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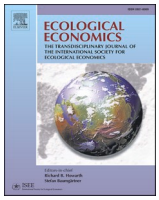

ANALYSIS

Labour productivity gains or offshoring? Implications for post-growth proposals on the future of work

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ABSTRACT

Two visions prevail about the future of work in sustainable post-growth economies. According to the first, labour productivity gains resulting from technological development will enable to work less. The second contends instead that such gains are not always desirable and could be constrained by a shift towards less polluting production, potentially resulting in more work. Yet, conventional measures of labour productivity on which these proposals are based can conceal a displacement of labour requirements abroad. In this paper, we conduct a case study on Germany in 1995–2020 to assess whether and to which extent labour productivity gains result from offshoring, and implications for post-growth proposals on the future of work. We first retrieve global labour requirements of German production across upstream supply chains. We then decompose conventional labour productivity gains to evaluate whether they result from a reduction in global labour requirements or of their increased displacement towards upstream sectors. Finally, we examine possible impacts on labour offshoring of shifting production to sectors with low productivity gains. We use a socially extended Multi-Regional Input-Output model based on OECD data. Our results show that a quarter of the global labour requirements for German production is provided abroad. This share increased until 2007 before it stabilized or decreased. We identify some potential for working time reduction without increases in labour offshoring. Shifting to service sectors could furthermore reduce labour offshoring relative to production. Yet critically, German production may cover only a fraction of domestic consumption. Related implications for post-growth proposals require further attention.

1. Introduction

High-income countries aiming to transit into safe and just planetary boundaries face the challenge to maintain good living conditions for all while drastically cutting back their environmental pressures (Fanning et al., 2021; O'Neill et al., 2018; Raworth, 2017). This is also a requirement for lower-income countries to benefit from their "fair share" (ibid). Empirical evidence suggests that this goal may not be compatible with continued economic expansion as GDP growth remains strongly coupled to environmental pressures such as carbon emissions (Haberl et al., 2020), resource use (Haberl et al., 2020; Wiedmann et al., 2015) and biodiversity loss (Otero et al., 2020). Furthermore, rare cases of observed decoupling fall short of the pace and scale required to meet climate and other sustainability targets (Haberl et al., 2020; Hickel and Kallis, 2019; Parrique et al., 2019; Vogel and Hickel, 2023). Finally, declining growth rates in high-income countries point towards overall slower growth in the 21st century (Fernald, 2018; Piketty, 2014) in what has been referred to as "the age of secular stagnation" (Jackson, 2019; Summers, 2016). In a context where continued economic expansion may no longer be possible or desirable for high-income countries, options for the future of work[1] in a low-growth or "post-growth" setting are being explored, sometimes adopting conflicted views about labour productivity (Gerold et al., 2023; Gómez-Baggethun, 2022; Jackson and Victor, 2011; Mair et al., 2020; Schor, 2008). In this paper, we contribute to these debates by investigating the role of labour offshoring in driving labour productivity and the related implications for such post-growth proposals.

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[1] Our analysis is limited to paid forms of labour, hereafter referred as "labour" for reading convenience. Non-paid labour is a key and often invisibilized component of provisioning (Dengler and Plank, 2024).

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A first prominent proposal assumes that labour productivity has been and will keep rising, thereby reducing the need for work (Cieplinski et al., 2021; Gorz, 1989; Schor, 2008). The proposal is therefore to use these gains for working time reduction rather than further growth in production (Cieplinski et al., 2021; Gómez-Baggethun, 2022; Gorz, 1989; Kallis et al., 2013; Pullinger, 2014; Schor, 2008). Environmental benefits are expected from the resulting stabilization in consumption (Knight et al., 2013; Pullinger, 2014). Social benefits may be significant too, by expanding leisure and enhancing 'work-life balance' (Gómez-Baggethun, 2022; Kallis et al., 2013; Pullinger, 2014). Finally, working time reduction is expected to counter unemployment by redistributing and sharing shrinking work requirements (Cieplinski et al., 2021; Kallis et al., 2013; Schor, 2014).

A second strand of literature argues instead that the future of work in a post-growth setting involves a necessary and desirable shift of production towards economic activities of lower productivity growth, typically service sectors such as care work (Druckman and Mair, 2019; Elkomy et al., 2020; Hardt et al., 2021; Isham et al., 2021; Jackson and Victor, 2011; Mair et al., 2020). Three main arguments back this rationale. First, current levels of labour productivity depend on the intensive consumption of fossil fuels and could be constrained by a transition towards less polluting and energy-intensive forms of production (Elkomy et al., 2020; Hardt et al., 2021; Mair et al., 2020; Snikersproge, 2024; Sorman and Giampietro, 2013). Second, labour productivity gains are not always desirable. This may hold particularly true for activities of which the quality is inherently linked to the amount of labour time provided (e.g., care or creative work) (Jackson, 2017), or when productivity gains actively harm the well-being of workers (Isham et al., 2021). Finally, labour productivity gains aggravate the dependence on growth in economies where access to a livelihood is tied to paid employment: if the need for labour decreases due to productivity gains, further growth is required to maintain full employment (Jackson and Victor, 2011). Hence this strand expects limited scope for working time reductions in a postgrowth context. Yet there could be "better" and more meaningful work under certain conditions, including: good wages and work-life balance, high levels of autonomy and safety, opportunities for self-realisation and social interaction, or contribution to the common good with good quality output (Druckman and Mair, 2019; Jackson, 2017; Snikersproge, 2024).

As we detail later in this paper, labour productivity can be defined in several ways. Here, both proposals understand it as the ratio of *real* goods and services produced per unit of labour inputs.[2] Labour inputs are typically measured as the total hours worked or the number of employed people *within* the production activity considered (OECD, 2001). In this paper, this will be further referred to as a "direct" approach to labour productivity. Take for example a car manufacturer: "direct" labour productivity could typically compare a measure reflecting the number of cars leaving the assembly lines to the number of people employed in the factories of this manufacturer. Historically, significant gains in "direct" labour productivity[3] have been observed in high-income countries: annual growth rates above 4 % were not uncommon in OECD countries in the second half of the XXth century (OECD, 2025a). A persistent slowdown is however being observed over recent decades (Bergeaud et al., 2016; Dieppe, 2021; Jackson, 2019).

Importantly for our discussion, "direct" metrics dismiss that beyond the labour directly provided within a sector, "indirect" labour is also required in upstream sectors to produce intermediate inputs (Timmer, 2017). Such patterns are indeed prevalent in the present globalised economy, of which a core characteristic is the fragmentation of production processes along international supply chains (Baldwin, 2013; Baldwin and Freeman, 2022; Baldwin and Lopez-Gonzalez, 2015; Los et al., 2015; Pahl and Timmer, 2019; Timmer, 2017). To account for such patterns, *embodied* labour requirements are defined as the direct and indirect labour provided across supply chains (Hornborg, 2023; Pasinetti, 1973). It is hence possible that gains in "direct" labour productivity do not result from a reduction in total (embodied) labour requirements, but rather from their increased displacement (or *outsourcing*) towards upstream sectors (Timmer, 2017). We will refer to (i) *"domestic labour outsourcing"* to refer to a displacement of embodied labour requirements towards upstream sectors located within the same country, (ii) *labour offshoring* when this displacement occurs towards upstream sectors located abroad and (iii) *net labour productivity gains* for a reduction in total (embodied) labour requirements per unit of production output. For example, labour offshoring could occur if an industry decreases their own labour requirements by stopping the internal production of a component and instead starts buying it from another industry located abroad. Conversely, net labour productivity gains do not conceal a displacement of labour requirements. Such gains could happen through technical change, for example when an industry replaces their use of a component produced by hand with one produced more efficiently by a machine (provided that the embodied labour requirements of producing the machine are lower than the ones related to hand production).

If it turns out that "direct" labour productivity gains result from labour offshoring, this has important implications for the aforementioned post-growth proposals. "Productivity-led" working time reduction in high-income countries would be hence achieved by displacing labour requirements abroad rather than by net productivity gains. Such displacement patterns raise distributive questions, as they would further aggravate the already highly uneven international allocation of working time described by the theory of Ecologically Unequal Exchange (Althouse et al., 2023; Hickel et al., 2024; Hornborg, 2023): higher-income countries benefit from large amounts of labour time provided in lower-income countries for the production of the commodities they import, while they devote comparatively little time to exports (Alsamawi et al., 2014; Dorninger et al., 2021; Hickel et al., 2024; Pérez-Sánchez et al., 2021; Sakai et al., 2017). As such, labour offshoring from high- to low-income countries could be arguably described as a form of cost-shifting (Kapp, 1978; Trettel-Silva, 2022). Conversely, "direct" labour productivity gains could also be curbed if some of the labour requirements currently offshored had to be reshored. Finally, proposals to shift production towards sectors with lower labour productivity growth could also impact overall labour offshoring at the national level. The latter is indeed the aggregation of sectoral labour offshoring: if the share of employment in sectors with low levels of labour offshoring increases, overall labour offshoring will be reduced.[4]

In this paper, we conduct a case study on Germany in 1995–2020 to assess whether and to which extent "direct" labour productivity gains result from offshoring, and discuss implications for post-growth proposals on the future of work. The rest of the paper is organized as following: in Section 2, we review how previous contributions have accounted for the role of labour offshoring in driving "direct" labour productivity changes. We argue that so far, these do not enable to assess whether "direct" labour productivity gains conceal a displacement of labour requirements towards upstream activities. To do so, the *embodied* labour requirements relative to the *gross output* of *domestic production* must be assessed at the *sectoral level* and along *global* supply chains. We adopt this approach to conduct an empirical analysis in Germany between 1995 and 2020. We clarify our methodological approach in

[2] We refer to *real* goods and services to distinguish them from their monetary value. As detailed later in this paper, multiple approaches can be taken to account for production output. Although these are typically based on monetary measures, a restricted number of them may reflect real production. Note for now that the measure of production output against which labour productivity is defined should be carefully considered.

[3] Here measured as price-corrected GDP per person employed.

[4] Such aggregate changes attributable to changes in the sectoral composition are commonly referred to as structural change effects (Maudos et al., 2008).

Section 3. In Section 4, we present four empirical contributions. First, we assess the overall embodied labour requirements relative to gross output and the labour share which is provided abroad, i.e., offshored (Section 4.1). Second, we estimate and confront two measures of "direct" and "embodied" labour productivity relative to gross output (Section 4.2). Third, we decompose direct labour productivity changes as the result of changes in embodied labour productivity, labour offshoring and domestic labour outsourcing (Section 4.3). Finally, we examine patterns of labour offshoring in sectors with low potential for labour productivity gains (Section 4.4). We discuss uncertainties of our results and their implications for post-growth proposals in Section 5. Section 6 concludes.

2. The role of labour offshoring in driving labour productivity

"Direct" labour productivity may (at least partially) account for labour offshoring depending on how exactly production output is being measured. Two conventional alternatives are to consider either gross output or value-added (Cobbold, 2003; Eldridge and Powers, 2023; OECD, 2001). *Gross output* is the monetary value of the *real* goods and services produced. *Value-added* is the residual obtained when deducting the monetary value of purchased intermediate inputs from gross output: it hence primarily reflects the ability of an industry to generate net incomes (Cobbold, 2003; Eldridge and Powers, 2023; Meade, 2010). Value-added-based labour productivity is argued to be of limited sensitivity to offshoring, as a reduction in labour inputs caused by offshoring is likely to be compensated by a reduction in value-added due to increased intermediate inputs (OECD, 2001). However, value-added is conceptually difficult to reconcile with any physical understanding of production output, as it conflates gross output and intermediary inputs of heterogeneous nature[5] using their monetary value as weight (Cobbold, 2003; Fischer, 2011; Meade, 2010). If one is interested about the labour requirements of producing *real* goods and services, value-added-based labour productivity is not suited. Conversely, gross output can reflect the production of real goods and services, provided that it is considered at a sufficiently disaggregated level and is adjusted by changes in prices.[6] "Direct" labour productivity relative to gross output is yet oblivious to labour offshoring, hence the need for "embodied" approaches.

Contemporary work on "embodied" labour requirements can be tracked down at least to Pasinetti's (1973) concept of "vertically integrated" production. It is based on Leontief's (1936) Input-Output framework, and consists in retrieving embodied labour requirements provided along upstream supply chains relative to the production of outputs for final demand. It has been extensively used to assess job-related interdependencies across domestic industries (Bivens, 2019; Cresti et al., 2023). Studies by Dietzenbacher et al. (2000) and Lind (2020) illustrate how this framework can also be applied to empirically assess labour productivity based on embodied labour requirements. Yet such applications remained for long restricted to considering only the domestic labour provided along national supply chains (Timmer and Ye, 2020). Only recent progress in data availability has enabled to account for foreign embodied labour requirements along *global* supply chains (Lenzen et al., 2017; Tukker and Dietzenbacher, 2013).

Hence, Simas et al. (2015) introduced for the first time a "consumption-based" measure of labour productivity considering international labour requirements along *global* supply chains. They define their metric as the ratio of Gross National Expenditure (i.e., monetary value of final demand aggregated at the national level) to their associated global embodied labour requirements. They confront it to a "territorial-based" measure of labour productivity, defined as the ratio of Gross Domestic Product (i.e., value-added of production aggregated at the national level) to their associated direct labour requirements. Their empirical results show that international disparities in "consumption-based" labour productivity are much less pronounced than with a "territorial-based" approach: in 2000, "territorial-based" labour productivity was 66 times higher in Norway (the country with the highest levels among the ones studied) than in India (the country with the lowest levels). In contrast, the "consumption-based" indicator shows much more moderate differences, with productivity levels 31 times higher in Norway than in India. These results temper the common view that high-income countries have achieved particularly high levels of labour productivity, if one considers the *global embodied labour* requirements relative to their *consumption* rather than the *domestic labour* requirements relative to their *production*.

Another approach to labour productivity which accounts for global embodied labour requirements is suggested by Hardt et al. (2020). They define "embodied" labour productivity at the sectoral level as the ratio of domestic production output that goes to final demand to their associated global embodied labour requirements. Hardt et al. (2021) confront this "embodied" measure to a "direct" one defined as the ratio of value-added to direct labour inputs. Empirical results from Hardt et al. (2021) show that in Germany and the United Kingdom, "embodied" labour productivity gains have been low (i.e., lower than +1 %/year) or even declining between 1995 and 2011 for respectively seventeen (Germany) and seven (United Kingdom) sectors out of the twenty-one studied. In Germany, this includes seven manufacturing sectors (out of eight), although these show high levels of "direct" labour productivity gains. Hardt et al. (2021) observe that in 1995–2011, "embodied" labour productivity gains have been generally much slower than "direct" gains.

Overall, these contrasting approaches confirm the relevance of "embodied" approaches to consider more carefully the potential role of labour offshoring in driving "direct" labour productivity. Yet if one is interested to investigate whether "direct" labour productivity gains result from displacing labour to upstream activities, the "embodied" metrics presented above are subject to important limitations. First, the metrics suggested by Simas et al. (2015) are aggregated at the national level. Although their estimates are adjusted by a general index of international differences in prices, such aggregate measures provide limited information on the labour requirements of producing *real* goods and services of heterogeneous nature (Fischer, 2011; Røpke, 2022). To get closer from a physical understanding of labour productivity, sectoral analysis in the fashion of those conducted by Hardt et al. (2020, 2021) should be prioritized. Furthermore, the consideration of Simas et al. (2015) for value-added-based "direct" labour productivity is also difficult to reconcile with any physical understanding of productivity, as explained beforehand. Then, Simas et al. (2015) emphasize themselves that their "consumption-" and "territorial-based" metrics are of limited comparability: the first measures the "efficiency of demand" (namely, the labour requirements relative to final demand) whereas the second measures the "efficiency of supply" (i.e., the labour requirements relative to production). Hence their "embodied" measure does not enable to conclude whether "direct" labour productivity gains result from displacing labour requirements to upstream sectors, as it is simply not defined relative to the same output. In this regard, the metrics suggested by Hardt et al. (2020, 2021) are subject to similar limitations, as they are based respectively on value-added and output to final demand.

To assess the "direct" and "embodied" labour requirements of producing *real* goods and services in a consistent way, it seems therefore

[5] By heterogeneous commodities, we mean that these do not share a priori any common characteristics aside from the fact they are being assigned prices (Fischer, 2011; Røpke, 2022).

[6] For example: if one knows that the monetary value of bikes sold by the bike industry has doubled between two years while bikes prices have also doubled, then one can deduct that as many *physical* units of bikes were sold in both years. Alternatively: if one only knows that the *aggregate* monetary value of bikes sold and healthcare services has doubled between two periods, there is not much to be deducted about the number of bikes sold and patients cared for, even knowing that bike prices have doubled and healthcare service prices have tripled.

that we are left with considering labour productivity relative to *gross output*. Among the different measures of production output mentioned above, gross output is indeed the only one meeting the three following criteria: (i) it is compatible with a physical understanding of labour productivity, (ii) it is commonly used to measure "direct" labour productivity and (iii) the related "embodied" labour requirements can be measured (Szyrmer, 1992). This last point will be developed in Section 3.2. To the best of our knowledge, only Milana (1985) has empirically assessed sectoral embodied labour requirements relative to gross output. The author provides estimates for 44 sectors of the Italian economy in 1975. Their aim was mainly to demonstrate the theoretical and empirical divergences between embodied requirements relative to consumption and production. Furthermore, the study provides results for only one year: labour productivity changes over time are not assessed. Finally, embodied labour requirements are assessed only along domestic supply chains. The existing literature should be hence conveniently complemented by the empirical work conducted in the rest of this paper, namely: a *sectoral* assessment of changes in the *"direct"* and *"embodied"* labour requirements relative to *gross output* of *domestic production* along *global* supply chains.

3. Methods

3.1. Key concepts

For a given production sector, we define the total *embodied labour requirements* (L^E) relative to gross output as the sum of the direct labour requirements in that sector (L^D), the indirect labour requirements in domestic upstream sectors ($L^{I-domestic}$) and the indirect labour requirements in foreign upstream sectors ($L^{I-foreign}$):

$$L^E = L^D + L^{I-domestic} + L^{I-foreign} \tag{1.1}$$

The *rate of labour offshoring* ($r^{foreign}$) is the ratio of indirect foreign to total embodied labour requirements:

$$r^{foreign} = \frac{L^{I-foreign}}{L^E} \tag{1.2}$$

Labour offshoring is here defined as a *relative* indicator: it does not inform about the *absolute* level of foreign labour on which production relies, but rather about its level as compared to total embodied labour requirements. We furthemore define *domestic embodied labour requirements* ($L^{domestic}$) as the sum of direct and indirect domestic labour requirements, and the *rate of domestic labour outsourcing* ($r^{domestic}$) as the ratio of indirect domestic to domestic labour requirements.[7]

To evaluate net labour productivity gains, we define a sectoral measure of *embodied labour productivity relative to gross output* (p^E) as the ratio of deflated gross output (X_d) to the associated total embodied labour requirements (L^E):

$$p^E = \frac{X_d}{L^E} \tag{1.3}$$

The subscript d indicates the use of a deflated measure of gross output (i.e., expressed in constant prices). As standard, gross output is available in nominal terms: it is the monetary value of the goods and services produced. It must be adjusted by changes in prices so that changes in gross outputs reflect changes in the production of *real* goods and services. The same concern to relate to a physical understanding of labour productivity leads us to define p^E only at the sectoral level (and not at the national one). As such, gross outputs account for the monetary value of relatively homogeneous groups of *real* goods and services. For reading convenience, p^E is further referred to as *"embodied labour productivity"*.[8] Gains in p^E reflect a decrease in global embodied labour requirements per unit of gross output. Note that net labour productivity gains do not indicate a decrease in global labour requirements relative to production: those also depend on absolute levels of production.

Finally, we define "direct" labour productivity (p^D) as the ratio of deflated gross outputs (X_d) to direct labour inputs (L^D). In Section 4.4, we identify sectors with low potential for direct labour productivity gains by retrieving annual compound growth rates with log-lin models (Gujarati, 2009, pp. 162–166).

3.2. Socially extended MRIO analysis

In this section, we give a plain-text overview of the procedure followed to retrieve sectoral time-series of direct (L^D), indirect domestic ($L^{I-domestic}$) and indirect foreign ($L^{I-foreign}$) embodied labour requirements and the associated deflated production gross output (X_d), using a socially-extended Multi-Regional Input-Output model. A detailed presentation of our calculations can be found in the Suplementary Materials.

Introduced by Leontief (1936), the Input-Output (IO) framework consists in a comprehensive account of the amounts of goods and services that are bought ("inputs") and sold ("outputs") across production sectors and final consumers (Erickson and Kane, 2017; Miller and Blair, 2022). These interactions are usually (but not necessarily) accounted in terms of their monetary value for one year (ibid). They can be reported for either single or multiple ("multi-regional") economic areas. When "extended" with data on direct social (e.g., labour inputs) or environmental impacts (e.g., greenhouse gas emissions[9]), IO models enable to trace-back "embodied" impacts across comprehensive supply chains. We refer readers to Erickson and Kane (2017) and Geschke (2017) for plain-text introductions to socially extended MRIO models, Miller and Blair (2022) for a comprehensive introduction to Input-Output analysis, and Wiedmann and Lenzen (2018) for an overview of applications using socially and environmentally extended MRIO models.

We highlighted in Section 2 that in order to assess whether "direct" labour productivity gains conceal any displacement of labour requirements towards upstream activities, it should be compared to an "embodied" measure of labour productivity defined relative to gross output. To retrieve the global embodied labour requirements relative to domestic gross output, we follow a "total flow" approach (Szyrmer, 1992), also known as "hypothetical extraction" (Gallego and Lenzen, 2005; Lenzen et al., 2007; Miller and Blair, 2022). The "total flow" approach is the single alternative enabling to retrieve embodied requirements relative to gross output with a MRIO model[10] (Milana,

[7] $r^{domestic}$ is dependent on the level of sector aggregation: higher levels of aggregation lead to lower domestic outsourcing. At the national level, there is no domestic outsourcing.

[8] Here, "embodied labour productivity" differs from the measure defined by Hardt et al. (2020, 2021) relative to output to final demand.

[9] See for example Meng et al. (2018) and Espinosa-Gracia et al. (2023).

[10] In contrast, the more common Leontief framework enables to retrieve embodied requirements relative to final demand. The Leontief framework can account for either total final demand (including final demand met with imports of final commodities), or outputs to final demand supplied by domestic production sectors only. In the second case, the output considered may be more comparable to gross outputs. Yet even in this case, the Leontief framework leads to diverging results as compared to the total-flow approach (Milana, 1985; Szyrmer, 1992). This is due to the fact that only part of the gross output produced is used for final demand. The rest is used as intermediary inputs by other production sectors or as self-consumption. Hence for one unit of final consumption, more than one unit of gross output is produced. As shown by Milana (1985) and Szyrmer (1992), the embodied requirements per unit of output to final demand are systematically higher than the ones per unit of gross output. For production sectors with low shares of output to final demand (e.g., the mining sector), probing the embodied requirement per unit of output to final demand may lead to diverging or even dubious results. Smaller differences may be found in sectors where gross output is mainly intended for final demand (ibid).

1985). Importantly, the embodied labour requirements relative to gross output are non-additive: once retrieved, they cannot be summed across sectors as this would lead to double counting errors (Gallego and Lenzen, 2005; Milana, 1985). The indirect requirements relative to gross output of a given sector may indeed be accounted as the direct requirements of another one (ibid). We therefore aggregate data at the relevant level of analysis prior to processing. This also entails that sectoral measures of embodied labour requirements should be interpreted separately from each other. Furthermore, their sum does not result in embodied labour requirements at the national level (these are computed separately).

We retrieve sectoral measures of deflated gross outputs based on time-series of nominal gross outputs available from the MRIO dataset. We first deflate these time-series with sectoral production price indexes available at the same level of aggregation as the MRIO dataset. We then aggregate results into twenty sectors using previous-year Laspeyre-weighted indexes (Eurostat, 2016; Tuke and Reed, 2001). This consists in computing year-by-year volume change rates in aggregated deflated gross outputs, using non-deflated gross outputs from the previous year as weights.

Finally, we smooth the time-series of embodied labour inputs and deflated gross output to buffer yearly fluctuations and emphasize medium-term trends. We use uniform kernel regressions (Altman, 1992), meaning smoothed values are retrieved as the average of values for neighbouring years. We use bandwidths of 2 years.

3.3. Index decomposition analysis

We conduct an Index Decomposition Analysis (Ang, 2015; Goh and Ang, 2019) to assess the extent to which changes in direct labour productivity result from changes in (i) embodied labour productivity, (ii) labour offshoring, or (iii) domestic labour outsourcing. For any production sector considered, direct labour productivity can be decomposed as the product of three terms associated with these drivers:

$$p^D = \frac{X_d}{L^D} = \frac{X_d}{L^E} \cdot \frac{L^E}{L^{domestic}} \cdot \frac{L^{domestic}}{L^D} = p^E \cdot \alpha \cdot \beta \tag{2.1}$$

The coefficient $\alpha = 1/(1 - r^{foreign})$ reflects changes attributable to labour offshoring as it increases along with it. Similarly, $\beta = 1/(1 - r^{domestic})$ reflects changes attributable to domestic labour outsourcing. IDA are commonly used to decompose both intra-sectoral and inter-sectoral (i.e., structural change) effects (Goh and Ang, 2019). Yet here, we conduct our analysis on single sectors: no inter-sectoral effect is considered.

We follow an additive approach (Ang, 2015; Goh and Ang, 2019): changes in direct labour productivity (Δp^D) between two consecutive years y and $y+1$ are decomposed as the sum of the effect from changes in embodied labour productivity (ΔV_{p^E}), labour offshoring (ΔV_α) and domestic labour outsourcing (ΔV_β):

$$\Delta p^D = \Delta V_{p^E} + \Delta V_\alpha + \Delta V_\beta \tag{2.2}$$

For any driver of change K, ΔV_K is expressed in the same unit as p^D. It represents the volume of change in p^D that can be attributed to a change in K. We use the LMDI-I method to assess ΔV_K, as this is the method recommended by Goh and Ang (2019) and Ang (2015) for additive decompositions with more than two drivers of change without leaving any residual. Since we conduct our analysis on single sectors, the formula presented by Ang (2015) becomes here:

$$\Delta V_K = \Delta p^D \cdot \frac{\ln\left(\frac{K_{y+1}}{K_y}\right)}{ln\left(\frac{p^D{}_{y+1}}{p^D{}_y}\right)} \tag{2.3}$$

Each effect is first computed for consecutive years before the cumulative effect over time is retrieved as their cumulative sum (Ang et al., 2010).

3.4. Case study

We conduct our empirical analysis on Germany. This is first motivated by the fact that Germany is one of the high-income countries where production is particularly well diversified. In particular, it covers a wide range of manufacturing sectors that are virtually non-existent in other high-income countries (Deutsche Bundesbank, 2011; OECD, 2025b). On the other side, the relative stability in German manufacturing output has come along with a specialization in "headquarter" activities and the last stages of manufacturing processes, while other "fabrication" stages got increasingly offshored (Baldwin and Lopez-Gonzalez, 2015; Deutsche Bundesbank, 2011, 2016; Timmer et al., 2019). The results obtained for Germany might be indicative of trends in other countries with similar industries. Yet a generalisation of our results to other countries is out of the scope of this paper.

3.5. Data

Our analysis is primarily based on data from the OECD, namely: the Inter-Country Input-Output (ICIO) tables (OECD, 2022), labour inputs from the "Trade In Employment" (TiM) dataset (OECD, 2023a) and production output price index from the "STAN Industrial Analysis" (STAN) dataset (OECD, 2025b). We consider years from 1995 to 2020, the largest time span available across the three datasets.

We use the 2022 release of the ICIO tables ("regular" version) (OECD, 2022). It covers trade flows in basic current prices between 45 sectors in 76 countries and one "Rest of the World" region.

We measure embodied labour requirements in terms of people employed. The 2023 edition of the TiM dataset (OECD, 2023a) provides sectoral labour inputs for 61 countries of the ICIO tables, including all OECD countries and other large economies including China, Mexico, Brasil, Indonesia and South Africa. Yet no labour data is available from TiM for 15 countries of the ICIO tables and a large "Rest of the World" region. For these, we used complementary labour data from GLORIA, version 059a (Lenzen et al., 2017, 2022). The results obtained with GLORIA are exploratory and subject to high uncertainties. We use them only to probe the validity of the main results obtained with TiM. Details about the countries missing in TiM and how we integrated data from GLORIA can be found in the Supplementary Materials.

We deflate gross output in constant 2020 prices with sectoral output price indexes from the STAN dataset (OECD, 2025b). Those are expressed in national currency, whereas the ICIO tables are in USD. We convert gross output in national currency with annual exchange rates from the OECD National Account Statistics (OECD, 2023b). The STAN deflators are provided at the same level of sector aggregation as the ICIO tables, except for four ICIO sectors. We explain how we remediate those cases in the Suplementary Materials.

We present results for twenty aggregated sectors. Their concordance with the elementary sectors from the ICIO tables is available in the Suplementary Materials.

4. Results

Four main findings stand out. First, about a quarter of the embodied labour relative to the goods and services produced in Germany was provided in upstream sectors located abroad between 1995 and 2020. This share is particularly high in manufacturing sectors, and increased in most sectors before 2007 before to stabilize or even decrease. Second, we observe some net labour productivity gains in most sectors. Third, the decomposition analysis shows that in most sectors, labour offshoring has played only a limited role in driving direct labour productivity gains. Finally, labour offshoring turns out to be lower in service sectors with low potential for labour productivity gains. Those four findings are

detailed below. Detailed results underlying the figures can be found in the Supplementary Materials.

4.1. Embodied labour: total requirements and offshoring

Fig. 1 illustrates the embodied labour requirements relative to total production activities in Germany between 1995 and 2020. We distinguish (i) direct labour inputs, (ii) indirect foreign labour inputs provided in countries covered by the TiM dataset and (iii) those provided in other countries missing from TiM. The latter are exploratory results retrieved with complementary data from the GLORIA dataset.

Total embodied labour inputs to production have steadily increased between 1995 and 2020. In 2020, direct labour represented about 45 M people (38 M in 1995). In addition to those, our estimates suggest that 21 M people were required abroad to sustain production in Germany (19 M in 1995). Most of the foreign labour (about 70 % during the whole period) is located in countries covered by the TiM dataset.

Sectoral results are presented in Fig. 2. They indicate that embodied labour inputs have been the highest in service sectors, mainly as the result of direct labour inputs. The lowest inputs are found in sectors relating to material extraction ("Agriculture, forestry, fishing", "Mining and quarrying") as well as the "Manufacturing: clothing" and the "Arts, entertainment, recreation" ones. Between 1995 and 2020, embodied labour inputs have decreased in seven sectors: "Agriculture, forestry, fishing", "Mining and quarrying", "Construction" and four manufacturing ones ("Food", "Clothing", "Wood, cork, paper", "Other"). They have been either relatively stable or increased in the other ones.

Table 1 provides average values (in blue) of labour offshoring at the sectoral and national level between 1995 and 2020. We provide two estimates: the first one includes indirect foreign labour inputs provided worldwide, including complementary labour data from GLORIA. The second one includes only foreign labour provided in countries covered by TiM. For the second estimate only, we also report changes in labour offshoring over the three following periods: 1995–2007, 2007–2020 and 1995–2020. Positive changes (>0) are in orange, and negative ones (<0) in purple. The stronger the colour shade, the more significant the value.

Average labour offshoring obtained with and without exploratory data for countries missing in TiM diverge by 8 % at the national level. Variations are larger than 10 % for five sectors. The largest differences are found in the following sectors: "Mining and quarrying" (19 %) and "Manufacturing: chemicals, petrochemicals" (18 %). For other sectors, considering only foreign labour inputs covered by TiM is less likely to conceal significant underestimations. In the rest of this analysis, we consider only foreign labour inputs provided in countries covered by TiM.

At the national level, labour offshoring (to countries covered by TiM) has oscillated around an average of 26 %, with a slight decrease observed between 1995 and 2020 (−0.8 %). The highest rates of labour offshoring are observed in sectors relating to material transformation:

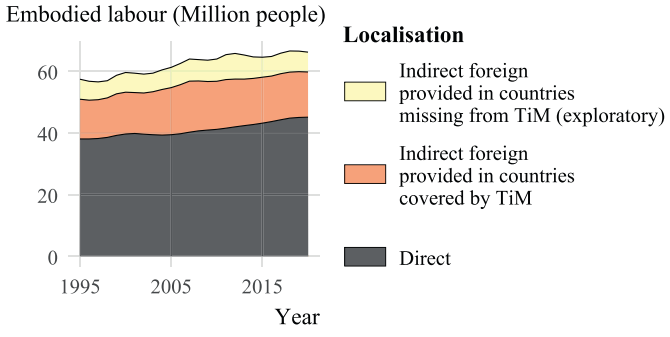

Fig. 1. Embodied labour inputs relative to production in Germany from 1995 to 2020 (national level).

they culminate above 40 % in six manufacturing sectors. Labour offshoring tends to be lower in service sectors, and bottoms out around 11 % in the "Health, education, public administration", "Arts, entertainment, recreation" and "Other services" ones. The most significant increase in labour offshoring between 1995 and 2020 is found in the "Information and Communication" sector (+8.6 %). Other important increases are observed in sectors relating to material extraction and transformation (+4.6 % or more in four of them). On the other side, significant decreases are found in the "Manufacturing: clothing" (−15.7 %), "Hotels and restaurants" (−9.9 %) and "Manufacturing: food" (−5.2 %) sectors. Interestingly, we find a clear rupture in labour offshoring trends before and after 2007. Between 1995 and 2007, labour offshoring increased in all sectors except three. After 2007, labour offshoring decreased in all sectors but four. Yet even in sectors where labour offshoring increased after 2007, this was at a much more moderate pace than during the first period. The "Other services" sector is the only one where labour offshoring first decreased in 1995–2007 (−0.6 %) before increasing in 2007–2020 (+0.7 %). Those variations are yet small as compared to the ones observed in other sectors.

4.2. Embodied labour productivity

Fig. 3 illustrates changes in direct (p^D) and embodied labour productivity (p^E) between 1995 and 2020 across the twenty sectors studied. Relative changes in p^D are represented as an index standardized against ${p^D}_{1995} = 100$. We provide two indexes of p^E: one is standardized against the same reference as p^D, and the second is standardized against ${p^E}_{1995} = 100$. The first emphasizes absolute differences between p^E and p^D. The second highlights relative changes in p^E as compared to its initial value and thus enables straightforward comparisons with relative changes in p^D.

Unsurprisingly, the results show that in absolute terms, p^E is significantly lower than p^D for sectors with high rates of labour offshoring. This is especially the case for sectors relating to material extraction and transformation. The smallest differences are found in service sectors. More unexpectedly, we find that embodied labour productivity increased in all sectors where direct gains are also observed. The largest gains in p^E are found in the "Information and Communication" (+126 %), followed by the "Manufacturing: clothing" (+106 %) and "Manufacturing: transport equipment" (+57 %) sectors. In other sectors where gains are observed, these range between +52 % and + 14 %. Finally, p^E decreased in three sectors (i.e., these got more labour intensive): "Other services" (−11 %), "Hotels and restaurants" (−14 %) and "Arts, entertainment, recreation" (−19 %). Relative changes in p^E tend to follow those of p^D, even though at a slower pace across most sectors. In three sectors, gains in p^E outpace those in p^D ("Manufacturing: food", "Manufacturing: clothing" and "Mining and quarrying"). Finally, we find a generalized slowdown in both p^D and p^E towards the end of the period covered, particularly in sectors where significant gains are first observed.

4.3. Drivers of change in direct labour productivity gains

The results of the decomposition analysis conducted on direct labour productivity (p^D) are summarized in Fig. 4. For each sector, the lines represent the respective contribution of (i) changes in embodied labour productivity, (ii) labour offshoring and (iii) domestic labour outsourcing to (iv) the resulting total changes in direct labour productivity.

The results show that between 1995 and 2020, changes in direct labour productivity have been mainly driven by changes in embodied labour productivity in all sectors except two: in the "Manufacturing: chemicals, petrochemicals", they are mainly explained by the cumulative effect of domestic labour outsourcing (33 %) and labour offshoring (19 %). In the second case ("Hotels and restaurants"), domestic labour outsourcing and labour offshoring explain respectively 26 % and 34 % of

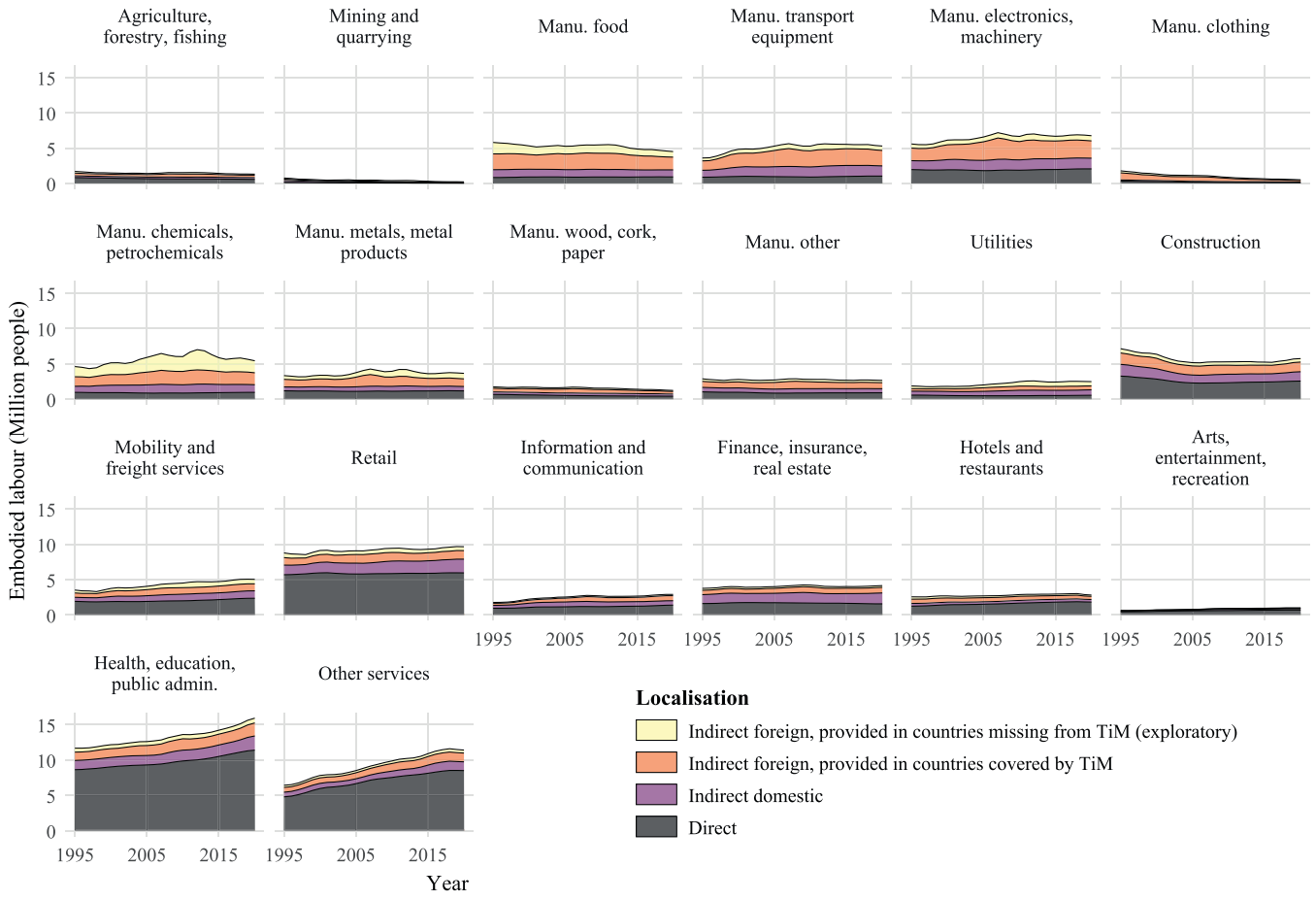

Fig. 2. Embodied labour inputs relative to production in Germany from 1995 to 2020 (sectoral level).

the decrease in direct labour productivity. The contribution of labour offshoring to direct labour productivity gains is also significant in the "Mining and quarrying" sector (21 %). Finally, in the "Manufacturing: clothing" sector, the significant decrease in labour offshoring observed beforehand translates here as a negative (<0) contribution to direct labour productivity. In all other sectors, changes in direct labour productivity have been mainly driven by changes in embodied labour productivity.

4.4. *Labour offshoring in sectors with low potential for productivity gains*

Finally, Fig. 5 shows average labour offshoring across the twenty sectors studied according to their annual compound growth rate in direct labour productivity between 1995 and 2020. The results confirm that labour offshoring tends to be lower in service sectors with low potential for labour productivity gains (i.e., gains lower than +1 %/year), namely: "Hotels and restaurants", "Arts, entertainment, recreation", "Health, education, public administration" and "Other services".

5. Discussion

5.1. *Uncertainties*

Our results are subject to several uncertainties. First, full coverage of countries missing in the TiM dataset could significantly impact our findings, especially in sectors where we identified important divergences in labour offshoring retrieved with and without exploratory data from GLORIA. Foreign labour requirements may be further underestimated in some countries where informal employment is prevalent (ILO, 2018). Finally, we measured labour inputs in terms of people employed, although considering hours worked would have been conceptually more adequate (OECD, 2001). Yet, the availability of robust sectoral data on hours actually worked is more limited for many countries (Dieppe, 2021; OECD, 2001).

Furthermore, our attempt to stay close from a physical understanding of labour productivity is limited in two important ways. First, we used deflated monetary measures to estimate changes in the production of real goods and services. Deflators attempt at capturing changes in the price, nature and quality (e.g., computation capacity of computers) of the real goods and services produced. This necessarily requires normative choices, in particular on the most important characteristics of products being compared over time (Triplett, 2004). Yet, the normative assumptions underlying the deflators we used are not reported in the source dataset (OECD, 2025b). We provide detailed accounts of these deflators in the Suplementary Materials. The second limitation relates to the fact that even when deflated, monetary measures of output remain homogenous expressions of heterogeneous commodities (Fischer, 2011; Røpke, 2022). The more aggregated the measure, the less homogeneous the outputs. A comparable characteristic must necessarily be considered to weight the relative contribution of heterogeneous outputs to changes in the aggregated measure considered. We followed the common practice of using their relative monetary value as weights (Eurostat, 2016). Hence, increases in the real output of expensive food items will have more influence on increases in the real output of the "Manufacturing: food" sector than cheaper food products even if, e.g., their calorific

Table 1
Labour offshoring relative to production in Germany between 1995 and 2020.

		World (exploratory)	Countries covered by TiM			
		Average value (%)	Average value (%)	Change (%)		
		1995-2020	1995-2020	1995-2007	2007-2020	1995-2020
Material extraction	Agriculture, forestry, fishing	37.1	28.3	+4.0	-1.5	+2.5
	Mining and quarrying	55.5	36.5	+10.1	-5.5	+4.6
Material transformation	Manu. food	62.3	52.0	+0.4	-5.6	-5.2
	Manu. transport equipment	53.4	47.2	+9.5	-4.3	+5.2
	Manu. electronics, machinery	47.3	41.2	+11.4	-6.2	+5.1
	Manu. clothing	68.3	62.0	+1.8	-17.6	-15.7
	Manu. chemicals, petrochemicals	63.7	45.5	+6.1	-3.2	+2.9
	Manu. metals, metal products	50.8	40.0	+9.2	-9.6	-0.4
	Manu. wood, cork, paper	44.2	36.5	+7.6	-7.6	+0.0
	Manu. other	44.8	37.0	+7.4	-5.2	+2.2
	Utilities	44.8	29.1	+8.1	-2.8	+5.2
	Construction	32.3	25.9	+3.4	-2.1	+1.3
Services	Mobility and freight services	32.4	22.8	+5.1	-2.6	+2.5
	Retail	18.4	13.2	+1.4	-1.2	+0.3
	Information and communication	28.0	23.0	+7.1	+1.5	+8.6
	Finance, insurance, real estate	24.2	19.1	+1.9	+0.7	+2.6
	Hotels and restaurants	29.5	22.4	-4.0	-5.9	-9.9
	Arts, entertainment, recreation	15.2	11.3	-0.9	+0.0	-0.9
	Health, education, public admin.	15.2	11.3	+1.3	+0.2	+1.4
	Other services	14.4	10.9	-0.6	+0.7	+0.1
	National level	**34.1**	**26.2**	**+3.9**	**-4.6**	**-0.7**

content is lower. We provided results at an intermediate level of aggregation to avoid aggregating products of completely different nature (e.g., food products and financial services) while preserving the readability of our results.

Finally, we could not correctly allocate the labour requirements related to capital used in production. Capital is here understood as the man-made "stock" of real goods and services used over long periods of time, either for the sake of final consumption (e.g., residential buildings) or intermediate production (e.g., industrial machinery) (United Nations, EC, OECD, IMF, World Bank, 2009; Weisz et al., 2015). In national accounting (and therefore in MRIO datasets, as they are based on the same accounting approach), capital formation is reported as final demand (United Nations et al., 2009). Consequently, labour requirements relative to the production of capital are not accounted for as intermediate inputs to the sectors using that capital. The correct allocation of capital used as intermediate inputs in MRIO models may become more accessible in the future (Södersten et al., 2018; Weisz et al., 2015) and could significantly impact the outcomes of our analysis.

5.2. Possible causes underlying outsourcing patterns

A noteworthy observation of the analysis is the stabilization of labour offshoring across all sectors after 2007. At the national level, this may be partially explained by the growing importance of service sectors associated with lower rates of labour offshoring. Yet our analysis shows that the trend holds true at the sectoral level. We can only speculate on the underlying causes of this result, as a formal identification lies outside the scope of this paper.

First, this result could conceal an increasing share of foreign labour requirements provided in the countries missing in the TiM dataset. This may be typically the case for the "Manufacturing: clothes" sector: we could not accurately account for foreign labour inputs from Pakistan, Bangladesh, Morocco, and Tunisia despite that those countries have become global major suppliers to the textile and clothing industries over the last decades (Mair et al., 2019; Nikolina, 2022).

Besides mismeasurements, the stabilization of labour offshoring might be influenced by a decline in production offshoring practices. This explanation would be consistent with the observation of a persistent

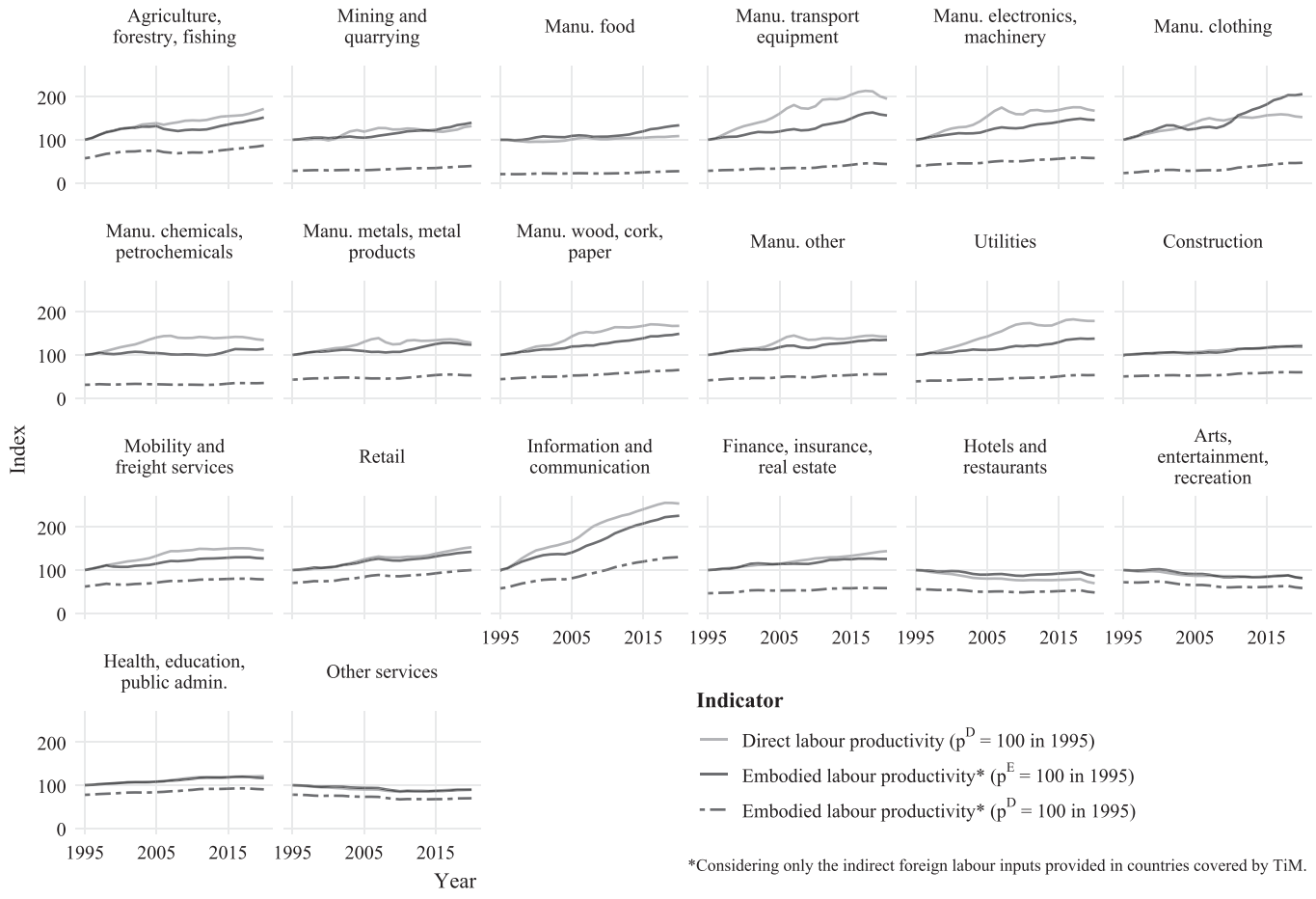

Fig. 3. Direct and embodied labour productivity in Germany between 1995 and 2020. Direct labour productivity is indexed against its initial value in 1995 (grey line). Embodied labour productivity is indexed against its initial value in 1995 (black line) and indexed against direct labour productivity in 1995 (black dashed line).

generalized slowdown in international trade flows in the aftermath of the trade collapse of 2008–2009 (Antràs, 2020). To check for a possible stabilization in production offshoring practices, we report in the Suplementary Materials the ratios of the monetary value (at current prices) of imported intermediate inputs to gross output. These results indicate that across most sectors, the value share of intermediate imports relative to gross output continued to rise after 2007, though at a somewhat slower pace. In line with observations from Antràs (2020), this points to the possibility that whereas the 2008–2009 trade collapse definitely marks a turning point in offshoring practices, it slowed down a continuously increasing trend rather than reverted it. The fact that the relative value of intermediate imports kept rising suggests the existence of further causes to explain the decrease in labour offshoring after 2007.

Another possible cause to the decrease in labour offshoring after 2007 could be a faster increase in direct labour productivity across foreign upstream sectors than in the domestic ones. If this is the case, this would result in a reduction in the relative share of foreign labour requirements although this would not be due to a change in offshoring practices. This hypothesis may be especially relevant to consider as German industries have tended to retain "headquarters" activities and final production stages at home while offshoring other "fabrication" stages (Baldwin and Lopez-Gonzalez, 2015; Deutsche Bundesbank, 2016; Timmer et al., 2019). As noted by Timmer et al. (2019), the potential for direct labour productivity gains may differ across these stages.

Finally, we found stable rates of domestic labour outsourcing across all sectors. This stability could be explained by the relatively high level of sectoral aggregation considered. Domestic outsourcing occuring across sub-sectors (or firms) belonging to the same "aggregated" sectors are hence not visible in our results. This is not problematic for our analysis, as what could be accounted as "outsourced" labour at more disaggregated levels is correctly accounted for as "direct" labour at the "aggregated" sector level.

5.3. *Implications for post-growth proposals on the future of work*

Our results indicate that direct labour productivity gains observed across German production sectors did not conceal any significant increase in the share of the embodied labour requirements provided in upstream sectors. Hence, working time reduction schemes aligned on past direct labour productivity gains (Cieplinski et al., 2021) would not necessarily be based on increased reliance on foreign labour. However, labour offshoring is significant: a quarter of the embodied labour to German production is provided abroad. This rate is even higher in manufacturing sectors. A re-shoring of this labour, either chosen or forced, would certainly curb direct labour productivity and the potential for working time reduction. Furthermore, although the share of the labour requirements provided abroad was stable or slightly declined during the period studied, the absolute level of foreign labour requirements to German production activities slightly increased due to higher levels of production. Following the taxonomy of environmental decoupling studies (Haberl et al., 2020; Hickel and Kallis, 2019; Parrique et al., 2019; Vogel and Hickel, 2023), this indicates a form of relative rather than absolute decoupling. Finally, our results show that service sectors with slower direct labour productivity gains are also characterized by lower labour offshoring. Hence, further shifting towards these sectors could alleviate labour offshoring related to production.

Importantly, our analysis addressed the labour requirements of

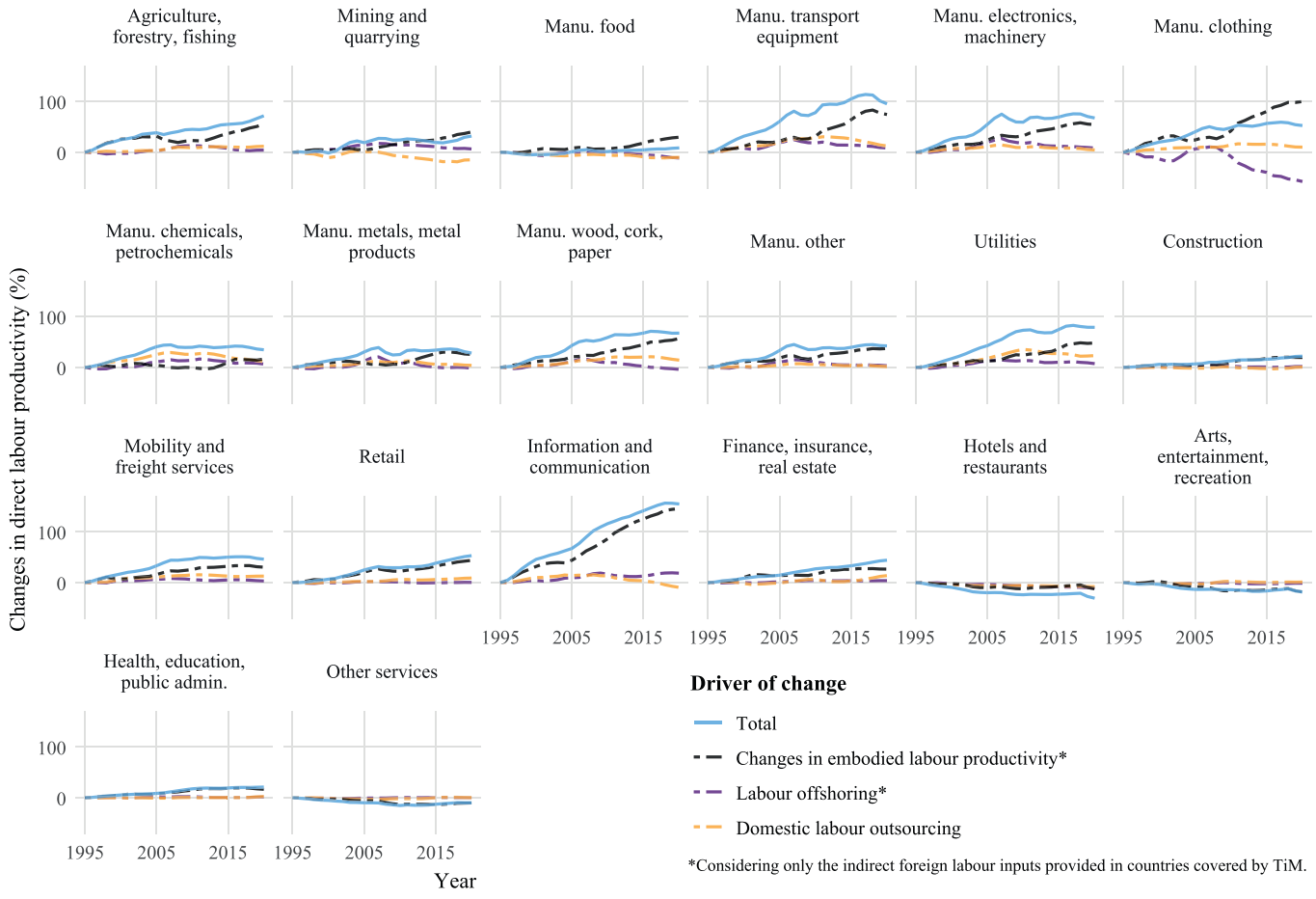

Fig. 4. Drivers of changes in direct labour productivity in Germany between 1995 and 2020.

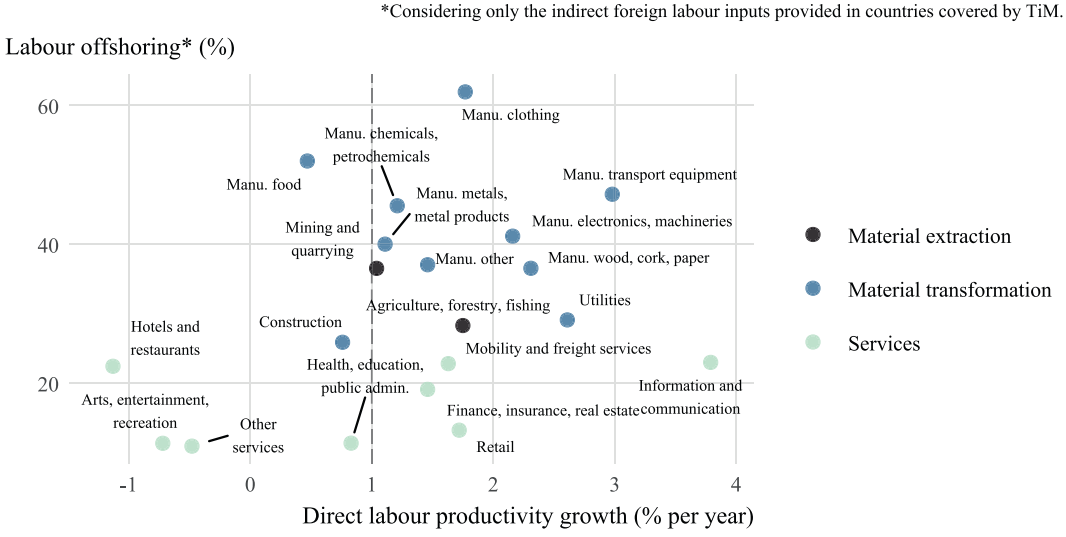

Fig. 5. Average labour offshoring according to direct labour productivity growth across production sectors in Germany, 1995–2020.

production activities. Yet high-income countries such as Germany may produce only a fraction of the commodities they consume and meet the rest of their consumption through the import of ready-made commodities. As such, net labour productivity gains are not tantamount to a *genuine emancipation from work*, which we suggest defining as an absolute reduction in embodied labour requirements relative to both production and consumption. This difference is well illustrated by the extremely low levels we found for the embodied labour inputs relative to production by the "Manufacturing: clothing" sector. Other studies have shown that an important share of the labour embodied in final consumption of EU countries relates to clothes consumption (Simas and Wood, 2017). Our results may hence reflect that clothes consumption in Germany is almost entirely met with imports of ready-made garments produced by foreign labour, and not that the labour requirements

relative to clothes consumption have vanished. Further attention is therefore needed about the labour requirements relative to consumption and their implications for post-growth proposals. In particular, working time reduction could get further challenged if a larger share of domestic consumption was to be met with domestic production (Manfroni et al., 2021; Pérez-Sánchez et al., 2021). Furthermore, shifting production towards sectors with less potential for labour productivity growth such as education, care or culture (Jackson, 2017; Mair et al., 2020) could paradoxically lessen labour offshoring relative to production while increasing labour offshoring relative to consumption: there are some material prerequisites for well-being (Rao and Min, 2018), and those are necessarily imported if not produced domestically. As a promising avenue for future research, recent empirical work suggested that in high-income countries, these prerequisite may be met within safe environmental limits at much lower levels of consumption (Millward-Hopkins et al., 2020) and related embodied labour requirements (McElroy and O'Neill, 2025) than current ones, provided yet that current consumption inequalities are addressed (Gough, 2017; Millward-Hopkins and Oswald, 2021). It is worth noting that the scenarios suggested by McElroy and O'Neill (2025) assume no changes to current labour productivity levels. Direct comparison with our results is not possible as they analyse labour requirements of consumption, while we analyse labour requirements of production. However, our finding of embodied labour productivity growth suggests an interesting area for future research on labour requirements of reduced consumption patterns.

6. Conclusion

It is generally assumed that labour productivity has increased rapidly in high-income countries, resulting in gradual reduction of work requirements at given production levels. Yet, conventional measures of labour productivity can conceal the displacement of labour requirements in upstream activities located abroad. Such “labour offshoring” has implications for proposals on the future of work in a post-growth setting, by arguably representing a form of cost-shifting towards lower-income countries.

Our empirical analysis indicates that between 1995 and 2020, a quarter of the embodied labour requirements to German production was provided abroad. The share of labour offshored is especially high in sectors relating to material extraction and transformation. It has yet stabilized or decreased in all sectors after 2007. We also found some embodied labour productivity gains in most sectors between 1995 and 2020. Hence, direct labour productivity gains appear to result mainly from a reduction in global labour requirements per unit of output, rather than by their increased displacement towards upstream sectors. Finally, we observed that service sectors with low potential for labour productivity gains are also less reliant on labour offshoring.

Those results are subject to important uncertainties, and their generalizability to other high-income countries beyond Germany remains to be verified. Yet, if their overall validity is confirmed, they have important implications for post-growth proposals on the future of work. There has been some net labour productivity gains between 1995 and 2020 that could be translated into working time reduction without increasing labour offshoring if production was stabilized. Alternatively, further shifting towards service activities with low potential for labour productivity growth could reduce labour offshoring related to production.

Critically, the potential for working time reduction would be limited if labour requirements currently offshored were to be re-internalized. Furthermore, a shift of production towards service activities may paradoxically alleviate labour offshoring related to production while increasing reliance on imports to meet material needs. These issues could be especially thorny given that currently, high-income countries such as Germany may produce only a fraction of the commodities they consume. Related implications for labour displacement and post-growth proposals on the future of work require further attention.

CRediT authorship contribution statement

Lukas Godé: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Simon Mair:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Erik Gómez-Baggethun:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Code availability

The source code supporting our findings is openly available in the following repository: https://doi.org/10.5281/zenodo.16944059.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2025.108778.

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