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Wide-range estimation of various substitution elasticities for CES production functions at the sectoral level☆,☆☆

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ABSTRACT

This paper provides a broad range of various substitution elasticity values for sectoral nested constant elasticity of substitution (CES) production functions, estimated through panel data techniques and using the World Input-Output Database (WIOD) as the main data source. Although the related empirical literature has been growing over the recent years, there is still no single study focused on a large-scale estimation of various, both product- and industry-specific, elasticities with the use of an internally consistent database and a common methodology for all the production function nests. This paper constitutes an attempt to fill this gap. The obtained estimates may subsequently be used by computable general equilibrium (CGE) modellers in their applied research – covering fiscal, labour market, trade, energy or environmental topics. Significant heterogeneity in the estimated elasticity values is observed between various industries/products as well as between various nests of the production function. This constitutes a strong argument against the arbitrary use of Leontief and/or Cobb-Douglas specifications in multi-sector CGE models.

1. Introduction

A common argument that is often raised against the reliability of macroeconomic and sectoral analyses based on computable general equilibrium (CGE) models originates from the fact that their results are determined to a large extent by the assumed values of exogenous ("free") parameters that cannot be calibrated based on the data from National Accounts[1] – see Baccianti (2013), Broadstock et al. (2007), Fragiadakis et al. (2012), Koesler and Schymura (2015) and van der Werf (2008). The above-mentioned set of "free" parameters includes mainly elasticities of substitution in production functions.

Németh et al. (2011) argued that the elasticities of substitution play such an important role in explaining CGE-based results because they determine the degree to which economic agents respond to price changes. They also distinguished two ways to obtain substitution elasticities for CGE models. The first one is statistical/econometric analysis, while the second one is the implementation of externally estimated values from literature studies.

The problem, however, is that, despite this meaningful role of elasticities, the empirical literature containing estimates of the required elasticities is still quite modest (Turner et al., 2012; van der Werf, 2008). As a result, CGE analysts often take advantage of elasticity values from unrelated sources and/or from different conceptual frameworks. Zachłod-Jelec and Boratyński (2016) underlined the fact that the available empirical evidence is not only scarce but also even ambiguous. They also argued that it is not an easy task to find appropriate estimates, tailored to a given CGE model, taking into account its specific sectoral and regional disaggregation, nesting structure or assumed interactions between economic agents.

Therefore, such an approach of employing (potentially) inconsistent elasticity estimates may be a reason for the criticism regarding the use of CGE models (Henningsen et al., 2019; Koesler and Schymura, 2015; Németh et al., 2011). Kemfert (1998) explained those arbitrarily chosen elasticity values as "guestimations" that often replace econometric "estimations" in CGE-based analyses. Dawkins et al. (2001) even described such behaviour of modellers as an "idiot's law of elasticities" and defined those arbitrarily chosen values as "coffee table elasticities". According to Turner et al. (2012), it is important to identify the key parameters that may play a crucial role in determining the results of

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[1] These sources are usually limited to input–output (I—O) data or supply and use tables (SUT).

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CGE analyses. These parameters should be given priority in the estimation exercise, provided that appropriate data are available.

Against this backdrop, the main goal of this paper is to perform a comprehensive, wide-range estimation of various types of, both product- and industry-specific, substitution elasticities for CES production functions, using an internally consistent database and a uniform methodology for all the production function nests. These estimates may subsequently be used by CGE modellers in their research work. Although the empirical literature related to elasticity estimation has been growing over the recent years, still no single study has focused on a large-scale estimation of various, both product- and industry-specific, elasticities with the use of an internally consistent database and a common methodology. Hence, this study constitutes an attempt to fill this identified gap.

This study is also relevant to the area of energy economics for several reasons. Firstly, computable general equilibrium (CGE) models are commonly used in broad-based research areas related to the analysis of energy, environment or trade policy issues (Beckman et al., 2011). Secondly, the existing empirical literature (Baccianti, 2013; Koesler and Schymura, 2015; van der Werf, 2008) implicitly highlights the key role and the need for special treatment of energy compared with other, non-energy inputs. Thirdly, a proper distinction of energy within the production structure requires both changes in the production function nesting and an econometric estimation of the corresponding substitution elasticity values. Fourthly, it is becoming apparent that such special treatment of the energy inputs is inevitable in CGE models (Brockway et al., 2017) – even those that do not deal directly with the environment and/or energy-related topics. As noted by Frondel and Schmidt (2004), “energy seems to be an indispensable production factor under separability aspects”.

This paper is divided into seven sections. The introduction in Section 1 is followed by a description of the main characteristics of a (nested) CES production function and its role in empirical research in Section 2. Section 3 provides a review of the literature with similar conceptuality to this study. Section 4 describes the data sources and the necessary modifications made to prepare the final database. Sections 5 and 6 explain, respectively, the econometric methodology applied and the estimation results. Section 7 concludes and discusses the policy implications.

2. (Nested) CES production function and elasticity of substitution

The most popular type of production function used in empirical research, including the use of CGE models, is the constant elasticity of substitution (CES) function, which originates from the seminal work of Arrow et al. (1961). In its most general form, the CES function is as follows:

$$Y_{i,t} = A_{i,t} \cdot \left[\alpha_i K_{i,t}^{-\rho_i} + (1-\alpha_i) L_{i,t}^{-\rho_i}\right]^{-1/\rho_i}, \tag{1}$$

where $Y_{i,\,t}$ stands for output (value added), while $K_{i,\,t}$ and $L_{i,\,t}$ represent factor inputs (capital and labour, respectively). $A_{i,\,t}$ is a parameter of technology (total factor productivity, TFP), α_i is the capital income share and $(1-\alpha_i)$ is the labour income share, while ρ_i is a determinant of substitution elasticity (σ_i). The elasticity of substitution is defined as $\sigma_i = \frac{1}{1+\rho_i}$. Subscripts i and t denote sectoral (industrial) and time dimensions, respectively. It is also apparent that not all the parameters are assigned a time subscript t. This results from the fact that they are either calibrated to the base-year data (distribution/share parameters) or set exogenously (substitution elasticity) and assumed to be constant over time.

In particular, the CES function is a general form of the Cobb-Douglas and Leontief production functions. The former is defined as $Y_{i,\,t} = A_{i,\,t} K_{i,\,t}^{\alpha_i} L_{i,\,t}^{1-\alpha_i}$ and the latter as $Y_{i,\,t} = A_{i,\,t} \cdot \min\{\alpha_i K_{i,\,t}, (1-\alpha_i) L_{i,\,t}\}$. The same parameter definitions as stated previously hold.

It follows that $-1 < \rho_i \neq 0$, which implies that $\sigma_i > 0$. Hence, these constraints require non-negativity of substitution elasticity. With $\rho_i \approx 0$, the elasticity of substitution approaches unity ($\sigma_i \approx 1$) and the CES function reduces to the Cobb-Douglas form. With $\rho_i \to \infty$, the elasticity of substitution approaches zero ($\sigma_i \approx 0$) and the CES function reduces to the Leontief form. Tipper (2012) provided an in-depth explanation of the CES production function theory.

The underlying economic theory distinguishes between many definitions of substitution elasticity. The marginal rate of technical substitution (MRTS), Hicks/direct elasticity of substitution (HES), cross price elasticity (CPE), Allen-Uzawa elasticity of substitution (AES) and Morishima elasticity of substitution (MES) are the most prominent measures of elasticity (Broadstock et al., 2007; Brockway et al., 2017). Broadstock et al. (2007), as well as Brockway et al. (2017), argued that an appropriate measure of substitution elasticity, consistent with the CES functions applied in most of the CGE models, is the Hicksian elasticity of substitution – HES[2] (Hicks, 1932), defined as[3]:

$$\sigma_i = \frac{\partial\left(\frac{K_{i,t}}{L_{i,t}}\right) / \left(\frac{K_{i,t}}{L_{i,t}}\right)}{\partial\left(\frac{w_{i,t}}{r_{i,t}}\right) / \left(\frac{w_{i,t}}{r_{i,t}}\right)}. \tag{2}$$

Following this definition, substitution elasticity measures the percentage change in factor input proportions (in this case, the capital-labour ratio: $\frac{K_{i,t}}{L_{i,t}}$) relative to the percentage change in factor price proportions (in this case, the wage to capital rental rate ratio: $\frac{w_{i,t}}{r_{i,t}}$) in sector i and in period t, keeping the output level fixed.[4] Therefore, this elasticity may be interpreted either as the ease of compensating for a decrease in one input with an increase in another one, keeping the output constant, or as the ease of changing the composition of inputs in response to changes in their relative prices. HES was originally tailored to production functions with two inputs only. However, this measure may be generalised to production functions with multiple inputs, in which case it is called direct elasticity of substitution (Chambers, 1988). Hence, the common name “Hicks/direct elasticity of substitution” holds.

While the distribution parameter α_i is typically assigned a sector-specific value (i.e. calibrated), using the information from input-output or supply and use tables, the value of parameter σ_i under the CES framework needs to be assigned exogenously, that is, from outside the database on which a given CGE model is based. The assignment of a specific value to the elasticity coefficient ρ_i (and hence the parameter σ_i) allows for the subsequent calibration of the technology parameter:

$$A_{i,t} = \frac{Y_{i,t}}{\left[\alpha_i K_{i,t}^{-\rho_i} + (1-\alpha_i) L_{i,t}^{-\rho_i}\right]^{-1/\rho_i}}. \tag{3}$$

However, such a simplified framework significantly restricts the underlying production structure, as it assumes equal substitution elasticity between all inputs (Henningsen and Henningsen, 2011; Koesler and Schymura, 2015). To address this issue, Sato (1967) introduced a two-level, “nested” CES function, in which all or some of the inputs at the

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[2] Zachłod-Jelec and Boratyński (2016) highlighted that empirical studies have applied several definitions of substitution elasticities, but only a few of them have used the HES measure, which is consistent with the CES functions applied in CGE models.

[3] See Broadstock et al. (2007) as well as Tipper (2012) for more details.

[4] In fact, HES is a symmetric measure; hence, an inversion of ratios of input quantities and prices does not change its value.

"upper" level of the production process may be represented by another CES function of further sub-inputs at the "lower" level. It is quite easy to illustrate the idea of a two-level, nested CES function with a simple example. Suppose that, in the top nest, the output ($Y_{i,\,t}$) is a CES function of value added ($VA_{i,\,t}$) and intermediate inputs ($II_{i,\,t}$):

$$Y_{i,t} = A_{1,i,t}\cdot\left[\alpha_{1,i}\cdot VA_{i,t}^{-\rho_{1,i}} + (1-\alpha_{1,i})\cdot II_{i,t}^{-\rho_{1,i}}\right]^{-1/\rho_{1,i}}. \tag{4}$$

In the lower nest, the value added is itself represented by a CES function of capital ($K_{i,\,t}$) and labour ($L_{i,\,t}$) – similarly to the previous example:

$$VA_{i,t} = A_{2,i,t}\cdot\left[\alpha_{2,i}\cdot K_{i,t}^{-\rho_{2,i}} + (1-\alpha_{2,i})\cdot L_{i,t}^{-\rho_{2,i}}\right]^{-1/\rho_{2,i}}. \tag{5}$$

The elasticities of substitution in the upper (top) and lower nests are given by $\sigma_{1,i} = \frac{1}{1+\rho_{1,i}}$ and $\sigma_{2,i} = \frac{1}{1+\rho_{2,i}}$, respectively. Distribution parameters $\alpha_{1,\,i}$ and $(1-\alpha_{1,\,i})$ stand for the shares of value added and intermediate inputs in the gross output, respectively. Distribution parameters $\alpha_{2,\,i}$ and $(1-\alpha_{2,\,i})$ are defined as the shares of capital and labour income in the value added, respectively. Technology parameters $A_{1,\,i,\,t}$ and $A_{2,\,i,\,t}$ measure the total factor productivity (TFP) in the production process of the gross output and value added, respectively.

These two separate production functions may be combined analytically into a nested CES function:

$$Y_{i,t} = A_{1,i,t}\cdot\left\{\alpha_{1,i}\cdot\left[A_{2,i,t}\cdot\left(\alpha_{2,i}\cdot K_{i,t}^{-\rho_{2,i}} + (1-\alpha_{2,i})\cdot L_{i,t}^{-\rho_{2,i}}\right)^{-1/\rho_{2,i}}\right]^{-\rho_{1,i}} + (1-\alpha_{1,i})\cdot II_{i,t}^{-\rho_{1,i}}\right\}^{-1/\rho_{1,i}}. \tag{6}$$

Fig. 1 provides a graphical representation of such a two-level, nested CES production function.

Obviously, the concept of a two-level CES may easily be extended to more complicated nesting structures, in terms of both the number of nests and the correspondence between them. Fig. 2 provides a graphical representation of a nesting structure used in the estimation procedure for the purpose of this paper, together with the respective elasticities. At the top level, the output consists of a non-energy intermediate inputs (II) composite and a capital-labour-energy (KLE) composite, with the elasticity $\sigma_{top,\,i}$. The non-energy intermediate inputs composite (II) in a given industry constitutes a Leontief combination of all non-energy intermediate product composites (II_Arm). These are Armington (1969) composites that combine domestic (II_dom) and imported (II_imp) bundles for each of the non-energy products used by a given industry, with the elasticity $\sigma_{armi,\,g}$. The KLE composite is made up of an energy bundle (E) and value added (VA), with the elasticity $\sigma_{kle,\,i}$. The energy bundle consists of the Armington composites of energy commodities,[5] which are themselves products of domestic (E_dom) and imported (E_imp) bundles for each of the energy products used by a given industry, with the elasticity $\sigma_{armi,\,g}$. Value added is a product (with the elasticity $\sigma_{va,\,i}$) of capital (K) and labour (L), the latter consisting of higher-skilled (L_U) and low-skilled (L_L) labour inputs (with the elasticity $\sigma_{labu,\,i}$). In the bottom nest, higher-skilled labour constitutes a product of high- (L_H) and medium-skilled (L_M) labour, with the elasticity $\sigma_{labl,\,i}$. In particular, each nest (except for the Armington nest) is characterised by its own sector- or industry-specific elasticity value (hence the presence of the subscript i). The elasticities within the non-energy and energy Armington nests are product- or good-specific (hence the presence of the subscript g[6]) and industry-uniform. Such an approach stems from the fact that Armington (1969) actually introduced his concept as products' (goods') differentiation by the source of origin.

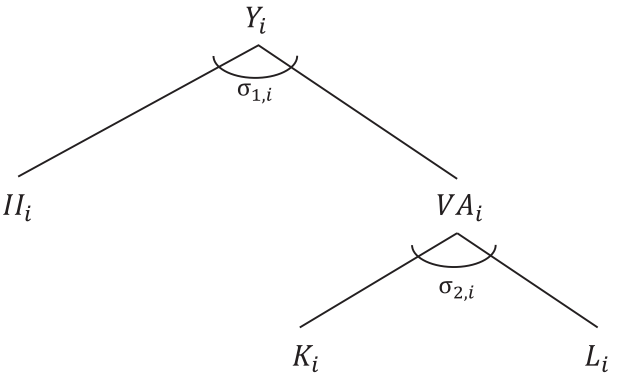

Fig. 1. Two-level, nested CES production structure.
(Source: own elaboration.)

3. Literature review

As previously mentioned, the empirical evidence on estimates of substitution elasticities is still quite modest. In addition, different papers have focused on different definitions of elasticities, functional forms, econometric techniques and databases – with different regional and sectoral coverage and different time slices (Zachłod-Jelec and Boratyński, 2016). Some of the reported estimation outcomes even seem to be contradictive. Within this context, this section describes the main findings from relatively new econometric literature based on panel estimation of the Hicksian elasticity of substitution (HES) for various production function nests within the CES framework.

Baccianti (2013) estimated the substitution elasticities between capital, labour and energy within a one-nest CES function with factor-augmenting technological progress. Besides, three alternative nesting structures – (KL)E, (KE)L and (LE)K – were assessed.[7] The panel estimation with fixed effects was based on a data set covering 27 countries and 33 industries within the time span 1995–2008, which combined information from the World Input-Output Database Socio-Economic Accounts (WIOD SEA) and the OECD Energy Prices and Taxes. To improve the identification of the estimated parameters, the production function was subjected to a normalisation procedure. The author concluded that most of the estimated elasticity values were located below unity (i.e. there were rather few substitution possibilities), which implied an increase in the cost share of the input becoming relatively more expensive. The only exception was the substitutability between capital and labour within the value added nest of the (KL)E structure, for which the Cobb-Douglas specification of unitary elasticity was justified. The same findings held at the whole economy's level after aggregation over all the activity sectors.

Fragiadakis et al. (2012) estimated the substitution elasticities between capital and labour in a CES framework with total factor productivity growth, using pooled data techniques. They also took advantage of the WIOD SEA database for the period 1995–2009, aggregated into six economic sectors. Besides, three pooled data sets for three groups of regions

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[5] The elasticities of substitution between the energy inputs in a given industry, denoted by η_i in Fig. 2, have not been subjected to the econometric estimation as part of this paper. To estimate such inter-fuel elasticities properly, data with greater disaggregation of fuels than those provided by the WIOD should be used instead.

[6] Notably, the subscript g is not explicitly visible within the particular Armington composites (II_Arm) as well as within the domestic (II_dom) and imported (II_imp) products, as shown in Fig. 2. This results from the fact that all the non-energy Armington bundles are presented individually, starting from the first element of the set g ("agr") and ending with the last one ("srv") – with the exception of the energy products ("min", "pet" and "ele") and all the remaining elements reflected by an ellipsis. Those energy products are explicitly shown in the energy Armington bundles. For a complete list of the products, that is, the elements of the set g, please refer to Table 4.

[7] The (KL)E structure implies that capital and labour are aggregated into a capital-labour composite in the lower nest, which is subsequently combined with energy in the upper nest. The analogical interpretation holds for all the remaining structures.

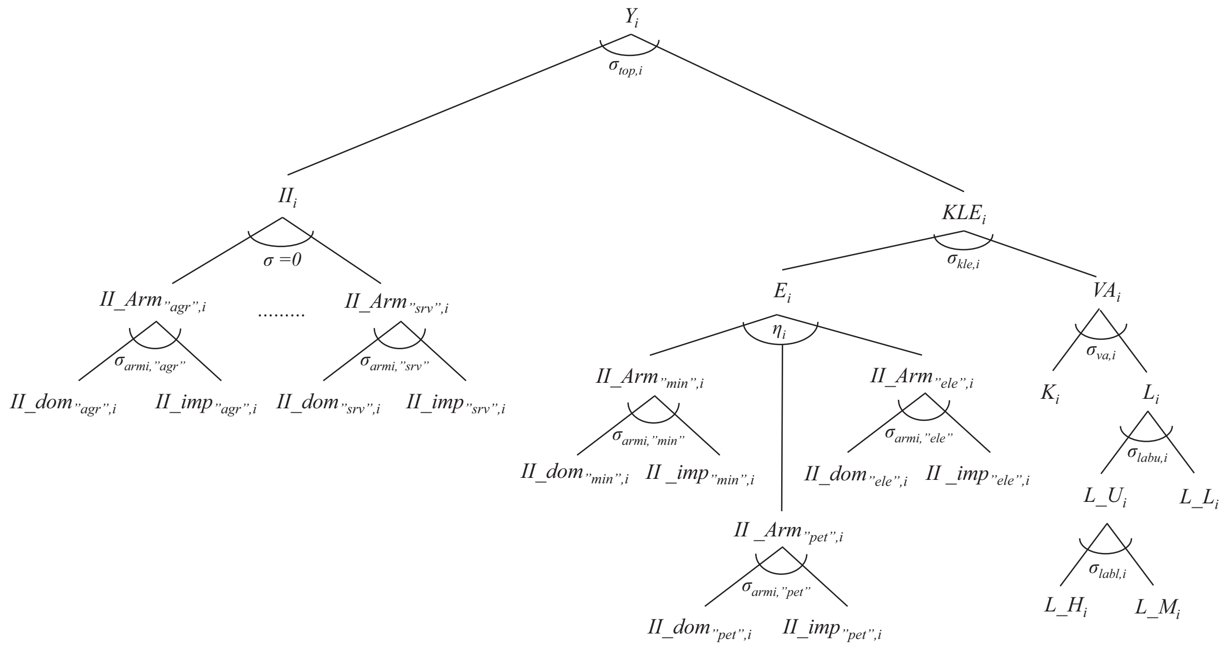

Fig. 2. Multi-level, nested CES production structure used in the estimation procedure.
(Source: own elaboration.)

were constructed. The authors concluded that – in most cases – the values of short-run elasticities were lower than one (i.e. the Cobb-Douglas specification) and sometimes even close to zero (i.e. the Leontief specification), while the long-run elasticities were located above unity.

Koesler and Schymura (2015) estimated three-level nested CES functions, of a (KL)*E*-M form,[8] either with the Hicks-neutral technological change (i.e. TFP) or without any technical progress, using non-linear econometric techniques for panel data. The estimation was based on the WIOD Socio-Economic Accounts and WIOD Energy Use data sets. These formed a balanced panel of 40 regions in the period 1995–2006 for each of 35 sectors. The authors argued that the common practice of using the Cobb-Douglas or Leontief production functions in applied CGE analyses must be rejected in most cases, given the complexity and heterogeneity of the estimates obtained across sectors.

Németh et al. (2011) provided estimates of Armington elasticities for two-level nested CES, with the domestic-imported goods choice in the upper nest and the intra-import choice between various countries of origin in the lower nest. This was aimed at reflecting Armington's (1969) assumption. The econometric estimation was based on panel data techniques, with fixed and random effects in the upper and lower nests, respectively. The data sources included Eurostat's COMEXT and National Accounts databases over the period 1995–2005. The authors drew the conclusion that the relative demand changes in reaction to the relative price changes were less sensitive between domestic and imported bundles (upper nest) than within the intra-import basket (lower nest), with higher elasticity values obtained in the latter case. Moreover, the short-term elasticities tended to be lower than their long-term values in most cases.

Saito (2004) estimated Armington elasticities of substitution between domestic and imported bundles of commodity aggregates (*intergroup elasticities* – estimated from multilateral data) as well as between import baskets from various countries of origin (*intragroup elasticities* – estimated from bilateral data), using panel data techniques with fixed effects. Her data set included information from the International Sectoral Data Base and the International Trade by Commodities Statistics, covering 14 regions over the period 1970–1990. In addition, the OECD Input-Output Database was used for auxiliary calculations. Actually, *intergroup elasticities* were treated as country-specific (estimation based on each country's time series), while *intragroup elasticities* were treated as country-uniform (based on panel data for all 14 countries). The author concluded that the *intergroup elasticities* (estimated from multilateral data) were higher than the *intragroup elasticities* (obtained from bilateral trade data) in the intermediate input sectors but equal to or lower than them in the final consumption sectors.

van der Werf (2008) concentrated on the empirical verification, with the use of pooled and panel data techniques, of three important elements of each CGE model, namely the production (nesting) structure, substitution possibilities and technological change. His database was constructed on the basis of the IEA Energy Balances and the OECD International Sectoral Database, creating a panel of 12 countries and 7 industries within the 1978–1996 time span. The author provided empirical evidence of all possible nesting structures for the capital-energy-labour (KEL) composite within the CES framework. He concluded that the (KL)E nesting structure, in which capital and labour are first combined into a value added component and then put together with energy, fitted the historical data best, with country- and sector-specific elasticity values significantly lower than unity (i.e. the Cobb-Douglas specification). In addition, the null hypothesis of total factor (Hicks-neutral) productivity growth should be rejected in favour of factor-augmenting (input-specific) technical change.

Table 1 offers an overview of the differences in the methodological aspects and the underlying assumption demonstrated in each of the above-mentioned papers.

4. Data sources

The econometric analysis undertaken is based on panel data techniques. By combining cross section and time series variability, panel estimation allows for a better distinction between input substitution and technological change than time series analysis (Baccianti, 2013). In addition, Németh et al. (2011) suggested that the use of panel data enables researchers to account for individual heterogeneity between cross sections and therefore to control for biased results, as well as helping to

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[8] "M" stands for materials, that is, non-energy intermediate inputs.

Table 1
Summary of the methodological aspects, the underlying assumptions and the results obtained in the previous studies.
(Source: own elaboration.)

Author(s)	Elasticity type	Data source(s)	Data coverage	Nesting	Analytical approach	Technical progress	Production function normalisation	Estimation method	Key results
Baccianti (2013)	Capital vs. labour vs. energy	WIOD Socio-Economic Accounts, IEA Energy Prices and Taxes	33 activity sectors, 27 countries from EU/OECD + Taiwan, 1995–2008	KLE, (KL)E, (KE)L, (LE)K,	Profit maximisation: log-transformation of FOCs	Factor-augmenting	Yes	Panel estimation with fixed effects and generalised method of moments with HAC	$\sigma_{KLE} =$ 0.39–0.89 $\sigma_{KL,\,E} =$ 0.00–0.82 $\sigma_{K,\,L} =$ 0.59–1.05 $\sigma_{KE,\,L} =$ 0.00–1.31 $\sigma_{K,\,E} =$ 0.36–1.03 $\sigma_{LE,\,K} =$ 0.00–1.96 $\sigma_{L,\,E} =$ 0.20–0.87
Fragiadakis et al. (2012)	Capital vs. labour	WIOD Socio-Economic Accounts	6 sectoral groups, 20 countries (EU15, USA, Canada, China, India, Japan), 1995–2009	n/a	Profit maximisation: log-transformation of FOCs	None/TFP	No	Pooled estimation of partial adjustment models, error correction models and equations for differenced series	$\sigma_{K,\,L} =$ 0.02–0.93
Koesler and Schymura (2015)	Capital vs. labour; value added vs. energy; KLE vs. intermediates	WIOD Socio-Economic Accounts, WIOD Energy Use	35 activity sectors, 40 regions, 1995–2006	(KL)*E*-M	Direct estimation of the production function	None/TFP	No	Panel estimation with non-linear least squares	$\sigma_{K,\,L} =$ 0.00–2.72 $\sigma_{KL,\,E} =$ 0.00–7.86 $\sigma_{KLE,\,M} =$ 0.00–1.33
Németh et al. (2011)	Armington: domestic vs. imported (D,M); intra-import (IM)	Eurostat's COMEXT and National Accounts	8 sectoral groups, EU25 countries excluding Ireland, Malta and Cyprus, 1995–2005	n/a	Utility maximisation: log-transformation of FOCs	None	No	Panel estimation with fixed/random effects and dynamic adjustments: instrumental variables approach	$\sigma_{D,\,M} =$ 0.57–3.60 $\sigma_{IM} =$ 0.23–5.24
Saito (2004)	Armington: domestic vs. imported (D,M); intra-import (IM)	International Sectoral Database, International Trade by Commodities Statistics, OECD Input-Output Database	10 non-service sectors, 14 industrialised countries, 1970–90	n/a	Utility maximisation: log-transformation of FOCs	None	No	Time series/panel estimation with fully-modified ordinary least squares	$\sigma_{D,\,M} =$ 0.94–3.53 $\sigma_{IM} =$ 0.24–1.39
van der Werf (2008)	Capital vs. labour vs. energy	IEA Energy Balances, OECD International Sectoral Database	7 industrial sectors, 12 industrialised countries, 1978–1996	(KL)E, (KE)L, (LE) K,	Cost minimisation: log-transformation of FOCs	Factor-augmenting	No	Pooled/panel estimation with fixed effects and least square dummy variables	$\sigma_{KL,\,E} =$ 0.16–0.62 $\sigma_{K,\,L} =$ 0.22–0.59 $\sigma_{KE,\,L} =$ 0.81–1.04 $\sigma_{K,\,E} =$ 0.88–1.00 $\sigma_{LE,\,K} =$ 0.18–0.48 $\sigma_{L,\,E} =$ 0.52–0.86

Table 2
Variables from the WIOD SEA used in the process of database preparation.
(Source: Timmer et al. (2015).)

Variable	Description
GO	Gross output by industry at current basic prices (in millions of national currency)
II	Intermediate inputs at current purchasers' prices (in millions of national currency)
VA	Gross value added at current basic prices (in millions of national currency)
LAB	Labour compensation (in millions of national currency)
CAP	Capital compensation (in millions of national currency)
GFCF	Nominal gross fixed capital formation (in millions of national currency)
H_EMP	Total hours worked by persons engaged (millions)
GO_P	Price indices of gross output, 1995 = 100
II_P	Price indices of intermediate inputs, 1995 = 100
VA_P	Price indices of gross value added, 1995 = 100
K_GFCF	Real fixed capital stock, 1995 prices
LABHS	High-skilled labour compensation (share in total labour compensation)
LABMS	Medium-skilled labour compensation (share in total labour compensation)
LABLS	Low-skilled labour compensation (share in total labour compensation)
H_HS	Hours worked by high-skilled persons engaged (share in total hours)
H_MS	Hours worked by medium-skilled persons engaged (share in total hours)
H_LS	Hours worked by low-skilled persons engaged (share in total hours)

overcome the multicollinearity problems that occur in time series analysis.

Since, for the sake of the substitution elasticity estimation, both price and quantity data for various macroeconomic categories are required, the following data sources were used extensively to produce the final database:

- WIOD Socio-Economic Accounts (WIOD SEA);
- WIOD Energy Use (WIOD EU);
- WIOD World Input-Output Tables (WIOT);
- WIOD National Input-Output Tables (NIOT);
- OECD Energy Prices and Taxes.

The first four belong to the World Input-Output Database (Timmer et al., 2015) – a consistent data set with comprehensive sectoral coverage (Koesler and Schymura, 2015). Several papers have taken advantage of the WIOD Socio-Economic Accounts as their main data source, including Baccianti (2013), Fragiadakis et al. (2012) and Koesler and Schymura (2015). In particular, the last two of these exploit the WIOD Energy Use as well. The examples of other panel data sources employed in the literature include Eurostat's National Accounts and COMEXT (Németh et al., 2011), the IEA Energy Balances and the OECD International Sectoral Database (Saito, 2004; van der Werf, 2008) as well as the OECD International Trade by Commodities Statistics and the OECD Input-Output Database (Saito, 2004).

Table 2 contains the set of variables in the WIOD SEA database (17 out of 25 available items) that were used to construct the final database. For this purpose, the categories described above had to be subjected to transformation – this idea was partially derived from Fragiadakis et al. (2012). Table 3 provides details of this procedure. Notably, the subscripts r, i and t stand for regional (country), sectoral and time dimensions, respectively.

The OECD Energy Prices and Taxes had to be used due to the fact that WIOD Socio-Economic Accounts do not separate energy from the aggregate use of intermediate inputs, while WIOD Energy Use provides only data on the energy quantities used, without any information on the energy prices. In the process of merging information from various databases, yet another issue had to be addressed. WIOD Input-Output Tables and WIOD Socio-Economic Accounts provide data for 35 activity sectors and 40 countries (see Tables 4–5) for the period 1995–2011, while WIOD Energy Use additionally offers, as a fourth dimension, information on energy consumption from 26 energy carriers over the period 1995–2009. However, the information from the last of those databases needs to be combined with the information from the OECD Energy Prices and Taxes (category “Energy prices in national currency per toe”[9]), which covers 34 countries and 14 fuels over the time span 1978–2016. The product of this mapping procedure is a final database covering 34 sectors[10] and 26 countries (common to all the data sources[11]) with a time span from 1995 to 2009.[12] In particular, while reconciling different energy carriers from the WIOD and OECD databases, 15 out of 26 WIOD fuels were used in the calculation of the industry-specific energy use levels and the industry-specific energy prices. For more details of this concordance scheme, see Tables A1–A2 in the Appendix.

Consequently, following Baccianti (2013), industry- and country-specific time series of aggregate energy use and energy prices[13] were constructed, based on the OECD data:

- $PE_{r,\,i,\,t}$ – the aggregate price level of energy (national currency units per TJ);
- $QE_{r,\,i,\,t}$ – the gross energy use in TJ.

In addition, the World Input-Output Database does not provide ready-to-use data for the capital-labour-energy (KLE) aggregate, that is, the product of the nest with elasticity $\sigma_{kle,\,i}$. These quantity and price (unit cost) data for the KLE composite are actually essential for the estimation of the substitution elasticity between the KLE bundle and the non-energy intermediate input composite – within the nest with elasticity $\sigma_{top,\,i}$. Therefore, industry- and country-specific time series for the capital-labour-energy composite (KLE) were also constructed:

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[9] To address the issue of missing data, information from the category “Indices of energy prices by sector” was also used to some extent.

[10] Excluding the sector “Private households with employed persons”, for which the lack of data on capital compensation (CAP) and capital stock (K_GFCF) in the WIOD SEA made the construction of the capital input (QK) and capital price (PK) variables impossible.

[11] Although there are actually as many as 29 countries common to all the data sources, Latvia, Luxembourg and Turkey were excluded from the sample due to the large number of missing data items.

[12] Due to numerous data shortages for capital stocks in 2008–2009, the estimation of substitution elasticities between capital and labour was performed based on the 1995–2007 time span.

[13] Notably, the OECD database offers data on energy prices categorised only by energy carriers, not by economic sectors – hence, the price of a given carrier in this database is industry-specific. However, the fuel mix differs between industries, which implies that the effective energy price level, calculated as the weighted average over all the energy input prices and with the weights compiled based on the use of particular fuels by each industry, becomes industry-specific.

Table 3
Variables created for the estimation purposes.
(Source: own elaboration based on Fragiadakis et al. (2012) and Timmer et al. (2015).)

Code	Definition	Formula
LABH	Labour compensation (millions of national currency), high-skilled persons	$LABH_{r,i,t} = LABHS^{*}_{r,i,t} \cdot LAB^{*}_{r,i,t}$
LABM	Labour compensation (millions of national currency), medium-skilled persons	$LABM_{r,i,t} = LABMS^{*}_{r,i,t} \cdot LAB^{*}_{r,i,t}$
LABL	Labour compensation (millions of national currency), low-skilled persons	$LABL_{r,i,t} = LABLS^{*}_{r,i,t} \cdot LAB^{*}_{r,i,t}$
LABU	Labour compensation (millions of national currency), upper-skilled persons	$LABU_{r,i,t} = LABH_{r,i,t} + LABM_{r,i,t}$
H_H	Total hours worked by high-skilled persons (millions)	$H\_H_{r,i,t} = H\_HS^{*}_{r,i,t} \cdot H\_EMP^{*}_{r,i,t}$
H_M	Total hours worked by medium-skilled persons (millions)	$H\_M_{r,i,t} = H\_MS^{*}_{r,i,t} \cdot H\_EMP^{*}_{r,i,t}$
H_L	Total hours worked by low-skilled persons (millions)	$H\_L_{r,i,t} = H\_LS^{*}_{r,i,t} \cdot H\_EMP^{*}_{r,i,t}$
H_U	Total hours worked by upper-skilled persons (millions)	$H\_U_{r,i,t} = H\_H_{r,i,t} + H\_M_{r,i,t}$
PG	Price index of gross output (1995=1)	$PG_{r,i,t} = GO\_P^{*}_{r,i,t}$
PI	Price index of intermediate inputs (1995=1)	$PI_{r,i,t} = II\_P^{*}_{r,i,t}$
PV	Price index of gross value added (1995=1)	$PV_{r,i,t} = VA\_P^{*}_{r,i,t}$
PL	Price level of labour (units of national currency per hour)	$PL_{r,i,t} = LAB^{*}_{r,i,t}/H\_EMP^{*}_{r,i,t}$
PLU	Price level of upper-skilled labour (units of national currency per hour)	$PLU_{r,i,t} = LABU_{r,i,t}/H\_U_{r,i,t}$
PLH	Price level of medium-skilled labour (units of national currency per hour)	$PLH_{r,i,t} = LABH_{r,i,t}/H\_H_{r,i,t}$
PLM	Price level of high-skilled labour (units of national currency per hour)	$PLM_{r,i,t} = LABM_{r,i,t}/H\_M_{r,i,t}$
PLL	Price level of low-skilled labour (units of national currency per hour)	$PLL_{r,i,t} = LABL_{r,i,t}/H\_L_{r,i,t}$
PK	Price level of capital (per cent of real fixed capital stock value)	$PK_{r,i,t} = CAP^{*}_{r,i,t}/K\_GFCF^{*}_{r,i,t}$
QG	Gross output volume at 1995 prices (millions of national currency)	$QG_{r,i,t} = \frac{GO^{*}_{r,i,t}}{PG_{r,i,t}}$
QI	Intermediate inputs volume at 1995 prices (millions of national currency)	$QI_{r,i,t} = \frac{II^{*}_{r,i,t}}{PI_{r,i,t}}$
QV	Gross value added volume at 1995 prices (millions of national currency)	$QV_{r,i,t} = \frac{VA^{*}_{r,i,t}}{PV_{r,i,t}}$
QL	Labour input volume at 1995 prices (millions of national currency)	$QL_{r,i,t} = H\_EMP^{*}_{r,i,t}$
QLU	Upper-skilled labour input volume at 1995 prices (millions of national currency)	$QLU_{r,i,t} = H\_U_{r,i,t}$
QLH	High-skilled labour input volume at 1995 prices (millions of national currency)	$QLH_{r,i,t} = H\_H_{r,i,t}$
QLM	Medium-skilled labour input volume at 1995 prices (millions of national currency)	$QLM_{r,i,t} = H\_M_{r,i,t}$
QLL	Low-skilled labour input volume at 1995 prices (millions of national currency)	$QLL_{r,i,t} = H\_L_{r,i,t}$
QK	Capital input volume at 1995 prices (millions of national currency)	$QK_{r,i,t} = K\_GFCF^{*}_{r,i,t}$

Note: asterisks (*) indicate the original WIOD items, while the grey font – the auxiliary variables that do not directly take part in the estimation process.

- $PKLE_{r,\ i,\ t}$ – the aggregate price index of the capital-labour-energy composite (1995 = 1);
- $QKLE_{r,\ i,\ t}$ – the capital-labour-energy composite volume at 1995 prices (millions of national currency).

The aggregate price index of the capital-labour-energy composite was calculated as the weighted average of the value added price index from the WIOD Socio-Economic Accounts and the previously described aggregate price level of energy, converted into a price index (1995 = 1). The respective weights were derived from the value added in current prices (from the WIOD Socio-Economic Accounts) and the energy input value in current prices (from the WIOD Socio-Economic Accounts and the WIOD National Input-Output Tables). The capital-labour-energy composite volume was obtained by dividing the sum of the value added and the energy input value in current prices by the previously obtained aggregate price index of the capital-labour-energy composite.

As already indicated, a certain limitation of the WIOD SEA database is related to the fact that the industry-specific variables associated with the aggregate intermediate input value (II), as well as their prices (II_P) and quantities (II_QI), have not been split into particular products as well as into domestic and imported flows. This in turn prevents the direct estimation of product- rather than industry-specific Armington elasticities, using this database as the only data source. In addition, the aggregate, industry-specific intermediate input variables contain the use of both non-energy and energy products within each industry, while the latter should be excluded from such an aggregate indicator for the sake of a reliable estimation of substitution elasticities between the total, non-energy intermediate inputs and the capital-labour-

Table 4
Sectoral disaggregation of the World Input-Output Database (WIOD).
(Source: own elaboration based on Timmer et al. (2015).)

Industry	NACE 1.1	Code
Agriculture, hunting, forestry and fishing	AtB	agr
Mining and quarrying	C	min
Food, beverages and tobacco	15t16	foo
Textiles and textile products	17t18	tex
Leather, leather and footwear	19	lea
Wood and products of wood and cork	20	woo
Pulp, paper, printing and publishing	21t22	ppp
Coke, refined petroleum and nuclear fuel, industrial gas	23	pet
Chemicals and chemical products	24	chm
Rubber and plastics	25	rub
Other non-metallic mineral	26	nmm
Basic metals and fabricated metal	27t28	mtl
Machinery, nec	29	mch
Electrical and optical equipment	30t33	eeq
Transport equipment	34t35	teq
Manufacturing, nec; recycling	36t37	oth
Electricity, gas and water supply	E	ele
Construction	F	con
Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel	50	mvh
Wholesale trade and commission trade, except of motor vehicles and motorcycles	51	whs
Retail trade, except of motor vehicles and motorcycles; repair of household goods	52	trd
Hotels and restaurants	H	htl
Inland transport	60	ltr
Water transport	61	wtr
Air transport	62	atr
Other supporting and auxiliary transport activities; activities of travel agencies	63	trv
Post and telecommunications	64	com
Financial intermediation	J	fin
Real estate activities	70	rea
Renting of m&eq and other business activities	71t74	ren
Public administration and defence; compulsory social security	L	pub
Education	M	edu
Health and social work	N	hea
Other community, social and personal services	O	srv
Private households with employed persons	P	

Note: the sector "Private households with employed persons", for which the lack of data on capital compensation (CAP) and capital stock (K_GFCF) in the WIOD SEA made the construction of capital input (QK) and capital price (PK) variables impossible, was excluded from the analysis.

energy composite in the top nest of the production function to avoid the double counting of energy inputs.[14] The essential disaggregation of intermediate input flows, as well as the differentiation between energy and non-energy products, is however possible with the use of the National Input-Output Tables and the World Input-Output Tables. A similar procedure, but based on different data sources, was previously used by Saito (2004). Using the economic flows observed in the NIOT and WIOT databases, it is possible to track the source (domestic/imported), country of origin and product mix used by a given industry in a given country. This information, combined with the gross output prices (GO_P) as a proxy for the unit cost of the purchase of a given intermediate input (product) from a domestic source or as an import from a given country, enabled the subtraction of the use of energy products from the total intermediate input values (II) and price indices (II_P) for a given industry, thus transforming them into aggregates of non-energy intermediate inputs in a given industry. Besides, these data allowed for the subsequent division of the total (i.e. both energy and non-energy) intermediate inputs (II) in a given industry into domestic (II_dom) and imported (II_imp, an aggregate over all regions) flows and into particular products, thus including the source of origin and product dimensions in these variables. Subsequently, these data were aggregated over industries, leaving the product, source of origin and time dimensions. The data from the NIOT and WIOT data sets also enabled the construction of domestic and imported intermediate input price indices for each product in each country. Finally, the availability of domestic and imported input values and prices allowed the construction of domestic and imported input quantity variables. As a result, the following variables (product- and country-specific) were created:

- $PD_{r,g,t}$ – the price index of domestic intermediate inputs ($1995 = 1$);
- $PM_{r,g,t}$ – the price index of imported intermediate inputs ($1995 = 1$);
- $QD_{r,g,t}$ – the domestic intermediate input volume at 1995 prices (millions of national currency);
- $QM_{r,g,t}$ – the imported intermediate input volume at 1995 prices (millions of national currency).

It is noteworthy that this analysis takes advantage of the 2013 version of the WIOD project. In the meantime, a new version of this database, labelled as 2016, has been released. This covers 56 sectors and 43 regions of the world economy within the time span 2000–2014. However, it does not include an updated version of the WIOD Energy Use or a split of labour stocks by skill levels within the WIOD Socio Economic Accounts. Hence, it was not possible to use this 2016 update for the purpose of this analysis.

5. Methodology and econometric techniques

The CES function is non-linear in parameters, which implies that their values cannot be estimated directly with standard linear regression techniques, using ordinary least squares (OLS). Henningsen and Henningsen (2011) argued that the econometric estimation of substitution elasticities is not frequently undertaken due to this limitation. To address this issue, they developed the R-package micEconCES, tailor-made for direct, non-linear estimation of substitution elasticities within (nested) CES functions, without the need to deliver price data as an estimation input.[15] Henningsen et al. (2019) defined such an estimation strategy as a *technical approach*. However, the last aspect constitutes a disadvantage rather than an advantage of this package, since the use of price data is essential for an appropriate estimation of Hicks/direct elasticity of substitution (HES) – see Broadstock et al. (2007). Another problem with non-linear estimation is the need to provide starting values of the estimated parameters and to reach estimation convergence. In fact, Koesler and Schymura (2015) admitted that, in several cases, they had not managed to achieve an acceptable level of convergence in their own estimation.[16] An alternative approach to non-linear estimation is Kmenta (1967) approximation, which may however yield potentially biased and inconsistent results (Thursby and Lovell, 1978). In addition, Maddala and Kadane (1967) pointed to the fact that Kmenta approximation does not always result in reliable estimates of substitution elasticities.

Against this backdrop, another method – OLS estimation of linearised equations – was applied in this study. The equations to be estimated may be derived from the first-order conditions either for the profit maximisation or for the cost minimisation problem. This stems from the fact that, under the price-taking assumption of firms' behaviour, the profit maximisation problem is equivalent to the cost minimisation problem (Mas-Colell et al., 1995). Both approaches enable researchers to obtain the relations of conditional factor demands as a function of, inter alia, their price ratios. These relations may subsequently be log-transformed and become subject to econometric

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[14] In this context, Henningsen et al. (2018) highlighted the need for the construction of the KLE composite, which constitutes a combination of value added and energy inputs, instead of using just the value added as an output. Otherwise, the obtained elasticity estimates tend to be biased.

[15] Among the reviewed articles, Koesler and Schymura (2015) employed the micEconCES package.

[16] A similar problem was highlighted by Henningsen et al. (2018).

Table 5
Countries covered by the final database used in the estimation procedure.
(Source: own elaboration based on Timmer et al. (2015).)

AUS	Australia	DEU	Germany	POL	Poland
AUT	Austria	GRC	Greece	PRT	Portugal
BEL	Belgium	HUN	Hungary	SVK	Slovak Republic
CAN	Canada	IRL	Ireland	SVN	Slovenia
CZE	Czech Republic	ITA	Italy	ESP	Spain
DNK	Denmark	JPN	Japan	SWE	Sweden
EST	Estonia	KOR	Korea, Republic of	GBR	United Kingdom
FIN	Finland	MEX	Mexico	USA	United States
FRA	France	NLD	Netherlands		

Table 6
Quantity and price variables used for estimation purposes in each of the production function nests.
(Source: own elaboration.)

Nest	Quantity variables	Price variables
$\sigma_{top,\ i}$	$QI_{r,\ i,\ t}$, $QKLE_{r,\ i,\ t}$	$PI_{r,\ i,\ t}$, $PKLE_{r,\ i,\ t}$
$\sigma_{armi,\ g}$	$QD_{r,\ g,\ t}$, $QM_{r,\ g,\ t}$	$PD_{r,\ g,\ t}$, $PM_{r,\ g,\ t}$
$\sigma_{kle,\ i}$	$QV_{r,\ i,\ t}$, $QE_{r,\ i,\ t}$	$PV_{r,\ i,\ t}$, $PE_{r,\ i,\ t}$
$\sigma_{va,\ i}$	$QK_{r,\ i,\ t}$, $QL_{r,\ i,\ t}$	$PK_{r,\ i,\ t}$, $PL_{r,\ i,\ t}$
$\sigma_{labu,\ i}$	$QLU_{r,\ i,\ t}$, $QLL_{r,\ i,\ t}$	$PLU_{r,\ i,\ t}$, $PLL_{r,\ i,\ t}$
$\sigma_{labl,\ i}$	$QLH_{r,\ i,\ t}$, $QLM_{r,\ i,\ t}$	$PLH_{r,\ i,\ t}$, $PLM_{r,\ i,\ t}$

estimation. Henningsen et al. (2019) defined such an estimation strategy as an *economic approach*. Among the reviewed studies, profit maximisation with respect to the underlying production function was applied by Baccianti (2013), Balistreri et al. (2003), Fragiadakis et al. (2012) and Németh et al. (2011). Cost minimisation with respect to the underlying production function was conducted by van der Werf (2008).

The empirical verification of the nesting structure, described in Section 2 and shown in Fig. 2, was not undertaken for several reasons. Most importantly, a production function with such a complicated nesting structure would be extremely difficult to estimate. In fact, the previous econometric estimations of the CES function, conducted by Kemfert (1998) and van der Werf (2008), merely focused on the various ways of nesting capital, labour and energy (KLE) inputs only. They both concluded that the KL(E) nesting, in which capital and labour constitute a value added composite that is subsequently combined with energy, is the most appropriate in terms of fitting the historical data.[17] This nesting scheme was also adopted by Koesler and Schymura (2015). Hence, it was also applied here – within the nest with substitution elasticity $\sigma_{kle,\ i}$. In addition, the WIOD Socio-Economic Accounts provide ready-to-use quantity and price data for the KL (i.e. the value added) composite. The choice of another form of nesting would require a significant rearrangement of this database, which in turn could undermine its consistency and quality. Particular elasticities were also estimated separately for each nest; specifically, separate equations for all the sector-nest combinations were constructed, without an explicit, joint estimation of all the nests within a single equation for a given sector. As argued by Németh et al. (2011), correspondence between the nests is ensured by the use of an internally consistent database, which allows the fulfilment of the inter-nest accounting identities.[18]

The derivation of an economic relationship, the parameter values of which are to be estimated econometrically to obtain substitution elasticity values, is based on a standard problem of firm's profit maximisation – subject to the constraint in the form of a neoclassical production function. Notably, this function was initially normalised (Klump et al., 2012). As indicated by Mućk (2017), the normalisation of the production function allows researchers to control the heterogeneity in the long-run properties of economies that are included in the panel. This procedure also allows them to address the problem of the lack of economic interpretation of the parameters estimated from the data expressed in various units (Klump et al., 2012). For the sake of brevity, the algebra outlined in this section describes the estimation procedure for the value added bundle, consisting of labour and capital inputs (the nest with elasticity $\sigma_{va,\ i}$). Analogous schemes hold for all the other nests, as shown in Fig. 2. The acronyms for particular variables and subscripts are also consistent with those presented in Table 3.

Given that $\rho_i = \dfrac{1-\sigma_i}{\sigma_i}$,a firm in country *r* in sector *i* maximises the profit from producing value added (the capital-labour bundle) in period *t*, subject to the normalised production function[19]:

$$\max_{QK_{r,i,t},QL_{r,i,t}} \{\Pi_{r,i,t} = PV_{r,i,t}\cdot QV_{r,i,t} - PK_{r,i,t}\cdot QK_{r,i,t} - PL_{r,i,t}\cdot QL_{r,i,t}\} \tag{7}$$

$$s.t. QV_{r,i,t} = QV_{r,i,0}\cdot\left[\alpha_{r,i}\cdot\left(A^K_{r,i,t}\cdot\frac{QK_{r,i,t}}{QK_{r,i,0}}\right)^{\frac{\sigma_i-1}{\sigma_i}} + (1-\alpha_{r,i})\cdot\left(A^L_{r,i,t}\cdot\frac{QL_{r,i,t}}{QL_{r,i,0}}\right)^{\frac{\sigma_i-1}{\sigma_i}}\right]^{\frac{\sigma_i}{\sigma_i-1}}, \tag{8}$$

where $A^K_{r,\ i,\ t}$ and $A^L_{r,\ i,\ t}$ are defined, respectively, as factor-augmenting productivity levels of capital and labour in region *r*, in sector *i* and in period *t*. $QV_{r,\ i,\ 0}$, $QK_{r,\ i,\ 0}$ and $QL_{r,\ i,\ 0}$ denote, respectively, the gross value added volume, real capital stock and number of hours worked in country *r* in sector *i* at the normalisation point of the production function. The values of those variables at the normalisation point were calculated as the geometric averages of their values in sector *i* and in country *r* over the entire time sample. Parameters $\alpha_{r,\ i}$ and $(1-\alpha_{r,\ i})$ define the shares of capital and labour compensation in value added in country *r* and sector *i*. The values of those parameters at the normalisation point were calculated as arithmetic averages of their values in sector *i* and in country *r* over the entire time sample. Such a normalisation procedure was previously suggested by Mućk (2017).

The derivation of first-order conditions for the above-mentioned optimisation problem leads to the following relationship:

$$\frac{QK_{i,t}}{QL_{i,t}} = \left(\frac{\alpha_i}{1-\alpha_i}\right)^{\sigma_i}\cdot\left(\frac{QK_{i,0}}{QL_{i,0}}\right)^{1-\sigma_i}\cdot\left(\frac{A^K_{i,t}}{A^L_{i,t}}\right)^{\sigma_i-1}\cdot\left(\frac{PL_{i,t}}{PK_{i,t}}\right)^{\sigma_i}. \tag{9}$$

It is also assumed that the growth in productivity of capital and labour is constant over time, country-uniform and sector-specific. The productivities of capital and labour are respectively defined as $A^K_{r,\ i,\ t} = e^{\gamma^K_i(t-t_0)}$ and

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[17] However, Baccianti (2013) argued that such R (Arrow et al., 1961)-based assessments provided by Kemfert (1998) may be contested, because models with different dependent variables were actually compared for this purpose. A similar critique might also be applied to van der Werf (2008).

[18] For instance, the value added used, by every sector *i*, as an input in the capital-labour-energy nest (with elasticity $\sigma_{kle,\ i}$) is equal to the value added produced as an output in the value added nest (with elasticity $\sigma_{va,\ i}$).

[19] For a comprehensive derivation of the normalised production function, see León-Ledesma et al. (2010).

Table 7
Likelihood ratio test for the statistical significance of country-specific fixed effects.
(Source: own elaboration.)

	σ(top)		σ(armi)		σ(kle)		σ(va)		σ(labu)		σ(labl)	
	F-statistic	*p*-Value	F-statistic	*p*-Value	F-statistic	*p*-Value	F-statistic	*p*-Value	F-statistic	*p*-Value	F-statistic	*p*-Value
agr	0.0053	1.0000	4.4605	0.0000	0.0271	1.0000	0.0268	1.0000	0.0156	1.0000	0.0254	1.0000
min	0.0151	1.0000	0.8224	0.7132	0.0094	1.0000	0.0330	1.0000	0.0108	1.0000	0.0000	1.0000
foo	0.0064	1.0000	3.9528	0.0000	0.0185	1.0000	0.0040	1.0000	0.0002	1.0000	0.0009	1.0000
tex	0.0060	1.0000	0.8917	0.6176	0.0184	1.0000	0.0100	1.0000	0.0001	1.0000	0.0001	1.0000
lea	0.0265	1.0000	0.5444	0.9587	0.0605	1.0000	0.0000	1.0000	0.3049	0.9996	0.1365	1.0000
woo	0.0018	1.0000	2.5006	0.0001	0.0342	1.0000	0.0488	1.0000	0.0037	1.0000	0.0012	1.0000
ppp	0.0075	1.0000	3.3379	0.0000	0.0121	1.0000	0.0106	1.0000	0.0013	1.0000	0.0000	1.0000
pet	0.2259	1.0000	5.3931	0.0000	0.1066	1.0000	0.1194	1.0000	0.0699	1.0000	0.0060	1.0000
chm	0.0925	1.0000	3.7483	0.0000	0.0110	1.0000	0.0035	1.0000	0.0003	1.0000	0.0048	1.0000
rub	0.0038	1.0000	4.2801	0.0000	0.0649	1.0000	0.0050	1.0000	0.0011	1.0000	0.0046	1.0000
nmm	0.0370	1.0000	7.7107	0.0000	0.0044	1.0000	0.0041	1.0000	0.0002	1.0000	0.0029	1.0000
mtl	0.0163	1.0000	4.5437	0.0000	0.0048	1.0000	0.0132	1.0000	0.0015	1.0000	0.0001	1.0000
mch	0.0052	1.0000	1.4975	0.0611	0.0615	1.0000	0.0163	1.0000	0.0146	1.0000	0.0001	1.0000
eeq	0.1392	1.0000	0.2858	0.9998	0.1962	1.0000	0.0119	1.0000	0.0018	1.0000	0.0016	1.0000
teq	0.0098	1.0000	2.7312	0.0000	0.0529	1.0000	0.0255	1.0000	0.0071	1.0000	0.0003	1.0000
oth	0.1184	1.0000	1.9074	0.0079	0.0643	1.0000	0.1393	1.0000	0.0030	1.0000	0.0003	1.0000
ele	0.0808	1.0000	1.2989	0.1559	0.0028	1.0000	0.0047	1.0000	0.0258	1.0000	0.0384	1.0000
con	0.0110	1.0000	3.0398	0.0000	0.0152	1.0000	0.0679	1.0000	0.0038	1.0000	0.1461	1.0000
mvh	0.0056	1.0000	0.6237	0.9222	0.0341	1.0000	0.0149	1.0000	0.0018	1.0000	0.0190	1.0000
whs	0.0034	1.0000	5.8024	0.0000	0.0162	1.0000	0.0154	1.0000	0.0298	1.0000	0.0017	1.0000
trd	0.0008	1.0000	4.0243	0.0000	0.0477	1.0000	0.0093	1.0000	0.0256	1.0000	0.0005	1.0000
htl	0.0098	1.0000	0.1650	1.0000	0.0172	1.0000	0.0049	1.0000	0.0854	1.0000	0.0001	1.0000
ltr	0.1101	1.0000	0.1999	1.0000	0.0324	1.0000	0.0550	1.0000	0.0042	1.0000	0.0063	1.0000
wtr	0.4178	0.9946	0.8945	0.5986	0.1603	1.0000	0.0061	1.0000	0.0004	1.0000	0.0045	1.0000
atr	4.0753	0.0000	0.7081	0.8496	0.2681	0.9951	0.0325	1.0000	0.0034	1.0000	0.0042	1.0000
trv	0.0175	1.0000	0.1713	1.0000	0.1638	1.0000	0.0101	1.0000	0.0053	1.0000	0.0076	1.0000
com	0.0209	1.0000	4.2025	0.0000	0.0614	1.0000	0.1089	1.0000	0.0508	1.0000	0.0168	1.0000
fin	0.0023	1.0000	1.3423	0.1287	0.0168	1.0000	0.0562	1.0000	0.0225	1.0000	0.0016	1.0000
rea	0.0092	1.0000	0.9796	0.4940	0.0405	1.0000	0.1088	1.0000	0.0030	1.0000	0.0031	1.0000
ren	0.0005	1.0000	4.4520	0.0000	0.0021	1.0000	0.0851	1.0000	0.0191	1.0000	0.0007	1.0000
pub	0.0127	1.0000	5.2282	0.0000	0.0277	1.0000	0.0806	1.0000	0.0090	1.0000	0.0001	1.0000
edu	0.0250	1.0000	1.4496	0.0776	0.1472	1.0000	0.1271	1.0000	0.0038	1.0000	0.0014	1.0000
hea	0.0071	1.0000	1.3734	0.1116	0.0242	1.0000	0.0292	1.0000	0.0040	1.0000	0.0000	1.0000
srv	0.0059	1.0000	3.8583	0.0000	0.0105	1.0000	0.0137	1.0000	0.0011	1.0000	0.0003	1.0000

Note: p-Value lower than 0.05 suggests rejecting the null hypothesis of no statistical significance of country-specific fixed effects.

$A^L_{r,\,i,\,t} = e^{\gamma^L_i (t-t_0)}$ (Mućk, 2017). This, combined with logarithmic transformation, yields the following specification to be estimated:

$$\log\left(\frac{QK_{r,i,t}}{QL_{r,i,t}}\right) = \sigma_i \log\left(\frac{\alpha_{r,i}}{1-\alpha_{r,i}}\right) + (1-\sigma_i)\cdot \log\left(\frac{QK_{r,i,0}}{QL_{r,i,0}}\right) + (\sigma_i-1)\cdot\gamma_i t + \sigma_i \log\left(\frac{PL_{r,i,t}}{PK_{r,i,t}}\right), \qquad (10)$$

where $\gamma_i = \gamma^K_i - \gamma^L_i$.

Noteworthily, this equation implicitly assumes that prices (RHS) determine quantities (LHS) – not the inverse. However, this assumption may be justified by the price-taking assumption made in the firm's optimisation problem (Mas-Colell et al., 1995).[20]

Analogical derivations were performed for the remaining nests of the production function. Due to limited space, they are not shown here. Instead, Table 6 provides a concordance scheme between the (dependent) quantity and the (independent) price variables, the ratios of which were used in the estimation process, as well as their corresponding substitution elasticities.[21]

Within the panel data framework applied in this study, separate equations were estimated for each of the sectors, based on separate databases pooled over all the countries and time periods. Therefore, for each activity sector *i*, the following relation was estimated de facto:

$$\log\left(\frac{QK_{r,t}}{QL_{r,t}}\right) = \beta_r + \sigma \log\left(\frac{\alpha_r}{1-\alpha_r}\right) + (1-\sigma)\cdot \log\left(\frac{QK_{r,0}}{QL_{r,0}}\right) + (\sigma-1)\cdot\gamma t + \sigma \log\left(\frac{PL_{r,t}}{PK_{r,t}}\right) + \varepsilon_{r,t}. \qquad (11)$$

Based on the above specification, it is not possible to measure the productivity growth rates of capital (γ^K) and labour (γ^L), as only their absolute difference may be identified ($\gamma = \gamma^K - \gamma^L$). However, it is exactly this difference that plays a crucial role in determining "correct" elasticity estimates. Besides, even abstracting from the correctness of the model's analytical specification, omitting the role of the relative, factor-augmenting technical change would yield biased estimates of substitution elasticities. As noted by Tipper (2012), excessively low/high elasticity values may stem from the overestimation/underestimation of relative changes in the productivity of factor inputs.

The appearance of the parameter β_r is also notable. It reflects the inclusion of cross-section (country) fixed effects in the model. The legitimacy of their presence for particular sector-nest combinations was formally verified with the likelihood ratio test. Its detailed results are presented in Table 7. In four production function nests – with substitution elasticities between value added and energy ($\sigma_{kle,\,i}$), between capital and labour ($\sigma_{va,\,i}$), between higher- and low-skilled labour ($\sigma_{labu,\,i}$) and between high- and medium-skilled labour ($\sigma_{labl,\,i}$) – there are no grounds to reject the null hypothesis of fixed effects' redundancy in all 34 economy branches. For the substitution elasticities between the non-energy materials and the capital-labour-energy composite ($\sigma_{top,\,i}$), the null hypothesis

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[20] It is also crucial not to use monetary values instead of quantities, since volume changes (LHS) need to be separated from price changes (RHS) – see Saito (2004). This was actually performed at the stage of preparing the database.

[21] Tables A3–A4 in the Appendix contain descriptive statistics of the respective ratios of the quantity and price variables for particular sectors of the economy.

should be rejected in favour of the alternative hypothesis assuming statistical significance of fixed effects in just one industry – namely, in *Air transport* (atr). For the remaining 33 economy branches, there is no reason to reject the null. However, because of the intention to maintain the coherence of the estimated specification for all industries within this production function nest, the fixed effects were ultimately not included in the equation's specification for *Air transport* (atr). It also turned out that, in this particular case, the difference in elasticity values obtained from these two alternative models' specifications was relatively small. Nevertheless, mostly heterogeneous results of the test were observed in the case of the substitution elasticities between domestic and imported products ($\sigma_{armi,\ g}$). For 16 products, there is no basis to reject the null of fixed effects' redundancy, while for 18 products it should be rejected in favour of the alternative hypothesis assuming their statistical significance. However, the fixed effects' specification was ultimately kept in all 34 cases. It was related to the fact that the preparation of the data necessary to estimate the elasticity values in this nest required far-reaching modifications of the original databases and some, previously described, simplifying assumptions. These modifications and simplifications might have caused a loss of some information about the trajectory of the volumes and prices of particular products in particular countries, thus generating unobserved heterogeneity within the data. A potential solution to this problem is just offered by using the fixed effects' specification in the estimation process.

The estimation procedure was based on ordinary least squares (OLS). The application of this methodology – that is, pooling one data set, over all countries and time slices, for each sector – implies that the estimated elasticities are sector-specific and country-uniform. In fact, such an assumption is very common, both in the construction of CGE models (Rutherford, 2010) and in empirical studies related to elasticity estimation – see Koesler and Schymura (2015) and Németh et al. (2011). The elasticities are also treated as equal over time, in line with all the mentioned studies. Koesler and Schymura (2015) argued that the panel data available in the WIOD database were too short in the time dimension to account properly for time stability tests.

6. Estimation results

Table 8 contains the estimated values of the substitution elasticity parameters for each of 6 production function nests and 34 sectors. Notably, the unrestricted econometric estimation might actually yield negative estimates of the elasticity values and thus create interpretation problems in single cases. However, such negative estimates may be perceived as indicating zero substitution (i.e. the Leontief specification) between input factors (Prywes, 1986).

The substitution elasticities within the top nest, that is, those between the non-energy materials and the capital-labour-energy composite ($\sigma_{top,\ i}$), are between zero (the Leontief specification) and unity (the Cobb-Douglas specification) in the vast majority of industries. The estimates are slightly higher than one for several industries. The elasticity values obtained range from 0.43 in the industry *Post and telecommunications* (com) to 1.13 in the industry *Health and social work* (hea). The average elasticity value in this nest equals 0.82, the standard deviation 0.18 and the variation coefficient 22%. The substitution elasticities within the Armington nest, that is, those between domestic and imported materials ($\sigma_{armi,\ g}$), are generally located relatively close to unity but with visible exceptions. The elasticity values obtained range from 0.31 for the product *Inland transport* (ltr) to 1.76 for the product *Water transport* (wtr). The average elasticity value in this nest equals 0.84, the standard deviation 0.30 and the variation coefficient 36%. The substitution elasticities within the capital-labour-energy nest, that is, between value added and energy ($\sigma_{kle,\ i}$), lie between zero and unity in almost all cases, except for one negative estimate in the industry

Table 8
Econometric estimates of the substitution elasticity values for particular industries/products and production function nests.
(Source: own elaboration.)

	σ(top)		σ(armi)		σ(kle)		σ(va)		σ(labu)		σ(labl)	
agr	0.7635	(0.0614)	0.7867	(0.0725)	0.2115	(0.0236)	0.1550	(0.0216)	0.1374	(0.1567)	0.0487	(0.1503)
min	0.4841	(0.0317)	0.3659	(0.0799)	0.2106	(0.0534)	−0.0042	(0.0178)	0.3182	(0.1284)	0.0074	(0.1505)
foo	0.5228	(0.0346)	0.6067	(0.0540)	0.3898	(0.0325)	0.4412	(0.0278)	0.0784	(0.1089)	0.5486	(0.1082)
tex	0.6187	(0.0763)	0.7738	(0.1617)	0.4983	(0.0348)	0.1686	(0.0224)	0.0596	(0.1189)	0.6229	(0.1291)
lea	0.7924	(0.0948)	0.9292	(0.2595)	0.3182	(0.0661)	0.0542	(0.0264)	0.0072	(0.1167)	0.6785	(0.1284)
woo	0.6670	(0.0629)	0.6789	(0.0785)	0.4682	(0.0419)	0.1443	(0.0218)	−0.1057	(0.1149)	0.4916	(0.1138)
ppp	0.8626	(0.0398)	0.8122	(0.0813)	0.3179	(0.0302)	0.3512	(0.0264)	−0.0877	(0.1145)	0.4062	(0.1248)
pet	0.8405	(0.0289)	1.1265	(0.0950)	0.4927	(0.0411)	0.1910	(0.0239)	−0.0883	(0.1128)	0.5888	(0.1239)
chm	0.9792	(0.0368)	0.9561	(0.0956)	0.2524	(0.0257)	0.4330	(0.0320)	0.1054	(0.1186)	0.6529	(0.1209)
rub	0.8374	(0.0582)	1.1043	(0.1044)	0.6383	(0.0328)	0.4197	(0.0305)	−0.0367	(0.1135)	0.5552	(0.1187)
nmm	0.9836	(0.0399)	0.9644	(0.0640)	0.5219	(0.0333)	0.4178	(0.0381)	0.0433	(0.1165)	0.4192	(0.1157)
mtl	0.9193	(0.0474)	0.9309	(0.0619)	0.3458	(0.0421)	0.1401	(0.0207)	−0.0425	(0.1172)	0.4563	(0.1048)
mch	1.0473	(0.0473)	0.6811	(0.1053)	0.7244	(0.0363)	0.4127	(0.0361)	−0.1069	(0.1092)	0.3415	(0.1209)
eeq	0.9577	(0.0571)	0.4001	(0.1385)	0.7863	(0.0359)	0.2504	(0.0257)	0.0666	(0.1125)	0.4193	(0.1201)
teq	0.7102	(0.0782)	1.2644	(0.1497)	0.4575	(0.0338)	0.1801	(0.0266)	0.1135	(0.0967)	0.3961	(0.1065)
oth	0.9101	(0.0307)	0.8118	(0.1195)	0.6269	(0.0398)	0.1712	(0.0213)	0.1209	(0.1088)	0.3656	(0.1219)
ele	0.8671	(0.0494)	0.6098	(0.1051)	0.0835	(0.0287)	0.3051	(0.0382)	0.3452	(0.1481)	1.2547	(0.1523)
con	0.8110	(0.0369)	0.8932	(0.1005)	0.3427	(0.0506)	0.1753	(0.0251)	−0.0574	(0.1242)	−0.8065	(0.1396)
mvh	1.0625	(0.0483)	0.5325	(0.1325)	0.3775	(0.0486)	0.3802	(0.0236)	0.0053	(0.0979)	0.5148	(0.0872)
whs	0.9117	(0.0472)	1.1132	(0.0914)	0.3955	(0.0456)	0.3786	(0.0362)	−0.0483	(0.1040)	0.1007	(0.1405)
trd	0.5004	(0.0712)	1.0444	(0.1028)	0.3589	(0.0557)	0.0989	(0.0203)	−0.0084	(0.1053)	0.2286	(0.1385)
htl	1.0139	(0.0590)	0.5547	(0.2725)	0.4296	(0.0532)	0.0616	(0.0208)	−0.2204	(0.1328)	0.0884	(0.0725)
ltr	0.8941	(0.0432)	0.3115	(0.1382)	0.0358	(0.0424)	0.1533	(0.0273)	0.0048	(0.1181)	−0.2842	(0.1345)
wtr	0.7430	(0.0486)	1.7630	(0.4041)	0.4328	(0.0417)	0.1138	(0.0422)	0.1011	(0.1156)	−0.3331	(0.1429)
atr	0.8183	(0.0317)	0.6716	(0.1559)	0.2484	(0.0584)	0.1280	(0.0269)	0.0773	(0.0592)	−0.3268	(0.1428)
trv	1.0335	(0.1150)	0.4108	(0.1957)	0.2579	(0.0562)	0.0536	(0.0193)	0.0220	(0.1237)	−0.3777	(0.1452)
com	0.4324	(0.0898)	0.7472	(0.0696)	0.5730	(0.0377)	0.4714	(0.0359)	0.2540	(0.1226)	−1.0186	(0.1567)
fin	0.6209	(0.0639)	0.7215	(0.1123)	0.3978	(0.0511)	0.1810	(0.0251)	0.2578	(0.1212)	−0.2024	(0.1964)
rea	0.6529	(0.0913)	1.1889	(0.2387)	0.1806	(0.0694)	0.1928	(0.0376)	0.1422	(0.0822)	−0.2056	(0.1003)
ren	0.7397	(0.0667)	0.7533	(0.0672)	0.1885	(0.0461)	0.4431	(0.0260)	−0.0706	(0.0807)	0.0073	(0.0964)
pub	1.0120	(0.0595)	1.3556	(0.1350)	0.2623	(0.0468)	0.1133	(0.0185)	−0.0475	(0.1472)	0.7732	(0.1452)
edu	0.8486	(0.0605)	0.9096	(0.1494)	−0.2250	(0.0501)	0.1115	(0.0170)	0.5299	(0.1191)	0.2864	(0.0956)
hea	1.1288	(0.0486)	0.7797	(0.1308)	0.3029	(0.0553)	0.1184	(0.0269)	0.1931	(0.1136)	0.2474	(0.1156)
srv	0.9298	(0.0261)	1.0670	(0.1033)	0.3063	(0.0443)	0.0071	(0.0250)	0.1957	(0.1097)	0.0570	(0.0880)

Note: The estimation errors of particular elasticity values are presented in brackets.

Table 9
Wald test for Leontief and Cobb-Douglas specification of production function – part I.
(Source: own elaboration.)

	σ(top)				σ(armi)				σ(kle)			
	σ = 0 (Leontief)		σ = 1 (Cobb-Douglas)		σ = 0 (Leontief)		σ = 1 (Cobb-Douglas)		σ = 0 (Leontief)		σ = 1 (Cobb-Douglas)	
	t-Statistic	*p*-Value	*t*-Statistic	*p*-Value	*t*-Statistic	*p*-Value	*t*-Statistic	*p*-Value	*t*-Statistic	*p*-Value	*t*-Statistic	*p*-Value
agr	12.43	0.00	−3.85	0.00	10.85	0.00	−2.94	0.00	8.97	0.00	−33.45	0.00
min	15.29	0.00	−16.29	0.00	4.58	0.00	−7.94	0.00	3.94	0.00	−14.77	0.00
foo	15.11	0.00	−13.79	0.00	11.25	0.00	−7.29	0.00	12.00	0.00	−18.78	0.00
tex	8.11	0.00	−5.00	0.00	4.78	0.00	−1.40	0.16	14.31	0.00	−14.41	0.00
lea	8.36	0.00	−2.19	0.03	3.58	0.00	−0.27	0.79	4.81	0.00	−10.31	0.00
woo	10.61	0.00	−5.30	0.00	8.65	0.00	−4.09	0.00	11.18	0.00	−12.69	0.00
ppp	21.66	0.00	−3.45	0.00	9.99	0.00	−2.31	0.02	10.51	0.00	−22.56	0.00
pet	29.13	0.00	−5.53	0.00	11.86	0.00	1.33	0.18	11.98	0.00	−12.33	0.00
chm	26.62	0.00	−0.57	0.57	10.00	0.00	−0.46	0.65	9.81	0.00	−29.07	0.00
rub	14.40	0.00	−2.80	0.01	10.58	0.00	1.00	0.32	19.44	0.00	−11.02	0.00
nmm	24.65	0.00	−0.41	0.68	15.06	0.00	−0.56	0.58	15.66	0.00	−14.35	0.00
mtl	19.41	0.00	−1.70	0.09	15.04	0.00	−1.12	0.27	8.21	0.00	−15.54	0.00
mch	22.12	0.00	1.00	0.32	6.47	0.00	−3.03	0.00	19.94	0.00	−7.59	0.00
eeq	16.78	0.00	−0.74	0.46	2.89	0.00	−4.33	0.00	21.89	0.00	−5.95	0.00
teq	9.08	0.00	−3.71	0.00	8.45	0.00	1.77	0.08	13.54	0.00	−16.05	0.00
oth	29.68	0.00	−2.93	0.00	6.79	0.00	−1.58	0.12	15.74	0.00	−9.37	0.00
ele	17.55	0.00	−2.69	0.01	5.80	0.00	−3.71	0.00	2.91	0.00	−31.90	0.00
con	21.99	0.00	−5.12	0.00	8.89	0.00	−1.06	0.29	6.77	0.00	−12.99	0.00
mvh	21.99	0.00	1.29	0.20	4.02	0.00	−3.53	0.00	7.77	0.00	−12.81	0.00
whs	19.30	0.00	−1.87	0.06	12.18	0.00	1.24	0.22	8.67	0.00	−13.25	0.00
trd	7.03	0.00	−7.02	0.00	10.16	0.00	0.43	0.67	6.45	0.00	−11.52	0.00
htl	17.19	0.00	0.24	0.81	2.04	0.04	−1.63	0.10	8.08	0.00	−10.73	0.00
ltr	20.71	0.00	−2.45	0.01	2.25	0.02	−4.98	0.00	0.84	0.40	−22.72	0.00
wtr	15.27	0.00	−5.28	0.00	4.36	0.00	1.89	0.06	10.39	0.00	−13.61	0.00
atr	25.81	0.00	−5.73	0.00	4.31	0.00	−2.11	0.04	4.26	0.00	−12.87	0.00
trv	8.99	0.00	0.29	0.77	2.10	0.04	−3.01	0.00	4.59	0.00	−13.20	0.00
com	4.81	0.00	−6.32	0.00	10.73	0.00	−3.63	0.00	15.19	0.00	−11.32	0.00
fin	9.71	0.00	−5.93	0.00	6.43	0.00	−2.48	0.01	7.79	0.00	−11.80	0.00
rea	7.15	0.00	−3.80	0.00	4.98	0.00	0.79	0.43	2.60	0.01	−11.81	0.00
ren	11.10	0.00	−3.91	0.00	11.21	0.00	−3.67	0.00	4.09	0.00	−17.59	0.00
pub	17.02	0.00	0.20	0.84	10.04	0.00	2.63	0.01	5.60	0.00	−15.75	0.00
edu	14.02	0.00	−2.50	0.01	6.09	0.00	−0.60	0.55	−4.49	0.00	−24.47	0.00
hea	23.23	0.00	2.65	0.01	5.96	0.00	−1.68	0.09	5.48	0.00	−12.60	0.00
srv	35.57	0.00	−2.69	0.01	10.33	0.00	0.65	0.52	6.91	0.00	−15.66	0.00

Note: p-Value lower than 0.05 suggests rejecting the null hypothesis of either the Leontief (σ = 0) or the Cobb-Douglas (σ = 1) specification of the production function.

Education (edu), equal to −0.23. The non-negative elasticity values range from 0.04 in the industry *Inland transport* (ltr) to 0.79 in the industry *Electrical and optical equipment* (eeq). The average elasticity value in this nest equals 0.36 and the standard deviation is 0.19, while the variation coefficient is 54%. The substitution elasticities in the value added nest, that is, between capital and labour ($\sigma_{va,\ i}$), are between zero and unity in practically all cases, except for one slightly negative estimate in industry *Mining and quarrying* (min). The non-negative elasticity values range from 0.01 in the industry *Other community, social and personal services* (srv) to 0.47 in the industry *Post and telecommunications* (com). The average elasticity value in this nest equals 0.22, the standard deviation 0.14 and the variation coefficient 65%. The substitution elasticities in the “upper labour nest”, that is, between higher- and low-skilled labour ($\sigma_{labu,\ i}$), turned out to be much less conclusive than in the case of the previously described nests. In 12 out of 34 industries, the estimates obtained are negative but “technically close to zero”. The non-negative elasticity values range from around zero in the industry *Inland transport* (ltr) to 0.53 in the industry *Education* (edu). The average elasticity value in this nest equals 0.07 and the standard deviation is 0.15, while the variation coefficient is 227%. Similar to the “upper labour nest”, the substitution elasticity estimates in the “lower labour nest”, that is, between medium- and high-skilled labour ($\sigma_{labl,\ i}$), also turned out to be much less conclusive than in the case of the previously described nests. In 7 out of 34 industries, the estimates obtained are negative, but some of them cannot be described as “technically close to zero”. The non-negative elasticity values range from 0.01 in the industry *Mining and quarrying* to 1.25 in the industry *Electricity, gas and water supply* (ele). The average elasticity value in this nest equals 0.21, the standard deviation 0.45 and the variation coefficient 221%.

As an extension, Tables 9–10 provide the results of the test for the Leontief and/or the Cobb-Douglas specification for particular economy sectors and production function nests. They indicate whether the estimated elasticity value in a given sector-nest combination is statistically different from zero and/or unity.

In the top nest, combining non-energy materials and the capital-labour-energy composite ($\sigma_{top,\ i}$), the null hypothesis of the Leontief specification should be rejected in all 34 industries, while, for the Cobb-Douglas specification, there are no grounds for rejecting the null in 10 out of 34 cases. In the Armington nest, combining domestic and imported materials ($\sigma_{armi,\ g}$), the null of the Leontief specification should be rejected in all 34 industries, while, for the Cobb-Douglas specification, there is no reason to reject it in 18 out of 34 cases. In the capital-labour-energy nest, combining value added and energy ($\sigma_{kle,\ i}$), the null of the Leontief specification should be rejected in 33 industries and that of the Cobb-Douglas specification in all 34 cases. Notably, in the sole case with a negative elasticity estimate, namely the industry *Education* (edu), the null of zero elasticity should also be rejected. Hence, from the purely statistical point of view, this elasticity value should not be interpreted as “technically close to zero”. In the value added nest, combining capital and labour ($\sigma_{va,\ i}$), the null hypothesis of the Leontief specification should be rejected in 32 industries, while, for the Cobb-Douglas specification, it should be rejected in all 34 cases. It is noteworthy that, in the sole case with a negative elasticity estimate, that is, the industry *Mining and quarrying* (min) there is no reason to reject the

Table 10
Wald test for Leontief and Cobb-Douglas specification of production function – part II.
(Source: own elaboration.)

	σ(va)				σ(labu)				σ(labl)			
	σ = 0 (Leontief)		σ = 1 (Cobb-Douglas)		σ = 0 (Leontief)		σ = 1 (Cobb-Douglas)		σ = 0 (Leontief)		σ = 1 (Cobb-Douglas)	
	t-Statistic	*p*-Value	*t*-Statistic	*p*-Value	*t*-Statistic	*p*-Value	*t*-Statistic	*p*-Value	*t*-Statistic	*p*-Value	statystyka *t*	*p*-Value
agr	7.19	0.00	−39.20	0.00	0.88	0.38	−5.50	0.00	0.32	0.75	−6.33	0.00
min	−0.24	0.81	−56.38	0.00	2.48	0.01	−5.31	0.00	0.05	0.96	−6.59	0.00
foo	15.89	0.00	−20.13	0.00	0.72	0.47	−8.47	0.00	5.07	0.00	−4.17	0.00
tex	7.53	0.00	−37.13	0.00	0.50	0.62	−7.91	0.00	4.83	0.00	−2.92	0.00
lea	2.05	0.04	−35.86	0.00	0.06	0.95	−8.51	0.00	5.28	0.00	−2.50	0.01
woo	6.61	0.00	−39.16	0.00	−0.92	0.36	−9.62	0.00	4.32	0.00	−4.47	0.00
ppp	13.31	0.00	−24.59	0.00	−0.77	0.44	−9.50	0.00	3.25	0.00	−4.76	0.00
pet	7.99	0.00	−33.85	0.00	−0.78	0.43	−9.65	0.00	4.75	0.00	−3.32	0.00
chm	13.54	0.00	−17.73	0.00	0.89	0.38	−7.54	0.00	5.40	0.00	−2.87	0.00
rub	13.77	0.00	−19.04	0.00	−0.32	0.75	−9.13	0.00	4.68	0.00	−3.75	0.00
nmm	10.97	0.00	−15.28	0.00	0.37	0.71	−8.21	0.00	3.62	0.00	−5.02	0.00
mtl	6.78	0.00	−41.61	0.00	−0.36	0.72	−8.89	0.00	4.35	0.00	−5.19	0.00
mch	11.42	0.00	−16.25	0.00	−0.98	0.33	−10.14	0.00	2.82	0.01	−5.45	0.00
eeq	9.75	0.00	−29.18	0.00	0.59	0.55	−8.30	0.00	3.49	0.00	−4.83	0.00
teq	6.78	0.00	−30.88	0.00	1.17	0.24	−9.17	0.00	3.72	0.00	−5.67	0.00
oth	8.03	0.00	−38.88	0.00	1.11	0.27	−8.08	0.00	3.00	0.00	−5.20	0.00
ele	7.99	0.00	−18.19	0.00	2.33	0.02	−4.42	0.00	8.24	0.00	1.67	0.10
con	6.97	0.00	−32.80	0.00	−0.46	0.64	−8.51	0.00	−5.78	0.00	−12.94	0.00
mvh	16.11	0.00	−26.26	0.00	0.05	0.96	−10.16	0.00	5.91	0.00	−5.57	0.00
whs	10.46	0.00	−17.17	0.00	−0.46	0.64	−10.08	0.00	0.72	0.47	−6.40	0.00
trd	4.88	0.00	−44.49	0.00	−0.08	0.94	−9.57	0.00	1.65	0.10	−5.57	0.00
htl	2.97	0.00	−45.19	0.00	−1.66	0.10	−9.19	0.00	1.22	0.22	−12.58	0.00
ltr	5.61	0.00	−30.97	0.00	0.04	0.97	−8.42	0.00	−2.11	0.04	−9.55	0.00
wtr	2.70	0.01	−21.00	0.00	0.88	0.38	−7.78	0.00	−2.33	0.02	−9.33	0.00
atr	4.75	0.00	−32.38	0.00	1.31	0.19	−15.57	0.00	−2.29	0.02	−9.29	0.00
trv	2.78	0.01	−49.07	0.00	0.18	0.86	−7.91	0.00	−2.60	0.01	−9.49	0.00
com	13.11	0.00	−14.70	0.00	2.07	0.04	−6.09	0.00	−6.50	0.00	−12.88	0.00
fin	7.21	0.00	−32.64	0.00	2.13	0.03	−6.13	0.00	−1.03	0.30	−6.12	0.00
rea	5.12	0.00	−21.45	0.00	1.73	0.08	−10.43	0.00	−2.05	0.04	−12.02	0.00
ren	17.05	0.00	−21.42	0.00	−0.87	0.38	−13.27	0.00	0.08	0.94	−10.30	0.00
pub	6.12	0.00	−47.89	0.00	−0.32	0.75	−7.11	0.00	5.33	0.00	−1.56	0.12
edu	6.58	0.00	−52.41	0.00	4.45	0.00	−3.95	0.00	3.00	0.00	−7.46	0.00
hea	4.40	0.00	−32.73	0.00	1.70	0.09	−7.10	0.00	2.14	0.03	−6.51	0.00
srv	0.28	0.78	−39.68	0.00	1.78	0.08	−7.33	0.00	0.65	0.52	−10.72	0.00

Note: p-Value lower than 0.05 suggests rejecting the null hypothesis of either the Leontief (σ = 0) or the Cobb-Douglas (σ = 1) specification of the production function.

null hypothesis of zero elasticity. This implies that there are no substitution possibilities between capital and labour within this sector, that is, the Leontief production function. In the “upper” labour nest, combining higher- and low-skilled labour ($\sigma_{labu,\ i}$), there are no grounds to reject the null hypothesis of the Leontief specification in as many as 29 industries, while, for the Cobb-Douglas specification, it should be rejected in all 34 cases. Moreover, in all 12 cases with negative estimates, there is no reason to reject the null of zero elasticity. This implies that there are no substitution possibilities between capital and labour within this sector, which is equivalent to the Leontief production function. In the “lower” labour nest, combining high- and medium-skilled labour ($\sigma_{labl,\ i}$), the null hypothesis of the Leontief specification should be rejected in 26 industries, while it should be rejected in 32 out of 34 cases for the Cobb–Douglas specification. Notably, in all 7 cases of negative elasticity estimates, the null of the zero elasticity value should be rejected. Hence, from a purely statistical point of view, those elasticity values should not be interpreted as “technically close to zero”.

7. Conclusion and policy implications

The aim of this paper was to provide a wide range of estimates of substitution elasticities for sectoral nested CES production functions, using panel data techniques, with the World Input-Output Database (WIOD) as the main data source. Such a large-scale estimation of various, both product- and industry-specific, elasticities with the use of an internally consistent database and a common methodology for all the production function nests constituted an attempt to close the identified research gap. The economic relations to be estimated were derived from the firm's profit maximisation problem, subject to the normalised production function.

Significant heterogeneity in the estimated values of substitution elasticities is observed – not only between various industries/products but also between various nests of production functions. In general, the substitution elasticities between the aggregate materials and the capital-labour-energy composite (top nest), between value added and energy, as well as between capital and labour, tend to lie, with individual exceptions, between zero (the Leontief specification) and unity (the Cobb-Douglas specification). It also turns out that the substitution possibilities at the top level are generally greater than those between energy and value added and especially between capital and labour. The substitution possibilities between low- and higher-skilled labour seem to be negligible. Relatively high elasticity values are, however, observable between medium- and high-skilled labour. Moreover, the Armington elasticities – between domestic and imported materials – are, with some exceptions, located around unity, that is, technically close to the Cobb-Douglas form. The results of the Wald tests for the Leontief/Cobb-Douglas specifications of the production functions suggest that the quite common practice of using arbitrary, sector-uniform elasticity values (“coffee table elasticities”) in CGE models may not be justified.

The elasticity estimates reported in this paper may subsequently be used by CGE modellers in their applied research – covering fiscal, labour market, trade, energy and environmental topics.

Appendix A

Table A1
Concordance between the regions in the World Input-Output Database and the OECD Energy Prices and Taxes.
(Source: own elaboration.)

WIOD		OECD
AUS	Australia	Australia
AUT	Austria	Austria
BEL	Belgium	Belgium
BRA	Brazil	
BGR	Bulgaria	
CAN	Canada	Canada
		Chile
CHN	China	
CYP	Cyprus	
CZE	Czech Republic	Czech Republic
DNK	Denmark	Denmark
EST	Estonia	Estonia
FIN	Finland	Finland
FRA	France	France
DEU	Germany	Germany
GRC	Greece	Greece
HUN	Hungary	Hungary
IND	India	
IDN	Indonesia	
IRL	Ireland	Ireland
		Israel
ITA	Italy	Italy
JPN	Japan	Japan
KOR	Korea, Republic of	Korea
LVA	Latvia	Latvia
LTU	Lithuania	
LUX	Luxembourg	Luxembourg
MLT	Malta	
MEX	Mexico	Mexico
NLD	Netherlands	Netherlands
		New Zealand
		Norway
POL	Poland	Poland
PRT	Portugal	Portugal
ROU	Romania	
RUS	Russia	
SVK	Slovak Republic	Slovak Republic
SVN	Slovenia	Slovenia
ESP	Spain	Spain
SWE	Sweden	Sweden
		Switzerland
TWN	Taiwan	
TUR	Turkey	Turkey
GBR	United Kingdom	United Kingdom
USA	United States	United States

Note: the grey font indicates the regions excluded from further analysis.

Table A2
Concordance between the energy carriers in the World Input-Output Database and the OECD Energy Prices and Taxes.
(Source: own elaboration.)

WIOD		OECD
HCOAL	Hard coal and derivatives	Steam coal
BCOAL	Lignite and derivatives	Steam coal
COKE	Coke	Coking coal
CRUDE	Crude oil, NGL and feedstocks	
DIESEL	Diesel oil for road transport	Automotive diesel
GASOLINE	Motor gasoline	Premium leaded gasoline Premium unleaded 95 RON Premium unleaded 98 RON Regular unleaded gasoline Regular leaded gasoline
JETFUEL	Jet fuel (kerosene and gasoline)	
LFO	Light Fuel oil	Light fuel oil
HFO	Heavy fuel oil	High sulphur fuel oil Low sulphur fuel oil
NAPHTA	Naphtha	
OTHPETRO	Other petroleum products	Liquefied petroleum gas
NATGAS	Natural gas	Natural gas
OTHGAS	Derived gas	Natural gas
WASTE	Industrial and municipal waste	
BIOGASOL	Biogasoline also including hydrated ethanol	Premium leaded gasoline Premium unleaded 95 RON Premium unleaded 98 RON Regular unleaded gasoline Regular leaded gasoline
BIODIESEL	Biodiesel	Automotive diesel
BIOGAS	Biogas	Natural gas
OTHRENEW	Other combustible renewables	
ELECTR	Electricity	Electricity
HEATPROD	Heat	
NUCLEAR	Nuclear	
HYDRO	Hydroelectric	
GEOTHERM	Geothermal	
SOLAR	Solar	
WIND	Wind power	
OTHSOURC	Other sources	
LOSS	Distribution losses	

Note: the grey font indicates the energy carriers excluded from further analysis.

Table A3
Descriptive statistics of particular variables used in the estimation process – part I.
(Source: own elaboration.)

	QI/QKLE				PI/PKLE				QD/QM				PD/PM				QV/QE				PV/PE			
	mean	std	min	max	mean	std	min	max	mean	std	min	max	mean	std	min	max	mean	std	min	max	mean	std	min	max
agr	1.01	0.15	0.60	1.83	0.98	0.35	0.43	2.49	0.85	0.31	0.26	2.49	10.21	9.84	0.78	72.94	0.08	0.06	0.00	0.33	12,583	50,602	30.8	281,746
min	0.90	0.23	0.22	1.55	0.66	0.30	0.16	2.11	0.83	0.31	0.15	2.05	1.76	3.85	0.01	35.13	0.12	0.10	0.00	0.46	2151	9764	11.7	85,374
foo	0.92	0.13	0.27	1.37	2.90	0.78	1.28	5.42	0.90	0.38	0.26	2.65	12.21	10.69	1.48	55.91	0.09	0.06	0.00	0.24	6442	22,358	36.3	121,412
tex	0.97	0.11	0.52	1.47	1.89	0.42	1.05	2.94	0.91	0.27	0.39	2.23	2.03	3.40	0.02	19.92	0.08	0.06	0.00	0.21	5768	18,578	48.4	109,870
lea	0.95	0.14	0.39	1.61	2.35	1.10	0.70	8.62	0.93	0.34	0.37	2.84	2.23	3.68	0.01	24.43	0.08	0.06	0.00	0.41	8149	25,912	37.9	150,408
woo	0.97	0.16	0.53	1.71	2.01	0.44	0.94	3.42	0.83	0.33	0.22	2.69	4.84	3.71	0.32	19.63	0.07	0.05	0.00	0.24	7571	26,923	44.4	154,501
ppp	1.01	0.23	0.70	3.12	1.62	0.42	0.35	2.89	0.90	0.25	0.36	1.95	5.40	7.17	0.26	43.36	0.09	0.06	0.00	0.29	5703	19,749	33.3	118,249
pet	0.73	0.32	0.03	1.97	0.89	1.05	0.05	9.42	0.91	0.45	0.13	3.07	3.43	3.23	0.00	18.67	0.17	0.42	0.00	4.23	151	452	0.1	2494
chm	0.94	0.19	0.29	1.98	1.71	0.63	0.58	4.28	0.91	0.38	0.23	2.91	1.35	2.37	0.03	14.07	0.13	0.19	0.00	1.27	1853	6706	1.4	40,948
rub	0.95	0.11	0.58	1.29	1.91	0.52	1.22	4.42	0.90	0.27	0.31	2.19	2.95	4.81	0.05	31.04	0.06	0.04	0.00	0.21	8711	32,095	31.2	205,470
nmm	0.92	0.14	0.41	1.17	1.08	0.29	0.51	2.61	0.88	0.30	0.29	2.34	6.04	5.74	0.19	35.92	0.11	0.11	0.00	0.68	1074	3312	4.1	18,610
mtl	0.93	0.13	0.41	1.37	1.78	0.52	0.84	4.71	0.84	0.30	0.11	2.29	2.84	3.28	0.21	20.69	0.10	0.07	0.00	0.30	1210	3737	4.5	21,895
mch	0.98	0.18	0.32	1.88	1.91	0.56	0.70	4.99	0.87	0.32	0.20	2.97	2.15	3.07	0.04	19.52	0.06	0.05	0.00	0.21	16,856	59,490	35.7	366,969
eeq	1.13	0.60	0.49	4.97	2.54	1.73	0.43	11.45	0.85	0.31	0.18	2.43	1.20	1.75	0.01	11.65	0.05	0.04	0.00	0.26	38,592	149,176	45.5	1,089,588
teq	1.00	0.15	0.55	1.80	3.12	1.26	0.72	8.67	0.82	0.26	0.19	2.04	2.67	7.52	0.01	58.50	0.06	0.05	0.00	0.28	14,008	50,329	39.1	320,285
oth	1.07	0.71	0.39	7.32	1.80	0.71	0.17	5.83	0.90	0.25	0.35	2.08	3.70	3.20	0.11	18.88	0.06	0.05	0.00	0.28	12,473	50,413	30.4	340,331
ele	0.93	0.19	0.33	1.52	0.39	0.20	0.12	1.60	0.97	0.49	0.24	3.40	90.80	143.17	0.36	1031.64	0.31	0.55	0.00	3.79	431	1402	0.4	7383
con	0.92	0.13	0.48	1.28	1.63	0.53	0.89	4.52	0.93	0.36	0.24	2.88	132.68	199.11	4.46	1437.79	0.07	0.05	0.00	0.25	15,172	63,777	38.9	371,797
mvh	1.00	0.25	0.57	3.69	0.89	0.38	0.16	2.35	0.98	0.37	0.27	2.80	173.55	172.77	8.20	1664.75	0.06	0.04	0.00	0.18	19,141	69,316	72.3	468,987
whs	1.09	0.43	0.69	4.20	0.80	0.33	0.07	1.62	0.89	0.36	0.29	2.94	27.96	33.42	0.19	202.23	0.05	0.04	0.00	0.22	17,701	62,236	111.3	414,198
trd	1.03	0.14	0.66	1.88	0.63	0.23	0.24	1.67	0.85	0.32	0.26	2.66	97.88	76.86	7.37	661.33	0.06	0.04	0.00	0.16	10,609	34,539	36.2	202,961
htl	0.91	0.12	0.36	1.16	1.12	0.47	0.37	4.17	0.94	0.35	0.32	2.80	270.96	715.49	0.22	4168.00	0.06	0.04	0.00	0.16	6721	23,567	43.1	144,383
ltr	0.89	0.14	0.31	1.14	0.88	0.30	0.35	2.04	0.91	0.33	0.30	2.51	40.32	141.97	1.16	957.29	0.08	0.05	0.00	0.23	2731	8160	12.3	46,306
wtr	0.94	0.23	0.08	1.81	2.25	1.90	0.30	16.45	0.93	0.39	0.31	2.87	32.74	144.07	0.00	1154.68	0.31	0.46	0.00	2.89	4985	39,779	4.2	568,436
atr	1.14	0.73	0.09	8.61	2.45	4.40	0.24	55.50	0.82	0.43	0.08	3.02	2.15	2.42	0.02	18.12	0.02	0.01	0.00	0.05	5227	16,998	22.8	86,855
trv	0.96	0.12	0.53	1.41	1.36	0.65	0.22	3.36	1.00	0.42	0.29	2.70	22.16	44.07	0.06	228.52	0.07	0.05	0.00	0.26	6867	20,439	42.5	112,043
com	1.13	0.33	0.74	3.03	0.77	0.37	0.16	2.44	0.78	0.31	0.18	1.92	36.31	87.55	2.17	548.90	0.06	0.05	0.00	0.22	35,573	138,470	184.4	928,374
fin	1.08	0.25	0.58	2.47	0.72	0.28	0.25	2.00	0.91	0.42	0.31	3.30	18.33	20.07	0.60	116.17	0.05	0.04	0.00	0.26	41,568	135,023	81.4	838,069
rea	0.97	0.12	0.60	1.47	0.40	0.26	0.08	1.98	0.92	0.32	0.27	2.08	455.14	629.19	7.20	4984.17	0.06	0.05	0.00	0.23	45,707	132,725	56.9	631,428
ren	0.94	0.12	0.52	1.47	0.86	0.27	0.39	2.10	0.92	0.48	0.24	3.55	13.05	14.17	0.25	104.68	0.07	0.05	0.00	0.23	50,999	215,127	83.0	1,516,243
pub	0.92	0.13	0.39	1.14	0.59	0.25	0.23	1.16	0.88	0.46	0.21	3.48	34.22	40.03	0.17	376.87	0.06	0.05	0.00	0.22	16,958	65,118	93.8	412,654
edu	0.92	0.11	0.57	1.10	0.26	0.13	0.06	0.73	0.86	0.43	0.21	3.22	85.00	121.10	0.35	856.42	0.07	0.05	0.00	0.36	17,559	60,838	63.8	453,399
hea	0.93	0.15	0.27	1.39	0.57	0.29	0.21	2.23	0.89	0.40	0.20	2.94	152.62	255.48	3.09	2213.77	0.07	0.05	0.00	0.26	15,938	61,097	71.6	459,390
srv	0.92	0.15	0.09	1.16	0.91	0.35	0.39	3.80	0.86	0.34	0.20	2.35	16.63	19.04	1.46	119.49	0.07	0.05	0.00	0.22	10,100	35,140	47.7	193,567

Table A4
Descriptive statistics of particular variables used in the estimation process – part II.
(Source: own elaboration.)

	QK/QL				PK/PL				QLU/QLL				PLU/PLL				QLH/QLM				PLH/PLM			
	mean	std	min	max	mean	std	min	max	mean	std	min	max	mean	std	min	max	mean	std	min	max	mean	std	min	max
agr	0.04	0.08	0.00	0.85	949	2964	0.8	21,262	1.56	0.33	0.84	2.57	2.28	2.08	0.02	9.88	1.36	0.32	0.79	2.66	0.23	0.23	0.02	1.28
min	0.01	0.01	0.00	0.08	5381	17,248	14.7	97,443	1.56	0.39	0.69	2.88	5.26	7.70	0.16	73.57	1.43	0.57	0.76	4.35	0.38	0.34	0.05	1.96
foo	0.02	0.03	0.00	0.17	1580	5075	5.8	33,886	1.61	0.34	0.88	2.71	3.96	3.65	0.11	25.34	1.42	0.30	0.79	2.98	0.31	0.25	0.05	1.59
tex	0.02	0.04	0.00	0.22	771	2776	2.1	23,699	1.63	0.36	0.90	2.71	3.59	3.27	0.11	25.34	1.41	0.28	0.79	2.61	0.29	0.23	0.05	1.38
lea	0.02	0.03	0.00	0.32	887	3261	1.8	30,490	1.63	0.35	0.90	2.71	3.61	3.29	0.11	25.34	1.42	0.32	0.79	2.88	0.30	0.23	0.05	1.38
woo	0.02	0.05	0.00	0.37	1012	3785	2.1	27,562	1.59	0.33	0.98	2.62	3.98	3.73	0.11	25.34	1.40	0.32	0.79	2.95	0.31	0.24	0.05	1.36
ppp	0.02	0.03	0.00	0.23	1294	4075	6.2	28,402	1.59	0.32	0.97	2.62	5.83	9.47	0.11	106.00	1.41	0.32	0.79	3.42	0.34	0.24	0.06	1.36
pet	0.03	0.15	0.00	1.72	16,248	61,230	0.7	345,496	1.58	0.32	1.04	2.62	14.16	111.04	0.11	2112.74	1.44	0.40	0.79	3.72	0.35	0.24	0.06	1.36
chm	0.02	0.03	0.00	0.20	3141	10,263	8.5	67,834	1.58	0.31	1.09	2.62	6.65	11.29	0.11	97.81	1.42	0.33	0.79	2.98	0.37	0.25	0.06	1.36
rub	0.02	0.03	0.00	0.34	1005	3079	3.0	16,903	1.60	0.31	1.09	2.62	4.54	4.51	0.11	29.41	1.40	0.31	0.79	2.83	0.31	0.23	0.06	1.36
nmm	0.02	0.02	0.00	0.12	2134	7624	4.4	56,319	1.58	0.32	0.85	2.62	4.14	4.03	0.11	25.34	1.39	0.33	0.79	2.94	0.32	0.24	0.06	1.36
mtl	0.02	0.02	0.00	0.14	1913	6939	3.9	39,865	1.57	0.32	0.95	2.62	4.52	4.99	0.11	31.88	1.40	0.35	0.79	3.06	0.31	0.23	0.06	1.36
mch	0.02	0.02	0.00	0.18	929	2903	1.6	16,113	1.59	0.32	1.05	2.53	5.29	6.22	0.11	41.00	1.41	0.33	0.79	2.76	0.32	0.24	0.05	1.69
eeq	0.02	0.04	0.00	0.36	1951	7423	2.9	53,966	1.60	0.31	1.05	2.53	6.17	10.10	0.11	107.23	1.43	0.32	0.79	2.72	0.34	0.25	0.05	1.36
teq	0.02	0.03	0.00	0.22	1548	4964	2.8	30,024	1.57	0.33	1.05	2.53	5.07	6.39	0.11	44.27	1.43	0.48	0.79	5.44	0.31	0.23	0.05	1.36
oth	0.03	0.05	0.00	0.34	761	2531	1.3	15,661	1.61	0.35	1.05	2.71	4.16	3.99	0.11	25.34	1.40	0.34	0.79	3.34	0.31	0.24	0.05	1.52
ele	0.00	0.00	0.00	0.02	29,729	119,736	100.8	842,443	1.50	0.29	0.99	2.45	16.69	40.79	0.30	486.21	1.43	0.53	0.83	3.99	0.49	0.44	0.09	2.40
con	0.05	0.09	0.00	0.54	190	629	2.0	3413	1.53	0.30	0.99	2.43	5.09	6.16	0.07	33.74	1.32	0.35	0.75	2.85	0.28	0.33	0.05	1.73
mvh	0.04	0.09	0.00	0.88	730	2369	2.0	14,931	1.67	0.44	0.45	3.13	8.13	9.06	0.21	50.44	1.44	0.36	0.63	3.12	0.28	0.22	0.04	1.19
whs	0.03	0.04	0.00	0.21	680	1958	3.3	10,230	1.69	0.40	1.05	3.13	9.41	11.48	0.21	50.89	1.43	0.31	0.76	2.66	0.29	0.23	0.06	1.19
trd	0.03	0.04	0.00	0.31	439	1317	2.0	6959	1.70	0.40	1.14	3.13	8.94	10.58	0.21	50.44	1.42	0.31	0.76	2.66	0.27	0.22	0.06	1.19
htl	0.03	0.06	0.00	0.40	377	1133	0.9	6947	1.59	0.60	0.72	4.84	4.45	5.21	0.14	27.22	1.32	0.30	0.71	2.59	0.19	0.14	0.03	0.73
ltr	0.01	0.02	0.00	0.12	2679	9732	6.1	65,731	1.55	0.32	0.98	2.88	5.68	6.33	0.35	45.17	1.34	0.33	0.78	2.95	0.29	0.21	0.05	1.17
wtr	0.01	0.01	0.00	0.10	3578	11,980	6.6	72,490	1.56	0.32	1.04	2.88	5.76	6.29	0.35	45.17	1.35	0.35	0.78	3.71	0.29	0.22	0.05	1.17
atr	0.02	0.26	0.00	4.70	5227	16,779	0.1	89,385	1.56	0.32	1.04	2.88	6.55	7.09	0.35	45.17	1.32	0.32	0.36	3.19	0.29	0.21	0.05	1.17
trv	0.01	0.03	0.00	0.18	3757	11,328	6.0	68,922	1.55	0.32	1.04	2.88	5.98	6.31	0.35	45.17	1.34	0.34	0.78	2.97	0.29	0.20	0.05	1.17
com	0.02	0.04	0.00	0.38	4589	15,058	5.0	78,969	1.51	0.32	0.90	2.67	10.83	21.28	0.35	230.11	1.36	0.46	0.78	5.16	0.29	0.19	0.02	1.14
fin	0.02	0.03	0.00	0.26	1217	3534	4.3	18,932	1.52	0.31	0.95	2.51	35.63	49.92	1.27	271.13	1.59	0.60	0.86	3.88	0.78	0.55	0.13	3.81
rea	0.01	0.01	0.00	0.09	52,672	129,571	247.1	607,876	1.68	0.31	0.99	2.79	9.68	9.97	1.03	86.14	1.85	0.46	1.02	3.42	0.91	0.49	0.14	2.55
ren	0.03	0.05	0.00	0.31	4574	21,100	1.9	143,881	1.72	0.31	1.16	2.79	17.00	39.89	1.03	264.41	1.86	0.46	1.02	3.73	0.96	0.49	0.17	2.55
pub	0.00	0.01	0.00	0.06	6310	24,761	12.3	165,621	1.47	0.17	0.93	1.88	15.55	19.65	0.57	124.80	1.50	0.36	0.67	3.15	0.81	0.64	0.19	3.80
edu	0.01	0.03	0.00	0.22	867	2618	1.8	16,060	1.64	0.32	1.03	2.46	19.65	21.98	1.90	137.09	1.81	0.49	1.03	3.56	2.57	2.11	0.40	11.78
hea	0.02	0.05	0.00	0.51	922	3307	0.8	19,018	1.65	0.28	1.16	2.40	10.69	12.47	0.71	101.22	1.65	0.40	0.96	3.25	0.95	0.74	0.18	3.80
srv	0.02	0.04	0.00	0.25	845	2258	1.9	11,274	1.53	0.25	0.77	2.66	6.05	6.93	0.15	44.23	1.50	0.33	0.83	2.84	0.47	0.20	0.15	1.06

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2019.07.016.

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