Structural Change and Economic Dynamics 61 (2022) 495–511

Contents lists available at ScienceDirect

Structural Change and Economic Dynamics

journal homepage: www.elsevier.com/locate/strueco

Productivity homogenisation trends of six advanced industrial economies: A vertically hyper-integrated approach

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ARTICLE INFO

Article history:
Received 29 April 2020
Revised 20 July 2021
Accepted 8 August 2021
Available online 18 August 2021

JEL classification:
C67
F14
O41
B51

Keywords:
Productivity
Vertically hyper-integrated sectors
Input-Output analysis

ABSTRACT

The present paper applies an Input-Output accounting framework, based on the logical device of vertical hyper-integration, to measure productivity trends across six advanced industrial economies (US, Germany, Japan, UK, France and Italy) during recent decades. Rather than measuring performance from the income side of the economy, as in traditional TFP growth analyses, disaggregated productivity changes are approximated from the expenditure side, i.e. the nominal counterpart to the system of physical quantities. Empirical findings suggest that the central tendency for convergence of hyper-integrated productivity levels across countries within each growing subsystem between 1995 and 2007 has been reversed between 2007 and 2015. And while service subsystems coincided in their direction of change, primary-*cum*-manufacturing sectors experienced more heterogeneous dynamics. Moreover, productivity gains accruing to wages were amongst the lowest in the three economies with highest overall hyper-integrated labour productivity growth.

1. Introduction

The empirical analysis of labour productivity within the last decades has been of considerable importance in the explanation of growth performance. The ‘convergence hypothesis’ is a case in point:

> The hypothesis asserts that at least since World War II, and perhaps for a considerable period before that, the group of industrial countries was growing increasingly homogeneous in terms of levels of productivity, technology, and per-capita income. In addition, there was a general catch-up toward the leader, with the gradual erosion of the gap between the leader economy, the United States throughout most of the pertinent period, and those of the countries lagging most closely behind it.
> (Baumol et al., 1994a, p. vii)

But is it plausible to expect that advanced industrial economies (and, eventually, even developing ones) acquire *levels* of net output per worker that are in *close proximity*?

Neoclassical explanations of the growth process suggest that diminishing returns to factor accumulation decelerate the pace of productivity growth for leading economies: with progressively falling marginal products, arbitrage leads to more profitable reallocation of capital to finance productive catch-up in laggard countries (Elmslie and Milberg, 1996, p. 155). Besides this mechanism based on the Neoclassical specification of production possibilities, forces analogous to diminishing returns limit the perpetual acceleration of productivity. For example, the imitation of (higher) consumption patterns of leading countries would tend to reduce saving rates of those catching up — *if* a consumption-investment long-period trade-off is assumed — and an ‘inherent’ productivity limit for some service industries *vis-à-vis* manufacturing would drag down the economy-wide rate of productivity growth, *as* the economy transitions towards a greater share of services in income (Baumol, 1994, p. 81).

Complementing (or substituting) diminishing returns, contagion-based explanations of convergence emphasise the relative ease to imitate with respect to innovate under competitive pressures, which lead laggard countries to catch up (Baumol, 1994, p. 73). Different contagion mechanisms, such as technology transfer, migratory flows and international competition contribute to explain the *inevitability* of convergence.

But such inevitability has been contested. Evolutionary accounts (such as Verspagen, 1991) warn that a country without an ‘intrinsic learning capability’ to absorb knowledge spillovers implied by technology transfers — as well as widely distant from the technological frontier — is bound to *diverge* in its productivity path. Even within a Neoclassical framework with increasing returns to scale (in the manufacturing industry, for example) and internationally

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https://doi.org/10.1016/j.strueco.2021.08.004
0954-349X/

mobile capital, a small ‘head start’ for a country will compound through time leading to ‘uneven development’ amongst competing economies (Krugman, 1981).

Hence, in view of contrasting theoretical standpoints, attention focused on testing empirically for productivity convergence (see e.g. Durlauf et al., 2005, for a review). Notwithstanding this vast literature on ‘growth regressions’, fewer attempts have scrutinised the theoretical foundations on which these empirical analyses of productivity changes were being performed.

As soon as it is recognised that ‘capital’ as an homogeneous ‘quantity’ cannot be measured independently of a system of prices (and therefore, of functional income distribution), and that fixed capital is among produced means of production, subject itself to technical change, then any productivity measure considering fixed capital goods as a non-produced primary ‘factor’ cannot depict the process of technical progress adequately (see, e.g. Elmslie and Milberg, 1996; Metcalfe, 2002). In fact, when computing productivity changes from the value added side (i.e. from a system of revenue-outlay relations), results should be qualified with respect to the particular distributive configuration and the numeraire which is being used to measure price aggregators for inputs and outputs (Steedman, 1983).

The most typical indicator of productivity performance, Total Factor Productivity (TFP, hereinafter) growth, is not only subject to the above-stated critique (being based on the notion of aggregate production function), but even more, when formulated in terms of its dual, value side (Hsieh, 1999; 2002), it is clear that it does not represent changes in physical productivity but changes in income distribution among real wages and the rate of return on fixed capital. It is not by chance that TFP convergence can be attributed to a convergence in income distribution patterns among advanced economies, rather than convergence in actual technology.

In fact, only by *assuming* that the *actual* economy is immersed in a Neoclassical general equilibrium, in which ‘factor’ prices have an equilibrium physical counterpart, disaggregated TFP figures may have a strictly physical interpretation (ten Raa, 2004). As this is not the case, following Harberger (1998), TFP growth essentially represents a ‘real cost reduction’.

To overcome the limitations of traditional measurement *and* conceptualisation of the process of technical change, the present paper adopts a Classical theoretical standpoint as introduced by Pasinetti (1959) in his critique of Solow (1957), and further elaborated in Pasinetti (1981, 1988, 1989). This standpoint consists in applying the method of *growing* or *hyper*-subsystems to the measurement of disaggregated physical productivity changes.

The notion of subsystem originates in Sraffa (1960, Appendix A, p. 89), and it consists in a self-sufficient circular flow containing all inputs required to reproduce one single product for final uses in the economy. Subsystems *logically* partition inputs and outputs into a series of relatively autonomous expenditure balances, one for each final product, which add up to the whole economy. By introducing mathematical operators to carry out this logical partition, Pasinetti (1973, p. 5) operationalised the concept of subsystem using the term ‘vertically integrated sector’.

Sraffa (1960) conceived subsystems for an economy in a self-replacing state. Instead, the *growing* character of subsystems advanced by Pasinetti (1988) is due to the fact that *gross* investments are included among the means of production, so that the logical partitioning of gross outputs, inputs and labour contemplates both self-replacement *and* expansion of the circular flow.

In this way, direct, indirect and *hyper*-indirect (Pasinetti, 1981, p. 102) labour requirements to reproduce each item of final consumption allow to assess the degree and extent of the division of labour, giving rise to the notion of (vertically) *hyper-integrated* labour productivity. This latter concept is closely related to that of *total* labour productivity, explicitly introduced by Vincent (1962, pp. 62-65), though already latent in Leontief (1953, p. 39). The main difference lies in the consideration of new investments (i.e. *hyper*-indirect requirements) as means of production induced by demand for final uses.

It may be thought that introducing a novel notion of labour productivity may be redundant, as cross-country comparisons of economic performance at the *industry* level have frequently adopted the concept of ‘real gross value added per hour worked’. However, a physical interpretation of the notion of *real* value added is difficult to maintain (Meade, 2010). Value added, as currently measured by the System of National Accounts (SNA), includes an industry’s operating surplus, which is a *residual* magnitude for which it is *not* possible to distinguish between a volume and price dimension (UN, 2009, p. 314).[1]

Instead, industry-specific direct labour productivities, while based on gross output in volume terms, reflect only partial views of the technique in use. For example, the productivity gap for a given industry across countries may have its origin on the productivity of the inputs supporting it, rather than on the activity itself.

Therefore, adopting a vertically hyper-integrated approach may cast light on the ‘convergence hypothesis’ from an alternative standpoint: system productivity measures summarise overall circularity in *each* single coefficient, so convergence in hyper-integrated productivity levels may provide a more accurate picture of sectoral gaps across countries. Performing an empirical exploration of this hypothesis for the case of six advanced industrial economies (US, Germany, Japan, UK, France and Italy) is precisely the main aim of this paper.

The interest in the six above-mentioned economies goes beyond the fact that they represent close to 45% of global GDP (in 2018). Recent trends of technological change have been characterised by industrial robot deployment and increasing digitalision (UNIDO, 2019). As of 2015, these countries concentrated 50.1% of the global stock of operational industrial robots (UNCTAD, 2017, p. 47, Table 3.3) and are at the frontier in global patenting and/or exporting of advanced digital production technologies (UNIDO, 2019, p. 48).

Specifically, the aim of this paper is two-fold. First, building on the approach introduced by Garbellini and Wirkierman (2014), to specify a disaggregated productivity accounting framework in hyper-integrated terms for a single-product Input-Output system, typical of databases generally available.[2] Second, to apply the concept of vertical hyper-integration to the analysis of convergence issues for advanced industrial economies. The significance of the shift in the disaggregated unit of analysis from the ‘industry’ to the ‘growing subsystem’ will be particularly relevant when interpreting and discussing results.

In order to fulfil this aim, the computable Input-Output productivity accounting framework employed is introduced in Section 2. Section 3 discusses empirical notions of productivity convergence, deciding upon one of them. Empirical results are reported in Section 4, concerning both aggregate dynamics and sectoral ho-

[1] In fact, this subtle but crucial point is too often overlooked. It is worth reproducing the logic of the argument in full: “When GDP is determined as the difference between output and intermediate consumption plus taxes less subsidies on production, gross value added is derived as an accounting residual. This is so in both current values and volume terms. In order for there to be an identity between different estimates of GDP in volume terms, it is not possible to give a price and volume dimension to gross value added. Rather the residual item is described as being ‘in real terms’. If volume estimates of consumption of fixed capital and compensation of employees are available, net operating surplus and net mixed income can be derived but only in real terms and without a volume and price dimension. Thus *it is not possible to derive an independent measure of GDP from the income approach since one item is always derived residually*”(UN, 2009, p. 314, italics added).

[2] Instead, the framework in Garbellini and Wirkierman (2014) was developed focusing on a set of square Supply-Use Tables, allowing for pure joint products.

Table 1
Input-Output Table(industry × industry) of domestic output at basic prices for n industries and k final demand categories.

	Industries	Final demand	Output
Domestic industries	$\boldsymbol{X}$	$\boldsymbol{F}$	$\boldsymbol{q}$
Imports	$\boldsymbol{M}_x$	$\boldsymbol{M}_f$	$\boldsymbol{m}$
Net taxes on products	$\boldsymbol{\tau}_x^T$	$\boldsymbol{\tau}_f^T$	τ
Gross Value Added	$\boldsymbol{y}^T$		
Gross Output	$\boldsymbol{q}^T$		

where:
$\underset{(n\times n)}{\boldsymbol{X}}$ = matrix of domestic intermediate transactions (industry by industry)
$\underset{(n\times n)}{\boldsymbol{M}_x}$ = matrix of imported intermediate transactions (industry by industry)
$\underset{(n\times k)}{\boldsymbol{F}}$ = matrix of final demand domestically produced (industry by category)
$\underset{(n\times k)}{\boldsymbol{M}_f}$ = matrix of imported final demand (industry by category)
$\underset{(1\times n)}{\boldsymbol{\tau}_x^T}$ = vector of taxes net of subsidies on products (by industry)
$\underset{(1\times k)}{\boldsymbol{\tau}_f^T}$ = vector of taxes net of subsidies on products (by category)
$\underset{1\times n}{\boldsymbol{y}^T}$ = vector of gross value added at basic prices (by industry)
$\underset{(n\times 1)}{\boldsymbol{q}}$ = vector of gross output at basic prices (by industry)
$\underset{(n\times 1)}{\boldsymbol{m}}$ = vector of imports (by industry of origin)
$\underset{(1\times 1)}{\tau}$ = taxes net of subsisdies on products

mogenisation trends. A summary of findings with some final remarks in Section 5 close the paper.

2. Productivity accounting framework

The starting point is a square industry × industry Input-Output accounting scheme as displayed in Table 1.[3]

Final demand categories generally include: household and general government consumption expenditure, exports and gross fixed capital formation. We will consider gross fixed capital formation *excluding* residential construction as an *induced* component of expenditure (denoted by $\boldsymbol{f}_k$). All other components of final demand will be aggregated into a final 'consumption' vector (denoted by $\boldsymbol{c}$). Therefore, if $\boldsymbol{F} = [\boldsymbol{f}_k \quad \boldsymbol{c}]$, the expenditure side for domestic output and the income side of the system may be written, respectively, as:

$$\boldsymbol{q} = \boldsymbol{X}\boldsymbol{e} + \boldsymbol{f}_k + \boldsymbol{c} \tag{1}$$

$$\boldsymbol{q}^T = \boldsymbol{e}^T\boldsymbol{X} + \boldsymbol{e}^T\boldsymbol{M}_x + \boldsymbol{\tau}_x^T + \boldsymbol{y}^T \tag{2}$$

Expression (1) represents the nominal counterpart to the product balances of the economy, depicting a process of commodity circulation, while expression (2) captures the cost-revenue relations of each industry. From the former, it is possible to recover the system of physical quantities, whereas from the latter, the system of relative prices. In fact, disaggregated system measures of physical productivity changes are based on expression (1), while profitability or 'real cost reduction' measures, like TFP growth, on expression (2).

In this paper, therefore, the focus will be on the expenditure side for domestic output (1). Note, in this regard, that the crucial distinction between gross fixed capital formation net of dwellings ($\boldsymbol{f}_k$) and final consumption demand ($\boldsymbol{c}$) is given by the capacity generating effects of the former with respect to the latter, i.e. to the fact that demand for new capital goods re-enter the circular flow while private and government consumption, together with exports and residential construction, constitute the physical surplus of the system.[4]

In this sense, it is assumed that *gross* investments (i.e. demand for replacements and new investments) are part of the means of production, and their level induced by the growth rate of demand for final uses. But given that $\boldsymbol{f}_k$ is a vector of gross investment by industry of *origin*, it will not suffice to describe expenditure on fixed capital goods by each *demanding* industry, so we actually need to specify:

$$\boldsymbol{f}_k = \boldsymbol{F}_k\boldsymbol{e} \tag{3}$$

where $\boldsymbol{F}_k$ is an $n \times n$ matrix of gross fixed capital flows domestically produced by industry of origin (row-wise) and destination (column-wise). By introducing (3) in (1), the expenditure system for domestic output can be written as:

$$\boldsymbol{q} = \boldsymbol{X}\boldsymbol{e} + \boldsymbol{F}_k\boldsymbol{e} + \boldsymbol{c} \tag{4}$$

A crucial point in (4) is that the notion of *net output* is modified with respect to the traditional concept of final demand. In this context, both aggregate and sectoral productivity measures shall be defined taking the final consumption vector $\boldsymbol{c}$ as the physical surplus, i.e. net output, of the system (Pasinetti, 1986). Note, moreover, that system (4) considers only domestically produced commodities,[5] and magnitudes are given at basic prices, i.e. taxes on products are separated from intermediate transactions, and trade and transport margins have been re-allocated to the corresponding specific cells of intermediate input matrices.[6]

Still, expression (4) depicts purely accounting relations. However, a necessary prerequisite for any productivity analysis should be to establish a connection with theoretical magnitudes. The key insight to establish such a bridge is that current inputs are met from past outputs. Hence, *observed* input matrices include *both* self-replacement and expansion/contraction components, i.e. growth is implicitly contained in observed empirical structures.[7] In fact, the separation between the technique in use and activity levels is analytical, and cannot be based on purely accounting grounds (Garbellini and Wirkierman, 2014). In this context, the analytical separation may be performed as follows:

$$\boldsymbol{X}\widehat{\boldsymbol{q}}^{-1} = \boldsymbol{A}(\boldsymbol{I} + \widehat{\boldsymbol{\rho}}_q) \tag{5}$$

$$\boldsymbol{F}_k\widehat{\boldsymbol{q}}^{-1} = \boldsymbol{A}_k + \boldsymbol{K}\widehat{\boldsymbol{\rho}}_q \tag{6}$$

$$\widehat{\boldsymbol{\rho}}_q = (\widehat{\boldsymbol{q}}_{(+1)} - \widehat{\boldsymbol{q}})\widehat{\boldsymbol{q}}^{-1} \tag{7}$$

where $\boldsymbol{A}$ is the matrix of circulating capital techniques in each industry, $\boldsymbol{A}_k$ is the matrix of fixed capital *replacement* (not depreciation) coefficients, $\boldsymbol{K}$ is a matrix of fixed capital *new* investment coefficients and, finally, $\widehat{\boldsymbol{\rho}}_q$ is the diagonal matrix of *empirically given* growth rates of industry (gross) output.[8]

[3] As regards notation, matrices are represented using boldface upper-case letters (e.g. $\boldsymbol{M}$), vectors with boldface lower-case letters (e.g. $\boldsymbol{v}$), all vectors are column vectors, and their transposition is explicitly indicated (e.g. $\boldsymbol{v}^T$). A vector with a hat (e.g. $\widehat{\boldsymbol{v}}$) indicates a diagonal matrix with each element of the vector on the main diagonal. Vector $\boldsymbol{e} = [1, \ldots, 1]^T$ is an $n \times 1$ column vector that sums across columns, while $\boldsymbol{e}_i = [0, \ldots, 0, 1, 0 \ldots, 0]^T$ is an $n \times 1$ column vector that selects the $i-th$ column. The same applies for vector $\boldsymbol{e}_i^T$ with respect to rows. All vectors are of dimension $n \times 1$, and all matrices are of dimension $n \times n$.

[4] As has been emphasized by Pasinetti (1981, p. 176): "It is this *derived demand* aspect of investment goods, due to their being used as means of production, that is new and typical of production systems".

[5] A separate set of product balances for imports could be constructed as well: $\boldsymbol{m} = \boldsymbol{M}_x\boldsymbol{e} + \boldsymbol{m}_k + \boldsymbol{m}_c$, where $\boldsymbol{m}_k$ and $\boldsymbol{m}_c$ are the vectors of imported fixed capital goods and final uses, respectively.

[6] See EUROSTAT (2008, p. 163) for a definition and discussion.

[7] See Lager (1997, 2000) on the analysis of the relations between theoretical production schemes and empirical Input-Output magnitudes.

[8] Fixed capital accounting in traditional productivity analyses emphasise the distinction between gross and *net* (rather than *new*) investment, based on subtracting

The case of circulating capital inputs in expression (5) is straightforward: the current technique matrix is applied to $t+1$ gross output levels.[9] Instead, the case of fixed capital inputs in expression (6) is more delicate, given that durable means of production do not exhaust in a single (national) accounting period. In fact, fixed capital replacements and new investments are summarised by different matrices: while new investments reflect the latest vintage of capital goods and depend only on current growth rates, replacement needs depend on the past growth trajectory of the economy.[10]

By introducing (5), (6) and (7) in (4), re-ordering and grouping terms, we have:

$$\boldsymbol{q} = (\boldsymbol{A}+\boldsymbol{A}_k)\boldsymbol{q} + (\boldsymbol{A}+\boldsymbol{K})\widehat{\boldsymbol{\rho}}_q\boldsymbol{q} + \boldsymbol{c} \tag{8}$$

Consider re-partitioning system (8) into n different parts, each producing a composite commodity for final uses, according to the product mix of industry j.[11] To each of these parts we shall call growing (or hyper-) subsystems (Pasinetti, 1981; 1988). In formal terms, vector $\boldsymbol{c}$ may be partitioned as:

$$\boldsymbol{c} = \sum_{j=1}^{n}\boldsymbol{c}^{(j)} = \sum_{j=1}^{n}\widehat{\boldsymbol{c}}\boldsymbol{e}_j = \sum_{j=1}^{n}\boldsymbol{e}_j c_j \tag{9}$$

where $\boldsymbol{c} = [c_j]$. Hence, we can write a self-replacing and expanding circular flow associated to each vector of final uses $\boldsymbol{c}^{(j)} = [0\dots c_j\dots 0]^T$, $j = 1,\dots,n$:

$$\boldsymbol{q}^{(j)} = (\boldsymbol{A}+\boldsymbol{A}_k)\boldsymbol{q}^{(j)} + (\boldsymbol{A}+\boldsymbol{K})\widehat{\boldsymbol{\rho}}_q\boldsymbol{q}^{(j)} + \boldsymbol{c}^{(j)} \tag{10}$$

where the three addenda on the right-hand-side reflect: (i) self-replacement requirements of circulating *and* fixed capital, (ii) new investments and (iii) final consumption, respectively.

Crucially, expression (10) depicts an *effective* growth path. If instead of considering actual industry output growth rates $\widehat{\boldsymbol{\rho}}_q$, we 'break' the accounting identities, and compute the output trajectory associated to an exponential growth in final consumption at subsystem-specific rates $\{r_j\}$, $j = 1,\dots,n$, we have:

$$\boldsymbol{\lambda}^{(j)} = (\boldsymbol{A}+\boldsymbol{A}_k)\boldsymbol{\lambda}^{(j)} + r_j(\boldsymbol{A}+\boldsymbol{K})\boldsymbol{\lambda}^{(j)} + \boldsymbol{c}^{(j)} \tag{11}$$

obtaining a *normative* growth path (with subsystem output levels $\boldsymbol{\lambda}^{(j)}$), like the one considered by Stone and Brown (1962) and Pasinetti (1988). The distinction between equation systems (10) and (11) should clarify that, in setting up our productivity accounting scheme, the focus is on effective growth paths as we intend to measure the *actual* (physical) surplus generating capacity of an economy, rather than studying counter-factual normative trajectories. This choice has an important implication: system (10) will allocate *effective* new investment flows of circulating and fixed capital demanded by *industry* i to subsystem j on the basis of the share of production from industry i *for* subsystem j in the industry's total gross output (i.e. $q_i^{(j)}/q_i$).

Therefore, gross industry outputs associated with hyper-subsystem j are given by:

$$\boldsymbol{q}^{(j)} = (\boldsymbol{I}-\boldsymbol{\Lambda})^{-1}\boldsymbol{c}^{(j)}, \quad j = 1,\dots,n \tag{12}$$

with:

$$\boldsymbol{\Lambda} = (\boldsymbol{X}+\boldsymbol{F}_k)\widehat{\boldsymbol{q}}^{-1} = (\boldsymbol{A}+\boldsymbol{A}_k) + (\boldsymbol{A}+\boldsymbol{K})\widehat{\boldsymbol{\rho}}_q \tag{13}$$

Each vector $\boldsymbol{q}^{(j)}$ contains total outputs required to reproduce and expand the composite commodity of industry j. Moreover, matrix $\boldsymbol{\Lambda}$ summarises the comprehensive (circulating and fixed capital) input requirements per monetary unit of output *when* industry output vector is $\boldsymbol{q}$, *and* it expands (or contracts) at rates $\widehat{\boldsymbol{\rho}}_q$.

Turning now to labour inputs, consider the industry employment vector $\boldsymbol{l} = [L_j]$, with $L = \boldsymbol{l}^T\boldsymbol{e}$. By defining the row vector of employment requirements per unit of industry output as: $\boldsymbol{a}_l^T = \boldsymbol{l}^T\widehat{\boldsymbol{q}}^{-1}$, a measure of *direct* labour productivity by industry is given by:

$$\alpha_l^{(j)} = \frac{q_j}{L_j} = \frac{1}{a_{l_j}}, \quad j = 1\dots n \tag{14}$$

where $q_j = \boldsymbol{e}_j^T\boldsymbol{q}$ is gross output of industry j. The empirical rate of change — based on continuous compounding — of direct labour productivity between time periods $t = 0,1$ may be obtained as: $\Delta\%\alpha_l^{(j)} = \ln(\alpha_{l1}^{(j)}) - \ln(\alpha_{l0}^{(j)})$.

Instead, comprehensive labour inputs associated to subsystem j are:

$$L_\eta^{(j)} = \boldsymbol{a}_l^T\boldsymbol{q}^{(j)} = \boldsymbol{\eta}^T\boldsymbol{c}^{(j)} = \boldsymbol{\eta}^T\boldsymbol{e}_j c_j = \eta_j c_j \tag{15}$$

$$\boldsymbol{\eta}^T = \boldsymbol{a}_l^T(\boldsymbol{I}-\boldsymbol{\Lambda})^{-1} \tag{16}$$

where $\boldsymbol{\eta}^T$ is the vector of vertically hyper-integrated labour coefficients, and scalar $L_\eta^{(j)}$ summarises total labour requirements to replace and expand (or contract) final uses of industry j. It is the product of two components: labour intensity per unit of final consumption, η_j, times (monetary) units of final consumption, c_j. Note also that:

$$L = \sum_{j=1}^{n} L_\eta^{(j)} = \sum_{j=1}^{n} L_j$$

i.e. adding up total labour activated across subsystems *or* total industry employment *equally* exhausts aggregate employment but, in general, $L_\eta^{(j)} \neq L_j$.

Every subsystem coefficient η_j depends on the technique in use of *all* industries. This is because it captures the redistribution of total employment that takes place when the unit of analysis is shifted from the industry to the *growing* subsystem. Differently from the traditional notion of vertically *integrated* labour coefficient, η_j includes the labour requirements to *expand* (and not only to self-replace) productive capacity.

Hence, *hyper-integrated* labour productivity for growing subsystem $j = 1\dots n$ can be obtained as:

$$\alpha_\eta^{(j)} = \frac{c_j}{L_\eta^{(j)}} = \frac{1}{\eta_j} = \frac{1}{\boldsymbol{a}_l^T(\boldsymbol{I}-\boldsymbol{\Lambda})^{-1}\boldsymbol{e}_j} \tag{17}$$

whereas the empirical rate of change between time periods $t = 0,1$ may be computed as:

$$\Delta\%\alpha_\eta^{(j)} = \ln(\alpha_{\eta 1}^{(j)}) - \ln(\alpha_{\eta 0}^{(j)}).$$

Note that $\alpha_\eta^{(j)}$ does not directly depend on the structure of final consumption. Instead, any aggregate measure of labour productivity changes will depend on the composition of net output

the 'consumption of fixed capital' (or depreciation) from gross magnitudes. However, such a distinction pertains to the value-added side of the economy, rather than to the expenditure system. Depreciation allowances are a balance sheet concept, whereas replacement needs (and retirements) correspond to physical quantities. Only in a stationary economy both concepts *may* coincide (Eisner, 1952, p. 826). For a detailed discussion, please see Garbellini and Wirkierman (2014, p. 159).

[9] In fact, $\boldsymbol{X} = \boldsymbol{A}(\boldsymbol{I}+\widehat{\boldsymbol{\rho}}_q)\widehat{\boldsymbol{q}} = \boldsymbol{A}\widehat{\boldsymbol{q}}_{(+1)}$, as $(\boldsymbol{I}+\widehat{\boldsymbol{\rho}}_q)\widehat{\boldsymbol{q}} = (\boldsymbol{I}+\widehat{\boldsymbol{q}}_{(+1)}\widehat{\boldsymbol{q}}^{-1}-\boldsymbol{I})\widehat{\boldsymbol{q}} = \widehat{\boldsymbol{q}}_{(+1)}$. Therefore, in principle, technique matrix $\boldsymbol{A}$ could be recovered by computing: $\boldsymbol{A} = \boldsymbol{X}\widehat{\boldsymbol{q}}^{-1}(\boldsymbol{I}+\widehat{\boldsymbol{\rho}}_q)^{-1}$.

[10] As a matter of fact, if neither fixed capital stocks nor data on retirements are available, it is not empirically possible to separate $\boldsymbol{A}_k$ from $\boldsymbol{K}$. Note that *incremental* fixed capital-output computations in this context give: $\boldsymbol{F}_k(\widehat{\boldsymbol{q}}_{(+1)}-\widehat{\boldsymbol{q}})^{-1} = \boldsymbol{A}_k\widehat{\boldsymbol{\rho}}_q^{-1}+\boldsymbol{K}$. Hence, only if fixed capital is "infinitely durable" (Gossling, 1974), so that $\boldsymbol{A}_k = \boldsymbol{0}$, we obtain $\boldsymbol{K} = \boldsymbol{F}_k(\widehat{\boldsymbol{q}}_{(+1)}-\widehat{\boldsymbol{q}})^{-1}$, i.e. Lange's 'purely technical' investment coefficients (Lange, 1969, pp. 61-2).

[11] Traditionally, subsystems have been defined with respect to a single commodity, even in square joint-product systems of commodity × activity type. However, given that our dataset is based on the application of the fixed product sales structure assumption (Yamano and Ahmad, 2006, section 7), each industry produces a composite commodity identifying every subsystem.

(Pasinetti, 1981, pp. 97-99). In particular, when working in hyper-integrated terms, the synthetic indicator relating subsystem productivity growth with the composition of final consumption demand is given by the standard rate of productivity growth, ρ^*, introduced by Pasinetti (1981, pp. 101-104).[12] In this context it can be defined as:

$$\rho^* = \frac{\sum_{j=1}^{n} \text{dln}(\alpha_\eta^{(j)}) L_\eta^{(j)}}{\sum_{j=1}^{n} L_\eta^{(j)}} \tag{18}$$

Expression (18) shows that ρ^* is a weighted average of the rates of change of vertically hyper-integrated labour productivity $\text{dln}(\alpha_\eta^{(j)})$, the weights being the quantities of total labour of the corresponding *subsystem* j, $L_\eta^{(j)}$. By inspecting (15) it can be immediately seen that $L_\eta^{(j)}$ depends on c_j.

Empirically, ρ^* may be computed as a Divisia index between time periods $t = 0, 1$:

$$\rho^* = \sum_{j=1}^{n} \frac{1}{2}\left[\frac{L_{\eta 0}^{(j)}}{L_0} + \frac{L_{\eta 1}^{(j)}}{L_1}\right] \times \left[\ln\left(\frac{1}{\eta_{j1}}\right) - \ln\left(\frac{1}{\eta_{j0}}\right)\right] \tag{19}$$

Even though it reflects an average productivity growth rate, ρ^* is affected not only by technological developments but also by the given composition of net output. In this sense, it would be important to find an *aggregate* indicator that can be decomposed into different effects, separating changes in labour and commodity requirements from shifts in the pattern of demand for final uses. To do so, consider the re-distribution of total employment in hyper-integrated terms, $L = \boldsymbol{\eta}^T \boldsymbol{c}$, as well as aggregate final consumption, $C = \boldsymbol{e}^T \boldsymbol{c}$. Then, hyper-integrated labour content per unit of final consumption is given by:

$$\frac{L}{C} = \frac{\boldsymbol{\eta}^T \boldsymbol{c}}{\boldsymbol{c}^T \boldsymbol{e}} = \boldsymbol{a}_l^T (\boldsymbol{I} - \boldsymbol{\Lambda})^{-1} (\boldsymbol{c}/C) \tag{20}$$

For time periods $t = 0, 1$, we have:

$$\frac{L_1/C_1}{L_0/C_0} = \frac{L_1}{C_1}\frac{C_0}{L_0} = \frac{\boldsymbol{a}_{l,1}^T (\boldsymbol{I} - \boldsymbol{\Lambda}_1)^{-1} (\boldsymbol{c}_1/C_1)}{\boldsymbol{a}_{l,0}^T (\boldsymbol{I} - \boldsymbol{\Lambda}_0)^{-1} (\boldsymbol{c}_0/C_0)} \tag{21}$$

Therefore, we may write the following multiplicative decomposition:[13]

$$\begin{aligned} \frac{L_1/C_1}{L_0/C_0} = & \underbrace{\frac{\boldsymbol{a}_{l,1}^T (\boldsymbol{I} - \boldsymbol{\Lambda}_0)^{-1} (\boldsymbol{c}_0/C_0)}{\boldsymbol{a}_{l,0}^T (\boldsymbol{I} - \boldsymbol{\Lambda}_0)^{-1} (\boldsymbol{c}_0/C_0)}}_{(I)} \times \\ & \times \underbrace{\frac{\boldsymbol{a}_{l,1}^T (\boldsymbol{I} - \boldsymbol{\Lambda}_1)^{-1} (\boldsymbol{c}_0/C_0)}{\boldsymbol{a}_{l,1}^T (\boldsymbol{I} - \boldsymbol{\Lambda}_0)^{-1} (\boldsymbol{c}_0/C_0)}}_{(II)} \times \\ & \times \underbrace{\frac{\boldsymbol{a}_{l,1}^T (\boldsymbol{I} - \boldsymbol{\Lambda}_1)^{-1} (\boldsymbol{c}_1/C_1)}{\boldsymbol{a}_{l,1}^T (\boldsymbol{I} - \boldsymbol{\Lambda}_1)^{-1} (\boldsymbol{c}_0/C_0)}}_{(III)} \end{aligned} \tag{22}$$

where:

(I) direct labour-saving effect:
if $(I) < 1$, there is a decrease in direct labour inputs per unit of gross industry output;

(II) circulating and fixed capital inputs saving effect:
if $(II) < 1$, there is a decrease in total requirements of capital inputs per unit of final consumption demand;

(III) compositional change in final demand effect:
if $(III) < 1$, the shift in the pattern of final consumption decreases labour content, for a given technique in use.

3. The productivity convergence hypothesis

The 'convergence hypothesis' has received attention in recent decades (see, e.g. Baumol et al., 1994a), maybe because the statement that 'initial effects disappear' (which is its heuristic basis) is quite reassuring for the dynamics of world income distribution.

However, if cross-country differences in productivity levels are assessed to be permanent rather than transitory, distilling whether there is a true 'structural heterogeneity' or whether these differences are the *effect* of initial conditions (Durlauf et al., 2005, p. 583) could lead to very different implications for economic policy.

In fact, it is easy to expect sharp disagreement in the interpretation of the results of statistical inference according to the 'growth theory' justifying the convergence mechanism. A marginalist view of the process of growth would emphasise that diminishing returns to production 'factors' drive the process, while an evolutionary perspective could instead focus on trajectories of technological diffusion and acquisition at an international level.

From a Classical perspective, neither 'factor' price equalisation and steady-state paths nor a straightforward technological 'catch-up' should be expected. First, because the mechanism at the basis of Neoclassical growth theory is simply based on questionable premises (particularly in its conceptualisation of 'capital', value and distribution). Second, because the institutional process regulating the distribution of income between wages and profits plays an important role in the choice of techniques that are implemented. And third, but most importantly, the process of changes of techniques in use cannot be circumscribed to the parametrisation of a set of initial conditions, as the consequences of mechanisation (and other forms of technical progress) for employment and effective demand clearly impede smooth satisfactory growth paths amongst interdependent economies.

The debate around the convergence hypothesis has given rise to a whole range of convergence concepts (for example, surveyed in Baumol et al., 1994b, pp. 7-11), of increasing complexity as the statistical techniques for their assessment become more involved.

The most diffused notion, β-convergence (Durlauf et al., 2005, pp. 585-592), is associated to 'growth regressions' searching for either unconditional or residual convergence, i.e. *causal* effects in a linear probability model of initial levels on growth rates, either gross or net of the effects of a set of controls. Besides traditional econometric problems of identification, endogeneity and measurement error, Quah (1993) advanced a critique that led to recognising that the "negative sign on the initial-condition coefficient [...] does not indicate a collapsing cross-section distribution" (Quah, 1993, p. 432).

Instead, σ-convergence pretends to evaluate whether the cross-sectional variance of productivity levels is reduced through time, but statistical inference in this case requires an assumption that the data generating process is *not* invariant, which makes it difficult to devise a distribution for the test statistic under the null hypothesis (Durlauf et al., 2005, p. 593). The problematic character of β- and σ-convergence is further evidenced by the fact that neither notion carries any implication for the other (Durlauf et al., 2005, p. 599).

As to the variable whose convergence path is being asserted, attention has mostly focused on labour productivity (measured as aggregate *real* value added per worker) or TFP. But as soon as we

[12] It is important to note that, whilst the model in Pasinetti (1981) is a closed Input-Output model, the method of hyper-integration may be applied to an open Input-Output system as well, for example, by considering the quantity system of Pasinetti (1988). Specifically, this also applies to the standard rate of productivity growth, ρ^*.

[13] Multiplicative decompositions are not unique (see Dietzenbacher et al., 2000, pp. 431-2), so (22) may be complemented by an alternative expression *reversing* the weights, i.e. time periods. In the empirical application considered below, meaningful results do not differ significantly by the choice between alternative decompositions.

inspect the total differential of the typical value added accounting identity of growth accounting procedures ($pY = rK + wL$), it is found that:

$$(pY)\rho_{tfp} = p\dot{Y} - r\dot{K} - w\dot{L} = \dot{r}K + \dot{w}L - \dot{p}Y$$

Hence, once $\rho_{tfp} = \dot{A}/A$ (the rate of TFP Growth) is seen from the dual side (the last equality in the expression above), the 'residual' becomes determined by changes in distributive variables. Therefore, TFP convergence may be interpreted as cross-country convergence in functional income distribution, not necessarily reflecting convergence in techniques (Elmslie and Milberg, 1996, p. 160).

The disruptive character of changing income distribution to analyse cross-country TFP convergence has been detected within the marginalist framework, and Bernard and Jones (1996) have advanced a measure labelled 'total technology productivity' (TTP), which can be shown to consist mainly in computing $TTP_{0,t} = (A_t/A_0)Y_0$, i.e. the output that would have resulted had there only been changes in the residual.

But this means precisely to freeze the proportions between means of production and labour to *measure* technical change, i.e. "it shows which country would produce more output if all countries employed exactly the same quantities of capital and labour" (Bernard and Jones, 1996, p. 1231).

Simply by noting that the changing degree of mechanisation (value of capital to labour ratio) is one of the most persistent features of technical change (Pasinetti, 1977, pp. 393-4) would suggest that 'TTP' discards precisely one of the main reasons to measure changes in technology.

In general, studies have mainly dealt with cross-country differences in aggregate productivity, while patterns of convergence by industry have shown more 'convoluted' results (see, e.g. Dollar and Wolff, 1994). But given that the aim of the present paper is precisely to unfold the dynamics of structure, the disaggregated dimension will be analysed.

Without in the least pretending to establish results through statistical inference on a point estimation of a probability model, we will limit to adopt the convergence concept of 'homogenisation':

> *Homogenization* refers to a reduction in the dispersion among some set of countries (or regions or industries) in terms of some measure of performance.
> (Baumol et al., 1994b, p. 7)

This concept is naturally related to σ-convergence, but limited only to trends obtained by means of descriptive statistics. It is implicitly adopted in studies like Dollar and Wolff (1988, p. 551) and Landesmann and Stehrer (2001, pp. 416-8) for direct labour productivity and Elmslie and Milberg (1996, p. 162) for vertically integrated labour productivity. This latter study is of particular interest and its empirical heuristics to measuring 'catch-up' will be closely followed here. However, while Elmslie and Milberg (1996) assess homogenisation trends for each *self-replacing* subsystem, the empirical analysis below focuses on both the industry and the *growing* subsystem as units of analysis, pursuing a comparative analysis of dispersion and gaps for alternative labour productivity indicators.

4. Empirical results

Having derived a set of measures for industry, subsystem and aggregate productivity changes in Section 2, and after the conceptual discussion of Section 3, this section reports empirical results on aggregate productivity trends and sectoral homogenisation trends for six advanced OECD economies: Germany (DEU), France (FRA), Italy (ITA), United Kingdom (GBR), Japan (JPN) and the United States (USA) during the period 1995–2015.[14]

4.1. Dataset characteristics

Table 2 enumerates different OECD databases that have been articulated into a unified dataset, with the purpose of measuring volume changes for a set of growing subsystems, and comparing these figures with traditional productivity indicators.

The choice of the 'group of six' (G6) economies (DEU, FRA, GBR, ITA, JPN, USA) is motivated by their enduring importance at a global scale. Though having lost 12.7 percentage points of their share in global income between 1995 and 2015, they still represented 43.4% of total value added in the world economy in 2018.[15] While it would be desirable to extend this empirical study to selected emerging economies with fast-paced productivity growth and increasing share in global income — such as China — data requirements prevent this.[16] Moreover, the fact that the six countries considered represent advanced industrial economies should be kept in mind when interpreting 'homogenisation' (or 'divergence') trends.

The analysis covers the period between 1995 and 2015, and two sub-periods have been considered: 1995–2007 and 2007–2015. The *a priori* perception of the impact of the Great Recession of 2008-09 on cross-country structural dynamics — motivating this periodisation — is confirmed by the results reported below.

To operationalise the indicators specified in Section 2, a sequence of data preparation procedures have been performed. First, a common minimum denominator to render compatible industry-level data across countries and OECD databases has been devised. Table A.1 in Appendix A specifies the industry classification scheme adopted.

Second, missing values from the `OECD-STAN` database for selected combinations of variables, industries and countries (GBR, USA and JPN, in particular) have been estimated, mostly by recourse to proportional methods applied on available data at a higher level of sectoral aggregation.[17] Third, in order to separate the autonomous component of investment, the share of dwellings (i.e. residential construction) in Gross Fixed Capital Formation (GFCF, hereinafter) has been estimated for each country and year.

Next, a series of matrices of domestically produced GFCF flows at basic prices by product of origin *and* industry of destination have been estimated. This has been done by applying the RAS biproportional matrix updating method (Bacharach, 1965) to row and column margins from Input-Output and STAN data, as well as data on the row structure of transactions in (broader) fixed capital categories, extracted from the OECD 'Capital Formation by Activity' database. Finally, Input-Output tables have been adjusted to industry gross output and gross value added figures from the STAN database, again using the RAS method.[18]

As an outcome, we obtained a series of Input-Output matrices for domestic output at basic (constant, 2010) prices, disaggregated

[14] Hereinafter, countries will be referred to by using their ISO 3166-1 alpha-3 codes. In particular, DEU: Germany, FRA: France, ITA: Italy, JPN: Japan, GBR: United Kingdom of Great Britain and Northern Ireland, and USA: United States of America.

[15] Measured at constant 2015 prices in US$. See, for example: https://unstats.un.org/unsd/snaama/.

[16] Crucially, detailed gross fixed capital formation flows by product of origin *and* industry of destination, price indices for gross output, employment data (measured in hours worked) and industry-level wages and salaries for a time-span covering recent decades.

[17] The original `OECD-STAN` database variables used were: `PROD`, `PRDK`, `VALU`, `VALK`, `LABR`, `WAGE`, `EMPN`, `EMPE`, `HRSN`, `HRSE` and `GFCF`.

[18] Incidentally, this updating process implied approximating a translation from ISIC Rev. 3 to ISIC Rev. 4 industries in those Input-Output tables for years before 2005.

Table 2
OECD Databases used to articulate a unified dataset.

OECD Code	Description
STANI4_2016	Structural Analysis Database (STAN) SNA08, ISIC Rev. 4 Edition
IOTS	Input-Output Tables (IOTs) Database, ISIC Rev. 3 Edition
IOTSI4_2018	Input-Output Tables (IOTs) Database, ISIC Rev. 4 Edition
PDB_GR	Growth in GDP per capita, productivity and ULC Database
Annual National Accounts Database:	
SNA_TABLE4	PPPs and exchange rates
SNA_TABLE8A	Capital Formation by Activity ISIC Rev. 4

Note: all databases can be freely accessed at https://stats.oecd.org/.

Table 3
Dynamics of employment ($\Delta\%L$), standard rate of productivity growth (ρ^*), real value added per hour worked (ρ_y) and TFP growth (ρ_{tfp}). *(period: 1995–2015, sub-periods: 1995–2007, 2007–2015; rates of change in average yearly percentage points).*

	$\Delta\%L$			ρ^*			ρ_y			ρ_{tfp}		
	95-07	07–15	95-15	95-07	07–15	95-15	95-07	07–15	95-15	95-07	07–15	95-15
DEU	−0.08	0.32	0.08	2.05	1.13	1.65	1.45	0.39	1.03	0.91	0.31	0.67
FRA	0.77	0.01	0.47	1.33	0.99	1.17	1.26	0.47	0.95	0.83	−0.08	0.47
GBR	0.80	0.70	0.76	1.93	0.32	1.26	1.94	0.39	1.31	1.57	−0.19	0.86
ITA	1.02	−1.11	0.17	0.81	0.52	0.70	0.36	0.06	0.26	−0.11	−0.45	−0.24
JPN	−0.54	−0.53	−0.53	1.80	0.67	1.31	1.52	0.37	1.04	0.66	0.47	0.58
USA	1.01	0.13	0.66	2.04	0.84	1.55	1.74	0.72	1.33	1.31	0.47	0.98

Source: Author's computation based on OECD Input-Output, STAN and National Accounts Databases

Table 4
Dynamics of nominal ($\Delta\%w$) and real ($\Delta\%(w/p_c)$) wage rates, price of the consumption basket ($\Delta\%p_c$) and real wage/productivity gap ($\Delta\%(w/p_c) - \rho^*$). *(period: 1995–2015, sub-periods: 1995–2007, 2007–2015; rates of change in average yearly percentage points).*

	$\Delta\%w$			$\Delta\%p_c$			$\Delta\%(w/p_c)$			$(\Delta\%(w/p_c) - \rho^*)$		
	95-07	07–15	95-15	95-07	07–15	95-15	95-07	07–15	95-15	95-07	07–15	95-15
DEU	1.57	2.72	2.03	0.62	1.11	0.82	0.95	1.61	1.21	−1.10	0.48	−0.44
FRA	2.92	1.84	2.49	1.65	1.00	1.39	1.27	0.84	1.10	−0.05	−0.15	−0.07
GBR	4.42	1.66	3.31	1.70	1.52	1.63	2.71	0.14	1.68	0.79	−0.19	0.43
ITA	3.18	1.61	2.55	2.80	1.47	2.27	0.38	0.14	0.28	−0.43	−0.39	−0.42
JPN	−0.13	0.22	0.01	−0.26	−0.22	−0.24	0.12	0.43	0.25	−1.68	−0.24	−1.07
USA	3.94	2.18	3.23	2.28	1.69	2.04	1.66	0.49	1.19	−0.38	−0.35	−0.36

Source: Author's computation based on OECD Input-Output, STAN and National Accounts Databases

into $n = 27$ industries, including a matrix of GFCF flows (separating and adding dwellings into final uses) for each country × year combination. Table A.2 in Appendix A reports a dictionary of variables, which may be used as a reference guide for the discussion of results.[19]

4.2. Aggregate trends

Key features of aggregate productivity growth and distributional dynamics between 1995 and 2015 are reported in Tables 3 and 4, respectively. In what follows, *hyper-integrated labour productivity growth*, ρ^*, will be considered the *benchmark productivity concept* for the analysis.

A first comparison between ρ^* and traditional productivity concepts (ρ_y and ρ_{tfp}) for sub-periods 1995–2007 and 2007–2015 shows an agreement in the relative ordering of change *within* each country. That is, for all countries and measures, the pace of productivity growth has been higher during the first sub-period (1995–2007), evincing the effects of the global financial crisis which started in 2008. However, there is disagreement as to the relative ordering *between* countries, especially in the second sub-period (2007–2015). This disagreement has its origins in the different methodological foundations of each measure.

According to ρ^*, Germany, the USA and Japan were the three most dynamic economies during the entire 1995–2015 period. Instead, income-side indicators (ρ_y and ρ_{tfp}) depict the USA and the UK as those countries with highest productivity growth. For the case of the UK, this is mainly due to the first sub-period.

Mismatches in country rankings reflect the different type of information conveyed by each productivity indicator. In terms of ρ^*, dynamism is based on increased labour-saving capacity to comprehensively reproduce *and expand* circulating *and fixed* capital items per unit of consumption. Instead, in terms of ρ_{tfp}, dynamism is based on the capacity to reduce production costs (in real terms). It is noticeable that, despite being considered a labour productivity indicator, ρ_y has a country ranking resembling that of TFP growth, rather than the relative ordering based on ρ^*. Hence, the technological dynamism of the US economy is reflected both in its labour-saving trends, as well as in its cost-reduction capacity.

The hyper-integrated productivity performance of Germany and the USA should alert on the need to look at ρ^* together with employment dynamics (column $\Delta\%L$ in Table 3). Being a productivity measure that depends primarily on labour inputs, a desirable situation implies both growing employment and productivity. For Germany this is not the case: its hours worked have been falling during the sub-period in which it experienced faster productivity growth (1995–2007). On the contrary, Italy, having the lowest value for ρ^*, has had the fastest employment expansion during the first sub-period, though it was almost completely offset afterwards. In this sense, the USA and the UK seemed to strike a balance of relatively high employment growth rates together with increasing hyper-integrated productivity, though only between 1995 and 2007. While some accounts may attribute the dynamism of these two 'liberal Anglo-Saxon' economies to relatively low labour market regulation, the comprehensive picture is more nuanced

[19] The data preparation procedures in the present paper are related to those developed in Garbellini and Wirkierman (2014), but with a single product industry system (rather than allowing for pure joint products), and with an exclusive focus on vertical hyper-integration (rather than also on vertical integration).

(Storm and Naastepad, 2012). In fact, after the Great Recession (2008-09), employment expansion in the UK continued, but productivity growth plummeted, whereas in the USA the pace of employment creation decelerated sharply.

Focusing on the race between money wage rates and prices, Table 4 shows that all countries but Germany and Japan have a slower increase in the (average) real wage rate when switching from 1995 to 2007 to 2007–2015 (column $\Delta\%(w/p_c)$). In this sense, it is possible to consider also the money wage-price decomposition of real wage rate changes: $\Delta\%(w/p_c) = \Delta\%w - \Delta\%p_c$. With the exception of Japan, nominal wage dynamics ($\Delta\%w$) across countries were more closely associated than price dynamics ($\Delta\%p_c$), which is probably due to the different composition of the household consumption basket in each country. In Germany, the price increase of the consumption basket accelerated during sub-period 2007–2015, whereas in all other countries experiencing inflation the opposite could be observed: wages, prices *and* the average real wage increased faster during the first sub-period (1995–2007).

When it comes to the relation between productivity and distribution, an interesting comparison consists in computing the difference between real wage dynamics and productivity growth (reported in column $\Delta\%(w/p_c) - \rho^*$). Only for the UK during 1995–2007 and Germany during 2007–2015 has real wage growth been greater than the rate of productivity increase. As a consequence, in all countries but the UK, overall productivity gains have not fully accrued to wages between 1995 and 2015. This result confirms the well-documented increasing gap between productivity and labour compensation in developed economies (ILO, 2013, p. 48). Multiple and interconnected determinants of this long-period trend involve the weakening bargaining power of labour in a context of (real and financial) globalisation, coupled with slacking trade union density and the gradual dismantling of employment protection legislation and insufficient active labour market policies (see, e.g. ILO, 2013, pp. 48-53).

In fact, the three countries having the highest values for ρ^* (Germany, the USA and Japan), have had a negative real wage / productivity gap (with yearly average differences of -0.44 p.p., -0.36 p.p. and -1.07 p.p., respectively). Thus, productivity gains accruing to wages are amongst the lowest in the three economies with highest overall productivity growth.

To contextualise this finding within ongoing trends of technological change, these three countries have had the highest shares of both the world stock and annual installation of operational industrial *robots* amongst developed economies between 2010 and 2015 (UNCTAD, 2017, p. 47, Table 3.3).[20] Hence, the three countries with fastest robotisation are those with a sharpest negative gap between real wage and productivity growth. This aspect deserves to be explored more in depth in future work.

From a broader standpoint, what the results convey about the connection between productivity and distribution may be interpreted under alternative growth theories. Within a Neoclassical framework, real wage rate dynamics (column $\Delta\%(w/p_c)$) may be compared to TFP growth (column ρ_{tfp}). For an economy in a competitive equilibrium, ρ_{tfp} is a share-weighted average of proportional changes in real factor prices (i.e. wage rate and rate of return on fixed capital, see Hsieh, 1999, p. 134). Hence, between 1995 and 2015, given that in all countries but Japan the real wage rate increased faster than TFP — and the (adjusted) wage share is generally not below 60% (Stockhammer, 2013, p. 41) — the rate of return should have increased at a relatively slower rate (or even decreased), which suggests a decelerating (or declining) trend for the marginal product of capital (and the incentive to invest).

From a Post-Keynesian perspective, empirical evidence for advanced economies suggests a wage-led productivity regime (Lavoie and Stockhammer, 2013, p. 28), i.e. a regime in which faster real wage growth *leads to* a higher pace of labour productivity growth and *vice-versa*. Comparing real value added per hour worked (column ρ_y) with real wage rate dynamics (column $\Delta\%(w/p_c)$) between sub-periods for each country, this regime seems to be confirmed for all countries but Germany and Japan, where, instead, a profit-led (productivity and/or demand) regime might be possible, i.e. a situation in which "wage restraint *leads to* productivity-enhancing investment" (Lavoie and Stockhammer, 2013, p. 27, italics added).

Finally, using the normative approach to structural economic dynamics introduced by Pasinetti (1963, 1981, 1993), it is possible to measure the implied natural rate of inflation — given by the difference between $\Delta\%w$ and ρ^* (Pasinetti, 1981, p. 163) — and compare it with the price dynamics of the consumption basket (column $\Delta\%p_c$). This comparison allows to *approximate* the degree to which the actual economy deviates from its natural configuration (in the sense of Pasinetti, 1981, Chapter VII) as regards the nexus between productivity and distribution. In this sense, amongst the economies further away from their natural distributive configuration are those with highest hyper-integrated productivity growth (Germany, the USA and Japan). Hence, a fast pace of technical progress on its own seems insufficient to achieve a distributive outcome in which the purchasing power of wages is maintained.

In a nutshell, by combining Tables 3 and 4, it is possible to depict country-specific price-quantity profiles: Japan emerges as a deflationary economy contracting employment. Germany constrains wage expansion during high productivity growth stages of its recent technological development. The USA and the UK had similar regimes of fast-paced productivity-*cum*-real wage growth in the decade building up to the 2008 financial crisis, but their paths diverge afterwards, the UK having the lowest productivity growth rate between 2007 and 2015. France exhibits a regime of moderate productivity expansion almost matched by its real wage dynamics. Finally, Italy presents a low productivity growth regime with highest price increases and one of the lowest rates of real wage expansion.

Table 5 reports the results of computing the multiplicative decomposition (22), which complements country-level profiles by singling out the relative importance of each component in hyper-integrated labour content per unit of final consumption (L/C): direct labour-saving trends (column $\boldsymbol{a}_l^T$), input-saving effects (column $(\boldsymbol{I} - \boldsymbol{\Lambda})^{-1}$) and compositional changes in final uses (column $\boldsymbol{c}/C$).[21]

Each column of the table shows the ratio between the final and initial year (measuring the accumulated change). When comparing the evolution of L/C with ρ^* (reported in Table 3) throughout the 1995–2015 period, the relative ordering among countries is preserved.[22]

In all countries the direct labour saving effect (column $\boldsymbol{a}_l^T$) is the most important.[23] Moreover, there has been a decrease in input intensity (column $(\boldsymbol{I} - \boldsymbol{\Lambda})^{-1}$) in all countries but France and

[20] At a world scale by 2015, only Germany had been surpassed by China and the Republic of Korea in terms of its share in the world stock of operational robots (UNCTAD, 2017, p. 47, Table 3.3).

[21] Please note that the inverse matrix $(\boldsymbol{I} - \boldsymbol{\Lambda})^{-1}$, defined in (12)-(13), captures direct, indirect and *hyper*-indirect input requirements per unit of final uses.

[22] Note that while both ρ^* and L/C refer to hyper-integrated labour content, they are aggregates each based on a different set of weights: $L_\eta^{(j)}/L$ and c_j/C, respectively. Moreover, a decrease in L/C corresponds to an increase in ρ^*, so that an increasing country ranking for the former corresponds to a decreasing country ranking for the latter.

[23] This is in accordance with a previous analysis for 1975–1985 by Dietzenbacher et al. (2000, p. 440), in which "the bulk of productivity increases is caused by [...] decreasing labor inputs per unit of gross output".

Table 5
Hyper-integrated labour content per unit of final consumption (1995–2015). *(period: 1995–2015; values are ratios of final/initial year; multiplicative decomposition of eq. (22)).*

	1995–2015						
	Labour content L/C	=	Direct labour $\mathbf{a}_l^T$	×	Input saving $(\mathbf{I}-\mathbf{\Lambda})^{-1}$	×	Consumption composition $\mathbf{c}/C$
DEU	0.686		0.748		0.976		0.941
FRA	0.785		0.775		1.026		0.988
GBR	0.760		0.752		1.058		0.955
ITA	0.872		0.910		0.954		1.004
JPN	0.750		0.847		0.943		0.940
USA	0.747		0.759		0.978		1.006

Source: Author's computation based on OECD Input-Output, STAN and National Accounts Databases

Table 6
Homogenisation Trends in Levels (1995–2015). *(central tendency across sectors of cross-country dispersion within each industry or subsystem)*

Variable for sector j		Median(CV) 1995	2007	2015	Median(Range Ratio) 1995	2007	2015
Industry employment share	L_j/L	0.284	0.277	0.333	2.173	1.939	2.094
Subsystem labour share	$L_\eta^{(j)}/L$	0.340	0.337	0.344	2.531	2.623	2.532
Final consumption share	c_j/C	0.347	0.314	0.305	2.368	2.350	2.224
Wage rate differential	w_j/w	0.119	0.147	0.136	1.394	1.504	1.470
GVA per hour worked	$\alpha_y^{(j)}$	0.228	0.213	0.199	1.886	1.713	1.720
Direct labour productivity	$\alpha_l^{(j)}$	0.249	0.225	0.204	1.982	1.823	1.820
Hyper-integrated productivity	$\alpha_\eta^{(j)}$	0.230	0.209	0.213	1.851	1.785	1.795

Source: Author's computation based on OECD Input-Output, STAN and National Accounts Databases

the UK. Instead, demand composition changes (column $\mathbf{c}/C$) have had a labour-saving effect in all countries but the USA and Italy, where compositional changes in final uses have been (approximately) neutral.

Thus, figures from Table 5 suggest three differentiated profiles. First, the one shared by the USA and Germany, where prominent direct labour saving trends are coupled with overall input savings and, for the case of Germany, sharp labour saving induced by changes in the composition of final uses. Second, the profile shared by France and the UK, characterised by both direct and consumption-structure-induced labour saving trends but *without* overall input savings. Finally, the profile shared by Japan and Italy, in which there is a relative balance between the role of technical change in the reproduction of capital goods (input saving effect) and that played by an increasing division of labour (direct labour saving).

Hence, while from Tables 3 and 4 we infer country-level profiles as regards their technological trajectory, Table 5 describes the structural factors accounting for that trajectory. In this sense, it is noteworthy that the three economies with fastest pace of productivity growth (Germany, the USA and Japan) had each a different structural composition of labour-saving trends.

4.3. Homogenisation trends

We report in Table 6 a summary of homogenisation trends in industry employment shares (L_j/L), subsystem labour shares ($L_\eta^{(j)}/L$), the structure of hyper-subsystem final demand (c_j/C), industry wage rate differentials (w_j/w) and three different productivity level concepts: GVA per hour worked ($\alpha_y^{(j)}$), direct labour productivity ($\alpha_l^{(j)}$), and vertically hyper-integrated labour productivity ($\alpha_\eta^{(j)}$).[24]

All these trends refer to homogenisation *across* countries *within* industries or hyper-subsystems. For each year and variable, the first three columns of Table 6 display the average of sector-specific coefficients of variation (CV),[25] while the second three columns display the median of sector-specific range ratios.[26] In formal terms, these two alternative descriptive statistics of dispersion and 'gap' between R countries (index r) within each of the n sectors (index j) for level variable x are computed as:

$$CV_j = \frac{s_{xj}}{\bar{x}_j}, \quad \text{where:}$$
$$s_{xj} = \sqrt{\frac{\sum_{r=1}^{R}\left(x_{rj}-\bar{x}_j\right)^2}{R-1}};$$
$$\bar{x}_j = \frac{\sum_{r=1}^{R} x_{rj}}{R}, \quad j = 1, \ldots, n$$
$$\text{Range Ratio}_j = \frac{\max\left(x_{rj}\right)}{\min\left(x_{rj}\right)}, \quad j = 1, \ldots, n$$

A reduction in CV implies a decrease in dispersion ('convergence'), and a decline in the Range Ratio implies a smaller gap between the country with the highest and that with the lowest value for the considered variable within a given industry/subsystem.[27] Moreover, the choice of the median instead of the mean to show a central tendency measure across sector-specific CV or Range Ratios

[24] Levels of labour productivity have been computed using 2010 as base-year, and applying GDP purchasing power parity (PPP) conversion rates to make constant local currency prices internationally comparable. Clearly, applying *scalar* rates of currency conversion to *sectoral* magnitudes is, at best, an approximation for the accurate comparison of value over space at a certain point in time. Ideally, solving for a system of endogenous conversion rates *and* world prices would have been preferable (Reich, 2001, p. 73), but data requirements to do so go beyond availability. At any rate, PPP imputations are an analytical device to avoid forces determining nominal exchange rates distort comparisons in *real* terms. However, PPPs are subject to stringent assumptions and limitations, e.g. commonly-priced products are not equally representative across countries (see EUROSTAT, 2012, for details). Hence, further work on standards of value to compare productivity *levels* is required.

[25] The coefficient of variation is the standard deviation divided by the sample mean.

[26] The range ratio is the ratio between the maximum and minimum value for the variable and sector in question.

[27] Note that a decreasing CV does not necessarily go hand in hand with a decrease in the Range Ratio, as there may be 'club' homogenisation, without however reducing the distance to the frontier.

is motivated by the presence of outliers and the skewness of the empirical distribution of variables.

It emerges from Table 6 that, between 1995 and 2015, employment shares by both industry and hyper-subsystem evinced increasing dispersion (higher CV). The full picture, though, involved first a decrease in dispersion during the 1995–2007 sub-period, which was reverted only afterwards.[28] In contrast, dispersion in final consumption shares has declined throughout the 1995–2015 period, i.e. there has been a tendency towards the equalisation of (constant-price) shares of final consumption items across countries. Thus, converging consumption patterns and employment shares between 1995 and 2007 contribute to explain the decreasing dispersion in hyper-integrated productivity *levels*, whereas diverging employment shares afterwards reversed the homogenisation trend in sectoral productivities.

While changes in the cross-country dispersion of industry wage rate differentials were contained, a divergence trend can be observed between 1995 and 2015. Together with increasing dispersion in industry employment shares, this suggests that the inter-industry distribution of wage bills has increasingly differentiated between countries, but mostly due to uneven sectoral employment reallocations, rather than to changes in cross-country wage rate differentials *within* each industry.

Interestingly, the alternative productivity concepts in the last three rows of Table 6 show a similar pattern of decreasing dispersion during the first sub-period (1995–2007), which is maintained for GVA per hour worked and direct labour productivity but is *reversed* for hyper-integrated labour productivity during the second sub-period (2007–2015). This is (mostly) so for both the CV and range ratio.[29]

While the median is a robust non-parametric statistic, to better grasp the details of homogenisation trends in productivity levels, Fig. 1 displays box plots summarising the entire likelihood structure of cross-country dispersion in sectoral productivities.

Three points may be noted. First, the shift towards the origin of the dispersion distribution between 1995 and 2007 is reversed between 2007 and 2015 for hyper-integrated productivity and, to a lesser extent, for GVA per hour worked. Second, for this latter indicator, as well as for direct labour productivity, the mean and median move in opposite directions between 2007 and 2015, suggesting a trend towards divergence in a minority of sectors which affects the average.

Third, and most importantly, a smaller box plot indicates that cross-country dispersion is relatively more homogeneous across sectors. This is precisely the case for hyper-integrated productivity, when compared to the other two indicators. Hence, data seems to confirm a methodological intuition. *Each single* hyper-integrated labour *coefficient* contains (directly, indirectly and hyper-indirectly) a portion of direct labour coefficients by industry through productive interdependencies. Therefore, industry heterogeneities are tamed, whereas comprehensive structural differences can be identified by combining direct labour coefficients composing the productivity of each hyper-integrated sector.

Thus, Table 6 and Fig. 1 suggest that the central tendency for cross-country convergence of hyper-integrated productivity levels within each growing subsystem between 1995 and 2007 has been *reversed*. To better understand the nature of this contrast, we explore the underlying sectoral details.

4.4. Sectoral details

The transition from decreasing to increasing dispersion in productivity levels when switching between sub-periods 1995–2007 and 2007–2015, suggests that their sectoral details should be explored separately. Tables 7 and 8 report cross-country homogenisation trends for hyper-integrated labour productivity levels within each subsystem for each sub-period.[30]

Recent attempts at linking the relative *tradability* of primary and manufacturing products over services to the convergence in industry productivity levels (Inklaar and Diewert, 2016), as well as to their differential influence on aggregate productivity growth (Friesenbichler and Glocker, 2019), motivates organising sectoral information into separate panels for primary-*cum*-manufacturing and service sectors (panels (A) and (B), respectively). Within each panel, subsystems are displayed in decreasing order of cross-country average productivity growth.

Table 7 evinces that, within the 1995–2007 sub-period, there was a generalised decline of cross-country dispersion in productivity levels across *service* subsystems — in Panel (B). Instead, primary-*cum*-manufacturing sectors — in Panel (A) — experienced a more heterogeneous dynamics. In particular, medium/high-tech equipment (26CEQ, 27ELQ, 29T30MTR, 28MEQ) and mineral-based/diffused input subsystems (05T09MIN, 22T23RPM, 24T25MET) had decreasing dispersion and (mostly) a faster pace of productivity growth. Instead, natural resource-based (01T03AGR, 10T12FOD, 13T15TEX, 16T18WPP, 31T33OTM) and chemical-based (19PET, 20T21CHM) sectors had increasing dispersion and relatively slower productivity growth. As an outcome, central tendency indicators of dispersion — the median and average for Panel (A) — moved in opposite directions, though the trend towards decreasing dispersion prevailed.

The 1995–2007 sub-period witnessed increasing international fragmentation of production (Baldone et al., 2007). Notably, amongst sectors widely engaging in such process, medium/high R&D intensity sectors (in the sense of Galindo-Rueda and Verger, 2016) — such as ICT Equipment (26CEQ) and Transport Equipment (29T30MTR) — have narrowed the cross-country gap in productivity levels, whereas for low R&D intensity ones — such as Textiles and Apparel (13T15TEX) and Food products (10T12FOD) — global sourcing practices went hand in hand with productivity divergence.

Hence, the coupling of medium/high R&D intensity and increasing internationalisation of production coincided with homogenisation in sectoral productivity levels and a faster productivity growth between 1995 and 2007.

Comparing panels (A) and (B) in Table 7, the average productivity growth rate for primary-*cum*-manufacturing — Panel (A) — subsystems was 2.2 times higher than that of service sectors — Panel (B). As a counterpart to such faster productivity growth, the former lost 4.2 p.p. of their share in aggregate employment (representing less than 24% of the total in 2007). This confirms the argument put forward by Baumol (1967), but from a *subsystem* perspective: relatively sluggish service subsystems absorb employment from dynamic manufacturing sectors. Note that the employment absorbed within service subsystems is also provided by manufacturing industries (e.g. pharmaceutical products used in the health services subsystem), whereas employment expelled by manufacturing sectors also contracts labour provided by service industries (e.g. professional services purchased for the production of pharmaceutical products).

[28] The higher dispersion was coupled with a nearly constant (or slightly decreasing) distance between the highest and lowest country (Range Ratio), suggesting a polarisation between constant (or narrowing) extremes.

[29] The range ratio for GVA per hour worked between 2007 and 2015 sightly increases.

[30] The interpretation of homogenisation trends is mostly based on the evolution of the coefficient of variation (CV). There are only 5 (1995–2007) and 3 (2007–2015) cases in which the direction of change of the CV disagrees with that of the Range Ratio.

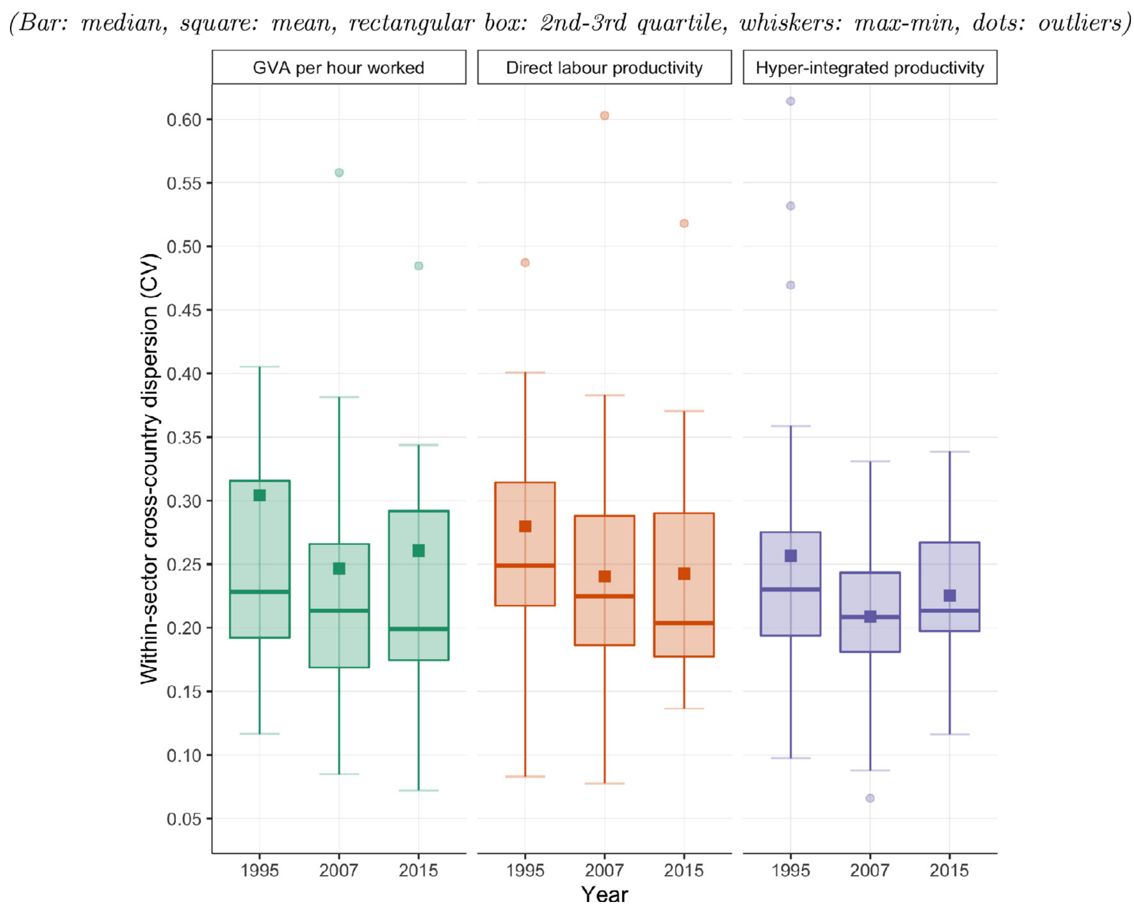

Fig. 1. Within-sector cross-country coefficient of variation (CV) in productivity levels (1995–2015). *(Bar: median, square: mean, rectangular box: 2nd-3rd quartile, whiskers: max-min, dots: outliers)*. Source: Author's computation based on OECD Input-Output, STAN and National Accounts Databases. Note: outliers beyond $CV = 0.60$ are not shown in the plot.

A different picture emerges from Table 8. When switching to sub-period 2007–2015, a central tendency towards increasing cross-country dispersion in productivity levels is observed. This is generalised across service subsystems — Panel (B) — but, again, primary-*cum*-manufacturing sectors — Panel (A) — follow heterogeneous dynamics. In fact, also in this case the median and average for Panel (A) moved in opposite directions.

In particular, while some medium/high-tech equipment subsystems deepened their homogenisation trend (27ELQ, 28MEQ), others reversed their behaviour, increasing cross-country dispersion (26CEQ, 29T30MTR). Instead, reversals involving a shift towards decreasing dispersion occurred for agriculture-based (01T03AGR, 10T12FOD) and chemical-based (19PET, 20T21CHM) sectors. Finally, other natural resource-based (13T15TEX, 16T18WPP, 24T25MET) and mineral-based subsystems (05T09MIN, 31T33OTM) increased their cross-country dispersion in productivity levels.

It is interesting to interpret sectoral dynamics within the context of the 2007–2015 sub-period. The decline in global trade during the Great Recession of 2008-09 (Bems et al., 2011) was followed by a deceleration of international production fragmentation (Timmer et al., 2016). For low technological intensity sectors prominent in off-shoring practices, such as Textiles and Apparel (13T15TEX), the trend of increasing cross-country dispersion and sluggish productivity continued. Instead, the two most dynamic subsystems, which are medium/high-tech sectors engaged with global input sourcing — ICT Equipment (26CEQ) and Transport Equipment (29T30MTR) — reversed their previous trend and increased their dispersion in productivity levels.

However, the slowdown in international fragmentation may not be the most relevant factor which could have played a role in the shift towards productivity divergence for the two latter subsystems (26CEQ, 29T30MTR). In fact, global annual installation of industrial robots became prominent since 2010 (UNCTAD, 2017, p. 47), and the two industries accounting for more than 60% of the global share in robot deployment in 2015 are, precisely, Transport (29T30MTR) and ICT Equipment (26CEQ). And while Japan, the USA and Germany have been leading the process, France, Italy and the UK have been lagging behind in this regard (UNCTAD, 2017, p. 47). Hence, cross-country heterogeneity in industrial robot adoption went hand in hand with increasing dispersion in productivity levels for the two most dynamic subsystems.

Notably, the gap in the ratio of average productivity growth between primary-*cum*-manufacturing — Panel (A) — and service — Panel (B) — subsystems has narrowed considerably between subperiods (from 2.2 to less than 1.5), evincing the effects of the 'global trade collapse' following the Great Recession of 2008-09 (Bems et al., 2011) on the productivity growth of tradable subsystems. This is in line with Inklaar and Diewert (2016, p. 431), who found that the TFP slowdown since 2007 was entirely due to the group of industries producing tradables with respect to the non-traded sector of the economy.

Finally, as reported in Table 6, the *central tendency* of homogenisation trends in productivity levels for hyper-integrated labour and GVA per hour worked went in a similar direction for the first sub-period (1995–2007) but diverged afterwards. From a methodological standpoint, real GVA per hour worked has been obtained from the income side of the system, whereas hyper-integrated

Table 7
Hyper-integrated Labour Productivity: homogenisation trends in levels, average growth rates ($\Delta\%(\alpha_{\eta}^{(j)})$) and subsystem employment shares ($L_{\eta}^{(j)}/L$) (1995–2007). (within-sector cross-country dispersion — CV and Range Ratio; cross-country average productivity growth and employment shares).

Hyper-subsystem		CV		Range Ratio		$\Delta\%(\alpha_{\eta}^{(j)})$	$L_{\eta}^{(j)}/L$	
Label	Sector	1995	2007	1995	2007	1995–2007	1995	2007
	Panel (A)			*Primary Sectors and Manufacturing*				
26CEQ	ICT Equipment	0.469	0.276	4.379	2.611	7.670	1.919	1.528
27ELQ	Electrical Equipment	0.260	0.219	2.084	1.986	3.610	0.686	0.860
29T30MTR	Transport Equipment	0.281	0.251	2.040	2.050	3.444	3.357	3.587
28MEQ	Machinery Equipment	0.269	0.236	2.044	1.952	3.279	1.917	2.181
01T03AGR	Agriculture	0.314	0.323	2.369	2.655	3.003	2.577	2.153
13T15TEX	Textiles and Apparel	0.181	0.261	1.546	2.309	2.962	2.754	1.295
22T23RPM	Non-metal mineral prod.	0.205	0.186	1.652	1.764	2.793	1.130	1.022
20T21CHM	Chemicals and Pharma	0.208	0.230	1.747	2.024	2.769	1.892	2.137
16T18WPP	Wood products	0.102	0.148	1.362	1.448	2.678	1.090	0.670
31T33OTM	Other Manufacturing	0.097	0.184	1.289	1.617	2.646	2.105	1.253
24T25MET	Metal products	0.224	0.178	2.044	1.595	2.359	1.361	1.689
10T12FOD	Food products	0.183	0.215	1.567	1.859	2.245	6.554	4.795
19PET	Refined Petroleum	0.235	0.270	1.925	2.047	0.668	0.432	0.399
05T09MIN	Mining	0.614	0.331	5.699	2.940	−0.277	0.161	0.173
Panel (A)	Median	0.229	0.233	1.982	2.005	2.781		
	Average	0.260	0.236	2.268	2.061	2.846		
	Total						27.937	23.741
	Panel (B)				*Service sectors*			
58T63ITS	ITS and Telecomm.	0.255	0.184	1.913	1.583	3.531	1.710	2.539
49T53TRN	Transport and Logistics	0.230	0.209	1.784	1.910	2.115	4.585	5.486
45T47WRT	Trade	0.151	0.146	1.537	1.490	2.091	11.047	11.021
64T66FIN	Finance	0.148	0.066	1.439	1.194	2.024	2.871	3.478
84GOV	Public Admin.	0.240	0.145	2.156	1.561	1.567	11.098	10.401
35T39EGW	Energy services	0.331	0.191	2.804	1.711	1.544	1.694	1.646
69T82OBZ	Business Services	0.359	0.207	2.798	1.785	0.935	2.355	3.880
68REA	Real Estate	0.532	0.292	3.814	2.236	0.880	3.172	3.591
55T56HTR	Accomodation and Food	0.168	0.166	1.524	1.553	0.710	5.906	5.962
90T99OTS	Other services	0.230	0.220	1.685	1.695	0.541	5.727	7.181
86T88HTH	Health	0.210	0.192	1.632	1.602	0.451	10.456	9.322
41T43CON	Construction	0.219	0.230	1.851	1.906	0.436	5.571	5.481
85EDU	Education	0.214	0.088	1.779	1.272	−0.215	5.871	6.270
Panel (B)	Median	0.230	0.191	1.784	1.602	0.935		
	Average	0.253	0.180	2.055	1.654	1.278		
	Total						72.063	76.259
Economy-wide	Median	0.230	0.209	1.851	1.785	2.115		
	Average	0.257	0.209	2.165	1.865	2.091		
	Total						100.000	100.000

Source: Author's computation based on OECD Input-Output, STAN and National Accounts Databases

productivity has been instead derived from the expenditure side. Table A.3 in Appendix A provides a detailed picture of the contrast in homogenisation trends between productivity indicators, which alert on the need to carefully consider their alternative methodological foundations. While hyper-integrated labour productivity is measured for each *(growing) subsystem*, GVA per hour worked is an *industry* magnitude. Therefore, homogenisation trends refer to a different (though related) *unit of analysis*.[31]

Disagreement between productivity-level indicators in Table A.3 cuts across all sectoral groups (primary, manufacturing, services). In general, cross-country dispersion (measured by either CV or Range Ratio) tends to be higher for industry-level magnitudes, even though there are exceptions which, however, vary according to the year and dispersion measure considered.

More in general, results support the claim put forward by Friesenbichler and Glocker (2019): aggregate productivity growth is not independent from the economy's sectoral composition. And by making cross-country comparisons in terms of growing subsystems, sectoral productivity growth rates embed the change in the structural proportions with which different industries participate in every hyper-integrated sector. Hence, the shift from industries to growing subsystems has also the potential to capture the comprehensive labour-displacing effects of technological change, not only by tracking the upstream industries supplying employment, but also by linking the change in labour requirements to the product activating them.

5. Summary of findings and concluding remarks

The aim of this paper has been to apply the logical device of vertical hyper-integration (Pasinetti, 1981; 1988; 1989) to the measurement of disaggregated physical productivity changes. It has been argued that the notion of hyper-integrated labour productivity is rooted in the application of the method of *growing* (or *hyper-*) subsystems to the expenditure side (i.e. the nominal counterpart to the system of physical quantities) of an Input-Output Table.

By considering changes in total (direct, indirect and hyper-indirect) labour requirements per unit of final uses, the degree and extent of the division of labour can be depicted even at a disaggregated level. Adopting this perspective, the productivity con-

[31] Table A.11 has been organised in three panels (A)-(C), according to the (dis)agreement between indicators as to the direction of the homogenisation trend in productivity levels between 1995 and 2015.

Table 8
Hyper-integrated Labour Productivity: homogenisation trends in levels, average growth rates ($\Delta\%(\alpha_\eta^{(j)})$) and subsystem employment shares ($L_\eta^{(j)}/L$) (2007–2015). *(within-sector cross-country dispersion — CV and Range Ratio; cross-country average productivity growth and employment shares).*

Hyper-subsystem		CV		Range Ratio		$\Delta\%(\alpha_\eta^{(j)})$	$L_\eta^{(j)}/L$	
Label	Sector	2007	2015	2007	2015	2007–2015	2007	2015
	Panel (A)			*Primary Sectors and Manufacturing*				
26CEQ	ICT Equipment	0.276	0.308	2.611	2.565	3.131	1.528	1.133
29T30MTR	Transport Equipment	0.251	0.318	2.050	2.539	2.116	3.587	3.293
01T03AGR	Agriculture	0.323	0.296	2.655	2.401	1.333	2.153	2.056
27ELQ	Electrical Equipment	0.219	0.205	1.986	1.795	1.062	0.860	0.856
20T21CHM	Chemicals and Pharma	0.230	0.213	2.024	1.932	1.008	2.137	2.104
16T18WPP	Wood products	0.148	0.200	1.448	1.714	0.865	0.670	0.622
10T12FOD	Food products	0.215	0.197	1.859	1.789	0.686	4.795	4.635
22T23RPM	Non-metal mineral prod.	0.186	0.205	1.764	1.694	0.669	1.022	0.979
28MEQ	Machinery Equipment	0.236	0.234	1.952	1.791	0.549	2.181	1.952
31T33OTM	Other Manufacturing	0.184	0.198	1.617	1.660	0.545	1.253	1.137
24T25MET	Metal products	0.178	0.214	1.595	1.716	0.442	1.689	1.519
19PET	Refined Petroleum	0.270	0.216	2.047	1.995	0.166	0.399	0.374
13T15TEX	Textiles and Apparel	0.261	0.300	2.309	2.599	−0.096	1.295	1.067
05T09MIN	Mining	0.331	0.338	2.940	3.525	−0.305	0.173	0.203
Panel (A)	Median	0.233	0.215	2.005	1.864	0.677		
	Average	0.236	0.246	2.061	2.123	0.869		
	Total						23.741	21.930
	Panel (B)			*Service sectors*				
58T63ITS	ITS and Telecomm.	0.184	0.237	1.583	1.774	1.895	2.539	2.562
68REA	Real Estate	0.292	0.294	2.236	2.093	1.609	3.591	3.454
84GOV	Public Admin.	0.145	0.161	1.561	1.606	1.195	10.401	9.654
45T47WRT	Trade	0.146	0.156	1.490	1.497	0.924	11.021	11.069
64T66FIN	Finance	0.066	0.116	1.194	1.359	0.865	3.478	3.388
86T88HTH	Health	0.192	0.197	1.602	1.816	0.695	9.322	10.900
41T43CON	Construction	0.230	0.201	1.906	1.728	0.484	5.481	4.761
69T82OBZ	Business Services	0.207	0.211	1.785	1.811	0.469	3.880	5.036
90T99OTS	Other services	0.220	0.255	1.695	1.831	0.162	7.181	7.286
85EDU	Education	0.088	0.124	1.272	1.358	0.130	6.270	6.482
55T56HTR	Accomodation and Food	0.166	0.172	1.553	1.605	0.000	5.962	6.176
49T53TRN	Transport and Logistics	0.209	0.239	1.910	1.954	−0.201	5.486	5.630
35T39EGW	Energy services	0.191	0.279	1.711	2.117	−0.635	1.646	1.672
Panel (B)	Average	0.191	0.201	1.602	1.774	0.484		
	Average	0.180	0.203	1.654	1.734	0.584		
	Total						76.259	78.070
Economy-wide	Median	0.209	0.213	1.785	1.795	0.669		
	Average	0.209	0.225	1.865	1.936	0.732		
	Total						100.000	100.000

Source: Author's computation based on OECD Input-Output, STAN and National Accounts Databases

vergence hypothesis in traditional analyses of technical change has been discussed.

In empirical terms, we have studied the dynamics of aggregate and sectoral hyper-integrated productivity for six advanced industrial economies (USA, Germany, Japan, UK, France and Italy), together with an assessment of homogenisation trends in productivity levels for the 1995–2015 period. Among the varied notions of convergence (divergence), we have limited the analysis to singling out decreasing (increasing) dispersion of levels and shares of selected variables *across* countries *within* sectors.

The implementation of Pasinetti's (1981) standard rate of productivity growth (ρ^*) evinced differences in the relative ordering of performance across countries with respect to TFP growth. While the former indicator captures comprehensive labour-saving trends, the latter focuses on the economy's cost-reduction capacity. The technological dynamism of the US economy is confirmed by both indicators. Instead, Germany and Japan are top performers in terms of labour-saving, but less dynamic as regards real cost reductions when compared to the UK (mostly due to its performance before the Great Recession of 2008-09). Finally, France and Italy experienced a lower pace of hyper-integrated labour productivity and TFP growth.

At a disaggregated level, the productivity convergence hypothesis has been explored by focusing on the contrast between two sub-periods: 1995–2007 and 2007–2015. The central tendency for decreasing cross-country dispersion in hyper-integrated productivity levels within each growing subsystem between 1995 and 2007 has been reversed afterwards.

While (almost) all service subsystems coincided in the direction of change, primary-*cum*-manufacturing sectors experienced a more heterogeneous dynamics. During the first sub-period (1995–2007), characterised by increasing internationalisation of production, medium/high-tech subsystems evinced a trend towards productivity homogenisation and a fast pace of productivity growth, whereas for sectors with relatively lower technological content, global sourcing practices went hand in hand with productivity divergence.

Instead, during the second sub-period (2007–2015), comprising the aftermath of the Great Recession of 2008-09, the two most dynamic subsystems — ICT (`26CEQ`) and Motor Transport (`29T30MTR`) Equipment — reversed their trend, heading towards productivity divergence. Notably, these were the two industries accounting for more than 60% of the global share in robot deployment by 2015. The asymmetry in industrial robot adoption between Japan, the USA and Germany *vis-à-vis* the UK, France and Italy may help to explain this trend towards increasing productivity dispersion for the two most dynamic subsystems. Hence, the unequal diffusion pace of advanced digital production technologies *might* be a potential source of productivity divergence in the global economy.

Finally, uneven cross-country evolution of the real wage-productivity gap allowed us to describe alternative price-quantity profiles in expanding economies. In fact, an interesting interplay between productivity increases and distribution has been obtained: productivity gains accruing to wages are amongst the *lowest* in the three economies with *highest* overall hyper-integrated labour productivity growth (Germany, Japan and the USA), when considering the entire 1995–2015 period.

Beyond the particular case considered, shifting the unit of analysis from a traditional ‘industry’ perspective to the ‘growing subsystem’ provides a complementary view on actual processes of structural change. For example, the monitoring of industrial policy interventions (which target *activities*) could be more comprehensively assessed by means of hyper-integrated sectors. Current policy debates (and challenges), emphasising the need of ‘rebalancing the economy’, make apparent the importance of *systemic* (and interdependent) characterisations of performance to an otherwise granular ‘targeting of industries’.

Some limitations ought to be mentioned. While the empirical analysis has *illustrated* the application of the method of growing subsystems, it would be desirable to carry out a detailed exploration of sectoral specificities behind the reported results, as well as provide a deeper discussion of the institutional conditions and policy frameworks that might have contributed to explain the economy-wide trends found.

Moreover, the discussion of results barely touched upon the relationship between the evolution of productivity and international production linkages (Johnson and Noguera, 2012). In fact, whereas competitiveness remains *national*, productivity has increasingly become an *international* concept: the pace of productivity growth across a value chain — whose final product is articulated by an advanced industrial economy — may have *imported* labour-saving trends at its origin. Thus, a direction for further research would be to devise and implement a framework for measuring the evolution in homogenisation trends of *internationally* (hyper-)integrated labour content (Baldone et al., 2007). This may also trigger challenging questions and uncover an inherent tension between the *inter-country* nature of *sectoral* performance and the *within-country* possibilities for pursuing industrial policies.

Declaration of Competing Interest

I wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

I confirm to have considered the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In doing so I confirm that I have followed the regulations of my institution concerning intellectual property.

The following division of tasks leading to the current version of the manuscript can be identified:

Ariel L. Wirkierman: Conceptualisation; Formal Analysis; Empirical Implementation; Writing; Review and Editing.

Acknowledgments

I would like to thank two anonymous referees that helped to substantially improve the paper. Responsibility for any errors in the resulting work remains my own.

Appendix A. Additional Tables

Table A1
Sectoral Classification: Correspondence with OECD Input-Output and STAN Databases based on ISIC Rev. 4 and ISIC Rev. 3.

Sector		OECD Classification	
Label	Descriptor	ISIC Rev. 4	ISIC Rev. 3
01T03AGR	Agriculture	D01T03	C01T05
05T09MIN	Mining	D05T06, D07T08, D09	C10T14
10T12FOD	Food products	D10T12	C15T16
13T15TEX	Textiles and Apparel	D13T15	C17T19
16T18WPP	Wood products	D16, D17T18	C20, C21T22
19PET	Refined Petroleum	D19	C23
20T21CHM	Chemicals and Pharma	D20T21	C24
22T23RPM	Non-metal mineral prod.	D22, D23	C25, C26
24T25MET	Metal products	D24, D25	C27, C28
26CEQ	ICT Equipment	D26	C30T33X
27ELQ	Electrical Equipment	D27	C31
28MEQ	Machinery Equipment	D28	C29
29T30MTR	Transport Equipment	D29, D30	C34, C35
31T33OTM	Other Manufacturing	D31T33	C36T37
35T39EGW	Energy services	D35T39	C40T41
41T43CON	Construction	D41T43	C45
45T47WRT	Trade	D45T47	C50T52
49T53TRN	Transport and Logistics	D49T53	C60T63
55T56HTR	Accomodation and Food	D55T56	C55
58T63ITS	ITS and Telecomm.	D58T60, D61, D62T63	C64, C72
64T66FIN	Finance	D64T66	C65T67
68REA	Real Estate	D68	C70
69T82OBZ	Business Services	D69T82	C71, C73T74
84GOV	Public Admin.	D84	C75
85EDU	Education	D85	C80
86T88HTH	Health	D86T88	C85
90T99OTS	Other services	D90T96, D97T98	C90T93, C95

Source: Own elaboration based on OECD Input-Output and STAN Databases

Table A2
Dictionary of variables and correspondence(s) with OECD Input-Output (IOTS), Structural Analysis (STAN), Annual National Accounts (ANA) and Productivity (PDB) datasets.

Analytical Variable			Computed from OECD	
Symbol	Descriptor	Unit	Database(s)	Variable(s)$^{(*)}$
L_j	Employment in industry j	(in hours worked)	STAN	HRSN
$L_\eta^{(j)}$	Labour requirements activated by hyper-subsystem j	(in hours worked)	STAN, IOTS, ANA	
$L = \sum_{j=1}^{n} L_j$	Aggregate employment	(in hours worked)	STAN	HRSN
q_j	Gross output by industry j	(in 10^6 constant PPP USD)	STAN	PRDK
c_j	Final expenditure domestically produced of products from industry j	(in 10^6 constant PPP USD)	STAN, IOTS	
$C = \sum_{j=1}^{n} c_j$	Aggregate final expenditure domestically produced	(in 10^6 constant PPP USD)	STAN, IOTS, ANA	
w_j	Average wage per hour worked in industry j	(in current LCU per hour worked)	STAN	WAGE, HRSE
w	Economy-wide average wage per hour worked	(in current LCU per hour worked)	STAN	
p_c	Price index of the *household* final consumption basket	(base $2010 = 1$)	STAN, IOTS, ANA	
$\alpha_l^{(j)} = q_j / L_j$	Direct labour productivity of industry j	(in constant PPP USD per hour worked)	STAN	
$\alpha_\eta^{(j)} = c_j / L_\eta^{(j)}$	Hyper-integrated labour productivity of subsystem j	(in constant PPP USD per hour worked)	STAN, IOTS, ANA	
$\alpha_y^{(j)}$	Real Gross Value Added (GVA) per hour worked of industry j	(in constant PPP USD per hour worked)	STAN	VALK, HRSN
ρ^*	Standard rate of productivity growth	(in percentage points)	STAN, IOTS, ANA	
ρ_y	Growth of economy-wide real GVA per hour worked	(in percentage points)	STAN	VALK, HRSN
ρ_{tfp}	Total Factor Productivity (TFP) growth	(in percentage points)	PDB	T_MFP

Notes: PPP stands for Purchasing Power Parity; base year for price indices 2010=1; LCU stands for local currency units; $(*)$ reported *only* for those variables that can be *directly* obtained from the *source* OECD database, with *no* further computations involved.

Table A3
Homogenisation trends in levels: Hyper-integrated Labour Productivity and Gross Value Added (GVA) per hour worked (1995–2015). *(cross-country dispersion within each subsystem or industry).*

Sector		Hyper-integrated productivity				GVA per hour worked			
		CV		Range Ratio		CV		Range Ratio	
Label	Descriptor	1995	2015	1995	2015	1995	2015	1995	2015
	Panel (A)	*Similar direction of homogenization trend*							
05T09MIN	Mining	0.614	0.338	5.699	3.525	1.048	0.707	14.305	10.790
68REA	Real Estate	0.532	0.294	3.814	2.093	0.405	0.315	3.432	2.375
26CEQ	ICT Equipment	0.469	0.308	4.379	2.565	0.749	0.485	12.442	3.284
69T82OBZ	Business Services	0.359	0.211	2.798	1.811	0.400	0.219	3.083	1.685
84GOV	Public Admin.	0.240	0.161	2.156	1.606	0.214	0.199	1.592	1.696
27ELQ	Electrical Equipment	0.260	0.205	2.084	1.795	0.273	0.189	2.014	1.654
28MEQ	Machinery Equipment	0.269	0.234	2.044	1.791	0.343	0.190	2.583	1.866
64T66FIN	Finance	0.148	0.116	1.439	1.359	0.185	0.072	1.599	1.239
41T43CON	Construction	0.219	0.201	1.851	1.728	0.261	0.160	1.868	1.572
86T88HTH	Health	0.210	0.197	1.632	1.816	0.228	0.180	1.767	1.628
24T25MET	Metal products	0.224	0.214	2.044	1.716	0.200	0.170	1.845	1.646
45T47WRT	Trade	0.151	0.156	1.537	1.497	0.117	0.127	1.346	1.377
49T53TRN	Transport and Logistics	0.230	0.239	1.784	1.954	0.166	0.179	1.573	1.692
90T99OTS	Other services	0.230	0.255	1.685	1.831	0.268	0.298	1.979	2.155
29T30MTR	Transport Equipment	0.281	0.318	2.040	2.539	0.288	0.320	2.599	2.179
31T33OTM	Other Manufacturing	0.097	0.198	1.289	1.660	0.170	0.181	1.610	1.614
13T15TEX	Textiles and Apparel	0.181	0.300	1.546	2.599	0.182	0.258	1.532	2.452
	Panel (B)	*Converging hyper-subsystems and diverging industries*							
85EDU	Education	0.214	0.124	1.779	1.358	0.153	0.198	1.504	1.721
35T39EGW	Energy services	0.331	0.279	2.804	2.117	0.248	0.278	1.966	1.846
19PET	Refined Petroleum	0.235	0.216	1.925	1.995	0.691	0.774	4.775	35.286
01T03AGR	Agriculture	0.314	0.296	2.369	2.401	0.215	0.344	2.002	2.825
58T63ITS	ITS and Telecomm.	0.255	0.237	1.913	1.774	0.214	0.286	1.886	2.185
	Panel (C)	*Diverging hyper-subsystems and converging industries*							
22T23RPM	Non-metal mineral prod.	0.205	0.205	1.652	1.694	0.165	0.147	1.463	1.556
55T56HTR	Accomodation and Food	0.168	0.172	1.524	1.605	0.230	0.207	1.951	1.720
20T21CHM	Chemicals and Pharma	0.208	0.213	1.747	1.932	0.352	0.265	2.282	2.138
10T12FOD	Food products	0.183	0.197	1.567	1.789	0.224	0.127	1.859	1.398
16T18WPP	Wood products	0.102	0.200	1.362	1.714	0.228	0.162	1.815	1.593
Economy-wide	Median	0.230	0.213	1.851	1.795	0.228	0.199	1.886	1.720
	Average	0.257	0.225	2.165	1.936	0.304	0.261	2.914	3.451

Source: Author's computation based on OECD Input-Output, STAN and National Accounts Databases

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