UNIVERSITY OF HOHENHEIM

Hohenheim Discussion Papers in Business, Economics and Social Sciences

COMPETITIVENESS AT THE COUNTRY-SECTOR LEVEL: NEW MEASURES BASED ON GLOBAL VALUE CHAINS

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12-2018

wiso.uni-hohenheim.de

Discussion Paper 12-2018

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ISSN 2364-2084

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April 26, 2018

Abstract

We propose the so-called domestic "embodied unit labor costs" (EULC) at the country-sector level as a new cost-related basis for measures of international competitiveness. EULC take into account that a sector's labor costs constitute only a small share of its total cost which to a large extent consist of expenses for intermediate goods from other sectors. In line with a simple Leontief-type model, the proposed measure is constructed as a weighted average of unit labor costs of all domestic sectors contributing to the final goods of a specific sector. The contribution is expressed in value-added terms and takes global supply chains into account. We also show how EULC can be consistently calculated for sectoral aggregates such as the tradable goods sector. Based on EULC we propose the "embodied real effective exchange rate" (EREER) at the country-sector level as a new competitiveness indicator where the relevance of trading partners is quantified by an appropriate value-added measure. The chosen value-added concept replaces gross exports traditionally used as the weight basis in effective exchange rates. Using the World Input-Output Database (WIOD) we employ the proposed indicators to shed new light on changes in cost competitiveness at the sectoral level for Germany, and compare the empirical evidence with selected other euro area countries.

Keywords: unit labor costs, real effective exchange rate, global supply chains, input-output analysis, sectoral analysis, international competitiveness, WIOD, Germany

JEL Classification: J30, C67, E01, F16, F23

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1 Introduction

The ongoing debate about causes and consequences of current account imbalances has led to a renewed interest in the competitiveness of nations and industries. A common way to assess external competitiveness is to compare price- or cost-related indicators across countries, typically by means of real effective exchange rates (REERs).[1] A cost-related indicator that is often used for this purpose is unit labor costs (ULC). One advantage of ULC lies in the fact that they reflect changes in competitiveness also in situations where pricing to market prevails, another one is the wide availability of data on wage costs. However, the use of ULC is not free of problems. At the sectoral level, a sector's own ULC constitute only a small share of total cost which to a large extent consist of expenses for intermediate goods from other sectors. The same problem still emerges at the aggregate level if ULC in manufacturing are used as cost indicator for the manufacturing sector or the whole economy. For example, for manufacturing in the euro area the share of ULC in total cost is only about 20 percent (Ca'Zorzi & Schnatz, 2007). Christodoulopoulou and Tkačevs (2014) show that the REER based on ULC in manufacturing behaves differently from other REERs for some euro area countries. This observation strengthens the hypothesis that a too narrow ULC measure may give a misleading picture of changes in international competitiveness.

It has already been noted in the literature that a narrow focus on a sector's ULC may not reflect its competitive stance. For example, Dustmann et al. (2014) argue that for the period 1995 to 2007 the increase in German competitiveness may be partially explained by the manufacturing sector drawing on inputs from domestically provided nontradable goods and tradable services. Taking account of this argument, we develop a modified ULC measure at the sectoral level that better describes the competitive stance of each sector. The "embodied unit labor costs" (EULC) of a specific sector not only consider that sector's own ULC but also take account of the ULC incorporated in the intermediate goods delivered to this sector, and therefore are a weighted average of ULC

[1]Different price- and cost-related REERs are, for example, compared in Marsh and Tokarick (1996), Chinn (2006), Ca'Zorzi and Schnatz (2007), Christodoulopoulou and Tkačevs (2014) and Fischer et al. (2016). Usually it is found that neither competitiveness indicator clearly outperforms the other.

of all domestic and foreign sectors contributing to the production of this sector. The weights are calculated using global inter-country input-output (ICIO) tables and thus reflect global supply chains. We demonstrate how these weights can be derived from a simple Leontief-type model, and also show how EULC can be consistently calculated for sectoral aggregates, such as the tradable goods sector.

Since statements about the external competitiveness of industries should rely on a comparison of *domestic* cost (or price) developments with those in other countries, we we consider a re-weighted measure of EULC, called domestic EULC, that is based on contributions of domestic sectors only. However, also in the case of domestic EULC global ICIO tables have to be used because domestic value-added contributions may be embodied in imported intermediate goods.

We then propose a novel measure of REER at the sectoral level that introduces two innovations in comparison to traditional sectoral relative ULC measures: (i) the new measure, called "embodied real effective exchange rate" (EREER), is based on domestic EULC, and thus takes the contribution of other domestic sectors to the competitiveness of a given sector via the intermediate-goods linkages into account, (ii) the weights for competing sectors in trading partner countries are based on domestic value added embodied in bilateral sectoral gross exports, which can be seen as a natural value-added counterpart of gross export measures usually used in national-level studies.

Due to the rising importance of global supply chains gross exports no longer constitute the appropriate basis for the weights calculation because they contain foreign value added embodied in intermediates inputs used by the domestic economy to produce gross exports. Moreover, gross exports are "contaminated" by "pure double counting", i.e. multiple counting of the same value added embodied in intermediates crossing the same border several times.[2] For these reasons, an export-related value-added measure is better suited to calculate weights reflecting the importance of trading partners. A well-known measure is value-added exports which are, for example, used to calculate the VAX ratio (ratio of value-added exports to gross exports) suggested by Johnson and Noguera (2012) as an aggregate measure for the intensity of production sharing. Value-added exports describe

[2] A detailed discussion of "pure double counting" is provided in Koopman et al. (2014).

the domestic value added in a country's gross exports that is ultimately absorbed abroad. However, in our context where the aim is to determine weights for trading partners in the computation of ULC the concept of value-added exports seems not to be a suitable measure. Value-added exports would also partly capture competition with "intermediate" countries along international production chains, whereas our proposed bilateral value-added weights measure competition between direct trade partners and thereby constitute the value-added counterpart of the traditionally used bilateral gross export weights.

For example, value-added exports from the German chemical industry to Italy may reflect intermediate good exports to France that, after reprocessing, are exported to Italy and are absorbed in Italy's final demand. Hence, the value-added exports of the German chemical industry to Italy consist of a component that is not contained in the gross exports of the German chemical industry to Italy. Our suggested concept reflects solely the value added embodied in the gross exports of the German chemical industry to Italy irrespectively of whether these exports are ultimately absorbed in Italy or any other foreign country.

Koopman et al. (2014) were the first to provide a unified framework for the decomposition of a country's total gross exports into different value-added and double-counted components. Their framework encompasses various approaches suggested in the literature, such as value-added exports, as special cases. However, their approach only holds at the aggregate level (gross exports of the total economy to all countries) so that it is not readily applicable to the calculation of the domestic value-added content in bilateral gross export flows at the sectoral level.

As Wang et al. (2013) show, a value-added decomposition at the sectoral, bilateral or bilateral sectoral level requires a more demanding framework. The decomposition at the sectoral level is complicated by the fact that domestic value added can be decomposed from the producer's (forward-linkage) or the user's (backward-linkage) perspective. The forward-linkage perspective takes into account that a sector's value added may not only be exported in its own gross exports but also be exported indirectly through gross exports of other domestic sectors. The backward-linkage perspective takes into account that domestic value added embodied in a sector's gross exports can include value added from other domestic sectors.

Based on the value-added decomposition suggested in Wang et al. (2013), we calculate the domestic value added in sector-level bilateral gross exports that is absorbed abroad and use that measure in our double weighting scheme to quantify the importance of partner countries at the sectoral level. The value-added concept behind our weight calculation uses the backward-linkage perspective, i.e. it represents the domestic value added in a sector's gross exports that contains value-added contributions of all domestic sectors. This feature makes it a natural and suitable basis for EREER weights attached to EULC which are also defined in the backward-linkage spirit.

Our suggested EREER measure satisfies the three criteria for any suitable measure of international cost (or price) competitiveness (Durand and Giorno, 1987; Clostermann, 1998): first, the measure should refer to the sectors exposed to international competition - and only those. This is taken into account by deriving the EREER measure at the sectoral level or for suitable sectoral aggregates such as the tradable goods sector. Second, the measure should encompass the overall cost situation of the tradable goods sector. This is accomplished by our concept of EULC. Third, the measure should be constructed from internationally fully comparable data. This is achieved using data from global ICIO tables such as the World Input-Output Database (WIOD) for the derivation of the EREER measure.

Using data from the World Input-Output Database we employ the proposed indicators to shed new light on changes in cost competitiveness at the sectoral level for Germany, and compare the German evidence for the three sectoral aggregates "tradable manufacturing", "tradable services" and "nontradable goods" with the evidence for other selected euro area countries. Contrary to Dustmann et al. (2014), we show that it is tradable services that profited from more favorable ULC developments in manufacturing and not the other way round. A similar picture emerges if EREERs are compared to standard REERs, where the latter are REERs based on standard ULC and calculated with gross output weights. Regarding the role of the weighting scheme, we show that using value-added weights instead of gross export weights for the sectors in trading partner countries leads to more pronounced increases in international cost competitiveness for both tradable manufacturing and tradable services in Germany irrespectively of whether EREERs or standard REERs are considered. Hence, the less precise gross exports weights that are used in most of the literature may blur actual chances in cost competitiveness.

The remainder of the paper is organized as follows. Section 2 explains the calculation of EULC and domestic EULC based on global ICIO tables and shows how these measures can be justified in the light of a simple Leontief-type model. It is also shown how domestic EULC can be consistently calculated for sectoral aggregates such as the tradable goods sector. Based on domestic EULC, Section 3 derives EREER as a new REER measure at the sectoral level with value-added bilateral weights for the corresponding sectors in trading partner countries. Section 4 uses data from the World Input-Output Database (WIOD) to calculate EULC and EREER for sectoral aggregates and individual sectors in Germany, and to illustrate the differences compared to standard ULC and standard REER. For the sectoral aggregates the development of EULC and EREER is also compared to the corresponding developments in other euro area countries. Section 5 contains a summary and some conclusions.

2 Embodied unit labor costs (EULC)

2.1 EULC based on global ICIO tables

To see how the information contained in global inter-country input-output (ICIO) databases can be used to calculate unit labor costs (ULC) embodied in a sector's production (EULC), the structure of a global ICIO table is explained first. Examples for ICIO databases are the Global Trade Analysis Project (GTAP) and the World Input-Output Database (WIOD).[3] Note that an ICIO database can, apart from the ICIO table, contain supplementary data. Let G denote the total number of countries and H the total number

[3]The term "global ICIO" database, also used by Koopman et al. (2014), may be better suited than the term "global multi-regional input-output (GMRIO)" database often used in the environmental literature, because regional information within countries is not available in those databases. For a description and comparison of global ICIO (GMRIO) databases see, for example, Tukker and Dietzenbacher (2013), Inomata and Owen (2014), and the references therein.

Table 1: The structure of a global ICIO table

Use / Supply		Use by country-industries							Final use by countries			Total use
		Country 1			...	Country G			Coun.1	...	Coun.G	
		Ind.1	...	Ind.H	...	Ind.1	...	Ind.H				
Coun.1	Ind.1	z_{11}^{11}	...	z_{11}^{1H}	...	z_{1G}^{11}	...	z_{1G}^{1H}	f_{11}^{1}	...	f_{1G}^{1}	q_1^1
	$\vdots$	$\vdots$	$\ddots$	$\vdots$		$\vdots$	$\ddots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$
	Ind.H	z_{11}^{H1}	...	z_{11}^{HH}	...	z_{1G}^{H1}	...	z_{1G}^{HH}	f_{11}^{H}	...	f_{1G}^{H}	q_1^H
$\vdots$	$\vdots$	$\vdots$		$\vdots$		$\vdots$		$\vdots$	$\vdots$		$\vdots$	$\vdots$
Coun.G	Ind.1	z_{G1}^{11}	...	z_{G1}^{1H}	...	z_{GG}^{11}	...	z_{GG}^{1H}	f_{G1}^{1}	...	f_{GG}^{1}	q_G^1
	$\vdots$	$\vdots$	$\ddots$	$\vdots$		$\vdots$	$\ddots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$
	Ind.H	z_{G1}^{H1}	...	z_{G1}^{HH}	...	z_{GG}^{H1}	...	z_{GG}^{HH}	f_{G1}^{H}	...	f_{GG}^{H}	q_G^H
Value added		y_1^1	...	y_1^H	...	y_G^1	...	y_G^H				
Gross output		q_1^1	...	q_1^H	...	q_G^1	...	q_G^H				

of industries. It is assumed that each industry in each country produces one homogenous good that differs from the goods produced by all other industries. For this reason the terms "industry" and "good" can be used interchangeably in the following considerations. With these assumptions in the world a total of GH goods is produced by the same number of industries.

A global ICIO table basically consists of four parts, see Table 1: (i) the $(GH \times GH)$ matrix $\mathbf{Z}$ of intermediate sales (or interindustry sales) describing the intermediate input linkages between all industries of all countries, (ii) the $(GH \times G)$ matrix $\mathbf{F}$ denoting final demand, which consists of all GH goods that are sold as final goods to all G countries, (iii) the $(GH \times 1)$ vector $\mathbf{y}$ of value added of each industry in each country, and (iv) the $(GH \times 1)$ vector $\mathbf{q}$ of output (or production).

In Table 1 the single elements of these matrices and vectors are denoted in lowercase letters. Throughout the paper, country indices $i, j \in \{1, \ldots, G\}$ are written as subscripts and industry indices $m, n \in \{1, \ldots, H\}$ as superscripts. For example, z_{ij}^{mn} represents the intermediate input sales by industry m in country i to industry n in country j. The variable f_{ij}^{m} denotes final goods produced by sector m in country i and sold to country j.[4]

[4]Depending on the ICIO dataset used, final production may be subdivided into K categories, such as

As can be seen from Table 1, all gross output produced by sector m in country i must be used as either an intermediate good or a final good either at home or abroad. Therefore, gross output q_i^m has to satisfy the following accounting relationship:

$$q_i^m = \sum_{j=1}^{G} \sum_{n=1}^{H} z_{ij}^{mn} + \sum_{j=1}^{G} f_{ij}^m \qquad \text{for } i = 1, \ldots, G \qquad m = 1, \ldots, H$$

This system of equations can also be written in matrix notation:

$$\mathbf{q} = \mathbf{Z} \cdot \mathbf{e}_{GH} + \mathbf{F} \cdot \mathbf{e}_G, \tag{1}$$

where $\mathbf{e}_{GH}$ and $\mathbf{e}_G$ denote vectors of ones with dimension $(GH \times 1)$ and $(G \times 1)$, respectively. For the following analysis, the matrix $\mathbf{A}$ of technical coefficients (also called input-output coefficients or direct input coefficients) is introduced as

$$\mathbf{A} \equiv \mathbf{Z} \cdot [\text{diag}(\mathbf{q})]^{-1}, \tag{2}$$

where $[\text{diag}(\mathbf{q})]^{-1}$ is a $(GH \times GH)$ diagonal matrix with the elements $1/q_j^n$ on its main diagonal. The elements of matrix $\mathbf{A}$, $a_{ij}^{mn} \equiv z_{ij}^{mn}/q_j^n$, show how many units of intermediate inputs industry n in country j buys from industry m in country i to produce one unit of gross output. In input-output analysis these technical coefficients are taken to be fixed, implying that inputs are used in fixed proportions and economies of scale are ignored.

Since $\mathbf{Z} = \mathbf{A} \cdot \text{diag}(\mathbf{q})$, eq. (1) can be written as

$$\mathbf{q} = \mathbf{A} \cdot \text{diag}(\mathbf{q}) \cdot \mathbf{e}_{GH} + \mathbf{F} \cdot \mathbf{e}_G = \mathbf{A} \cdot \mathbf{q} + \mathbf{F} \cdot \mathbf{e}_G, \tag{3}$$

where

$$\begin{gathered}
\mathbf{q} \equiv \begin{pmatrix} \mathbf{q}_1 \\ \vdots \\ \mathbf{q}_G \end{pmatrix}, \quad \mathbf{A} \equiv \begin{pmatrix} \mathbf{A}_{11} & \cdots & \mathbf{A}_{1G} \\ \vdots & \ddots & \vdots \\ \mathbf{A}_{G1} & \cdots & \mathbf{A}_{GG} \end{pmatrix}, \quad \mathbf{F} \equiv \begin{pmatrix} \mathbf{F}_1 \\ \vdots \\ \mathbf{F}_G \end{pmatrix}, \qquad \text{and} \\
\mathbf{q}_i \equiv \begin{pmatrix} q_i^1 \\ \vdots \\ q_i^H \end{pmatrix}, \quad \mathbf{A}_{ij} \equiv \begin{pmatrix} a_{ij}^{11} & \cdots & a_{ij}^{1H} \\ \vdots & \ddots & \vdots \\ a_{ij}^{H1} & \cdots & a_{ij}^{HH} \end{pmatrix}, \quad \mathbf{F}_i \equiv \begin{pmatrix} f_{i1}^1 & \cdots & f_{iG}^1 \\ \vdots & \ddots & \vdots \\ f_{i1}^H & \cdots & f_{iG}^H \end{pmatrix}
\end{gathered} \tag{4}$$

private consumption or investment. In Table 1 it is assumed that the K final demand components have been summed up to f_{ij}^m.

In input-output analysis the demand (and production) of final goods is considered to be exogenously given. The solution of equation system (3), consisting of GH equations, is

$$\mathbf{q} = \mathbf{B} \cdot \mathbf{F} \cdot \mathbf{e}_G, \tag{5}$$

where the matrix $\mathbf{B}$ denotes the so-called Leontief inverse

$$\mathbf{B} \equiv (\mathbf{I}_{GH} - \mathbf{A})^{-1} = \begin{pmatrix} \mathbf{B}_{11} & \mathbf{B}_{12} & \cdots & \mathbf{B}_{1G} \\ \mathbf{B}_{21} & \mathbf{B}_{22} & \cdots & \mathbf{B}_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{B}_{G1} & \mathbf{B}_{G2} & \cdots & \mathbf{B}_{GG} \end{pmatrix}, \text{ with } \mathbf{B}_{ij} \equiv \begin{pmatrix} b_{ij}^{11} & \cdots & b_{ij}^{1H} \\ \vdots & \ddots & \vdots \\ b_{ij}^{H1} & \cdots & b_{ij}^{HH} \end{pmatrix} \tag{6}$$

$\mathbf{I}_{GH}$ denotes the $(GH \times GH)$ identity matrix. The elements b_{ij}^{mn} of the Leontief inverse $\mathbf{B}$ are also referred to as "total requirement coefficients" in the input-output literature (Koopman et al., 2014). They show how much output of industry m in country i is needed to produce one extra unit of final good n in country j. Note that this final production satisfies world final consumption (i.e. besides domestic absorption in country j the exports of the final good n to other countries are included as well). It must be stressed that in eq. (5) all direct and indirect intermediate good linkages between sectors along international production chains are taken into account.

As a next step, the diagonal matrix $\mathbf{V}$ for (direct) sectoral value-added shares is introduced. As is evident from Table 1, total output of a good can also be obtained by summing up value added and all intermediate inputs needed for production. More specifically, it holds that

$$q_j^n = \sum_{i=1}^{G} \sum_{m=1}^{H} z_{ij}^{mn} + y_j^n \qquad \text{for } j = 1, \ldots, G \qquad n = 1, \ldots, H$$

In matrix notation

$$\mathbf{q} = \mathbf{Z}' \cdot \mathbf{e}_{GH} + \mathbf{y} \tag{7}$$

Since $\mathbf{Z}' \cdot \mathbf{e}_{GH} = \text{diag}(\mathbf{A}' \cdot \mathbf{e}_{GH}) \cdot \mathbf{q}$, it follows that

$$\mathbf{y} = \mathbf{q} - \mathbf{Z}' \cdot \mathbf{e}_{GH} = \mathbf{V} \cdot \mathbf{q}, \text{ where } \mathbf{V} \equiv \mathbf{I}_{GH} - \text{diag}(\mathbf{A}' \cdot \mathbf{e}_{GH}) = \text{diag}(\mathbf{e}_{GH} - \mathbf{A}' \cdot \mathbf{e}_{GH}) \tag{8}$$

The elements on the main diagonal of the $(GH \times GH)$ matrix $\mathbf{V}$ represent the share of value added in total output of industry n in country j. For later use $\mathbf{V}$ is written as

$$\mathbf{V} \equiv \begin{pmatrix} \mathbf{V}_1 & \mathbf{0}_{H,H} & \cdots & \mathbf{0}_{H,H} \\ \mathbf{0}_{H,H} & \mathbf{V}_2 & \cdots & \mathbf{0}_{H,H} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0}_{H,H} & \mathbf{0}_{H,H} & \cdots & \mathbf{V}_G \end{pmatrix}, \quad \text{with} \quad \mathbf{V}_j \equiv \begin{pmatrix} v_j^1 & 0 & \cdots & 0 \\ 0 & v_j^2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & v_j^H \end{pmatrix}, \tag{9}$$

where $\mathbf{0}_{H,H}$ is a $(H \times H)$ zero matrix, and $v_j^n \equiv y_j^n / q_j^n = [1 - \sum_{i=1}^{G} \sum_{m=1}^{H} a_{ij}^{mn}]/q_j^n$.

The elements of the $(GH \times GH)$ matrix $\mathbf{V} \cdot \mathbf{B}$ represent the value-added contributions of all sectors in all countries to final good production of each sector. For example, the first column of $\mathbf{V} \cdot \mathbf{B}$ contains the value-added contributions of all sectors in all countries to the final good production of sector 1 in country 1. Note that these value-added contributions take all intermediate input linkages along international production chains into account, i.e. one sector may indirectly contribute to production of another sector by selling intermediate goods to third sectors that may also be located in other countries. As will be shown in the next subsection using a simple Leontief type model, the elements of the matrix $\mathbf{V} \cdot \mathbf{B}$ constitute the weights to calculate the embodied unit labor costs (EULC) of a sector that not only reflect its own ULC, but also ULC of other sectors that are embodied in the intermediate inputs delivered to this sector. The extent to which ULC of other sectors are taken into account depends on the value-added contribution of others sectors to the final good production of this sector. The precise definition is summarized in the following

Definition 1 (**Embodied unit labor costs (EULC)**). *Let* $\mathbf{u}$ *be the* $(GH \times 1)$ *vector containing the unit labor costs of all* H *sectors in all* G *countries. Then, an embodied unit labor cost measure for each sector based on its own unit labor costs and the unit labor costs incorporated in the intermediate inputs that a sector receives from all other sectors in all countries is calculated as*

$$\mathbf{u}^{emb} \equiv \mathbf{\Omega}' \cdot \mathbf{u}, \tag{10}$$

where $\mathbf{\Omega} \equiv \mathbf{V} \cdot \mathbf{B}$ *is the* $(GH \times GH)$ *matrix containing the sector-specific weights for the unit labor costs of all sectors.* $\mathbf{B}$ *is defined in eq. (6) and* $\mathbf{V}$ *in eq. (8).*

The relevant weights to calculate EULC for sector n in country j are in the $[(j-1)H + n]$-th column of matrix $\mathbf{\Omega}$, with $\omega_{ij}^{mn} = v_i^m b_{ij}^{mn}$ and $\sum_{i=1}^{G} \sum_{m=1}^{H} \omega_{ij}^{mn} = 1$. Evidently, in each element of $\mathbf{u}^{\text{emb}}$ both the ULC from domestic sectors and those from foreign sectors are included. However, in the literature the focus often is on the question how domestic wage developments affect the competitiveness of domestic sectors, as has already been outlined in the introduction using Germany as an example. Moreover, as will be shown in Section 3, the calculation of real effective exchange rates is based on a comparison of domestic cost (or price) developments with those of trading partner countries. For these reasons, a modified EULC measure, $\widetilde{\mathbf{u}}$, is proposed that only takes account of the ULC of domestic sectors. Note that domestic ULC may not only be embodied in domestic intermediates but also in imported inputs. For this measure one needs the block diagonal matrix $\widetilde{\mathbf{B}}$ that contains the $\mathbf{B}_{ii}$ submatrices from matrix $\mathbf{B}$ defined in eq. (6), i.e.

$$\widetilde{\mathbf{B}} \equiv \begin{pmatrix} \mathbf{B}_{11} & \mathbf{0}_{H,H} & \cdots & \mathbf{0}_{H,H} \\ \mathbf{0}_{H,H} & \mathbf{B}_{22} & \cdots & \mathbf{0}_{H,H} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0}_{H,H} & \mathbf{0}_{H,H} & \cdots & \mathbf{B}_{GG} \end{pmatrix} \tag{11}$$

Normalizing the weights of the domestic sectoral contributions to production of a specific domestic sector so that their sum equals one gives the following

Definition 2 (**EULC based on domestic sectors only ("domestic EULC")**). *An EULC measure based on domestic unit labor costs only, i.e. a sector's own unit labor costs and the unit labor costs embodied in the intermediate inputs that a sector receives from all other domestic sectors, is calculated as*

$$\widetilde{\mathbf{u}} = \widetilde{\boldsymbol{\Omega}}' \cdot \mathbf{u} \tag{12}$$

with

$$\widetilde{\boldsymbol{\Omega}} \equiv (\mathbf{V} \cdot \widetilde{\mathbf{B}}) \cdot diag([\mathbf{e}'_{GH} \cdot (\mathbf{V} \cdot \widetilde{\mathbf{B}})]^{-1}), \tag{13}$$

where $\mathbf{e}_{GH}$ denotes a $(GH \times 1)$ vector of ones, $\mathbf{V}$ is defined in eq. (8), and $\widetilde{\mathbf{B}}$ is defined in eq. (11).

The matrix $\widetilde{\boldsymbol{\Omega}}$ is a block-diagonal matrix

$$\widetilde{\boldsymbol{\Omega}} \equiv \begin{pmatrix} \widetilde{\boldsymbol{\Omega}}_{11} & \mathbf{0}_{H,H} & \cdots & \mathbf{0}_{H,H} \\ \mathbf{0}_{H,H} & \widetilde{\boldsymbol{\Omega}}_{22} & \cdots & \mathbf{0}_{H,H} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0}_{H,H} & \mathbf{0}_{H,H} & \cdots & \widetilde{\boldsymbol{\Omega}}_{GG} \end{pmatrix} \tag{14}$$

where a single element in matrix $\widetilde{\boldsymbol{\Omega}}_{ii}$ is

$$\widetilde{\omega}_{ii}^{mn} = \frac{v_i^m b_{ii}^{mn}}{\sum_{m=1}^{H} v_i^m b_{ii}^{mn}} \qquad \text{and} \qquad \sum_{m=1}^{H} \widetilde{\omega}_{ii}^{mn} = 1$$

Note that for the precise calculation of $\widetilde{\mathbf{u}}$ the use of a national input-output table is not sufficient. As is shown in Appendix A, the value-added contributions of domestic sectors are underestimated if national input-output tables are used. Intuitively, this is due to the fact that with national input-output tables it is not taken into account that imported intermediate inputs may also contain domestic value added via domestically produced intermediate inputs that had previously been exported.

2.2 Theoretical justification for EULC based on a Leontief-type model

The suggested measures for a sector's EULC quite naturally arise from a Leontief-type theoretical model that captures the features of the multi-country input-output analysis presented above. At first glance, a Leontief-type model may seem to be overly restrictive since the technical coefficients are assumed to be given and inputs are used in fixed proportions. However, these assumptions only hold within a given period, for example one year. Both, in the analysis of the previous subsection and in the Leontief model, technical coefficients and factor proportions are allowed to change over time but for simplicity time indices are omitted. With time-varying technical coefficients the analysis can be reconciled with the neoclassical production function that implies substitutability between production inputs (Rose & Casler, 1996). In the following, a simplified model with two countries and two sectors in each country is considered that can be easily extended to include G countries and H sectors, with $G, H > 2$. Each sector may produce final goods as well as intermediate goods for own production and the production of all other sectors. Gross output production of sector 1 in country 1 is described by

$$q_1^1 = \min\{\frac{1}{\nu_1^1} y_1^1, \frac{1}{a_{11}^{11}} z_{11}^{11}, \frac{1}{a_{11}^{21}} z_{11}^{21}, \frac{1}{a_{21}^{11}} z_{21}^{11}, \frac{1}{a_{21}^{21}} z_{21}^{21}\}, \tag{15}$$

where z_{i1}^{m1} denotes intermediate goods produced in sector m of country i and used in the production of sector 1 in country 1. Assuming that all inputs are used in the production process (implying that $a_{i1}^{m1} \neq 0,$ for $i, m = 1, 2$), efficient production requires

$$q_1^1 = \frac{1}{\nu_1^1} y_1^1 = \frac{1}{a_{11}^{11}} z_{11}^{11} = \frac{1}{a_{11}^{21}} z_{11}^{21} = \frac{1}{a_{21}^{11}} z_{21}^{11} = \frac{1}{a_{21}^{21}} z_{21}^{21} \tag{16}$$

Obviously, ν_1^1 denotes the direct value-added coefficient $\nu_1^1 = y_1^1 / q_1^1$, and a_{i1}^{m1} denote the input-output coefficients $a_{i1}^{m1} = z_{i1}^{m1} / q_{i1}^{m1}$. The production functions for q_1^2, q_2^1, q_2^2, and the the corresponding efficiency conditions are set up analogously (see Appendix B). Value added is produced by labor according to

$$y_i^m = \lambda_i^m L_i^m, \tag{17}$$

where L_i^m denotes the labor input and λ_i^m labor productivity in sector m of country i, respectively. It is assumed that wage levels differ across sectors, for example because of imperfect information or limited mobility of workers. Moreover, it is assumed that intermediate goods and final goods of a sector are sold at the same price p_i^m. In that case, the zero profit condition in terms of gross output for sector 1 in country 1 can be written as

$$p_1^1 q_1^1 - w_1^1 L_1^1 - \sum_{i=1}^{2} \sum_{m=1}^{2} p_i^m z_{i1}^{m1} = 0 \tag{18}$$

Taking account of eqs. (16) and (17), this can be rewritten as:

$$p_1^1 = \nu_1^1 \frac{w_1^1}{\lambda_1^1} + \sum_{i=1}^{2} \sum_{m=1}^{2} a_{i1}^{m1} p_i^m \tag{19}$$

If the similar conditions for the other three sectors are taken into account, one arrives at the following 4-equation system (for more details see Appendix B).

$$\mathbf{p} = \mathbf{A}' \cdot \mathbf{p} + \mathbf{V} \cdot \mathbf{u} = (\mathbf{V} \cdot \mathbf{B})' \cdot \mathbf{u} = \boldsymbol{\Omega}' \cdot \mathbf{u} \tag{20}$$

The elements of each column in matrix $\boldsymbol{\Omega}$ therefore quite naturally arise as the weights for the calculation of the EULC of each sector. From this also follows the weight matrix $\widetilde{\boldsymbol{\Omega}}$ for the value-added contributions of domestic sectors to the production of a specific domestic sector.

2.3 Domestic EULC for sectoral aggregates

For the presentation of stylized facts on changes in competitiveness it is often useful to condense sectoral information into sectoral aggregates, for example "tradable goods sector" and "nontradable goods sector". To construct EULC for sectoral aggregates, one intuitive procedure would be to aggregate the sectoral data prior to the computation of EULC and then apply the formulas for EULC or domestic EULC to the aggregated data. In this case, the weights for the ULC of the sectoral aggregates represent the value-added contribution of each sectoral aggregate to final goods production of a specific sectoral aggregate. Such an aggregation of input-output tables can be performed along the lines explained in Appendix C. However, because of the aggregation the information on the input-output linkages between individual sectors within and between sectoral aggregates is lost which results in less precise EULC calculations at the aggregate level.

In this section it is explained how this problem is overcome and how EULC can be consistently calculated at a more aggregated level using the information on individual sectors in global ICIO tables. The focus is on domestic EULC because domestic wage developments are often the main concern, as has been outlined in the introduction. The idea is to weight the ULC of each of the H domestic sectors by its value-added contribution to final goods production of the sectoral aggregate, where the value-added contribution (again) takes global value chains into account. Consider, for illustration, the calculation of domestic EULC for the overall manufacturing sector man in a country i, denoted as $\tilde{u}_i^{man}$:

$$\begin{aligned} \tilde{u}_i^{man} &= \sum_{m=1}^{H} \widetilde{\omega}_{ii}^{m,man}\ u_i^m, \quad \text{with} \\ \widetilde{\omega}_{ii}^{m,man} &= \frac{\sum_{n\in I_{man}} v_i^m\ b_{ii}^{mn}\ f_i^n}{\sum_{m=1}^{H}\sum_{n\in I_{man}} v_i^m\ b_{ii}^{mn}\ f_i^n}, \end{aligned} \tag{21}$$

where $\widetilde{\omega}_{ii}^{m,man}$ is the weight of ULC in sector m that is determined by the contribution of that sector to final goods production of the manufacturing sector, I_{man} denotes the set of individual sector indices belonging to manufacturing, and $f_i^n = \sum_{j=1}^{G} f_{ij}^n$ denotes the final goods production of sector n in country i for the use in all G countries (also compare Table 1). More specifically, the numerator of $\widetilde{\omega}_{ii}^{m,man}$ contains the value-added contributions of a specific sector m to the final goods production of all n sectors belonging to the manufacturing sector, i.e. $n \in I_{man}$. The denominator contains the sum of value-added contributions of all domestic sectors to the final goods production of all n sectors belonging to the manufacturing sector, therefore $0 < \widetilde{\omega}_{ii}^{m,man} < 1$ and $\sum_{m=1}^{H} \widetilde{\omega}_{ii}^{m,man} = 1$.

For the calculation of EULC for sectoral aggregates it is important that the weight applied to the ULC of an individual sector correctly reflects the value-added contribution of this sector to final goods production of all sectors belonging to the sectoral aggregate. One could think of another potential procedure that is also based on data at a disaggregated level and that consists of two steps. First, sectoral ULC are aggregated to ULC in a sectoral aggregate. Second, weight for this aggregate is constructed based on the value-added contributions of individual sectors belonging to this aggregate. However, as is shown in Appendix D.1 using three sectoral aggregates—agriculture, manufacturing and services—this procedure is not correct as the implicit contributions of individual sectors to sectoral aggregates are biased.

Our proposed concept illustrated for the manufacturing sector in one particular country can be generalized to any sectoral aggregation for all countries in a global ICIO table simultaneously.[5] For each country, each of H individual sectors is assigned to one of $\widehat{H}$ sector aggregates, with $\widehat{H} < H$. In a first step, we introduce the $(GH \times GH)$ block-diagonal matrix $\mathbf{\Psi}$:

$$\mathbf{\Psi} = (\mathbf{V} \cdot \widetilde{\mathbf{B}}) \cdot \text{diag}(\mathbf{F} \cdot \mathbf{e}_G), \tag{22}$$

which, for each of the G countries, contains the value-added contributions of all H domestic sectors to final goods production of all H domestic sectors. The value-added contributions of individual sectors to sectoral aggregates can then be computed by an appropriate aggregation of elements of $\mathbf{\Psi}$. Let $I_{\widehat{n}}$ denote the index set containing the indices of sectors assigned to the sectoral aggregate $\widehat{n}$, where $\widehat{n} = 1, \ldots, \widehat{H}$. The $(H \times \widehat{H})$ aggregation matrix $\mathbf{R}$ for a single country is then defined as follows:

$$r^{m\widehat{n}} = \begin{cases} 1 & \text{if} \quad m \in I_{\widehat{n}} \\ 0 & \text{else,} \end{cases}$$

where m and $\widehat{n}$ denote row and column of the aggregation matrix, respectively. For the

[5]In the following analysis it is assumed that the same aggregation scheme holds for all countries, i.e. in all countries a sectoral aggregate contains the same individual sectors. For a discussion of the case in which a sectoral aggregate may contain different individual sectors in different countries, see Appendix D.2.

joint aggregation of sectors for all countries, the matrix $\mathbf{R}$ is extended as follows:

$$\mathbf{R}^* = \mathbf{I}_G \otimes \mathbf{R},$$

where $\mathbf{I}_G$ is a $(G \times G)$ identity matrix, and $\otimes$ denotes the Kronecker product. The $(GH \times G\widehat{H})$ matrix of value-added contributions of all sectors to sectoral aggregates in all countries is given by:

$$\mathbf{\Psi}^* = \mathbf{\Psi} \cdot \mathbf{R}^* \tag{23}$$

For example, the term in the first row and second column of this matrix contains the sum of the value-added contributions of sector 1 (of country 1) to those domestic sectors belonging to the second sectoral aggregate. Matrix $\mathbf{\Psi}^*$ is used in the following

Definition 3 (**Domestic EULC for sectoral aggregates**). *Assume that H individual sectors are condensed into $\widehat{H}$ sectoral aggregates. The $(G\widehat{H} \times 1)$ vector $\widetilde{\mathbf{u}}^{agg}$ containing domestic EULC for these sectoral aggregates for all G countries is then calculated according to*

$$\widetilde{\mathbf{u}}^{agg} = (\widetilde{\mathbf{\Omega}}^{agg})' \cdot \mathbf{u} \tag{24}$$

The $(GH \times G\widehat{H})$ matrix $\widetilde{\mathbf{\Omega}}^{agg}$ contains the weights for ULC of each of the H domestic sectors reflecting its value-added contribution to final goods production of the $\widehat{H}$ sectoral aggregates , for all G countries, with

$$\widetilde{\mathbf{\Omega}}^{agg} \equiv \mathbf{\Psi}^* \cdot [diag(\mathbf{e}'_{GH} \cdot \mathbf{\Psi}^*)]^{-1} \tag{25}$$

where $\mathbf{e}_{GH}$ denotes a $(GH \times 1)$ vector of ones, and $\mathbf{\Psi}^*$ is defined in eq. (23).

The term $[\text{diag}(\mathbf{e}'_{GH} \cdot \mathbf{\Psi}^*)]^{-1}$ is used for normalization so that the weights reflecting the sector contributions of all H domestic sectors to a sector aggregate sum up to one.

3 External cost competitiveness at the sectoral level

3.1 Embodied real effective exchange rate (EREER)

The real effective exchange rate (REER) is the most commonly used indicator of international price and cost competitiveness (Buldorini et al., 2002). It is a measure of relative prices or relative costs expressed in the same currency. Typically, REERs are published at the national level as a ratio of a national deflator and a weighted average of deflators of trading partners.[6] The averaging over foreign deflators is usually done by using geometric means. Weights used in empirical applications and in official statistics for REERs at the national level are simple weights and double weights, where the latter take into account third markets competition. Both types of weights usually rely on gross quantities (gross exports or gross trade flows, i.e. exports and imports).[7]

Though it is well known that measures of international competitiveness at the national level may hide quite diverse sectoral developments, only a few studies look at sectoral competitiveness by extending the concept of national REERs to the sectoral level as follows:

$$\varepsilon_i^n = \prod_{\substack{j=1,\\ j\neq i}}^{G} \left(\frac{d_i^n}{d_j^n}\right)^{\gamma_{ij}^n}, \qquad i = 1, \dots, G, \quad n = 1, \dots, H, \tag{26}$$

where ε_i^n denotes the REER relevant for sector n in country i. d_i^n and d_j^n denote a sectoral deflator for sector n in country i and j, respectively. The parameter γ_{ij}^n describes the weight attached to the deflator of sector n in a foreign country j depending on its importance as a trading partner for the same sector in country i. For example, Carlin et al. (2001) calculate sectoral REERs based on sectoral ULC, using gross export market shares at the industry level as the relevant weight.

We propose a novel measure for sectoral REERs, called the embodied real effective exchange rate (EREER), that differs from the conventional one with regard to both the deflator and the weights used for trading partners. As for the deflator, we suggest to use

[6] REERs at the national level are, for example, published by the following five international institutions: ECB (Buldorini et al., 2002; Schmitz et al., 2012) , OECD (Durand et al., 1992), IMF (Bayoumi et al., 2005), BIS (Turner & Van't dack, 1993; Klau & Fung, 2006), and the European Commission (see the Price and Cost Competitiveness Homepage: `https://ec.europa.eu/info/business-economy-euro/indicators-statistics/economic-databases/price-and-cost-competitiveness_en`). A short comparison of the different methods can be found in Schmitz et al. (2012), Appendix A.

[7] Among other advantages, geometric averaging ensures that the change in the exchange rate between two points in time is the same independently of which date is chosen as the base (the so-called "time-reversal" test), see Turner and Van't dack (1993). These authors also provide a detailed explanation of double weighting.

domestic EULC at the sectoral level thereby taking account of the unit cost developments of all domestic sectors according to their value-added contribution to the final goods production of a specific sector.[8] As for the weights for trading partners, we replace the traditionally used gross export weights by an appropriate value-added counterpart—weights based on the domestic value added embodied in sectoral gross exports that is absorbed abroad. These value-added weights better reflect the relevance of trading partner countries because gross exports contain more and more foreign value added due to the increasing importance of global value chains. Moreover, gross exports are contaminated by pure double counting, i.e. multiple counting of the same value added embodied in intermediates crossing the same border several times.[9] The formal definition of EREER is as follows:

Definition 4 (Embodied real effective exchange rate (EREER)). *Let $\tilde{u}_i^n$ and $\tilde{u}_j^n$ represent domestic EULC of sector n in country i and country j, respectively. The embodied real effective exchange rate (EREER) for sector n in country i is then defined as*

$$\tilde{\varepsilon}_i^n = \prod_{\substack{j=1, \\ j \neq i}}^{G} \left(\frac{\tilde{u}_i^n}{\tilde{u}_j^n} \right)^{\tilde{\gamma}_{ij}^n}, \tag{27}$$

[8]Domestic EULC instead of EULC should be used for the calculation of embodied REERs because otherwise foreign sectoral ULC would be included in the numerator and denominator which would make the interpretation of embodied REERs as competitiveness measures difficult.

[9]The term "pure double counting" is different from the notion "double counting", see Koopman et al. (2014) for details. Double-counted (domestic and foreign) terms can, similarly to pure double-counted terms, be present in gross exports of a particular sector if these gross exports include intermediate goods. However, double-counted terms capture those value-added terms that appear in gross exports statistics of sectors in several countries, and that are included in GDP of those countries where the respective value-added terms originate. In a two-country example, from the perspective of country i, double-counted terms in a sector's intermediate good exports to country j contain (apart from foreign value-added components) domestic value-added components which are part of GDP of country i and which return to country i if they are embodied in gross exports of country j to country i. These domestic value-added components from country i's perspective are at the same time foreign value-added components from country j's perspective, and in this sense they are double counted. In contrast to double-counted terms, pure double-counted terms are not included in GDP of any country and only artificially inflate gross exports when intermediate goods leave the country and return after some processing multiple number of times.

where the weights $\tilde{\gamma}_{ij}^{n}$ reflect the domestic value added embodied in the gross exports of sector n in country i to the receiving country j which is absorbed in that country or any other foreign country.

The next subsection shows how the weights $\tilde{\gamma}_{ij}^{n}$ are calculated. In the following, we provide more details on the concept behind these weights. Whereas bilateral gross exports at the sectoral level are unambiguously defined, the definition of their value-added counterpart is far from clear. One problem has to do with the sectoral dimension, the other one with the bilateral dimension of trade flows. Regarding the first problem, at the sectoral level one has to decide whether a so-called forward- or backward-linkage measure should be used.[10] Our proposed value-added measure—the domestic value added contained in the gross exports of a specific sector—constitutes a backward-linkage measure as it represents the value-added contributions of all domestic sectors to gross exports of the sector under consideration. In contrast, a forward-linkage measure sums up the value-added contributions of a particular sector to gross exports of all domestic sectors. However, as exports of other sectors are taken into account, this measure has the disadvantage that it is less related to gross exports of the respective sector than the backward-linkage measure. Using a backward-linkage measure offers the further advantage that $\tilde{\gamma}_{ij}^{n}$ constitute natural weights for EULC in the calculation of EREERs because EULC are also constructed in the backward-linkage manner.

Regarding the second problem, in the context of REER it is important to choose an appropriate value-added concept that reflects the potential competition with individual trading partner countries. This competition is not only related to final goods but also to intermediate goods. A potential candidate for such a concept would be value-added exports—a well established value-added measure that has often been used at the national level as a substitute for gross exports, see Johnson and Noguera (2012). Value-added exports from country i to country j measure the value added contained in gross exports to all countries that is ultimately absorbed in final demand in country j. The first disadvantage of this measure in our context is that it also encompasses value added in intermediates that are first exported to a third country k before they will be absorbed

[10] For a discussion of these two concepts at the sectoral level see Wang et al. (2013).

in country j. The amount of these exports of intermediates to country k (that are then included in intermediate good exports from country k to country j) reflect the importance of country k as a trading partner and should not be included in the weight of country j. In other words, weights resulting from value-added exports would be biased since they would be contaminated by the importance of country k for the intermediate goods exports of country i. In contrast, our proposed measure makes sure that the resulting weights refer to the direct trade links between countries i and j.

The second disadvantage of value-added exports in our context is that they neglect intermediate good exports from country i to country j that are ultimately absorbed in other countries (for example country k). The amount of these intermediate goods exports reflect the importance of country j as a trading partner country and should therefore be included in the weight for country j as is done with our measure. Interestingly, when total gross exports (to all countries together) are considered, value-added exports are identical to the proposed domestic value added in gross exports absorbed abroad.[11]

An empirical application that integrates an export-related value-added concept in the computation of REER, albeit in a context differing from ours in various respects, is a study by Lommatzsch et al. (2016). They make use of sectoral value-added exports to create weights for deflators, e.g. ULC, in individual sectors. Based on these sector weights a national deflator is constructed that is used in the computation of REERs at the national level. Note that in their framework it is not necessary to distinguish between value-added exports and our proposed bilateral measure since they consider total value-added exports of a sector. Other works that address value-added competitiveness are Bems and Johnson (2017) and Patel et al. (2014), where the latter also take the sectoral dimension into account. However, value-added REER are there derived as price-induced changes in demand in a model-based framework. Other works that in a way are related to some aspects of our paper, albeit not dealing with value-added competitiveness, are Bennett and Zarnic (2009) who build sector-level exchange rates, and Bayoumi et al. (2013) who incorporate trade in intermediates in their derivation of country-level exchange rates.

[11] This motivates why we do not include domestic value added in gross exports that eventually returns back and is consumed at home.

3.2 Value-added bilateral weights

Let $\tilde{\mathbf{x}}_{ij}$ denote the vector encompassing domestic value added in bilateral gross exports of all sectors of country i to country j. Then, from the decomposition of sectoral gross exports of country i to country j described in eq. (37) in Wang et al. (2013) it follows that:

$$\tilde{\mathbf{x}}_{ij} = (\mathbf{e}_H \cdot \mathbf{V}_i \cdot \mathbf{B}_{ii})' \circ \mathbf{f}_{ij} + (\mathbf{e}_H \cdot \mathbf{V}_i \cdot \mathbf{L}_{ii})' \circ (\mathbf{A}_{ij} \sum_{\substack{g=1,\\ g\neq i}}^{G} \sum_{\substack{k=1,\\ k\neq i}}^{G} \mathbf{B}_{jg}\mathbf{f}_{gk}), \tag{28}$$

where $\circ$ denotes the Hadamard product and $\mathbf{V}_i$ is the i-th block of the block diagonal matrix $\mathbf{V}$, see eq. (9). Moreover, $\mathbf{f}_{ij} = (f_{ij}^1, \ldots, f_{ij}^H)'$ gives sectoral final goods exports of country i to country j, and is the j-th column of matrix $\mathbf{F}_i$, see eq. (4). Lastly, $\mathbf{L}_{ii} = (\mathbf{I}_H - \mathbf{A}_{ii})^{-1}$ denotes the so-called local Leontief inverse, which corresponds to the Leontief inverse in the case of a national input-output analysis, where exports are considered to be exogenously given, also see Appendix A. The first term in eq. (28) represents the domestic value added in the sectoral exports of final goods to country j, whereas the second term captures value added that is embodied in intermediate goods exports and is absorbed abroad. Intermediate goods exports can be used in country j for production of final goods that are consumed either in country j or in a third country. Alternatively, they can be used in production of final goods in a third country that are consumed in any country except country i.

Based on $\tilde{\mathbf{x}}_{ij}$, REER weights can be computed for any sector n. Similarly to the case of weights based on gross quantities, simple and double weights can be employed. Taking into account that $\tilde{x}_{ii}^n = 0$ (since exports to the own country are by definition equal to zero), value-added simple export weights given by:

$$\tilde{\gamma}_{ij}^n = \frac{\tilde{x}_{ij}^n}{\sum_{g=1}^G \tilde{x}_{ig}^n},$$

where $\tilde{x}_{ij}^n$ denotes an n-th element of $\tilde{\mathbf{x}}_{ij}$. Double export weights are given by:

$$\tilde{\gamma}_{ij}^{(x),n} = \left(\frac{\tilde{x}_{ij}^n}{\sum_{g=1}^G \tilde{x}_{ig}^n}\right)\left(\frac{v_j^n}{v_j^n + \sum_{\substack{g=1,\\ g\neq i}}^G \tilde{x}_{gj}^n}\right) + \sum_{\substack{k=1,\\ k\neq i,j}}^{G}\left(\frac{\tilde{x}_{ik}^n}{\sum_{g=1}^G \tilde{x}_{ig}^n}\right)\left(\frac{\tilde{x}_{jk}^n}{v_k^n + \sum_{\substack{g=1,\\ g\neq i}}^G \tilde{x}_{gk}^n}\right), \tag{29}$$

where (x) in the weight superscript refers to exports. Value added v_j^n replaces gross output q_j^n in the traditional double weights formula.

The first component in eq. (29 captures "direct competition" between sector n in countries i and the same sector in country j, i.e. competition with sector n in country j in its domestic market. This is expressed by the value-added share of country j's sector n in total value added supplied by sector n from all countries (except country i), weighted by the relative importance of country j for the exports of sector n in country i, where the exports correspond to our value-added measure.

The second component in eq. (29 expresses "third markets competition" between sector n in countries i and the same sector in country j. It is the share of country's j sector n in total value added supplied by sector n from all countries (except country i) to a third market k, weighted by the relative importance of the third market for the exports of sector n in country i, where the exports correspond to our value-added measure. Of course, the summation is done over all k other markets.

To additionally take into account the importance of country j's sector n on the home market of country i, one can consider import weights that describe the competition between country j's sector n and the same sector of other trade partners of country i in the home market of country i:

$$\tilde{\gamma}_{ij}^{(im),n} = \frac{\tilde{x}_{ji}^{n}}{\sum_{g=1}^{G} \tilde{x}_{gi}^{n}},$$

where (im) in the weight superscript refers to imports. Finally, double export weight and import weight can be combined to the overall weight that reflects the overall importance of country j's sector n as a competitor sector of sector n in country i:

$$\tilde{\gamma}_{ij}^{n} = \alpha_i^n \tilde{\gamma}_{ij}^{(x),n} + (1 - \alpha_i^n)\tilde{\gamma}_{ij}^{(im),n}, \qquad \alpha_i^n = \frac{\sum_{g=1}^{G} \tilde{x}_{ig}^{n}}{\sum_{g=1}^{G} \tilde{x}_{ig}^{n} + \sum_{g=1}^{G} \tilde{x}_{gi}^{n}} \tag{30}$$

The parameter α_i^n represents the importance of the export weight in the overall weight. It is given by the share of domestic value added in gross exports of sector n to all countries (value-added exports of sector n) in the value-added counterpart of total trade of this sector that, apart from value-added exports, consists of value-added embodied in imports from the same sector n in all foreign countries.

3.3 EREER for sectoral aggregates

Analogously to the case of EULC, it may be useful to look at EREERs in larger sectoral aggregates to obtain stylized facts on the sources of external competitiveness of a country. Adopting the nomenclature introduced in Section 2.3, $\widehat{n}$ is a sectoral aggregate and $\widehat{H}$ gives the number of sectoral aggregates, so that $\widehat{n} = 1, \ldots, \widehat{H}$. Then, EREER in a sectoral aggregate $\widehat{n}$, $\tilde{\varepsilon}_i^{\widehat{n}}$, is obtained using eq. (27) and replacing EULC $\tilde{u}_i^n$ and $\tilde{u}_j^n$, and bilateral value-added weights $\tilde{\gamma}_{ij}^n$ for the individual sector n by those for the aggregate $\widehat{n}$.

If, similarly to Section 2.3, we consider the manufacturing sector as an example of a sectoral aggregate ($\widehat{n} = man$), $\tilde{u}_i^{man}$ and $\tilde{u}_j^{man}$ are obtained from eq. (21), whereas $\tilde{\gamma}_{ij}^{man}$ is based on $\tilde{x}_{ij}^{man}$ being the domestic value added in gross exports of the whole manufacturing sector from country i to j that is absorbed abroad. The quantity $\tilde{x}_{ij}^{man}$ is given by:

$$\tilde{x}_{ij}^{man} = \sum_{n \in I_{man}} \tilde{x}_{ij}^{n},$$

where I_{man} denotes the set of indices of sectors belonging to manufacturing. These considerations can be generalized to any division of all sectors into $\widehat{H}$ subgroups for all countries. Assuming that in all countries the sectoral composition in these subgroups is the same, then the $(G\widehat{H} \times 1)$ vector $\widetilde{\mathbf{u}}^{agg}$ of domestic EULC in the sectoral aggregates in all G countries, as given by eq. (24), can be used to extract EULC for the sectoral aggregate $\widehat{n}$ in countries i and j. The corresponding value-added based export measure $\tilde{x}_{ij}^{\widehat{n}}$ is then extracted as the $((i-1)\widehat{H} + \widehat{n})$-th element from the matrix:

$$\widetilde{\mathbf{X}}^{agg} = (\mathbf{R}^*)' \cdot \widetilde{\mathbf{X}}, \qquad \widetilde{\mathbf{X}} = \begin{pmatrix} \mathbf{0} & \tilde{\mathbf{x}}_{12} & \cdots & \tilde{\mathbf{x}}_{1G} \\ \tilde{\mathbf{x}}_{21} & \mathbf{0} & \cdots & \tilde{\mathbf{x}}_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{\mathbf{x}}_{G1} & \tilde{\mathbf{x}}_{G2} & \cdots & \mathbf{0} \end{pmatrix},$$

where $\mathbf{R}^*$ is the aggregation matrix defined in Section 2.3. The column vectors $\tilde{\mathbf{x}}_{ij}$ from matrix $\widetilde{\mathbf{X}}$ are computed according to eq. (28).

4 Empirical application: international cost competitiveness of German sectors

4.1 Data and computations

4.1.1 Original data

For our empirical analysis we resort to the World Input-Output Database (WIOD). Currently, two releases of the World Input-Output Database (WIOD) are publicly available that have have been published in the years 2013 and 2016, respectively; see `http://www.wiod.org/home`. Timmer et al. (2015) give an introduction to the WIOD based on the 2013 Release. More information on the 2016 Release can be found in Timmer et al. (2016). The main component of the WIOD are the World Input-Output Tables (WIOT) that are constructed from national supply and use tables, and national accounts; see Dietzenbacher et al. (2013) for more details on the compilation of WIOTs. WIOTs have a structure similar to that presented in Table 1. Entries that are included in the WIOTs but are, for simplicity, omitted in the schematic table result from bringing the supply and the use tables together which differ, for example, with respect to the applied price concept.

All quantities in the WIOTs are expressed in current prices (in millions of US dollars).[12] The quantities shown in Table 1 are denoted in basic prices that cover all costs borne by the producer; this is different from purchasers' prices that represent the amount paid by the consumer (and additionally include trade and transportation margins as well as net taxes). International trade flows, i.e. exports and imports of final goods and intermediate goods, are expressed in "free-on-board" (fob) prices which reflect all the costs measured at the border of the exporting country and do not include further costs that arise until the goods reach the buyer.

The WIOD also contains Socio-Economic Accounts (SEA) as an additional dataset

[12] WIOD Release 2013 also includes WIOTs in previous year's prices (pyp) from 1996 to 2009, which makes it possible to convert original data in current prices into data in constant prices for the time span 1995–2009.

that provides information on (i) employment and compensation (also by skill type), (ii) capital stock and investment, (iii) gross output and value added (at both current and constant prices). Another supplementary dataset is Environmental Accounts with information on energy use and emissions. Both satellite accounts datasets are provided at the industry level and can be conveniently combined with the WIOTs. At the time of writing this paper they are available for the WIOD Release 2013 only. Since the computation of the proposed competitiveness measures requires, among others, data on labor costs, we use WIOTs and SEA of the WIOD Release 2013.

WIOTs of Release 2013 are provided as annual data from 1995 to 2011 covering 40 countries, including all 27 members of the EU (as of January 1, 2007) and 13 other major economies plus a rest of the world (RoW) region. As Timmer et al. (2015) point out, together the 40 countries cover more than 85 percent of world GDP in 2008 (at current exchange rates). Moreover, the data is provided for 35 industries, mostly at the two-digit ISIC Rev. 3 level or groups thereof, covering the overall economy. SEA dataset of Release 2013 comprises the same time span, countries (except RoW) and sectors as the WIOTs. However, for some countries data on some variables is only available until 2009. Variables of SEA that are expressed in nominal terms, like gross output at current prices or labor compensation, are denominated in national currencies.

4.1.2 Final data

Before the concepts proposed in Sections 2 and 3 are applied, data from the WIOD is preprocessed. To make SEA data comparable across countries and consistent with the WIOT data, we convert all nominal values into US dollars. For that purpose, we use exchange rates provided as a complementary table for the WIOD Release 2013. The same exchange rates have been applied by the authors of the WIOD project to express the quantities in WIOTs for all countries in US dollars. To avoid problems that may arise in the calculations due to data issues, in the next step we aggregate some sectors and countries. Further, we eliminate two sectors: "Coke, Refined Petroleum and Nuclear Fuel" (ISIC code: 24) and "Private Households with Employed Persons" (ISIC code: P). The same sector/country transformation is applied to both the WIOTs and SEA data.

Lastly, we exclude RoW from WIOTs as no data on this region is available in SEA. A more detailed explanation of the reasons for data transformation as well as information on sectors and countries that have been aggregated can be found in Appendix C.4. After the initial data transformation the dataset covers 36 countries and 29 sectors, see Tables C.1 and C.2 in the appendix for more details.[13]

4.1.3 Computational details

Since the focus of our study lies on the assessment of a country's competition, in the empirical application we will resort to the concepts of *domestic* EULC and EREER, where the latter, as has been explained in Section 3, is defined in terms of relative *domestic* EULC. Throughout this section, we will write EULC as a shorthand when referring to *domestic* EULC. It should not be confused with the notion of EULC that also comprise the foreign contributions.

Sectoral EULC are calculated as follows. First, sectoral standard ULC are obtained as the ratio of sectoral labor costs and sectoral value added, where labor costs are represented by the variable labor compensation (labeled "LAB") from the SEA dataset and value added is taken from the WIOTs.[14] Since both variables are given in nominal terms, the resulting ULC are interpreted as real ULC. Whereas for many countries data on labor compensation is available until 2011, for some countries the sample already ends in 2009. For the analysis to be consistent, the data must refer to the same time span for all countries. Since ULC show extreme behavior around 2008–2009 due to the economic and financial crisis, we restrict the analysis to end in 2007 instead of 2009.

The next component needed to obtain EULC are sectoral weights given by the matrix $\widetilde{\mathbf{\Omega}}$ defined in eq. (14). All quantities used for the calculation of the weights are

[13]Throughout this section, we will additionally provide the WIOT code (number following the letter "c") while referring to a particular sector.

[14]SEA also contains another variable representing labor costs—compensation per employee (labeled "COMP"). However, in our view labor compensation is a more suitable measure as it also contains compensation of self-employed in addition to compensation of employees. Since labor and capital compensation sum up to value added, sectoral ULC computed with the labor compensation variable also represent the labor share in a sector.

retrieved from the WIOTs: value added, gross output and the matrix of intermediate sales.

As regards sectoral EREERs, the computations involve EULC from the previous step and value-added bilateral weights based on domestic value added in bilateral gross exports that is absorbed abroad, see eq. (28). For the computation of these EREER weights we utilize quantities taken from the WIOTs: value added, gross output, matrix of intermediate sales and final demand. For comparison purposes, we also calculate EREERs with gross export weights instead of value-added weights. In addition, we calculate two standard REER measures using standard ULC as a deflator which differ depending on whether value-added or gross export weights are used. For all four types of REER we resort to overall trade weights with double export weights that are given in eq. (30).

The subsequent part of this section sheds new light on changes in international competitiveness at the sectoral level for Germany, and compares the computed measures for German sectors with the corresponding ones in other selected euro area countries—Spain, Italy, France, Greece and Portugal. It is to be noted that the trading partner countries in the computations of different REER measures for Germany as well as each of the selected other euro area countries are always the other 35 countries from our sample. Hence, changes in the REER measure for a country always reflect changes in "overall" cost competitiveness, and not only changes in competitiveness relative to the other five countries from the comparison group. All ULC and REER series in the next subsection are depicted as index series, which, for each of the measures, are obtained by dividing the value in a particular year by the value in the first year in the sample (1995).

The presentation of stylized facts is facilitated by first considering sectoral aggregates instead of single sectors. Sectoral aggregates are constructed as follows. An industry in a particular country is classified as a nontradable (tradable) sector if gross exports of this industry lie below (above) the 25th percentile of the gross exports' distribution in this country in 1995. Tradable sectors belonging to manufacturing (services) are assigned to the subgroup tradable manufacturing (tradable services). The three sectoral aggregates considered in our analysis therefore are: nontradable sectors, tradable manufacturing and tradable services.

Applying the "25th-percentile rule" yields sectoral aggregates that may vary from country to country with respect to their sectoral composition. However, for a meaningful comparison of one country with other countries the same sector classification should be chosen. Since the focus of our empirical application is on the international cost competitiveness of German sectors, we assign sectors in the comparison countries to the sectoral aggregates—nontradable sectors, tradable manufacturing and tradable services—according to the German classification that is presented in Table E.3 in Appendix E. Note that the German sector c1: "Agriculture, Hunting, Forestry and Fishing" is a tradable sector that belongs neither to tradable manufacturing nor to tradable services. It is therefore subsumed under the group "other sectors" in Table E.3. This group is not explicitly examined, except in a few cases where information for this subgroup is useful for the interpretation of the results for the three main sectoral aggregates.

We calculate EULC for the three sectoral aggregates, as explained in Section 2.3, using sectoral standard ULC and the matrix $\widetilde{\mathbf{\Omega}}$. To obtain EREERs for the sectoral aggregates, we proceed as outlined in Section 3.3 by employing EULC computed in the previous step as well as bilateral value-added weights for nontradable sectors, tradable manufacturing and tradable services.

4.2 Stylized facts for Germany

4.2.1 Results for sectoral aggregates

To get a first intuition about the costs evolution in different sectors in an economy, it seems natural to start with a look at the evolution of wages. Figure 1 shows the development of real hourly wages in Germany for the three sectoral aggregates (tradable manufacturing, tradable services and nontradable sectors) from 1995 to 2007.[15] Real wages in tradable

[15]Real hourly wages in each of the aggregates are computed by deflating nominal hourly wages by the consumer prices index (CPI) in the total economy. Source of the CPI is the GENESIS database of the German Federal Statistical Office (`https://www-genesis.destatis.de/genesis/online`). Nominal hourly wages are obtained by dividing labor compensation by the number of hours worked (total hours worked by persons engaged) for the respective sectoral aggregate. Labor compensation and hours worked at the level of individual sectors are retrieved from the SEA database (labels "LAB" and "H_EMP",

manufacturing increased by about 13 percent over this period which is in stark contrast to the wage developments in the nontradable sectors and in tradable services for which real wages showed only a slight increase until 2003 and declined afterwards. This decline may be related to the Hartz reforms that started in 2003 and led to a sizable increase in low-wage employment, especially in the nontradable sectors. However, it would be premature to conclude that manufacturing has profited via intermediate-good linkages from stagnating real wages in other domestic sectors, since sectoral cost developments depend on the change in wages relative to changes in productivity, i.e. on ULC.

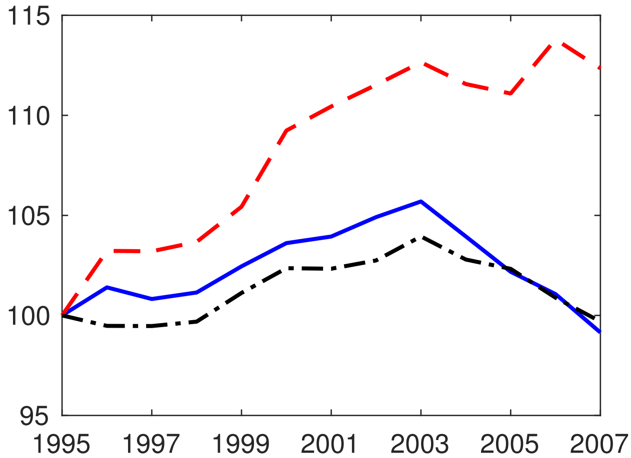
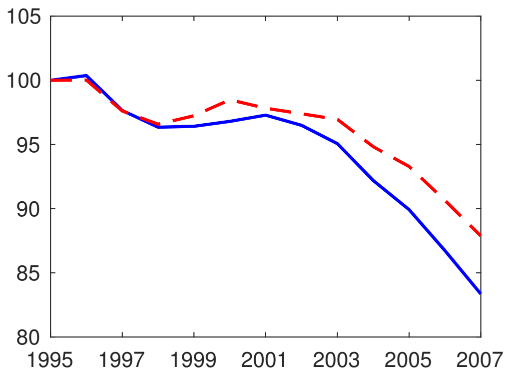


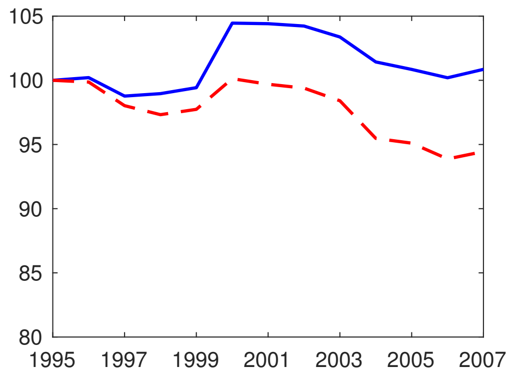
Figure 1: Real hourly wages in three German sectoral aggregates; red dashed line: tradable manufacturing, black dash-dot line: tradable services, blue solid line: nontradable sectors.

The blue solid lines in Figure 2 depict the development of standard ULC for the three sectoral aggregates. From 1995 to 2007, standard ULC declined by 16.6 percent in tradable manufacturing, stayed more or less constant in tradable services, and declined by 7.6 percent in nontradable sectors. Given the real wage developments discussed previously, these ULC developments are quite remarkable and point to a strong increase in labor productivity in tradable manufacturing that overcompensated the real wage increase, as opposed to only a slight increase in labor productivity in nontradable sectors and a roughly constant labor productivity in tradable services. Since standard ULC developed less favorably in nontradable sectors and tradable services in comparison to tradable

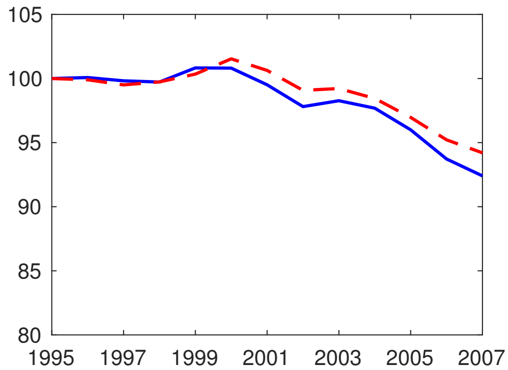
respectively) after the initial data preparation (see Section 4.1.2) and then aggregated to the level of nontradable sectors, tradable manufacturing and tradable services.



(a) Tradable manufacturing



(b) Tradable services



(c) Nontradable sectors

Figure 2: Standard ULC and embodied ULC (EULC) in three German sectoral aggregates; blue solid line: standard ULC, red dashed line: EULC

manufacturing, EULC (depicted by the red dashed line) in tradable manufacturing showed a smaller decline than standard ULC. In contrast, especially tradable services profited from the ULC decline in the other two sectoral aggregates.

To trace the sources for the differences between standard ULC and EULC in the sectoral aggregates, it may be informative to look at the individual sectors contributing to the sectoral aggregates. Table E.3 in the appendix reports the annual and total growth rate of standard ULC for all sectors and the respective value-added contribution to the final good in the three sectoral aggregates. For instance, for all sectors in tradable manufacturing, with the exception of sector c3: "Food, Beverages and Tobacco", standard ULC declined from 1995 to 2007. However, it must be taken into account that tradable services and nontradable sectors also contributed with their value added to tradable manufacturing. The most prominent example is the service sector c30: "Renting of Machinery & Equipment and Other Business Activities" which contributed with 9.4 percent to tradable manufacturing and experienced a 29.1 percent increase of standard ULC, thereby dampening the decline of EULC in tradable manufacturing.

In contrast, nontradable sectors and tradable manufacturing helped to increase competitiveness in tradable services. For example, the nontradable sector c17: "Electricity, Gas and Water Supply" contributed with 0.5 percent to final goods production in tradable services and experienced a 27.9 percent decline in ULC. Both, the manufacturing sectors c12: "Electrical and optical equipment" and c14: "Manufacturing, Nec; Recycling" had ULC declines of more than twenty percent over the sample period and contributed about 0.4 percent to tradable services. Even though the contribution of individual sectors from tradable manufacturing and nontradable sectors to tradable services is small, the total effect is large enough to bring about a 5.6 percent decline in EULC for tradable services from 1995 to 2007, whereas standard ULC increased by 0.9 percent over the sample period.

These results are at odds with one of the conclusions in the influential study of Dustmann et al. (2014) who, as mentioned in the introduction, claim that tradable manufacturing in Germany has increased competitiveness by using intermediate inputs from tradable services. This contradicting evidence requires some further elaborations.

First, it is important to note that the authors construct the same three sectoral aggregates by applying the same "25th-percentile rule" as in our paper (see Section 4.1.3). Despite other data sources, their reported standard ULC in the time span 1995–2007 (see "unit labor costs: value added" in Figure 4 of Dustmann et al., 2014) strongly resemble the standard ULC depicted in Figure 2 of this paper. In other words, the benchmark ULC in Dustmann et al. (2014) and in our paper are almost in line. The conclusion of the authors about the increased competitiveness in tradable manufacturing and the reasons behind this development is thus not a consequence of a different benchmark. It results from the application of an ULC measure based on gross output that, according to the authors, should take account of the inter-sectoral linkages and is considered in their paper as an alternative to the benchmark ULC. However, this measure yields ULC in tradable manufacturing (see "unit labor costs: end products" in Figure 4 of Dustmann et al., 2014) which lie below standard ULC. This outcome is explained by the authors mainly by the fact that manufacturing bought inputs from sectors that experienced a decrease in wages, especially from tradable services. Though it is true that wages in nontradable sectors and tradable services fell strongly after 2003 compared to tradable manufacturing, we would like to point out that it is not correct to base arguments on changes in competitiveness on these wages developments, since changes in productivity are also decisive. Hence, it is developments in ULC and not in wages which matter.

It has been shown above that ULC in tradable services and nontradable sectors declined less strongly relatively to manufacturing. Therefore, since manufacturing drew on inputs from other domestic sector aggregates, this must *reduce* the increase in competitiveness in tradable manufacturing. ULC that adequately take account of inter-sectoral linkages must show a smaller and not a stronger decline.[16] Our EULC concept with a Leontief-type model as its foundation produces such a result as it captures the impact of other sectors' cost developments for the competitiveness of a sector in a consistent manner. A further aspect which is not taken into account in the competitiveness analysis of Dustmann et al. (2014) but which is crucial in this context is that the evidence for the

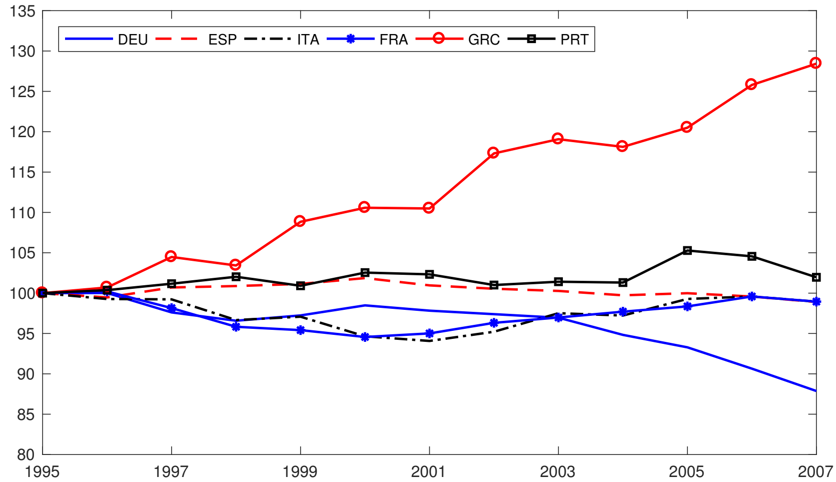
[16] In Appendix D.3, we explain in more detail why, in our view, "unit labor costs: end products"—the ULC measure considered by Dustmann et al. (2014)—is an inappropriate one and creates biased results.

three sectoral aggregates in Germany should be compared to some other countries. We address this aspect in the next step.[17]

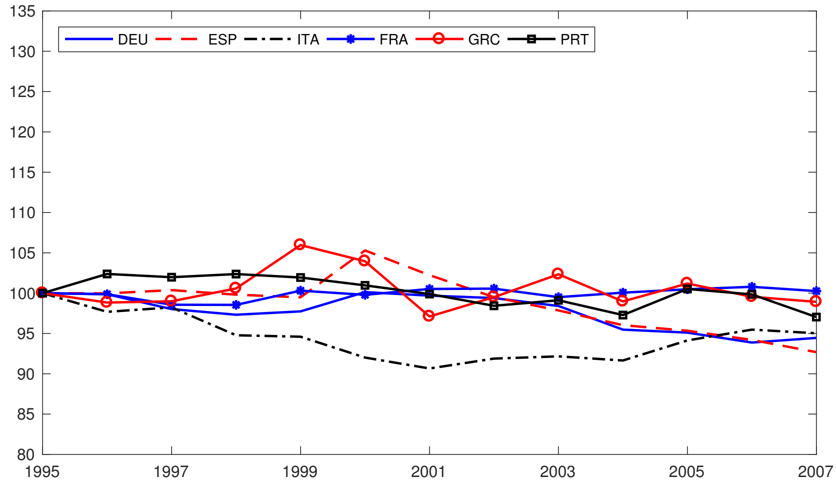
In Figure 3, the EULC of the three sectoral aggregates in Germany are compared to those in other selected euro area countries—Italy, France, Greece, Portugal and Spain. As has been already mentioned in Section 4.1.3, the same assignment of sectors to the three sectoral aggregates as in Germany is chosen for all other countries for a meaningful international comparison. In Germany, EULC in tradable manufacturing declined, and this decline became more pronounced from 2003 onwards, leading to a 12.1 percent lower EULC in 2007 in comparison to 1995. This is contrast to the other euro area countries where EULC in 2007 either stayed at about the level of 1995 or, in the case of Greece, were much higher than in 1995. With respect to tradable services and nontradable sectors the EULC development in Germany is more in line with that in the other euro area countries (with the exception of Greece for nontradable sectors).

In Figure E.1 in the appendix, standard ULC are depicted for the same group of countries. The most striking difference between ULC and EULC is observed for tradable manufacturing in Greece, where standard ULC increased only by 11.2 percent from 1995 to 2007, whereas the increase of EULC in the same time span amounted to 28.4 percent. At first, such a strong increase in EULC may seem puzzling, given that standard ULC in nontradable sectors increased "only" by 24.7 percent and standard ULC in tradable services even declined by 8.4 percent. This unfavorable development in tradable manufacturing in Greece can be explained with the help of Table E.4 in the appendix. First, standard ULC in sector c30: "Renting of Machines & Equipment and Other Business Activities" experienced an exorbitantly high increase (151.6 percent from 1995 to 2007) and provided a relatively large contribution of 7.3 percent to tradable manufacturing. Second, sector c1: "Agriculture, Hunting, Forestry and Fishing" also displayed a strong increase in ULC (143.1 percent) coupled with a contribution of 3.4 percent to tradable manufacturing. The agricultural sector is not explicitly represented in Figure E.1 (see Section 4.1.3), however, its ULC are also taken into account in the computation of EULC

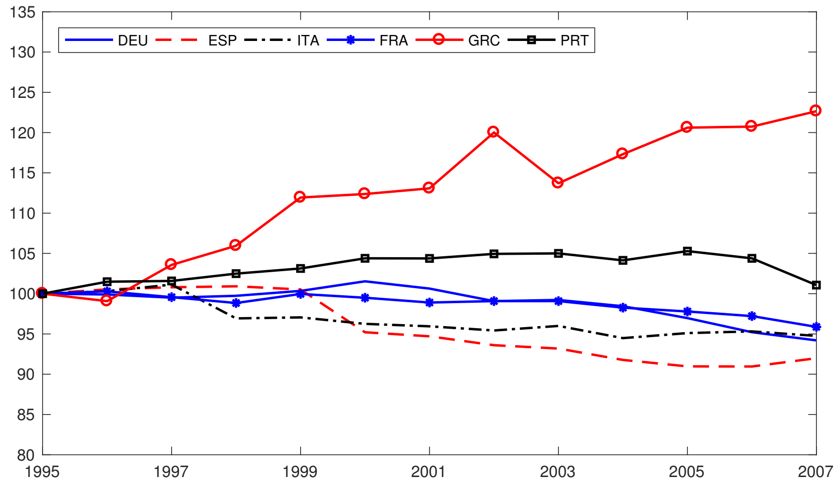
[17]The presented critique does not invalidate the many other contributions of Dustmann et al. (2014), for example the very convincing description of the transformation of industrial relations in Germany.



(a) Tradable manufacturing



(b) Tradable services



(c) Nontradable sectors

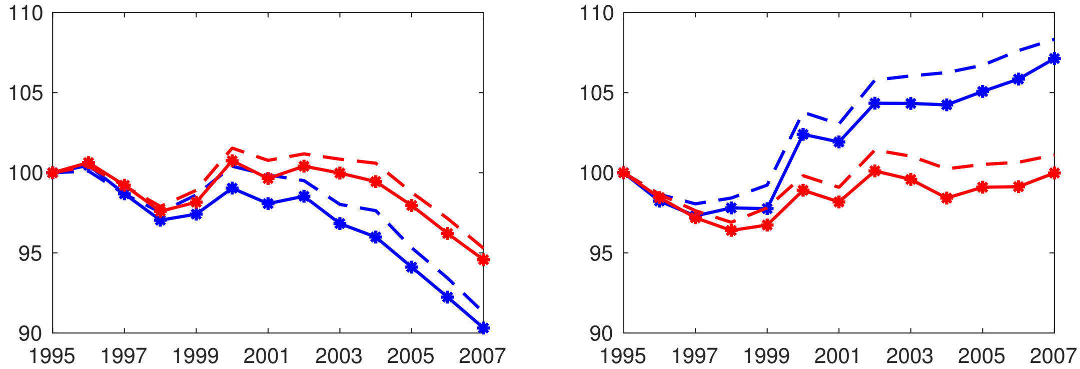
Figure 3: Embodied ULC (EULC) in three German sectoral aggregates in comparison with selected euro area countries; German classification of sectoral aggregates is applied to all countries.

for the sectoral aggregates. The value-added contribution of the agricultural sector to tradable manufacturing is, with 3.4 percent, much larger compared to its contribution to nontradable sectors (0.3 percent) and tradable services (0.6 percent), meaning that especially tradable manufacturing was influenced by the enormous ULC increase in agriculture. As is evident from this discussion, standard ULC do not depict the full extent of the deterioration of competitiveness for tradable manufacturing in Greece which is much better captured by EULC instead.

A remarkable difference between standard ULC and EULC in the international comparison can also be observed for tradable services in Germany. Standard ULC increased by 0.9 percent from 1995 to 2007 in Germany, whereas they declined for the other euro area countries (with the exception of France). However, when looking at EULC for tradable services, the picture changes. EULC in tradable services in Germany declined by 5.6 percent and showed a stronger decline than in the other euro area countries (with the exception of Spain). Hence, the ULC development in tradable services in Germany was even worse than in the comparison group of countries (with the exception of France). Since this result is reversed when looking at EULC, it is tradable services that has profited from the more favorable unit cost developments in tradable manufacturing and nontradable sectors, and not the other way round.

To obtain precise information on the change in cost competitiveness in a particular country it is, of course, not sufficient to compare the development of ULC for a few trading partner countries. A thorough competitiveness analysis should also employ a concept of REER that takes account of the competition of a specific country with most or all trading partners in the world. Figure 4 shows the development of REERs for tradable manufacturing and tradable services in Germany. The calculation for REERs is based on standard ULC and EULC, respectively. The respective ULC for tradable manufacturing or tradable services are compared to the respective ULC for the same sectoral aggregate in the 35 trading partner countries listed in Table C.2 in the appendix. For both measures the weights for trading partner countries are calculated using either gross export weights or value-added weights, as explained in Section 3 .

When interpreting the evidence in Figure 4, it should be borne in mind that a decline



(a) Tradable manufacturing **(b)** Tradable services

Figure 4: Real effective exchange rates (REERs) of two German sectoral aggregates; blue dashed line: REERs based on standard unit labor costs (ULC) and gross export weights, blue solid line with markers: REERs based on standard ULC and value-added weights, red dashed line: REERs based on embodied ULC (EULC) and gross export weights, red solid line with markers: embodied REERs (EREERs), i.e. REERs based on EULC and value-added weights; in all cases, overall weights with double export weights have been used in the computation of REERs.

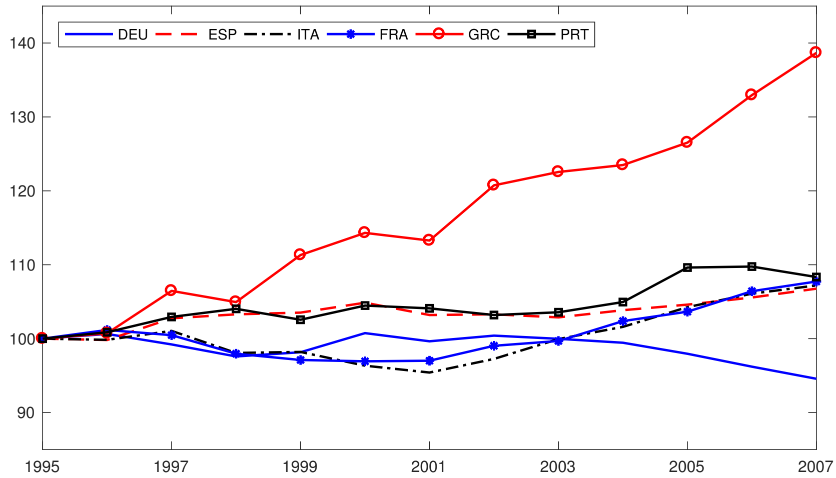
in the REER implies an increase in cost competitiveness. It is evident that REERs based on EULC point to a less pronounced increase in international cost competitiveness for German tradable manufacturing, and to a better competitiveness performance for German tradable services compared to REERs based on standard ULC. These results are in line with the development of EULC and standard ULC discussed above. Interestingly, using value-added instead of gross export weights for trading partner countries yields a picture of better competitiveness performance in all cases, i.e. for both tradable manufacturing and tradable services, and for both measures of REERs. Hence, the less precise gross exports weights that are used in most of the literature underestimate the increase in competitiveness in German tradable manufacturing and services.

Figure 5 compares the development of EREERs, i.e. REERs based on EULC, for Germany and the same euro area countries considered above using value-added weights for the trading partner countries. From 1995 to 2007, the EREER in German tradable manufacturing declined by slightly more than 5 percent, whereas EREERs for Italy and Spain increased by about 7 percent, for France and Portugal by about 8 percent and for Greece by even 39 percent. Hence, in 2007 the gap in cost competitiveness between German tradable manufacturing and other countries amounted to between 12 and 13 percentage points in the case of France, Italy, Portugal and Spain, and to about 44 percentage points in the case of Greece. The gain in competitiveness in German manufacturing occurred especially from 2003 onwards which coincides with the timing of the Hartz reforms. In Figure E.2, in the appendix REERs based on standard ULC (and again value-added weights) are depicted. For Greece, the standard REER increased only by about 24 percent, whereas it declined by 10 percent for Germany. As a result, Germany's increase in cost competitiveness in tradable manufacturing in comparison to Greece would be underestimated by 10 percentage points when using standard REERs instead of EREERs. In contrast, in the case of the other countries using standard REERs would overestimate the gain in German competitiveness. Standard REERs suggest that in 2007 the gap in competitiveness between Germany and other countries (difference between the REER change from 1995 and 2007 in Germany and the corresponding REER change in other countries) reaches 15-16 percentages points in the case of Portugal and Spain, about 18 percentage points in the case of France and about 21 percentage points in the case of Italy.

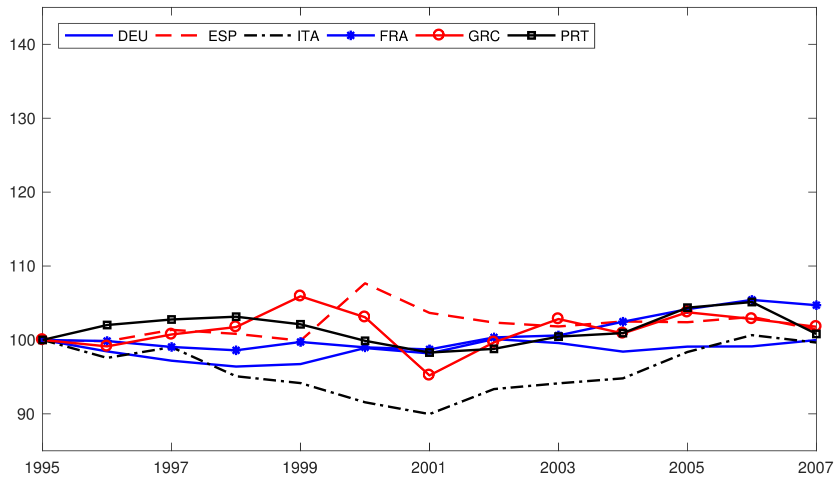
As regards tradable services, the development of EREERs is quite similar across countries. From 1995 to 2007, EREERs for tradable services remained roughly constant for Germany and Italy, increased by about 1 percent for Portugal and Spain, by 2 percent for Greece, and by about 5 percent for France. Interestingly, the ordering of countries would change if REERs based on standard ULC (again using value-added weights) are considered, as is evident from Figure E.2 in the appendix. In that case, with an increase of the REER of about 7 percent, Germany would show the worst performance together with France (8 percent), whereas Greece would show the best performance with a decline of the REER of nearly 5 percent.

4.2.2 Results for individual German sectors

In addition to the analysis from a more aggregated perspective, it may be informative to zoom in on the level of individual sectors, thereby exploiting the strength of our proposed concepts to the full extent. At the level of individual sectors results display a certain heterogeneity that is hidden when looking at the developments in sectoral aggregates.

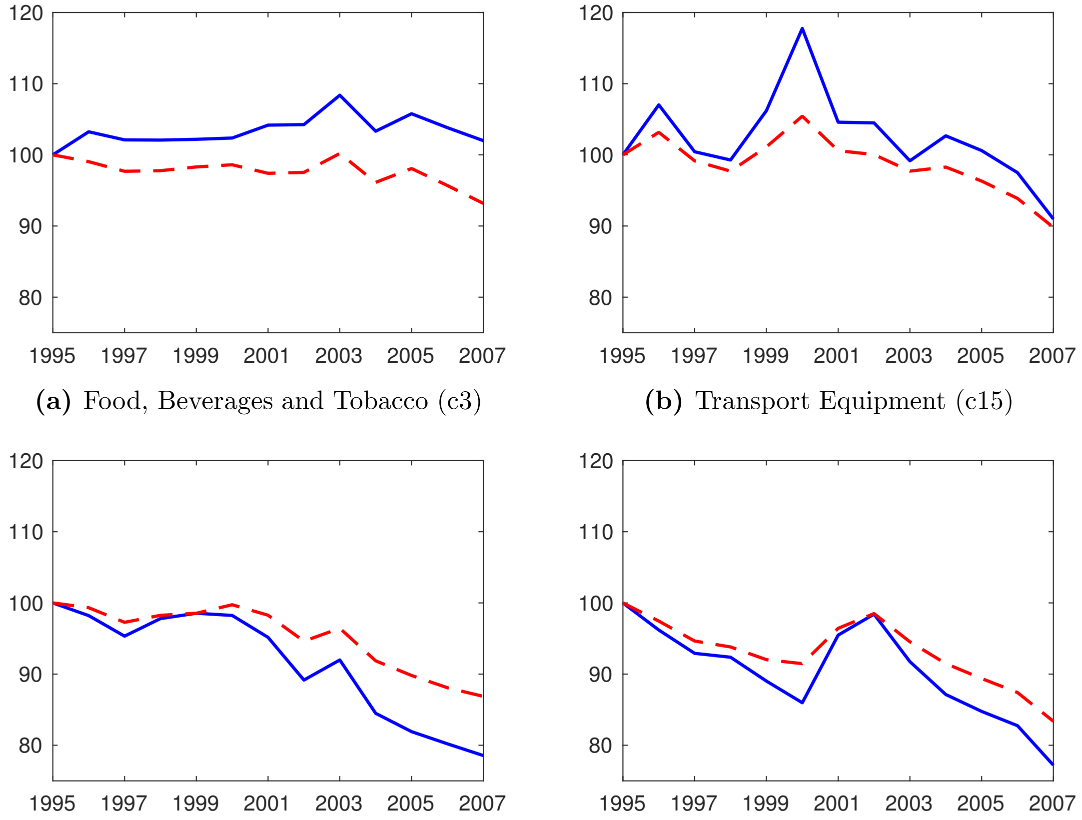


(a) Tradable manufacturing



(b) Tradable services

Figure 5: Embodied real effective exchange rates (EREERs) in two German sectoral aggregates in comparison with selected euro area countries; German classification of sectoral aggregates is applied to all countries. EREERs are based on embodied unit labor costs (EULC) and have been computed using overall value-added weights with double export weights.



(a) Food, Beverages and Tobacco (c3) **(b)** Transport Equipment (c15)

(c) Chemicals and Chemical Products (c9) **(d)** Electrical and Optical Equipment (c14)

Figure 6: Standard ULC and embodied ULC (EULC) in selected German sectors belonging to tradable manufacturing; blue solid line: standard ULC, red dashed line: EULC

For example, whereas EULC declined less than standard ULC for the whole tradable manufacturing, as has been shown in the previous subsection, this does not necessarily hold at the level of individual sectors. As an example, Figure 6 depicts standard ULC and EULC for four sectors belonging to tradable manufacturing in Germany. Sectors c3: "Food, Beverages and Tobacco" and c15: "Transport Equipment" exhibit a more favorable EULC development relatively to standard ULC, whereas the opposite is observed for sectors c9: "Chemicals and Chemical Products" and c14: "Electrical and Optical Equipment".

Figure E.3 in the appendix shows the REERs based on standard ULC (blue lines) and EULC (red lines) for all individual sectors belonging to tradable manufacturing or tradable services in Germany. For each individual sector, the weights for competitor sectors in trading partner countries have either been calculated based on gross exports weights (dashed lines) or value-added weights (solid lines), as has been explained in Section 4.1.3. Again, the results at the individual sector level are quite heterogenous. For some sectors the EREER always lies above the REER, for example for sector c12: "Basic Metals and Fabricated Metal", for others it is the opposite, such as for sector c15: "Transport Equipment". For some sectors the development of EREER relative to REER is even reversed at a particular time point. For example, in the case of sector c10: "Rubber and Plastics" the REER series based on standard ULC and EULC, respectively, intersect each other in 2002.

Regarding the weights for sectors in trading partner countries, huge differences can be sometimes observed depending on whether gross export weights or value-added weights are used, for example for sector c6: "Wood and Products of Wood and Cork" or sector c9: "Chemicals and Chemical Products". However, for some sectors, such as sector c3: "Food, Beverages and Tobacco" or sector c22: "Hotels and Restaurants", the use of different weights plays no important role.

The evidence presented above suggests that different ULC concepts and different types of weights have a quite heterogenous impact on the development of REERs at the sectoral level. It can therefore be expected that, for example, estimations of sectoral export equations using EREERs will lead to different results compared to the standard approach involving traditional REERs. However, a more profound empirical analysis of export equations or other empirical applications are beyond the scope of this paper and will be realized in a follow-up project.

5 Summary and conclusions

Based on the insight that a sector's own unit labor costs (ULC) constitute only a small share of its total cost, we propose embodied unit labor costs (EULC) as a more appropriate sectoral cost indicator because it takes account of other (domestic and foreign) sectors' ULC incorporated in their value-added contributions to final goods production of this sector. A theoretical underpinning for the EULC indicator is provided by analyzing a simple Leontief-type model. To compare domestic cost developments with those abroad we introduce the concept of domestic EULC that is based on domestic sector contributions only. A precise calculation of both cost indicators, EULC and domestic EULC, necessitates the use of international input-output tables since the value-added contribution of a sector to another one may be made via international supply chains. We also show how domestic EULC can be calculated for sectoral aggregates such as the tradable goods sector. In that case, the ULC weight of a single sector is determined by its value-added contribution to all sectors belonging to the sectoral aggregate relative to the value-added contributions of all domestic sectors to that aggregate.

To analyze the international cost competitiveness of industries we then develop a new real effective exchange rate (REER) indicator, called embodied real effective exchange rate (EREER). A sector's EREER is defined as this sector's domestic EULC relative to a weighted average of EULCs of the same sector in trading partner countries. The weights for a sector's foreign competitors is based on the domestic value-added embodied in this sector's bilateral gross exports to the respective country that is ultimately absorbed abroad. The weights are therefore based on the same backward-linkage principle that has already been used for the calculation of domestic EULC, i.e. the value-added contributions of all domestic sectors to gross exports of a specific domestic sector are taken into account when calculating the domestic value-added content of a sector's bilateral gross exports.

Using data from the World Input-Output Database we employ the proposed indicators to shed new light on changes in cost competitiveness at the sectoral level for Germany, and compare the German evidence for three sectoral aggregates—tradable manufacturing, tradable services and nontradable goods— with that in selected other euro area countries

(Spain, Italy, France, Greece and Portugal). For tradable manufacturing, EULC show a smaller decline than standard ULC. The reason is that ULC in tradable services or non-tradable sectors exhibit a less favorable ULC development than tradable manufacturing which is taken into account in the EULC measure for tradable manufacturing. Tradable services, however, profited from the stronger ULC decline in manufacturing and nontradable sectors, leading to a more favorable development of EULC relatively to standard ULC.

A similar picture emerges if EREERs are compared to standard REERs for tradable manufacturing and tradable services in Germany. Though the increase in international competitiveness for German tradable manufacturing is smaller when using EREERs, the EREER for this sectoral aggregate still declined by slightly more than 5 percent from 1995 to 2007, whereas it increased for the countries of the comparison group. The increase in competitiveness in German manufacturing occurred especially from 2003 onwards which coincides with the introduction of the Hartz reforms. Using the EREER measure, in 2007 the gap in cost competitiveness between German tradable manufacturing and tradable manufacturing in other countries amounted to between 12 and 13 percentage points in the case of France, Italy, Portugal and Spain, and to about 44 percentage points in the case of Greece. Interestingly, when using standard REER, the increase in German cost competitiveness relative to Greece is underestimated, whereas it is overestimated in the case of the other euro area countries.

Using value-added double weights instead of gross export double weights for the sectors in trading partner countries leads to more pronounced increases in international cost competitiveness for both tradable manufacturing and tradable services in Germany irrespectively of whether EREERs or standard REERs are considered. Hence, the less precise gross exports weights that are used in most of the literature may blur actual chances in cost competitiveness.

At the individual sector level, the comparison of different REER types yields more heterogenous results. This heterogeneity applies to the type of the cost indicator (ULC vs. EULC) and the type of weights (gross export weights vs. value-added weights). For some sectors it is not important whether gross export weights or valued-added weights are used, for others the development of the sectoral REERs crucially depends on which weight for competitor sectors in trading partner countries is used.

The presented methods and results provide substantial insights on the competitiveness of countries and industries which, for example, are relevant for the recent debates on global imbalances or international disputes about wage dumping. In light of the increasing fragmentation of production processes, it may be misleading to rely on standard ULC measures to assess international competitiveness or to derive policy recommendations. The concepts of EULC and EREER proposed in this paper are useful tools to obtain a more realistic description of sectoral cost developments and also allow to identify the sources of (cost) competitiveness. The relevance of these two aspects can, for example, be illustrated by means of the claim that Germany should enact a policy of rising wages in order to contribute to the reduction of global imbalances. This argument is most often brought up in relation to manufacturing since it comprises the most important exporting sectors. Our analysis shows that other domestic sectors, like nontradable sectors, also contribute with their wage developments to the competitiveness of manufacturing and thus should be taken into account in this debate and the recommended policy actions.

The concepts developed in this paper can also be applied and extended for other research questions, such as the impact of offshoring on production and employment. Moreover, the proposed measures have been formulated in a way that they are not only compatible to the World Input-Output Database used in this study, but can be calculated with all kinds of global inter-country input-output data.

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Appendix

A Biased domestic EULC measures based on national input-output tables

Calculating domestic EULC measures based on national input-output tables would lead to biased results. To show this mathematically, note that because of eq. (3) gross output for the H sectors of country i can be written as

$$\mathbf{q}_i = \sum_{j=1}^{G} (\mathbf{A}_{ij} \cdot \mathbf{q}_j) + \mathbf{F}_i \tag{A.1}$$

Denoting gross exports of both intermediate goods and final goods by $\mathbf{x}_i$, this equation can be rewritten as

$$\mathbf{q}_i = \mathbf{A}_{ii} \cdot \mathbf{q}_i + \mathbf{f}_{ii} + \mathbf{x}_i, \qquad \text{with} \quad \mathbf{x}_i = \sum_{\substack{j=1 \\ j \neq i}}^{G} (\mathbf{A}_{ij} \cdot \mathbf{q}_j) + \sum_{\substack{j=1 \\ j \neq i}}^{G} \mathbf{f}_{ij},$$

where the vector $\mathbf{f}_{ij}$ contains the goods produced by the H sectors of country i for final consumption in country j. $\mathbf{f}_{ij}$ corresponds to the j-th column of matrix $\mathbf{F}_i$ defined in eq. (3), i.e. $\mathbf{f}_{ij} = (f_{ij}^1, \ldots, f_{ij}^H)'$. Using only a national input-output table, $\mathbf{x}_i$ would be considered to be exogenously given, leading to the following solution for gross output:

$$\mathbf{q}_i = \mathbf{L}_{ii} \cdot (\mathbf{f}_{ii} + \mathbf{x}_i) \qquad \text{with} \qquad \mathbf{L}_{ii} = (\mathbf{I}_H - \mathbf{A}_{ii})^{-1}, \tag{A.2}$$

where $\mathbf{L}_{ii}$ is called the local Leontief inverse in line with Wang et al. (2013). To compare $\mathbf{L}_{ii}$ with $\mathbf{B}_{ii}$ defined in eq. (6), note that because of $\mathbf{B}$ being the inverse of $\mathbf{I}_{GH} - \mathbf{A}$ it holds that

$$\begin{pmatrix} \mathbf{B}_{11} & \mathbf{B}_{12} & \cdots & \mathbf{B}_{1G} \\ \mathbf{B}_{21} & \mathbf{B}_{22} & \cdots & \mathbf{B}_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{B}_{G1} & \mathbf{B}_{G2} & \cdots & \mathbf{B}_{GG} \end{pmatrix} \cdot \begin{pmatrix} \mathbf{I}_H - \mathbf{A}_{11} & -\mathbf{A}_{12} & \cdots & -\mathbf{A}_{1G} \\ -\mathbf{A}_{21} & \mathbf{I}_H - \mathbf{A}_{22} & \cdots & -\mathbf{A}_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ -\mathbf{A}_{G1} & -\mathbf{A}_{G2} & \cdots & \mathbf{I}_H - \mathbf{A}_{GG} \end{pmatrix}$$

$$= \begin{pmatrix} \mathbf{I}_H & \mathbf{0}_{H,H} & \cdots & \mathbf{0}_{H,H} \\ \mathbf{0}_{H,H} & \mathbf{I}_H & \cdots & \mathbf{0}_{H,H} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0}_{H,H} & \mathbf{0}_{H,H} & \cdots & \mathbf{I}_H \end{pmatrix}$$

$$= \begin{pmatrix} \mathbf{I}_H - \mathbf{A}_{11} & -\mathbf{A}_{12} & \cdots & -\mathbf{A}_{1G} \\ -\mathbf{A}_{21} & \mathbf{I}_H - \mathbf{A}_{22} & \cdots & -\mathbf{A}_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ -\mathbf{A}_{G1} & -\mathbf{A}_{G2} & \cdots & \mathbf{I}_H - \mathbf{A}_{GG} \end{pmatrix} \cdot \begin{pmatrix} \mathbf{B}_{11} & \mathbf{B}_{12} & \cdots & \mathbf{B}_{1G} \\ \mathbf{B}_{21} & \mathbf{B}_{22} & \cdots & \mathbf{B}_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{B}_{G1} & \mathbf{B}_{G2} & \cdots & \mathbf{B}_{GG} \end{pmatrix},$$

where $\mathbf{0}_{H,H}$ denotes a $(H \times H)$ zero matrix. It follows from that equation that

$$(\mathbf{I}_H - \mathbf{A}_{ii}) \cdot \mathbf{B}_{ii} - \mathbf{I}_H = \sum_{\substack{j=1 \\ j \neq i}}^{G} (\mathbf{A}_{ij} \cdot \mathbf{B}_{ji})$$

Multiplying this equation by $\mathbf{L}_{ii}$ leads to

$$\mathbf{B}_{ii} - \mathbf{L}_{ii} = \mathbf{L}_{ii} \cdot \sum_{\substack{j=1 \\ j \neq i}}^{G} (\mathbf{A}_{ij} \cdot \mathbf{B}_{ji}) \geq 0 \tag{A.3}$$

Based on national input-output tables the value-added contributions of all domestic sectors to production of each domestic sector would be calculated as $\mathbf{V}_i \cdot \mathbf{L}_{ii}$. In contrast, with multi-country input-output tables the value-added contributions of domestic sectors to each domestic sector are calculated as $\mathbf{V}_i \cdot \mathbf{B}_{ii}$. As is evident from eq (A.3), $\mathbf{V}_i\mathbf{B}_{ii} \geq \mathbf{V}_i\mathbf{L}_{ii}$. In this sense, the value-added contributions of domestic sectors are underestimated if national input-output tables are used. Intuitively, this is due to the fact that with national input-output tables it is not taken into account that imported intermediate inputs may also contain domestic value added via domestically produced intermediate inputs that had previously been exported.

B Calculations for the Leontief-type model

Gross output production for the two sectors in two countries is described by

$$
\begin{aligned}
q_1^1 &= \min\{\frac{1}{\nu_1^1}y_1^1, \frac{1}{a_{11}^{11}}z_{11}^{11}, \frac{1}{a_{11}^{21}}z_{11}^{21}, \frac{1}{a_{21}^{11}}z_{21}^{11}, \frac{1}{a_{21}^{21}}z_{21}^{21}\} \\
q_1^2 &= \min\{\frac{1}{\nu_1^2}y_1^2, \frac{1}{a_{11}^{12}}z_{11}^{12}, \frac{1}{a_{11}^{22}}z_{11}^{22}, \frac{1}{a_{21}^{12}}z_{21}^{12}, \frac{1}{a_{21}^{22}}z_{21}^{22}\} \\
q_2^1 &= \min\{\frac{1}{\nu_2^1}y_2^1, \frac{1}{a_{12}^{11}}z_{12}^{11}, \frac{1}{a_{12}^{21}}z_{12}^{21}, \frac{1}{a_{22}^{11}}z_{22}^{11}, \frac{1}{a_{22}^{21}}z_{22}^{21}\} \\
q_2^2 &= \min\{\frac{1}{\nu_2^2}y_2^2, \frac{1}{a_{12}^{12}}z_{12}^{12}, \frac{1}{a_{12}^{22}}z_{12}^{22}, \frac{1}{a_{22}^{12}}z_{22}^{12}, \frac{1}{a_{22}^{22}}z_{22}^{22}\}
\end{aligned}
$$

Efficient production requires

$$
\begin{aligned}
q_1^1 &= \frac{1}{\nu_1^1}y_1^1 = \frac{1}{a_{11}^{11}}z_{11}^{11} = \frac{1}{a_{11}^{21}}z_{11}^{21} = \frac{1}{a_{21}^{11}}z_{21}^{11} = \frac{1}{a_{21}^{21}}z_{21}^{21} \\
q_1^2 &= \frac{1}{\nu_1^2}y_1^2 = \frac{1}{a_{11}^{12}}z_{11}^{12} = \frac{1}{a_{11}^{22}}z_{11}^{22} = \frac{1}{a_{21}^{12}}z_{21}^{12} = \frac{1}{a_{21}^{22}}z_{21}^{22} \\
q_2^1 &= \frac{1}{\nu_2^1}y_2^1 = \frac{1}{a_{12}^{11}}z_{12}^{11} = \frac{1}{a_{12}^{21}}z_{12}^{21} = \frac{1}{a_{22}^{11}}z_{22}^{11} = \frac{1}{a_{22}^{21}}z_{22}^{21} \\
q_2^2 &= \frac{1}{\nu_2^2}y_2^2 = \frac{1}{a_{12}^{12}}z_{12}^{12} = \frac{1}{a_{12}^{22}}z_{12}^{22} = \frac{1}{a_{22}^{12}}z_{22}^{12} = \frac{1}{a_{22}^{22}}z_{22}^{22}
\end{aligned}
\tag{B.4}
$$

The zero profit conditions are

$$
\begin{aligned}
p_1^1q_1^1 - w_1^1L_1^1 - p_1^1z_{11}^{11} - p_1^2z_{11}^{21} - p_2^1z_{21}^{11} - p_2^2z_{21}^{21} &= 0 \\
p_1^2q_1^2 - w_1^2L_1^2 - p_1^1z_{11}^{12} - p_1^2z_{11}^{22} - p_2^1z_{21}^{12} - p_2^2z_{21}^{22} &= 0 \\
p_2^1q_2^1 - w_2^1L_2^1 - p_1^1z_{12}^{11} - p_1^2z_{12}^{21} - p_2^1z_{22}^{11} - p_2^2z_{22}^{21} &= 0 \\
p_2^2q_2^2 - w_2^2L_2^2 - p_1^1z_{12}^{12} - p_1^2z_{12}^{22} - p_2^1z_{22}^{12} - p_2^2z_{22}^{22} &= 0
\end{aligned}
\tag{B.5}
$$

Because of eqs. (B.4) and (17), it holds that

$$
z_{ij}^{mn} = a_{ij}^{mn}q_j^n \quad \text{and} \quad q_j^n = \frac{1}{v_j^n}y_j^n = \frac{1}{v_j^n}\lambda_j^n L_j^n \tag{B.6}
$$

Taking account of eq. (B.6) in eqs. (B.5) leads to

$$
\begin{aligned}
p_1^1 &= \nu_1^1\,\frac{w_1^1}{\lambda_1^1} + a_{11}^{11}p_1^1 + a_{11}^{21}p_1^2 + a_{21}^{11}p_2^1 + a_{21}^{21}p_2^2 \\
p_1^2 &= \nu_1^2\,\frac{w_1^2}{\lambda_1^2} + a_{11}^{12}p_1^1 + a_{11}^{22}p_1^2 + a_{21}^{12}p_2^1 + a_{21}^{22}p_2^2 \\
p_2^1 &= \nu_2^1\,\frac{w_2^1}{\lambda_2^1} + a_{12}^{11}p_1^1 + a_{12}^{21}p_1^2 + a_{22}^{11}p_2^1 + a_{22}^{21}p_2^2 \\
p_2^2 &= \nu_2^2\,\frac{w_2^2}{\lambda_2^2} + a_{12}^{12}p_1^1 + a_{12}^{22}p_1^2 + a_{22}^{12}p_2^1 + a_{22}^{22}p_2^2
\end{aligned}
$$

In matrix notation

$$\begin{pmatrix} p_1^1 \\ p_1^2 \\ p_2^1 \\ p_2^2 \end{pmatrix} = \begin{pmatrix} a_{11}^{11} & a_{11}^{21} & a_{21}^{11} & a_{21}^{21} \\ a_{11}^{12} & a_{11}^{22} & a_{21}^{12} & a_{21}^{22} \\ a_{12}^{11} & a_{12}^{21} & a_{22}^{11} & a_{22}^{21} \\ a_{12}^{12} & a_{12}^{22} & a_{22}^{12} & a_{22}^{22} \end{pmatrix} \cdot \begin{pmatrix} p_1^1 \\ p_1^2 \\ p_2^1 \\ p_2^2 \end{pmatrix} + \begin{pmatrix} v_1^1 & 0 & 0 & 0 \\ 0 & v_1^2 & 0 & 0 \\ 0 & 0 & v_2^1 & 0 \\ 0 & 0 & 0 & v_2^2 \end{pmatrix} \cdot \begin{pmatrix} w_1^1/\lambda_1^1 \\ w_1^2/\lambda_1^2 \\ w_2^1/\lambda_2^1 \\ w_2^2/\lambda_2^2 \end{pmatrix}$$

More compactly,

$$\mathbf{p} = \mathbf{A}' \cdot \mathbf{p} + \mathbf{V} \cdot \mathbf{u}$$

The solution for sectoral price levels therefore is

$$\mathbf{p} = [(\mathbf{I}_4 - \mathbf{A})']^{-1} \cdot \mathbf{V} \cdot \mathbf{u} = [(\mathbf{I}_4 - \mathbf{A})^{-1}]' \cdot \mathbf{V} \cdot \mathbf{u} = (\mathbf{V} \cdot \mathbf{B})' \cdot \mathbf{u} \tag{B.7}$$

C Aggregation of sectors and countries in global ICIO tables

It is assumed that the global ICIO table initially comprises $\bar{G}$ countries and $\bar{H}$ sectors. The table consists of four parts: (i) The $(\bar{G}\bar{H} \times \bar{G}\bar{H})$ matrix $\bar{\mathbf{Z}}$ reflects the intermediate goods linkages between all sectors of all countries, (ii) the $(\bar{G}\bar{H} \times \bar{G})$ matrix $\bar{\mathbf{F}}$ contains the production of all $\bar{G}\bar{H}$ sectors for final demand (all final demand components taken together) of all $\bar{G}$ countries, (iii) $\bar{\mathbf{q}}$ denotes the $(\bar{G}\bar{H} \times 1)$ vector of gross output, (iv) $\bar{\mathbf{y}}$ is the $(\bar{G}\bar{H} \times 1)$ vector of value added.

In the following, different aggregation schemes for these parts are presented: separate aggregation of sectors and countries (Appendices C.1 and C.2, respectively) and simultaneous aggregation of sectors and countries (Appendix C.3). In Appendix C.4, we briefly describe the World Input-Output Tables (WIOTs)—the global ICIO tables used in this paper—and explain the country and sector aggregation chosen in this paper.

C.1 Aggregation of sectors

Assume that some of the $\bar{H}$ sectors are aggregated, reducing the total number of sectors to $H < \bar{H}$. Let $I_{\bar{H}}$ be the set containing the indices of all individual sectors $\bar{n} = 1, \ldots, \bar{H}$, and let I_m denote the set containing the indices of all sectors belonging to the aggregate sector $m = 1, \ldots, H$, i.e. $I_m \subset I_{\bar{H}}$. For any two aggregated sectors m and $n \neq m$ it holds that $I_m \cap I_n = \varnothing$. The $(H \times \bar{H})$ aggregation matrix $\mathbf{S}$ for a single country consists of the elements

$$s^{m\bar{n}} = \begin{cases} 1 & \text{if} \quad \bar{n} \in I_m \\ 0 & \text{else,} \end{cases}$$

with m and $\bar{n}$ denoting the row and column dimension, respectively. Based on this equation, the elimination of a sector $\bar{n}$ is also possible. In this case, the sector $\bar{n}$ does not belong to any index set I_m, implying that the $\bar{n}$-th column in the matrix $\mathbf{S}$ is a $(H \times 1)$ vector of zeros.

If $\mathbf{I}_{\bar{G}}$ denotes a $(\bar{G} \times \bar{G})$ identity matrix, the aggregation matrix $\mathbf{S}^*$ performing the sectoral aggregation for all $\bar{G}$ countries is defined as

$$\mathbf{S}^* = \mathbf{I}_{\bar{G}} \otimes \mathbf{S},$$

where $\otimes$ denotes the Kronecker product. $\mathbf{S}^*$ is a $(\bar{G}H \times \bar{G}\bar{H})$ matrix. The new $(\bar{G}H \times \bar{G}H)$ matrix $\mathbf{Z}$ for the aggregated sectors is then obtained as

$$\mathbf{Z} = \mathbf{S}^* \cdot \bar{\mathbf{Z}} \cdot (\mathbf{S}^*)'$$

The aggregate final demand matrix is obtained by computing

$$\mathbf{F} = \mathbf{S}^* \cdot \bar{\mathbf{F}},$$

where $\mathbf{F}$ is a $(\bar{G}H \times \bar{G})$ matrix. The aggregate gross output and value added are, respectively, computed as:

$$\mathbf{q} = \mathbf{S}^* \cdot \bar{\mathbf{q}}, \qquad \mathbf{y} = \mathbf{S}^* \cdot \bar{\mathbf{y}},$$

where $\mathbf{q}$ and $\mathbf{y}$ are $(\bar{G}H \times 1)$ vectors.

C.2 Aggregation of countries

Assume that some of the $\bar{G}$ countries are put together to an "aggregate country" (i.e. "country group"), reducing the total number of countries to $G < \bar{G}$. Let $I_{\bar{G}}$ be the set containing indices of all individual countries $\bar{j} = 1, \ldots, \bar{G}$, and let I_i denote the index set containing the indices of all countries belonging to the aggregate country i, with $i = 1, \ldots, G$, i.e. $I_i \subset I_{\bar{G}}$. Moreover, for any two aggregated countries i and $j \neq i$ it holds that $I_i \cap I_j = \varnothing$. The $(G \times \bar{G})$ aggregation matrix $\mathbf{C}$ consists of the elements

$$c_{i\,\bar{j}} = \begin{cases} 1 & \text{if} \quad \bar{j} \in I_i \\ 0 & \text{else,} \end{cases}$$

with i and $\bar{j}$ denoting the row and the column dimension, respectively. Based on this equation, the elimination of a country $\bar{j}$ is also possible. In this case, the country $\bar{j}$ does not belong to any index set I_i, implying that the $\bar{j}$-th column in the matrix $\mathbf{C}$ is a $(G \times 1)$ vector of zeros.

If $\mathbf{I}_{\bar{H}}$ denotes an $(\bar{H} \times \bar{H})$ identity matrix, where $\bar{H}$ denotes the number of sectors for each country, the aggregation matrix $\mathbf{C}^*$ performing the country aggregation is defined as

$$\mathbf{C}^* = \mathbf{C} \otimes \mathbf{I}_{\bar{H}}$$

$\mathbf{C}^*$ is a $(G\bar{H} \times \bar{G}\bar{H})$ matrix. The new $(G\bar{H} \times G\bar{H})$ matrix $\mathbf{Z}$ is then obtained as

$$\mathbf{Z} = \mathbf{C}^* \cdot \bar{\mathbf{Z}} \cdot (\mathbf{C}^*)'$$

The aggregated final demand matrix is obtained by computing

$$\mathbf{F} = \mathbf{C}^* \cdot \bar{\mathbf{F}} \cdot \mathbf{C}',$$

where $\mathbf{F}$ is a $(G\bar{H} \times G)$ matrix. The aggregate gross output and value added are, respectively, computed as:

$$\mathbf{q} = \mathbf{C}^* \cdot \bar{\mathbf{q}}, \qquad \mathbf{y} = \mathbf{C}^* \cdot \bar{\mathbf{y}},$$

where $\mathbf{q}$ and $\mathbf{y}$ are $(G\bar{H} \times 1)$ vectors.

C.3 Aggregation of sectors and countries

The aggregation of sectors and countries can also be done simultaneously. If $\bar{G}$ countries are aggregated to G countries, and $\bar{H}$ sectors to H sectors, the matrix for aggregation along the country-sector dimension becomes

$$\mathbf{D}^* = \mathbf{C} \otimes \mathbf{S},$$

where $\mathbf{S}$ and $\mathbf{C}$ have been defined in Appendices C.1 and C.2, respectively. The matrix $\mathbf{D}^*$ is a $(GH \times \bar{G}\bar{H})$ matrix. The new $(GH \times GH)$ matrix $\mathbf{Z}$ is then obtained as

$$\mathbf{Z} = \mathbf{D}^* \cdot \bar{\mathbf{Z}} \cdot (\mathbf{D}^*)'$$

The aggregated $(GH \times G)$ final demand matrix is obtained by computing

$$\mathbf{F} = \mathbf{D}^* \cdot \bar{\mathbf{F}} \cdot \mathbf{C}'$$

The aggregate gross output and value added are, respectively, computed as:

$$\mathbf{q} = \mathbf{D}^* \cdot \bar{\mathbf{q}}, \qquad \mathbf{y} = \mathbf{D}^* \cdot \bar{\mathbf{y}},$$

where $\mathbf{q}$ and $\mathbf{y}$ are $(GH \times 1)$ vectors.

C.4 Sectors and countries in the World Input-Output Database

The World Input-Output Tables (WIOT) Release 2013 are available for each year from 1995 to 2011. They cover 40 countries plus the so-called "rest of the world" (RoW). For each country, data for 35 sectors (according to ISIC Rev. 3 classification) is provided.

Before the data can be used for the analysis, some transformation of sectors/countries is required. One of the reasons for such a transformation is that for some sectors in some or all countries gross output shows zero values for some or all years. Since the input-output matrix $\mathbf{A}$ is obtained by dividing columns of the intermediate sales matrix $\mathbf{Z}$ by sectoral gross output, zero values for gross output would lead to missing values in columns of $\mathbf{A}$. This would induce problems with the computation of the Leontief inverse $\mathbf{B} = (\mathbf{I} - \mathbf{A})^{-1}$ that is necessary to construct embodied unit labor costs (EULC) (see Section 2.1) as well as value-added contributions in gross exports (see Section 3.2). Another reason for a sector/country transformation is the presence of zero value added which would cause unit labor costs (ULC), computed as the ratio of labor costs and value added, in the affected sector to be undefined. In most cases, zero value added occurs simultaneously with zero gross output, one exception being the sector "Coke, Refined Petroleum and Nuclear Fuel" (code 24/index no. 8) in Latvia for which gross output is positive whereas value added is equal to zero in 2001 and 2008.

In order to overcome the problem with zero gross output and value added, we have decided to transform sectors as follows:

1. Sector "Textiles and Textile Products" (ISIC code: 17t18/WIOT code: c4) is combined with "Leather, Leather and Footwear" (ISIC code: 19/WIOT code: c5).

2. Sector "Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel" (ISIC code: 50/WIOT code: c19) is combined with "Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods" (ISIC code: 52/WIOT code: c20).

3. Sector "Public Admin and Defence; Compulsory Social Security" (ISIC code: L/WIOT code: c31) is combined with "Education" (ISIC code: M/WIOT code: c32) and "Health and Social Work" (ISIC code: N/WIOT code: c33).

4. Sector “Coke, Refined Petroleum and Nuclear Fuel” (ISIC code: 24/WIOT code: c8) is eliminated.

5. Sector “Private Households with Employed Persons” (ISIC code: P/WIOT code: c35) is eliminated.

An overview of sectors of the WIOTs Release 2013 that have been considered in our analysis as well as the chosen aggregation is provided in Table C.1.

The suggested sector transformation is sufficient to remedy the problem with zero gross output and value added so that an aggregation of countries does not seem necessary. However, for small countries values in individual table cells are sometimes very small which could make computation of particular quantities, like the Leontief inverse, unstable. Taking this aspect into account, we have chosen the following aggregation of countries:

1. Belgium and Luxembourg

2. Lithuania, Latvia and Estonia (as a group of Baltic countries)

3. Cyprus and Malta

The next issue that we take into account is that whereas RoW is covered in WIOTs it is not present in the Socio-Economic Accounts (SEA) which is the supplementary data used in our analysis mainly as a source of labor costs needed to compute ULC. We want to make sure that all quantities needed for the calculation of our proposed concepts are based on fully compatible datasets containing the same countries. Therefore, we exclude RoW from WIOTs so that the number of countries in the analysis is 36. Table C.2 lists the countries of WIOT Release 2013 that are used in our empirical analysis.

Table C.1: Sectors of World Input-Output Tables Release 2013 used in the analysis*

	No.	WIOT code	ISIC code	Industry desciption
	1	c1	AtB	Agriculture, Hunting, Forestry and Fishing
	2	c2	C	Mining and Quarrying
Manufacturing	3	c3	15t16	Food, Beverages and Tobacco
Manufacturing	4	c4 + c5	17t18 + 19	Textiles and Textile Products + Leather, Leather and Footwear
Manufacturing	5	c6	20	Wood and Products of Wood and Cork
Manufacturing	6	c7	21t22	Pulp, Paper, Paper, Printing and Publishing
Manufacturing	7	c9	24	Chemicals and Chemical Products
Manufacturing	8	c10	25	Rubber and Plastics
Manufacturing	9	c11	26	Other Non-Metallic Mineral
Manufacturing	10	c12	27t28	Basic Metals and Fabricated Metal
Manufacturing	11	c13	29	Machinery, Nec
Manufacturing	12	c14	30t33	Electrical and Optical Equipment
Manufacturing	13	c15	34t35	Transport Equipment
Manufacturing	14	c16	36t37	Manufacturing, Nec; Recycling
	15	c17	E	Electricity, Gas and Water Supply
	16	c18	F	Construction
Services	17	c19 + c21	50 + 52	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel + Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
Services	18	c20	51	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
Services	19	c22	H	Hotels and Restaurants
Services	20	c23	60	Inland Transport
Services	21	c24	61	Water Transport
Services	22	c25	62	Air Transport
Services	23	c26	63	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
Services	24	c27	64	Post and Telecommunications
Services	25	c28	J	Financial Intermediation
Services	26	c29	70	Real Estate Activities
Services	27	c30	71t74	Renting of M&Eq and Other Business Activities
Services	28	c31 + c32 + c33	L + M + N	Public Admin and Defence; Compulsory Social Security + Education + Health and Social Work
Services	29	c34	0	Other Community, Social and Personal Services

* The following sectors of the original WIOT Release 2013 have been eliminated: 1) ISIC code: 24/WIOT code: c8 (Coke, Refined Petroleum and Nuclear Fuel); 2) ISIC code: P/WIOT code: c35 (Private Households with Employed Persons) .

Table C.2: Countries of World Input-Output Tables Release 2013 used in the analysis

No.	Index in WIOT	Code	Name
1	1	AUS	Australia
2	2	AUT	Austria
3	3	BEL	Belgium
	+ 26	+ LUX	+ Luxembourg
4	4	BGR	Bulgaria
5	5	BRA	Brazil
6	6	CAN	Canada
7	7	CHN	China
8	8	CYP	Cyprus
	+ 29	+ MLT	+ Malta
9	9	CZE	Czech Republic
10	10	DEU	Germany
11	11	DNK	Denmark
12	12	ESP	Spain
13	13	EST	Estonia
	+ 25	+ LTU	+ Lithuania
	+ 27	+ LVA	+ Latvia
14	14	FIN	Finland
15	15	FRA	France
16	16	GBR	Great Britain
17	17	GRC	Greece
18	18	HUN	Hungary
19	19	IDN	Indonesia
20	20	IND	India
21	21	IRL	Irland
22	22	ITA	Italy
23	23	JPN	Japan
24	24	KOR	South Korea
25	28	MEX	Mexico
26	30	NLD	Netherlands
27	31	POL	Poland
28	32	PRT	Portugal
29	33	ROU	Romania
30	34	RUS	Russia
31	35	SVK	Slovakia
32	36	SVN	Slovenia
33	37	SWE	Sweden
34	38	TUR	Turkey
35	39	TWN	Taiwan
36	40	USA	USA

D EULC in sectoral aggregates: further issues

D.1 Drawbacks of an alternative approach

For the calculation of EULC for sectoral aggregates it is important that the weight applied to the ULC of an individual sector correctly reflects the value-added contribution of this sector to final goods production of all sectors belonging to the sectoral aggregate. As is shown in this appendix it would not be correct to first compute the ULC for sectoral aggregates and then construct weights for these aggregated ULC based on the value-added contributions of individual sectors, where these contributions are derived, similarly to (21), from the matrix $\mathbf{V} \cdot \widetilde{\mathbf{B}}$ computed with the disaggregated data. For example, let's assume that three aggregated sectors—agriculture, manufacturing and services—are considered and that the aim is to calculate EULC in manufacturing according to the following formula:

$$\tilde{u}_i^{man} = \widetilde{\omega}_{ii}^{agr,man} u_i^{agr} + \widetilde{\omega}_{ii}^{man,man} u_i^{man} + \widetilde{\omega}_{ii}^{serv,man} u_i^{serv} \tag{D.8}$$

where agr, man and $serv$ in the superscripts denote agriculture, manufacturing and services, respectively. ULC in the aggregated sectors are:

$$\begin{aligned} u_i^{agr} &= \sum_{m \in I_{agr}} \frac{y_i^m}{y_i^{agr}} u_i^m, & y_i^{agr} &= \sum_{m \in I_{agr}} y_i^m \\ u_i^{man} &= \sum_{m \in I_{man}} \frac{y_i^m}{y_i^{man}} u_i^m, & y_i^{man} &= \sum_{m \in I_{man}} y_i^m \\ u_i^{serv} &= \sum_{m \in I_{serv}} \frac{y_i^m}{y_i^{serv}} u_i^m, & y_i^{serv} &= \sum_{m \in I_{serv}} y_i^m \end{aligned}$$

The weights for ULC of the respective aggregated sectors in the EULC in manufacturing are based on the value-added contributions of individual sectors and calculated as

$$\begin{aligned} \widetilde{\omega}_{ii}^{agr,man} &= \frac{\sum_{m \in I_{agr}} \sum_{n \in I_{man}} v_i^m b_{ii}^{mn} f_i^n}{\sum_{m=1}^{H} \sum_{n \in I_{man}} v_i^m b_{ii}^{mn} f_i^n} = \sum_{m \in I_{agr}} \widetilde{\omega}_{ii}^{m,man} \\ \widetilde{\omega}_{ii}^{man,man} &= \frac{\sum_{m \in I_{man}} \sum_{n \in I_{man}} v_i^m b_{ii}^{mn} f_i^n}{\sum_{m=1}^{H} \sum_{n \in I_{man}} v_i^m b_{ii}^{mn} f_i^n} = \sum_{m \in I_{man}} \widetilde{\omega}_{ii}^{m,man} \\ \widetilde{\omega}_{ii}^{serv,man} &= \frac{\sum_{m \in I_{serv}} \sum_{n \in I_{man}} v_i^m b_{ii}^{mn} f_i^n}{\sum_{m=1}^{H} \sum_{n \in I_{man}} v_i^m b_{ii}^{mn} f_i^n} = \sum_{m \in I_{serv}} \widetilde{\omega}_{ii}^{m,man}, \end{aligned}$$

where I_{agr}, I_{man} and I_{serv} denote the sets of individual sector indices belonging to agriculture, manufacturing and services, respectively. Therefore, eq. (D.8) can be written as follows:

$$\tilde{u}_i^{man} = \left(\sum_{m\in I_{agr}} \widetilde{\omega}_{ii}^{m,man}\right)\left(\sum_{m\in I_{agr}} \frac{y_i^m}{y_i^{agr}} u_i^m\right) + \left(\sum_{m\in I_{man}} \widetilde{\omega}_{ii}^{m,man}\right)\left(\sum_{m\in I_{man}} \frac{y_i^m}{y_i^{man}} u_i^m\right) + \left(\sum_{m\in I_{serv}} \widetilde{\omega}_{ii}^{m,man}\right)\left(\sum_{m\in I_{serv}} \frac{y_i^m}{y_i^{serv}} u_i^m\right)$$

The previous equation can be also written in terms of ULC in individual sectors:

$$\tilde{u}_i^{man} = \sum_{m\in I_{agr}} \left(\sum_{n\in I_{agr}} \widetilde{\omega}_{ii}^{n,man}\right) \frac{y_i^m}{y_i^{agr}} u_i^m + \sum_{m\in I_{man}} \left(\sum_{n\in I_{man}} \widetilde{\omega}_{ii}^{n,man}\right) \frac{y_i^m}{y_i^{man}} u_i^m + \sum_{m\in I_{serv}} \left(\sum_{n\in I_{serv}} \widetilde{\omega}_{ii}^{n,man}\right) \frac{y_i^m}{y_i^{serv}} u_i^m$$

This representation makes clear that ULC of, e.g. , an individual service sector is weighted not only with its own contribution to manufacturing but also with the contribution of other sectors belonging to the whole service sector. Independently of whether a particular service sector does not contribute much or is a major supplier to manufacturing, its ULC would alway obtain the same weight. Hence, as plausible as this approach may seem at first glance, in contrast to our proposed approach it does not provide correct values for the aggregate EULC. Moreover, another drawback of this concept is that different aggregation schemes (e.g. , one could consider manufacturing and nonmanufacturing in eq. (D.8)) lead to different results which makes the choice of this alternative approach hard to justify.

D.2 EULC for country-specific sectoral aggregates

Suppose that groups of sectors have different size in different countries and/or they differ in the composition across countries. This can happen if the assignment to a chosen sectoral aggregate follows a specific rule. For example, a rule could specify that all sectors whose export volume is below a certain threshold are considered to belong to the sectoral aggregate “nontradable sectors”. Based on such a rule the sectoral aggregate “nontradable sectors” can contain different sectors and/or different number of sectors across countries.

Let I_H be the set containing the indices of all individual sectors $m = 1, \dots, H$ which is the same for all countries $i = 1, \dots, G$. Then, let $I_{i,\widehat{n}} \subset I_H$ denote the index set that contains indices of sectors that build an aggregated sector $\widehat{n} = 1, \dots, \widehat{H}$ in country i. Note that this allows for a country-specific assignment of sectors to sectoral aggregates, even though the number of sectoral aggregates is the same across countries. The $(H \times \widehat{H})$ aggregation matrix $\mathbf{R}_i$ for a single country is defined as follows:

$$r_i^{m\widehat{n}} = \begin{cases} 1 & \text{if} \quad m \in I_{i,\widehat{n}} \\ 0 & \text{else,} \end{cases}$$

where $r_i^{m\widehat{n}}$ denotes the $(m, \widehat{n})$-th element of $\mathbf{R}_i$. To perform joint selection of sectors for all countries, the aggregation matrices $\mathbf{R}_i$ corresponding to each country are combined to one matrix:

$$\mathbf{R}^* = \mathbf{R}_1 \oplus \dots \oplus \mathbf{R}_G,$$

where the symbol $\oplus$ denotes the direct sum of matrices. Further steps to compute EULC in sectoral aggregates are as explained in eqs. (23)–(24) in Section 2.3.

D.3 "Unit labor costs: end products" in Dustmann et al. (2014)

In order to get a more accurate information on German competitiveness than that delivered by standard ULC, Dustmann et al. (2014) analyze the ULC measure "unit labor costs: end products" which should take into account that sectors draw on inputs from other domestic sectors. Thus, this measure should summarize all information on inter-sectoral linkages on the one hand, on the other hand it should be free of foreign impacts. The data used by the authors for deriving the inter-sectoral linkages are national input-output tables for Germany provided by the German Federal Statistical Offices (Fachserie 18, Reihe 2, Years: 1995-2007).

Considering the information in the main text of Dustmann et al. (2014), one could think that the measure "unit labor costs: end products" is calculated analogously to the standard ULC measure where value added is replaced by gross output ("end products"). However, according to Table A.2 in their online appendix available at `https://www.aeaweb.org/articles?id=10.1257/jep.28.1.167`, "unit labor costs: end products" in tradable manufacturing and tradable services are calculated in a different way than suggested by the main text. Resorting partly to the nomenclature chosen in our paper, "unit labor costs: end products" in a sector aggregate $\widehat{n}$, where $\widehat{n}$ refers to tradable manufacturing or tradable services, are defined as:

$$\begin{aligned} \mathrm{tulc}_i^{\widehat{n}} &= \sum_{n \in I_{\widehat{n}}} \frac{x_i^n}{x_i^{\widehat{n}}} \, \mathrm{tulc}_i^n \qquad \text{with} \\ \mathrm{tulc}_i^n &= \sum_{m=1}^{H} l_{ii}^{mn} \, \mathrm{pulc}_i^m \end{aligned} \tag{D.9}$$

In eq. (D.9), $I_{\widehat{n}}$ describes the set with indices of those sectors belonging to the aggregate $\widehat{n}$. Dustmann et al. (2014) focus on Germany, hence the country index i refers to Germany. For that country, x_i^n and $x_i^{\widehat{n}}$ denote gross exports of sector n and sectoral aggregate $\widehat{n}$, respectively. Lastly, l_{ii}^{mn} is the (m, n)-th element of the block matrix $\mathbf{L}_{ii}$ being a submatrix of the local Leontief inverse $\mathbf{L}$, see Appendix A for more information on the local Leontief inverse. The fact that tulc_i^n involves elements from the local Leontief inverse $\mathbf{L}$ and not elements from the Leontief inverse $\mathbf{B}$ follows from the use of national input-output tables where international input linkages are missing.

The variable pulc_i^m denotes the total direct labor costs in sector m per unit of gross output in that sector. As is evident from eq. (D.9), $\mathrm{tulc}_i^{\widehat{n}}$ is the export-weighted mean of tulc_i^n over the sectors n belonging to the sectoral aggregate $\widehat{n}$. The role of tulc_i^n is to take account of the inter-sectoral linkages for the domestic economy.

Eq. (D.9) can be written as:

$$\mathrm{tulc}_i^{\widehat{n}} = \sum_{n \in I_{\widehat{n}}} \frac{x_i^n}{x_i^{\widehat{n}}} \left(\sum_{m=1}^{H} l_{ii}^{mn} \, \mathrm{pulc}_i^m \right) \tag{D.10}$$

Alternatively, this equation can be rewritten in terms of pulc of all individual sectors:

$$\mathrm{tulc}_i^{\widehat{n}} = \sum_{m=1}^{H} \omega_i^{\dagger\, m\widehat{n}} \mathrm{pulc}_i^m, \qquad \text{with} \tag{D.11}$$

$$\omega_i^{\dagger\, m\widehat{n}} = \sum_{n \in I_{\widehat{n}}} \frac{x_i^n}{x_i^{\widehat{n}}} \, l_{ii}^{mn} = \frac{1}{x_i^{\widehat{n}}} \sum_{n \in I_{\widehat{n}}} l_{ii}^{mn} \, x_i^n \tag{D.12}$$

Eq. (D.11) for $\mathrm{tulc}_i^{\widehat{n}}$ exhibits some similarity with our domestic EULC measure for a sectoral aggregate $\widehat{n}$ (see eq. (21) as an illustration for $\widehat{n} = man$) in that it includes ULC (in this case represented by pulc) of all domestic sectors ($m = 1, \ldots, H$) weighted by their respective contributions to the sectoral aggregate. However, the weights as well as the ULC measure of individual sectors differ from those employed in our EULC concept. In the following, we explain why in the case of $\text{tulc}_i^{\widehat{n}}$ both the weights and the chosen measure for ULC of individual sectors do not lead to a ULC measure for the sectoral aggregate that properly takes the domestic input-output linkages into account.[18]

Most importantly, pulc for individual sectors are computed as the ratio of sectoral labor costs (given by the wage bill in Dustmann et al., 2014) and sectoral gross output. The fact that gross output is used instead of value added gives the name "unit labor costs: end products" for the aggregate ULC measure. One problem with ULC based on gross output is that they do not capture the actual productivity of a sector since gross output also contains value added embodied in intermediates from other domestic sectors as well as from foreign sectors. Dustmann et al. (2014) show that the share of inputs in total output increased over time in tradable manufacturing (and also in tradable services) in Germany which can be traced back to the increased use of foreign inputs. As a result of the increasing inputs share in gross output, gross output increased more strongly than value added in German tradable manufacturing. We would like to add that intermediates produced in a sector are often sent to another (domestic or foreign) sector and then, after some processing, return to be used for further production. This means that the same value added (of the considered sector and, possibly, of other sectors) is counted multiple times and, thus, artificially blows up gross output. If, due to increasing specialization, the so-called pure double counting increased over time, this may have additionally increased gross output relative to value added over time.

Since gross output increased more strongly than value added, it comes as no surprise that ULC based on gross output in individual sectors from tradable manufacturing and tradable services exhibits a stronger decline than the corresponding sectoral standard ULC based on value added, as is evident from Figure 4 of Dustmann et al. (2014). Even though the authors' intention was to design a competitiveness indicator that filters out

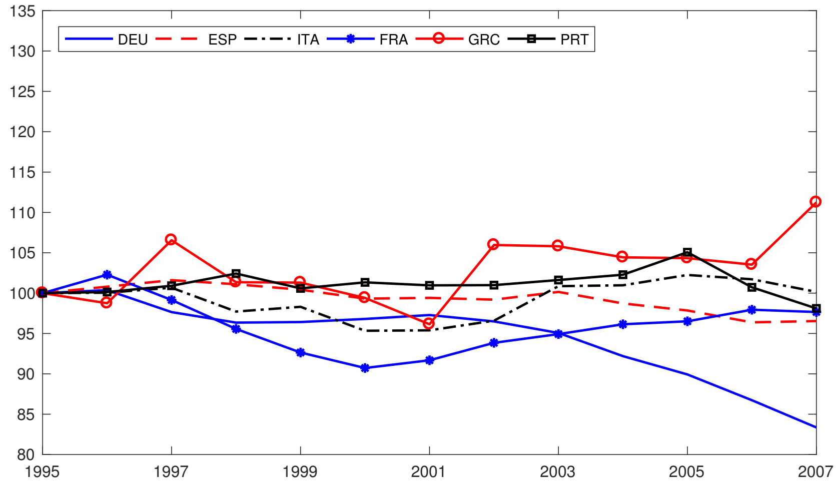
[18]Our critical remarks are based on the explanations provided in the online appendix to Dustmann et al. (2014). Of course, we cannot rule out the possibility that the authors have done some additional operations which are not documented.

foreign contributions, such foreign influence is indirectly present in ULC of individual domestic sectors and, thus, contaminates the competitiveness indicator.

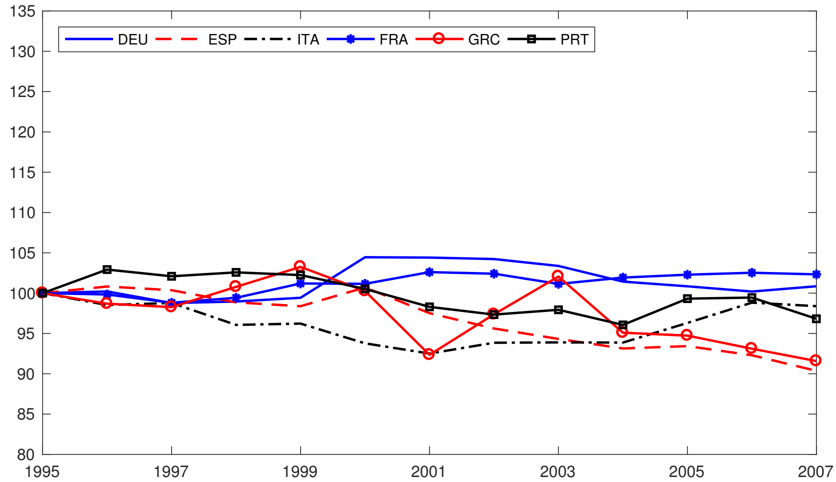
As regards the weights $\omega_i^{\dagger m\widehat{n}}$ in eq. (D.12), several problems are apparent. First, l_{ii}^{mn} tells how many units of output from sector m are required to produce one unit of final good in sector n. However, these output units of sector m contain not only value added of sector m but also value added of all other sectors. Therefore, l_{ii}^{mn} does not extract the contribution of sector m to sector n and should not be used in this form as a part of a proper weight attached to ULC of sector m. To obtain the pure contribution of sector m to one unit of final good of sector n, l_{ii}^{mn} has to be multiplied with v_i^m, i.e. the value-added share of sector m. That is done in our EULC measure, but since we use the information from global inter-country input-output tables we are able to use the more precise value-added contributions $v_i^m b_{ii}^m$ instead of $v_i^m l_{ii}^m$, also see the discussion in Appendix A.

Second, the term $\sum_{n\in I_{\widehat{n}}} l_{ii}^{mn}\, x_i^n$ in eq. (D.12) (after the second equals sign) should capture the total contribution of sector m to the aggregate $\widehat{n}$. In each component of the sum, l_{ii}^{mn} is multiplied with x_i^n—gross exports of sector n that include both final goods and intermediates—so that the product should express the contribution of sector m to gross exports of sector n. However, this measure is imprecise since gross exports are treated as exogenously given in the case of national input-output tables. In fact, exports of intermediate goods should be determined endogenously by taking international input-output linkages into account. This necessitates the use of global inter-country input-output tables. The resulting total requirements coefficients are taken from the Leontief inverse $\mathbf{B}$ and, thus, replace the less precise coefficients from the local Leontief inverse $\mathbf{L}$. Note that multiplying b_{ii}^{mn} with intermediate goods exports leads to double counting of some value added in gross exports, see also Wang et al. (2013) for a detailed discussion of gross exports accounting at the sectoral level. Therefore, to extract the contribution of sector m to gross exports of sector n, an appropriate decomposition of gross exports is required that would allow for eliminating foreign value added and all pure double-counted terms. Alternatively, one could concentrate on final goods exports only. In such a case, multiplying $v_i^m\, b_{ii}^{mn}$ with final goods exports of sector n would yield the correct contribution of sector m to sector n. Third, the weights $\omega_i^{\dagger m\widehat{n}}$ do not sum up to one, so that they do not represent proper weights.

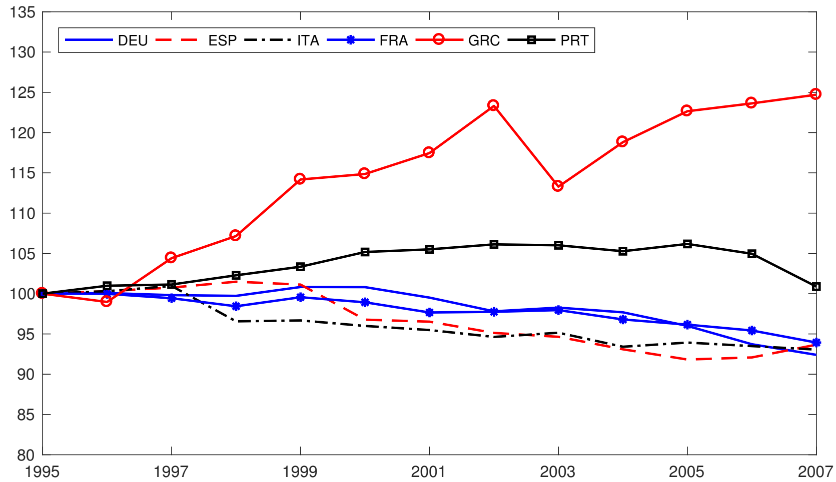
E Additional tables and figures



(a) Tradable manufacturing

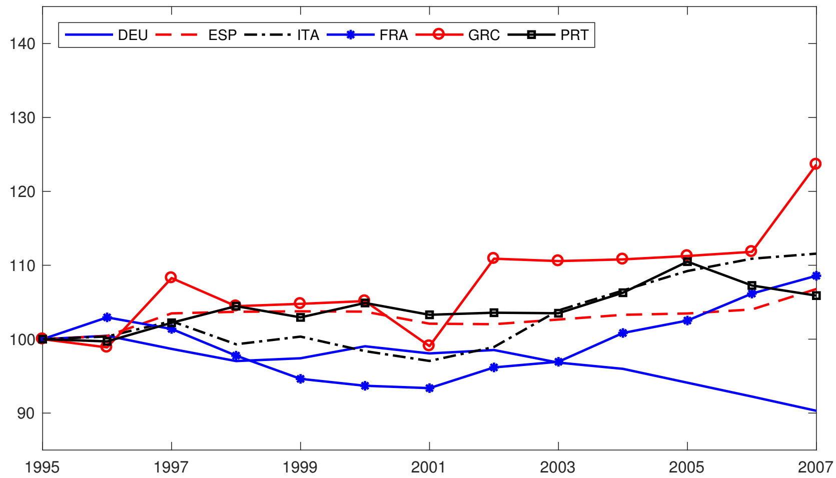


(b) Tradable services

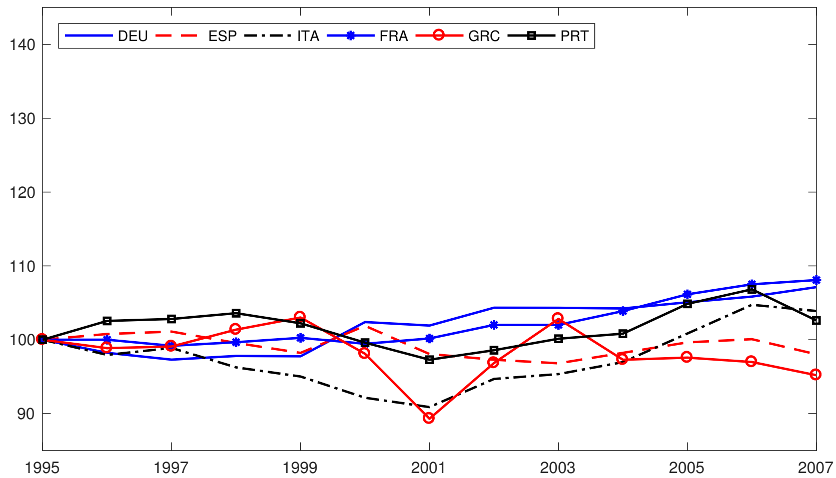


(c) Nontradable sectors

Figure E.1: Standard ULC in three German sectoral aggregates in comparison with selected euro area countries; German classification of sectoral aggregates is applied to all countries.

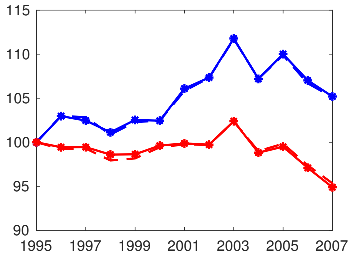


(a) Tradable manufacturing

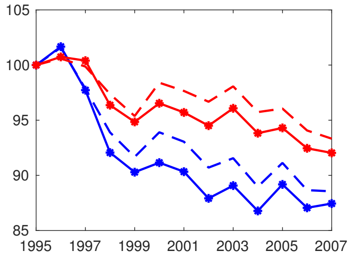


(b) Tradable services

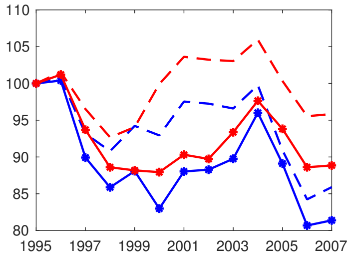
Figure E.2: Real effective exchange rates (REERs) in two German sectoral aggregates in comparison to selected euro area countries; German classification of sectoral aggregates is applied to all countries. REERs are based on standard unit labor costs (ULC) and have been computed using overall value-added weights with double export weights.



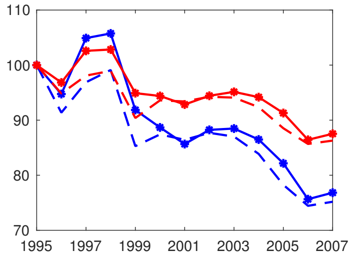
(a) c3



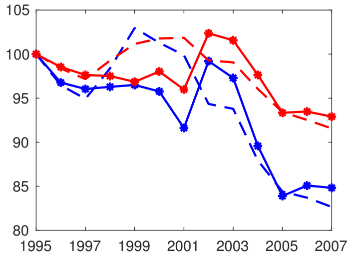
(b) c4 + c5



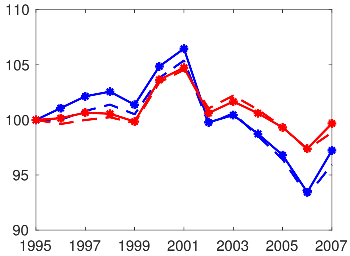
(c) c6



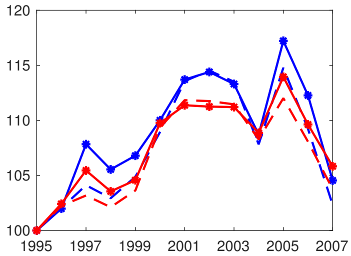
(d) c7



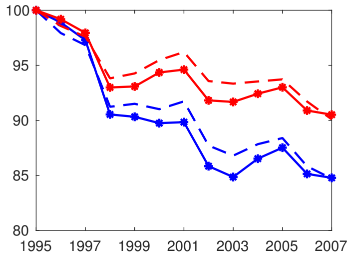
(e) c9



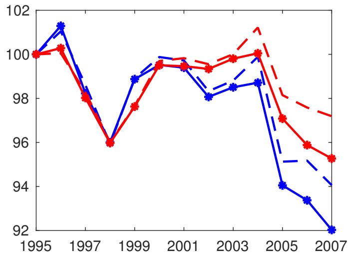
(f) c10



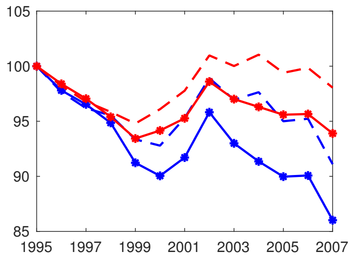
(g) c11



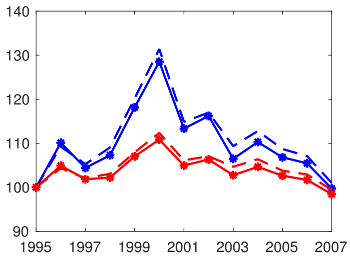
(h) c12



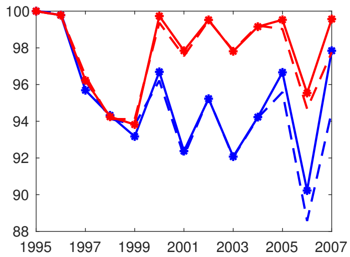
(i) c13



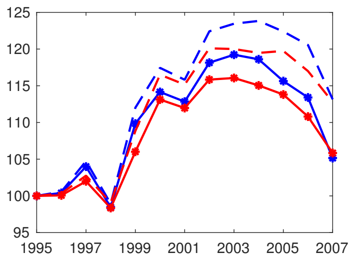
(j) c14



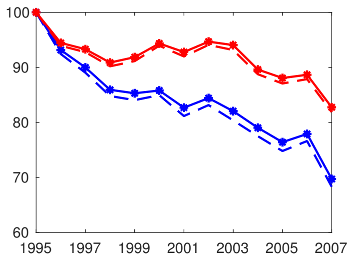
(k) c15



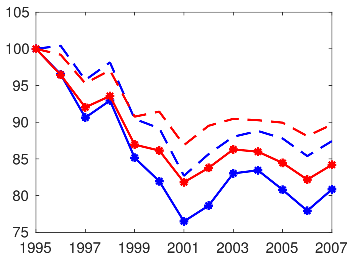
(l) c16



(m) c20



(n) c22



(o) c23

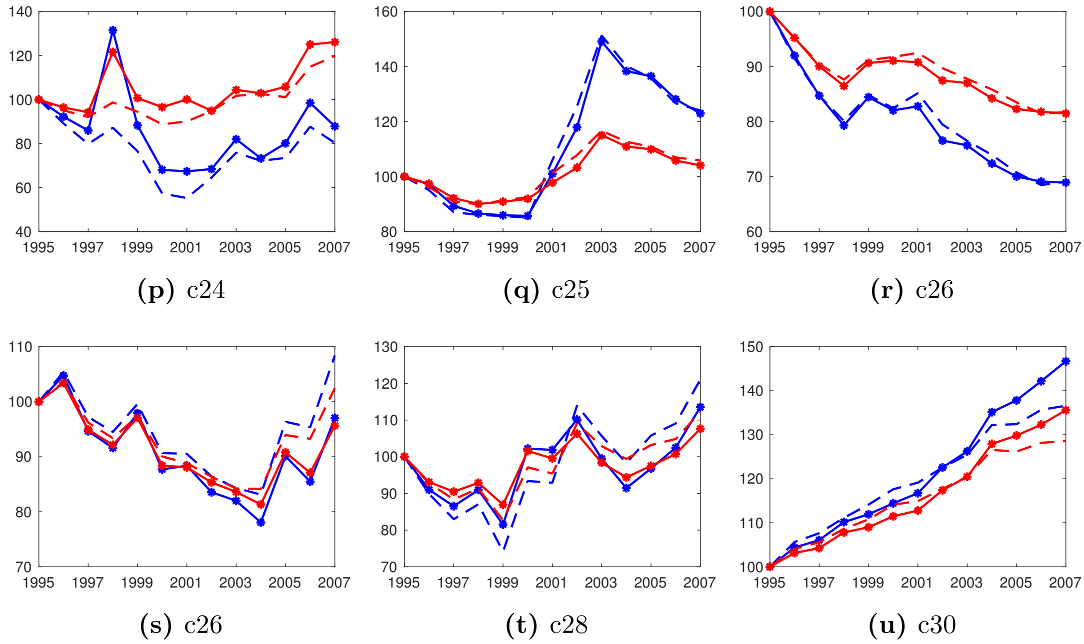


Figure E.3: Real effective exchange rates (REERs) in individual German tradable sectors except sector c1: "Agriculture, Hunting, Forestry and Fishing", i.e. sectors from tradable manufacturing and tradable services; blue dashed line: REER based on standard unit labor costs (ULC) and gross export weights, blue solid line with markers: REER based on standard ULC and value-added weights, red dashed line: REER based on embodied ULC and gross export weights, red solid line with markers: REER based on embodied ULC and value-added weights; in all cases, overall weights with double export weights have been used in the computation of REERs. Individual sectors are labeled by WIOT codes starting with the letter "c". Sector c4+c5 is an aggregated sector that is the result of the initial data transformation. For the overview over individual sectors before and after initial sectoral aggregation, and the meaning of the labels, see Table C.1. The classification of a particular sector as a tradable sector is explained in Section 4.1.2. Note that non-unique scaling has been applied to the subfigures for the sake of clarity.

Table E.3: Contributions of individual German sectors to embodied ULC in three sectoral aggregates: nontradable sectors, tradable manufacturing, and tradable services; German classification of sectoral aggregates is applied[a)]

Sectors[b)]		Average contribution to:[c)] NT	TM	TS	Average ULC growth in %[d)]	Total ULC growth in %[e)]
NT	c2	0.0060	0.0035	0.0013	0.7377	9.2199
	c17	0.0175	0.0098	0.0054	−2.6843	−27.8570
	c18	0.1254	0.0085	0.0089	0.1817	2.2026
	c19 + c21	0.1188	0.0636	0.0233	−0.3052	−3.6013
	c29	0.0177	0.0029	0.0043	−0.2705	−3.1982
	c31 + c32 + c33	0.0113	0.4630	0.0088	−0.3451	−4.0633
	c34	0.0784	0.0158	0.0177	0.0308	0.3702
TM	c3	0.0021	0.0730	0.0094	0.1647	1.9939
	c4 + c5	0.0003	0.0177	0.0002	−1.5139	−16.7282
	c6	0.0034	0.0094	0.0008	−2.1457	−22.9170
	c7	0.0053	0.0367	0.0071	−2.3999	−25.2858
	c9	0.0027	0.0427	0.0020	−1.9916	−21.4471
	c10	0.0042	0.0201	0.0017	−0.6630	−7.6726
	c11	0.0075	0.0122	0.0015	−0.5500	−6.4043
	c12	0.0092	0.0647	0.0041	−2.3885	−25.1806
	c13	0.0043	0.1200	0.0025	−1.5377	−16.9695
	c14	0.0095	0.0899	0.0044	−2.1337	−22.8033
	c15	0.0019	0.1288	0.0020	−0.7843	−9.0162
	c16	0.0008	0.0307	0.0005	−1.9312	−20.8642
TS	c20	0.0134	0.0476	0.1971	−0.2917	−3.4453
	c22	0.0020	0.0024	0.1466	−2.5041	−26.237
	c23	0.0065	0.0167	0.0815	−1.0706	−12.1175
	c24	0.0001	0.0005	0.0021	−7.1423	−58.9023
	c25	0.0006	0.0013	0.0091	2.1436	28.9831
	c26	0.0030	0.0124	0.0467	−2.3664	−24.9776
	c27	0.0063	0.0070	0.0545	−1.3400	−14.9467
	c28	0.0307	0.0240	0.1585	0.5306	6.5563
	c30	0.0568	0.0943	0.1913	2.1485	29.0573
Other	c1	0.0027	0.0327	0.0065	−1.8793	−20.3611

[a)] To make the results comparable across countries, it is meaningful to apply the sectoral assignment of a benchmark country. We choose Germany as the benchmark as it is the focus of our empirical illustration. A sector is classified as a nontradable (tradable) sector if gross exports of this sector lie below (above) the 25th percentile of the distribution of gross exports in Germany in 1995, see Section 4.1.2 for more details.

[b)] NT, TM and TS are labels for three sectoral aggregates; NT: nontradable sectors, TM: tradable manufacturing, TS: tradable services. The respective sectoral aggregates contain individual sectors that are labeled by WIOT codes starting with the letter "c". Some sectors have been aggregated as part of the initial data preparation (explained in Appendix C.4), which is marked by the "+" sign. For the overview over individual sectors before and after the initial sectoral aggregation, and the meaning of the labels, see Table C.1.

[c)] The average contribution of individual sectors to sectoral aggregates is measured by the average share of the individual ULC component in embodied ULC of a sectoral aggregate. The share is given as ULC multiplied with the weight given by the value-added contribution of an individual sector to the final good in a sectoral aggregate (for details on the computation of weights in the case of sectoral aggregates, see Section 2.3). The average (arithmetic mean) is computed over the time span 1995–2007.

[d)] Average ULC growth is the average year-on-year growth rate of individual ULC contributing to embodied ULC in a sectoral aggregate. The average growth rate over the time span 1995–2007 is computed using the geometric mean.

[e)] Total ULC growth is the relative change in ULC between 1995 (initial period) and 2007 (end period).

Table E.4: Contributions of individual Greek sectors to embodied ULC in three sectoral aggregates: nontradable sectors, tradable manufacturing and tradable services; German classification of sectoral aggregates is applied[a)]

Sectors[b)]		Average contribution to:[c)]			Average	Total
		NT	**TM**	**TS**	**ULC growth in %**[d)]	**ULC growth in %**[e)]
NT	c2	0.0050	0.0086	0.0028	0.2927	3.5694
	c17	0.0173	0.0136	0.0086	1.2356	−15.8777
	c18	0.1058	0.0066	0.0042	2.3425	32.0295
	c19 + c21	0.1517	0.0785	0.0396	2.4262	33.3317
	c29	0.0014	0.0029	0.0002	13.9417	378.8416
	c31 + c32 + c33	0.4797	0.0023	0.0025	0.6168	7.6583
	c34	0.0783	0.0041	0.0073	2.1935	29.7411
TM	c3	0.0013	0.1468	0.0227	2.0804	28.0284
	c4 + c5	0.0008	0.1193	0.0015	1.7336	22.9061
	c6	0.0030	0.0141	0.0015	−0.4929	−5.7572
	c7	0.0031	0.0484	0.0051	2.7237	38.0534
	c9	0.0032	0.0322	0.0027	2.7629	38.6865
	c10	0.0016	0.0138	0.0015	−0.8462	−9.6950
	c11	0.0142	0.0090	0.0017	−1.9712	−21.2511
	c12	0.0088	0.0345	0.0022	−0.0776	−0.9270
	c13	0.0063	0.0159	0.0012	−0.8778	−10.0400
	c14	0.0022	0.0232	0.0006	0.0483	0.5814
	c15	0.0004	0.0456	0.0004	−1.4799	−16.3820
	c16	0.0008	0.0430	0.0017	3.10232	44.2855
TS	c20	0.0213	0.0550	0.1804	0.6789	8.4574
	c22	0.0021	0.0011	0.1811	0.9060	11.4303
	c23	0.0168	0.0193	0.1410	−0.0814	−0.9726
	c24	0.0000	0.0000	0.0118	−21.8045	−94.7738
	c25	0.0017	0.0013	0.0198	−8.9933	−67.7238
	c26	0.0011	0.0011	0.0239	−4.6862	−43.7829
	c27	0.0076	0.0090	0.0531	−5.2832	−47.8656
	c28	0.0170	0.0245	0.1384	−1.5193	−16.7825
	c30	0.0447	0.0734	0.1081	7.9936	151.6383
Other	c1	0.0025	0.0344	0.0065	7.6835	143.1021

[a)] To make the results comparable across countries, it is meaningful to apply the sectoral assignment of a benchmark country. We choose Germany as the benchmark as it is the focus of our empirical illustration. A Greek sector is classified as a nontradable (tradable) sector if gross exports of the respective sector in Germany lie below (above) the 25th percentile of the distribution of gross exports in Germany in 1995, see Section 4.1.2 for more details.

[b)] NT, TM and TS are labels for three sectoral aggregates; NT: nontradable sectors, TM: tradable manufacturing, TS: tradable services. The respective sectoral aggregates contain individual sectors that are labeled by WIOT codes starting with the letter "c". Some sectors have been aggregated as part of the initial data preparation (explained in Appendix C.4), which is marked by the "+" sign. For the overview over individual sectors before and after the initial sectoral aggregation, and the meaning of the labels, see Table C.1.

[c)] The average contribution of individual sectors to sectoral aggregates is measured by the average share of the individual ULC component in embodied ULC of a sectoral aggregate. The share is given as ULC multiplied with the weight given by the value-added contribution of an individual sector to the final good in a sectoral aggregate (for details on the computation of weights in the case of sectoral aggregates, see Section 2.3). The average (arithmetic mean) is computed over the time span 1995–2007.

[d)] Average ULC growth is the average year-on-year growth rate of individual ULC contributing to embodied ULC in a sectoral aggregate. The average growth rate over the time span 1995–2007 is computed using the geometric mean.

[e)] Total ULC growth is the relative change in ULC between 1995 (initial period) and 2007 (end period).

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