture of motor vehicles, trailers and semi-trailers	Manufacturing	Low WFH	Above average digital intensive-using
C	30	Manufacture of other transport equipment	Manufacturing	Low WFH	Above average digital intensive-using
C	31	Manufacture of furniture	Manufacturing	Medium WFH	Above average digital intensive-using
C	32	Other manufacturing	Manufacturing	Medium WFH	Above average digital intensive-using
C	33	Repair and installation of machinery and equipment	Manufacturing	Medium WFH	Above average digital intensive-using
D	35	Electricity, gas, steam and air conditioning supply	Other industry	Medium WFH	Below average digital intensive-using
E	36	Water collection, treatment and supply	Other industry	Medium WFH	Below average digital intensive-using
E	37	Sewerage	Other industry	Medium WFH	Below average digital intensive-using
E	38	Waste collection, treatment and disposal activities; materials recovery	Other industry	Medium WFH	Below average digital intensive-using

E	39	Remediation activities and other waste management services	Other industry	Medium WFH	Below average digital intensive-using
F	43.2,43.3	Finishing construction sector/Ausbaugewerbe (non-international denomination, German subdivision)	Other industry	Low WFH	Below average digital intensive-using
F	41.2,42, 43.1,43.9	Key construction industry/Bauhauptgewerbe (non-international denomination, German subdivision)	Other industry	Low WFH	Below average digital intensive-using
G	45	Wholesale and retail trade and repair of motor vehicles and motorcycles	Market services	Medium WFH	Above average digital intensive-using
G	46	Wholesale trade, except of motor vehicles and motorcycles	Market services	Medium WFH	Above average digital intensive-using
G	47	Retail trade, except of motor vehicles and motorcycles	Market services	Medium WFH	Above average digital intensive-using
H	49	Land transport and transport via pipelines	Market services	Low WFH	Below average digital intensive-using
H	50	Water transport	Market services	Low WFH	Below average digital intensive-using
H	51	Air transport	Market services	Low WFH	Below average digital intensive-using
H	52	Warehousing and support activities for transportation	Market services	Low WFH	Below average digital intensive-using
H	53	Postal and courier activities	Market services	Low WFH	Below average digital intensive-using
I	55	Accommodation	Hospitality and culture	Low WFH	Below average digital intensive-using
I	56	Food and beverage service activities	Hospitality and culture	Low WFH	Below average digital intensive-using
J	58	Publishing activities	Market services	High WFH	Above average digital intensive-using*
J	59	Motion picture, video and television programme production, sound recording and music publishing activities	Market services	High WFH	Digital Producing
J	60	Programming and broadcasting activities	Market services	High WFH	Digital Producing
J	61	Telecommunications	Market services	Medium WFH	Digital Producing
J	62	Computer programming, consultancy and related activities	Market services	High WFH	Digital Producing
J	63	Information service activities	Market services	High WFH	Above average digital intensive-using*
K	64-66	Finance and insurance	Market services	Medium WFH	Above average digital intensive-using
M, N	70,72,75, 77,81	Other corporate services	Market services	Medium WFH	Above average digital intensive-using
M	69	Professional, scientific and technical activities	Market services	Medium WFH*	Above average digital intensive-using
M	71	Architectural and engineering activities; technical testing and analysis	Market services	Medium WFH	Above average digital intensive-using
M	73	Advertising and market research	Market services	High WFH	Above average digital intensive-using
M	74	Other professional, scientific and technical activities	Market services	High WFH	Above average digital intensive-using

N	78	Employment activities	Market services	Medium WFH	Above average digital intensive-using
N	79	Travel agency, tour operator and other reservation service and related activities	Market services	Medium WFH	Above average digital intensive-using
N	80	Security and investigation activities	Market services	Medium WFH	Above average digital intensive-using
N	82	Office administrative, office support and other business support activities	Market services	High WFH*	Above average digital intensive-using
O-Q	84-88	Public service providers, education, health	Non-market services	Medium WFH*	Below average digital intensive-using
R-T	90-98	Other service providers	Market services*	High WFH	Above average digital intensive-using

* These categories were assigned by the author, deviating from the approach of Vries et al. (2021). This deviation from the original approach is caused by differences in the data availability on industry-grouping level.

Appendix Table A4: Decomposition of within-industry productivity effects using three taxonomies, quarterly average (% change)

	2020-Q1	2020-Q2	2020-Q3	2020-Q4	2021-Q1	2021-Q2
Aggregate productivity growth	-2.0	3.1	-3.5	4.0	-3.2	7.3
Within industry productivity	-2.0	2.9	-3.4	3.9	-3.2	7.4
Static effect	0.0	0.2	-0.2	0.2	0.0	-0.1
Dynamic effect	0.0	0.0	0.0	-0.1	0.0	0.0
Sectors						
Total within-industry effect	-2.0	2.9	-3.4	3.9	-3.2	7.4
Hospitality and culture	.	-0.1	0.2	-0.2	-0.1	0.1
Manufacturing	1.1	0.1	-0.1	1.6	-0.8	2.3
Market services [b]	-0.4	3.1	-2.1	0.0	-0.6	3.0
Non-market services	0.4	-0.3	-0.2	-0.7	0.1	1.7
Other industry [c]	-1.1	0.3	-1.1	2.7	-2.1	0.5
Work-from-home intensity						
Total within-industry effect	-2.0	2.9	-3.4	3.9	-3.2	7.4
High WFH	0.0	-0.3	-0.1	0.2	0.2	0.1
Medium WFH	0.4	2.1	-0.3	-0.1	-0.5	4.9
Low WFH	-2.4	1.0	-0.4	3.8	-2.9	2.4
Digital intensity						
Total within-industry effect	-2.0	2.9	-3.4	3.9	-3.2	7.4
Above average digital-intensive	-1.6	2.2	-1.0	1.4	-1.9	3.5
Below average digital-intensive	-0.4	1.1	-2.3	2.0	-1.2	3.6
Digital producing	-0.1	0.3	-0.2	0.2	0.0	0.2

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